Secrets of success: the development of obstetric ultrasound in Scotland, 1963-1990

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Abstract

This thesis examines the diffusion of obstetric ultrasound technology in Scotland, from the early 1960s through to the end of the 1980s. Although the origins of obstetric ultrasound can be traced to 1955, and the pioneering work undertaken by Professor Ian Donald and his colleagues in Glasgow on the gynaecological applications of ultrasound, it was not until the early 1960s that the pathologies associated with pregnancy were directly investigated. Over the next thirty years, the technology underwent a number of significant transformations - in technical design, application and use, and organisation. The main focus of this thesis is on the uptake and implementation of obstetric ultrasound in new locations across Scotland, and on the dynamics of change associated with its use in clinical practice.

Using a case-study approach which centres on four individual Scottish hospitals, this thesis traces the complexity and heterogeneity evident in the diffusion of this technology. The definition of 'technology' employed in this thesis is three-dimensional - comprising of technical, cognitive and interactive/performative dimensions. Here it is argued that all three of these dimensions compose a technology, and that all three are open to adaptation and change, thus essentially changing the nature of the technology itself. This is highlighted through a comparative account, focussing on site-specific differences in the development, organisation and use of the technology.

The evidence presented here has been drawn from a variety of historical sources. The recollections of a number of actors involved in the introduction, use and development of obstetric ultrasound in Scotland, as well as of women who experienced ultrasound during their pregnancies, have been collected using semi-structured interviews. To this oral history has been added information from a variety of archival sources held at the British Medical Ultrasound Society's Historical Collection (housed at The Queen Mother's Hospital, Glasgow). These include specialist professional journals, correspondence relating to ultrasound, manufacturers' literature, draft versions of key published papers, transcripts of interviews with prominent actors in the field and material donated by ultrasound workers across Scotland. Furthermore, the Collection also boasts a wide array of visual information (including pictures of various types of ultrasound equipment and images generated from them) and artifacts (ultrasound machines dating from the 1950s through to the 1980s). These, less conventional, historical sources are also employed in this thesis.

In this comparative study of the diffusion of ultrasound, three related arguments are presented. Firstly, it is argued that innovation and diffusion are not mutually exclusive terms or periodising concepts, but are interwoven processes and forms of activity. The diffusion of obstetric ultrasound did not signal the 'end' of innovation, but merely the point at which new actors in new locations undertook it. Innovation is a crucial component in adapting a technology to new circumstances, users or contexts and thus it is argued that innovation and diffusion are inter-related, mutually dependent forms of interested human action.

Secondly, obstetric ultrasound is characterised in this thesis as an emergent phenomenon, shaped by both technical and social factors. When the development of this technology is examined in a variety of historical and spatial contexts, it is evident that the form it takes is determined by the interplay of social factors (professional relationships and interests, actors interpretations of technology, etc.) and more technical or material factors (the way a machine responds to new demands or itself requires certain types of human or social response). Thus a complete account of the diffusion of obstetric ultrasound necessitates an approach that considers both social and material influences on technological change.

Finally, this thesis explores the significance of site-specific local arrangements for the shaping of obstetric ultrasound. Interactions with technology take place within specific historical and locational settings. The specific character of each setting can affect the nature of inter-professional relationships, the organisation and administration of the technology, the characteristics of the patient population, and so on. Thus, the diffusion of obstetric ultrasound and the form that it takes in each new location are partly shaped by the way in which the technology interacts with new environments.

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I am deeply indebted to my supervisors Dr Malcolm Nicolson and Professor Ray Stokes. Without their guidance, patient support and encouragement this thesis may never have been completed. Furthermore, their experience and knowledge of their respective fields helped to shape my ideas into some form of coherence. For this, I will be indebted to them long after this thesis begins to gather dust in Glasgow University Library. With one supervisor steeped in sociology of science and medical history, and the other in history of technology, the emergent product is a true hybrid.

The progression of this thesis has also been greatly aided by the material accumulated by Malcolm Nicolson and John Fleming (along with Ian Spencer) on the history of diagnostic ultrasound. Their project has been an invaluable source of information for me and provided me with material which I would otherwise have been unable to access within the confines of PhD research. I am extremely grateful to Malcolm for making this material available to me.

I also owe a great deal to Mr. John Fleming, former colleague of Professor Ian Donald and curator of the British Medical Ultrasound Society's Historical Collection at The Queen Mother's Hospital in Glasgow. Not only did John provide a wealth of archival material and know instinctively where I might find the information I needed, but he has also been an invaluable font of knowledge in his own right. As well as providing me with lists of potential interviewees from his contacts in the field past and present, John patiently (and repeatedly) explained to me the physics and engineering aspects of ultrasound. Pointing out the key components of the machines in the collection, drawing diagrams and continuously simplifying the complex expert knowledge of physics into the required 'ultrasound for idiots' guide, John enabled a technologically illiterate historian to come to terms with the complicated world of diagnostic ultrasound. Any remaining inaccuracies are therefore mine alone.

Dr Margaret McNay, former consultant obstetrician at the Queen Mother's Hospital, was also an invaluable source of information, providing contacts and explaining the nature and significance of obstetric pathologies. I am also extremely indebted to all those involved with the development and use of ultrasound in Scotland who gave up their time to speak to me, and to the women who were prepared to share their ultrasound experiences. Without their co-operation, this thesis would not have been possible.

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Finally, but no less centrally, I wish to extend my heartfelt thanks to my parents. Throughout the trials and tribulations associated with the construction of this thesis they have been my rock and my refuge and to them I dedicate this work.

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Introduction: setting the scene(s)

Introduction

In 1963, Ian Donald (Regius Professor of Midwifery at Glasgow University) was presented with the world's first commercially produced obstetric ultrasound scanner – a 'Diasonograph' made in Scotland by Smiths Industries. The new machine was delivered to the Queen Mother's Maternity Hospital at Yorkhill in Glasgow, although the hospital itself was not officially opened for service until 1964. For Donald and those who worked with him, this piece of equipment marked the culmination of eight years of research into the clinical potential of ultrasound as a diagnostic tool in both gynaecology and obstetrics. However, in many ways, the production of the machine itself is where the story of the development of obstetric ultrasound really begins, rather than ends.

Over the course of the following thirty years, ultrasound would emerge as one of the most successful diagnostic technologies in medicine - both in terms of its widespread use across the world, and in terms of the number of clinical specialties that would incorporate ultrasound imaging as part of their diagnostic armoury. However, of all the medical uses to which ultrasound has been put, its closest and most well-known association has been with the specialty of obstetrics. Throughout the history of the use of ultrasound within obstetrics, the number of clinical conditions and pathologies that it could help diagnose has proliferated – making it one of the most commonly used technologies within the specialty. Indeed, it is possible to argue that ultrasound scans became an integral part of the very experience of pregnancy in the late twentieth century. By the end of the 1980s, 87% of pregnant women in Scotland would experience an ultrasound scan at least once during the course of their pregnancy[1], and for many a scan was something to be looked forward to with anticipation as the first opportunity to 'see' their unborn babies. In fact, it is now common for ultrasound scan images to be placed in baby albums as 'baby's first picture'. But how did this happen? What lies behind the success of this procedure? What processes and actions have led to its accepted and central role in hospital-based antenatal care? Or, to borrow from Casper and Clarke's terminology, how did it become the 'right tool for the

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[1] Scottish Home and Health Department/Scottish Health Services Planning Council, (1986), 'Obstetric ultrasound in Scotland: report of the ad hoc group appointed by the specialty sub-committee for obstetrics and gynaecology of the National Medical Consultative Committee' Her Majesty's Stationary Office, Edinburgh, p. 16.

job'?[2] To answer these questions attention has to be directed at the way in which this technology became embedded in the medical sphere and, indeed, at the way in which both technology and context were adapted and altered so that they 'fit' one another.

From the moment of its initial innovation, the history of obstetric ultrasound can be viewed as a multi-layered phenomenon. First of all, it was played out in a number of arenas - in the research and development laboratories of the various companies who were interested in its commercial production, in the board and committee rooms of funding bodies, university departments and laboratories, private Trust Funds, government planning departments, professional bodies and hospital managers, and in the clinic. Furthermore, these different arenas operated at different levels of abstraction from the point of actual practice. For example, government advisory bodies were involved in the planning and regulation of ultrasound at a national (both Scottish and UK) level whereas those operating in other arenas, such as obstetricians or radiographers using ultrasound within the clinic, interacted with the technology at a more local level. However, each of these different arenas impacted upon one another, and thus the activities enacted in one type of arena would affect others, thus mutually helping to shape the emerging technology. Furthermore, the boundaries between arenas were fluid. For example, clinicians who used the technology in the hospital might also sit on government advisory committees, while prototype machines might be loaned to hospitals to be assessed by operating staff. In order to observe how these relationships were played out in practice (without being subsumed beneath a complicated and ever-shifting narrative) this thesis will concentrate on the development of obstetric ultrasound from within the context of the clinic and thus activities occurring at other levels will be examined in terms of their effects on ultrasound in clinical practice.

For the purposes of this thesis, 'the clinic' is defined in very broad terms to encompass all events that take place in the realm of actual medical practice. In other words, the thesis will concentrate on changes that occurred while the technology was being used as a clinical diagnostic tool in hospitals and surgeries across Scotland. The exception to this is Chapter 1, which looks at the early activities of ultrasound workers in Glasgow where the technology

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[2] Casper, M.J. & Clarke, A.E., (1998), 'Making the Pap Smear into the "right tool" for the job: cervical cancer screening in the USA circa 1940-95' *Social studies of science,* Vol. 28, No. 2, pp. 255-90.

was first developed. Thus Chapter 1 lays out the background to ultrasound, and introduces it as a new imaging modality in medicine. Nevertheless, even at this early point in its development, ultrasound was essentially a clinical innovation, with much of the early work being carried out at the Western Infirmary where modified industrial flaw detecting equipment was used on the hospital's gynaecology patients.

Through focusing on the clinic, it should be possible to uncover the nature of the relationships between ultrasonic waves, medical personnel, pregnant women, hospital administrations, medical hierarchies and institutions. To this end, the thesis will consider the diffusion of obstetric ultrasound in Scotland - looking at the way in which the technology spread out from its origin and early use in Glasgow and at the way in which it was used and received in different locations throughout Scotland. Using a comparative approach, it will analyse the development of obstetric ultrasound in what Andrew Pickering refers to as 'real-time' - developments as they happened *in situ* and in the realm of practice.[3] In other words, this narrative will focus on new practices and techniques as they emerged, and will examine how they were perceived through a consideration of contemporary publications and the recollections of the actors involved. In this way, the meaning of ultrasound practices will not be imposed on its historical development retrospectively in light of the way in which the technology is currently perceived.

Analysing ultrasound within its clinical environment has two very important implications for the approach to be taken. First of all, it requires a focus on the *practice* of obstetric ultrasound. This means, therefore, that the narrative has to search beyond a simplistic definition of ultrasound which regards it merely as a technical artifact. Instead, it is perhaps more useful to consider ultrasound as a socio-technical activity - with both the technical and

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[3] Pickering, A., (1995), *The mangle of practice: time agency and science,* University of Chicago Press, Chicago and London; *idem*, (1995), 'Cyborg history and the World War II regime' *Perspectives on science,* Vol. 3, No. 1, pp. 1-48.

the social being represented and accounted for in the telling of its history.[4] Secondly, focusing on developments within the clinic entails that this must be a study of diffusion and development - of the extension of medical culture via the concrete day-to-day problem solving and practice of organising and operating obstetric ultrasound.[5] To borrow from Pickering's phraseology once more, ultrasound in each location needs to be viewed as an *emergent practice*[6] rooted in the particularities of its daily use and implementation in each site. In essence, therefore, this study is a contextualised account of technological development, which comparatively examines the technology's 'career' in a number of locations.

Using a case-study approach based on individual hospitals this thesis will map out the various ways in which obstetric ultrasound was introduced and utilised in Scotland. Indeed Scotland as a whole provides a good micro study of the various elements that can effect, and be affected by, a new medical technology such as ultrasound. Despite being a relatively small country, Scotland is notable for the variety of its social geography. As well as the large, urban industrial centres located mainly in the central belt, Scotland is also characterised by sparsely populated regions and small, relatively isolated, island communities. This in turn leads to diversity in terms of, for example, communication links,

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[4] Similar approaches to technology can be found in the following excellent collected volumes; Bijker, W.E., Hughes, T.P. & Pinch, T.J., (eds.), (1987), *The social construction of technological systems*, MIT Press, Cambridge Mass.; Bijker, W.E. & Law, J., (eds.), (1992), *Shaping technology/building society: studies in sociotechnical change,* MIT Press, Cambridge Mass.; MacKenzie, D. & Wajcman, J., (eds.), (1985), *The social shaping of technology: how the refrigerator got its hum,* Open UP, Milton Keynes. See also Bijker, W.E., (1995), *Of bicycles, bakelites, and bulbs: towards a theory of sociotechnical change,* MIT Press, London; Howell, J.D., (1995), *Technology in the hospital: transforming patient care in the early twentieth century,* John Hopkins University Press, Baltimore & London; Hughes, T.P., (1983), *Networks of power: electrification in western society, 1880-1930,* Johns Hopkins University Press, Baltimore & London; Law, J., (ed.), (1991), *A sociology of monsters: essays on power, technology and domination,* Routledge, London; Lawrence, G., (ed.), (1994), *Technologies of modern medicine,* Science Museum, London; MacKenzie, D., (1996), *Knowing machines: essays on technical change,* MIT Press, Cambridge Mass. & London; *idem*, (1993), *Inventing accuracy: a historical sociology of nuclear missile guidance,* MIT Press, Cambridge Mass. & London; Pasveer, B., (1992), 'Shadows of knowledge, making a representing practice in medicine: x-ray pictures and pulmonary tuberculosis, 1895-1930' PhD Thesis (University of Amsterdam), published by CIP-Gegevens Koninklijke Bibliotheek, Den Haag; *idem*, (1990), 'Knowledge of shadows: the introduction of x-ray images in medicine,' *Sociology of health and illness,* Vol. 11, No. 4, pp. 360-81; Pickering, A., (1995), *The mangle of practice;* Pickstone, J.V., (ed.), (1992), *Medical innovations in historical perspective,* St. Martins Press, New York.

[5] For comparable studies of diffusion see Bijker, W.E., (1995), *Bicycles, bakelites and bulbs*; Casper, M.J. & Clarke, A.E., (1998), 'Making the Pap Smear'; Clarke, A.E. & Fujimura, J.H., (eds.), (1992), *The right tools for the job: at work in twentieth century life sciences,* Princeton University Press, Princeton N.J.; Howell, J.D., (1995), *Technology in the hospital;* Hughes, T.P., (1983), *Networks of power;* Pickstone, J.V., (ed.), (1992), *Medical innovations.*

social and technical infrastructure and, in particular for the purposes of this thesis, medical services. Thus examining ultrasound in a variety of such settings and locations will uncover the sheer number of site-specific (and often unpredictable) factors that can influence development. For this reason, it provides an ideal location for constructing a micro study of the multiple ways in which a technology can be developed.

Understanding ultrasound

What is obstetric ultrasound? There are several ways of approaching this basic question. The first and, one might expect, the easiest, is to attempt to explain what the technology actually does, by emphasising what physical properties it employs and for what purpose. In essence, obstetric ultrasound machines use pulses of high frequency, inaudible sound to detect hidden structures *in utero.* In very simplistic terms, a transducer emits sound waves at a fixed frequency, which travel into the body.[7] There they are absorbed, transmitted or reflected (according to the physical make-up of the structures which they 'hit') and the resultant echoes are picked up and converted into some form of visual format. Nevertheless, even such a limited definition of ultrasound imaging is problematic. There are a number of ways in which the sound waves can be produced, transmitted and received and obstetric ultrasound itself has undergone many developments in transducer design and operation, and image display systems. Thus, the very nature of what obstetric ultrasound is and how it works has to be viewed as a complex and historically contingent phenomenon, which has emerged over time and as a result of continuous development and innovation.

Furthermore, obstetric ultrasound is about much more than the physics of ultrasonic waves, or the nuts and bolts of ultrasound equipment. Ultrasound is a technology and therefore, by definition, it is also a socially defined activity. That is to say, ultrasound is about more than simply the equipment itself - it forms a particular social activity, performed in a specific set

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[6] Pickering, A., (1995), *The mangle of practice.*

[7] For a basic understanding of the physical principles of this technology there are numerous guides for medics, physicists and laymen. See, for example, Hobbins, J.C., Winsberg, F. & Berkowitz, R.L., (1983), *Ultrasonography in obstetrics and gynaecology (2nd edition),* Williams & Wilkins, Baltimore, chapter 1; McDicken, W.N., (1976), *Diagnostic ultrasonics, principles and use of instruments,* Crosby Lockwood Staples, London; Wolbarst, A.B., (1999), *Looking within: how x-ray, CT, MRI, ultrasound, and other medical images are created and how they help physicians save lives,* University of California Press, London.

of social circumstances.[8] Therefore, the social dimensions of ultrasound must be analysed as both a part of the technology itself and as contributory factors in its development and diffusion. In other words, users themselves help to shape technology and they do so within specific social contexts. A company may make many ultrasound machines but unless there are personnel who are trained to use them, funds with which to buy them, pregnant women on which to use them and space in which to place them, they will not be utilised. Thus, to study the diffusion of obstetric ultrasound is to consider all of these dimensions and the way in which they are arrayed in different times and places - hence the advantage of a comparative approach.

But in what way should the social and the technical be viewed - what is the relationship between the two? In a sense, this is one of the main research questions to which this thesis is addressed. To examine the relationship between the social and technical elements of ultrasound, to uncover the way in which they impinge on one another and shape the development and diffusion of this technology, *is* to uncover the secrets of its success.

Herein, however, lies the problem: there exists a vast array of theoretical approaches into which a history of obstetric ultrasound could be placed. This is a technology that overlaps many current concerns in historical studies and the social sciences. As a medical practice developed mainly by men and applied exclusively to women it falls into the area of concern of women's studies and gender history.[9] As an expensive and intricate medical technology

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[8] See MacKenzie, D. & Wajcman, J., (eds.), (1985), *The social shaping of technology,* (especially the introductory chapter) for a three-strand definition of 'technology'.

[9] See, for example, Düden, B., (1993), *Disembodying women: perspectives on pregnancy and the unborn,* Harvard University Press, Cambridge Mass. & London; Ehrenreich, B. & English, D., (1979), *For her own good: 150 years of the expert's advice to women,* Pluto Press, London; Evans, F., (1985), 'Managers and labourers: women's attitudes to reproductive technologies' in Faulkner, W. & Arnold, E., (eds.), *Smothered by invention,* Pluto Press, London; Greig, R., (1995), *Pregnancy in a high-tech age – paradoxes of choice,* New York UP, New York; Inch, S., (1982), *Birthrights: a parent's guide to modern childbirth,* Hutchinson & Co., London; Oakley, A., (1987), 'From walking wombs to test-tube babies' in Stanworth, M., (ed.), *Reproductive technologies: gender, motherhood & medicine,* Polity Press, Cambridge; *idem.*, (1984), *The captured womb: a history of the medical care of pregnant women,* Blackwell, Oxford; Petchesky, R., (1987), 'Fetal images: the power of visual culture and the politics of reproduction' *Feminist Studies,* Vol. 2, No. 2, pp. 263-93; Rapp, R., (2000), *Testing women, testing the fetus: the social impact of amniocentesis in America,* Routledge, New York & London; *idem.,* (1997), 'Real-time fetus: the role of the sonogram in the age of monitored reproduction' in Downey, G.L. & Dumit, J., (eds.), *Cyborgs and citadels,* School of American Research Press, Santa Fe, New Mexico; Rowland, R., (1992), *Living laboratories: women and reproductive technologies,* Lime Tree, London; Stanworth, M., (ed.), (1987), *Reproductive technologies: gender, motherhood & medicine,* Polity Press, Cambridge.

of the late twentieth century, it could also be regarded as a central component of high technology medicine - part of an era in which technology appears to reign supreme in medical practice.[10] Thus depending on the type of account one might want to write, there are various ways to conceptualise and make sense of the development of this technology. Or, to put this another way, the history of obstetric ultrasound could be constructed to fit a number of grand narratives: narratives about 'Progress' and the technical superiority of the late 20th century, or about the medicalisation of the pregnant body by a profession dominated by men, or about medicine's increasing reliance (or dependency) on technology. However, in the construction of this particular history of ultrasound, a conscious attempt has been made to investigate and challenge the usefulness of such grand narratives. From the outset, the development of obstetric ultrasound was characterised by an unpredictability and heterogeneity which entail that it would not readily fit into any grand narrative without a high degree of simplification and abridgement. For this reason, this thesis will argue (as others have done elsewhere and in different contexts) that heterogeneity, diversity and unpredictability should be embraced in accounts of technological development, rather than glossed over.[11]

Themes

In this thesis, three specific (although inter-related) arguments will be presented. The first of these relates to the nature of the relationship between what are traditionally regarded as 'innovation' and 'diffusion'.

According to the *Oxford English Dictionary*, to 'innovate' is to 'bring in something new' or to 'make changes in something established'.[12] To diffuse, on the other hand, is to 'pour or send forth as from a center of dispersion' or to 'spread widely, shed abroad, disperse,

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[10] Reiser, S.J., (1978), *Medicine and the reign of technology,* Cambridge UP, Cambridge; Jennett, B., (1986), *High technology medicine: benefits and burdens,* Oxford UP, Oxford.
[11] Latour, B., (1992), 'Where are the missing masses? The sociology of a few mundane artifacts', in Bijker, W.E. & Law, J., (eds.), *Shaping technology/building society,* pp. 225-58; *idem,* (1987), *Science in action,* Harvard UP, Cambridge, Mass.; Law, J., (ed.), *A sociology of monsters: essays on power, technology and domination,* Routledge, London; Pickering, A., (1995), *The mangle of practice; idem,* (1995), 'Cyborg history'; *idem,* 'Practice and posthumanism: social theory and a history of agency' (unpublished paper); *idem,* 'The objects of the humanities and the time of the cyborg' (unpublished paper).
[12] *The Shorter Oxford English dictionary on historical principles, Volume I (1973 edition),* Oxford University Press, Oxford.

disseminate'.[13] Within technology studies, innovation has thus been used to refer to the invention and development of prototypes, while diffusion has been related to the wider uptake of such novel devices and practices. For this reason, traditional accounts of technological change tended to view the relationship between innovation and diffusion as unproblematic, with the latter following logically and chronologically from the former.

This is particularly true of attempts to construct generalised models of technological development, within which diffusion is often characterised as the 'final stage' of a general development process. John McKinlay, for example, proposes a seven-stage model of the 'career' of a medical innovation.[14] While, for McKinlay, the 'diffusion' stage is not the final one (the technology may subsequently go through stages of discreditation and rejection as a result of randomised controlled trials), his main thesis is that it *should* be. Randomised controlled trials (the 'Holy Grail' of scientific medicine) should be carried out, according to McKinlay, before diffusion occurs so that only 'good' technologies will make it into medical practice. Thus, for McKinlay, if the technology is properly (i.e. scientifically) investigated while still an 'innovation' it will succeed and be adopted in other centres. In a similar vein, H David Banta in his analysis of the diffusion of computed tomography (CT) scanning in the United States, traces the factors which effected the adoption of this technology in American hospitals.[15] For Banta, however, the research agenda appears to be related to identifying factors which might have prevented or constrained diffusion in certain centres or types of institution. Thus the implicit suggestion is that if such constraints were removed or avoided, the diffusion of CT would flow naturally and logically from innovation.

More recent approaches to technological development have attempted to problematise the relationship between innovation and diffusion by examining the dynamic nature of the

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[13] *ibid.*

[14] McKinlay, J.B., (1981), 'From "promising report" to "standard procedure": seven stages in the career of a medical innovation' *Millbank memorial fund quarterly,* Vol. 59, No. 3, pp. 374 - 411.

[15] Banta, H.D., (1980), 'The diffusion of the computed tomography (CT) scanner in the United States' *International Journal of Health Services,* Vol. 10, No. 2, pp. 251-69.

latter. Thomas Hughes' technological systems approach, for example, has been widely influential since the early 1980s.[16] Hughes' approach highlights the various ways in which key actors draw large systems together in order to secure the success of an innovation. Thus, Hughes' 'engineer-entrepreneurs' perform a variety of roles and switch easily between fields as diverse as politics, management, commerce, finance and technical engineering to create their systems. In other words, a good innovation is not enough: technological innovations rarely stand alone, but are instead encompassed within a wider network or system. The creation of such systems involves considerable effort and activity in the process normally labelled as 'diffusion'.

Another recent perspective is the social construction of technology (SCOT) approach of Pinch and Bijker.[17] In an attempt to close the gap developing between science studies and technology studies in the early 1980s, Pinch and Bijker adapted some of the key concepts used in the sociology of scientific knowledge (SSK) to provide a theoretical framework for the study of technology.[18] In their account the 'interpretative flexibility' of technical artifacts (or an artifact's ability to 'mean' different things to different groups of social actors) entails that the content and design of a technology only becomes stabilised once a certain meaning or interpretation becomes dominant. Thus diffusion creates the opportunity for the proliferation of possible meanings, as the technology is increasingly used by a wider variety of actors (or 'relevant social groups' which are Pinch and Bijker's main units of analysis).

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[16] Hughes, T.P., (1987), 'The evolution of large technological systems' in Bijker, W.E., Hughes, T.P. & Pinch, T., (eds.), *The social construction of technological systems*, pp. 51-82; *idem*, (1983), *Networks of power; idem*, (1979), 'The electrification of America: the systems builders' *Technology & culture*, Vol. 20, pp. 124-161.
[17] Bijker, W.E., (1995), *Of bicycles, bakelites, and bulbs*; Bijker, W.E., Hughes, T.P. & Pinch, T. (eds.), (1987), *Social construction of technological systems*; Bijker, W.E. & Law, J., (eds.), (1992), *Shaping technology/building society*; Pinch T. & Bijker, W., (1986), 'Science, technology and the new sociology of technology: reply to Russell' *Social studies of science*, Vol. 16, pp. 347-60; *idem*, (1984), 'The social construction of facts and artifacts; or how the sociology of science and the sociology of technology might benefit each other' *Social studies of science*, Vol. 14, pp. 399-441.
[18] In particular, Pinch and Bijker translated concepts from David Bloor's Strong Programme to technology studies. For the main tenets of the Strong Programme see Bloor, D. (1976), *Knowledge and social imagery*, Routledge, London; Pinch T. & Bijker, W., (1986), 'The new sociology of technology'; *idem*, (1984), 'The social construction of facts and artifacts'; Russell, S., (1986), 'The social construction of artifacts: a response to Pinch and Bijker,' *Social studies of science*, Vol. 16, pp. 331-46.

Thus as Bijker notes:

> Basic to all 'new' technology studies is the observation that even in the diffusion stage, the process of invention continues.[19]

Nevertheless, while such approaches provide a refreshing view of diffusion as a more dynamic process, little explicit attempt is made to account for the nature of the relationship between diffusion and innovation. This approach tends to side step the issue by appealing to a narrative of 'development' that nevertheless still concentrates on innovative practices. In a similar vein, Kathleen Jordan and Michael Lynch reject the term 'diffusion' in favour of 'dispersion' to disassociate their approach from the more rigid 'stage' models of technological change.[20] However, such exercises in semantics fail to address the fluid and messy relationship between innovation and diffusion, and the latter becomes somewhat subsumed within the former. Innovation maintains its position as the central area of interest and little effort is made to examine how diffusion affects the nature of innovation, or how the two interact.

Furthermore, the SCOT approach has tended to focus on the debate that surrounds new technologies while they are still controversial innovations. Behind this strategy (which also owes its origins to SSK) lies the idea that when technologies are new and controversial the discourses which underlie divergent opinion are more openly declared, or at least, more easy to detect.[21] Within medicine technologies which have become an institutionalised and accepted part of clinical practice do not tend to be openly debated until a rival technology is introduced, or in cases where its efficacy, safety or cost are called into question.[22] Thus if the intention is to concentrate directly on the dynamics of diffusion, on the way in which the

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[19] Bijker, W.E., (1992), 'The social construction of fluorescent lighting, or how an artifact was invented in its diffusion stage' in Bijker, W.E. & Law, J., (eds.), *Shaping technology/building society*, p. 97.

[20] Jordan, K. & Lynch, M., (1992), 'The sociology of a genetic engineering technique: ritual and rationality in the performance of the "plasmid prep"' in Clarke, A.E. & Fujimura, J.H., (eds.), *The right tools for the job*, pp. 77-114.

[21] For the benefits of focussing on controversies in science see Collins, H., (1982), (ed.), *Sociology of scientific knowledge*, Bath University Press, Bath.

[22] For an excellent account of the way in which scientific and technical black boxes are re-opened from a representational, semiotic perspective, see Latour, B., (1987), *Science in action: how to follow scientists and engineers through society*, Harvard UP, Cambridge, Mass.

uptake of technology is an active phenomenon, such controversy studies cannot be wholly relied upon to provide the necessary analytical tools. Most studies such as this appear to end as soon as the technology is placed into practice - be it in the home, in the factory or in the hospital.[23]

Even studies which attempt to give greater prominence to diffusion as a central feature of technological development have occasionally fallen into the trap of treating it as the final stage of development. Schwartz Cowan, for example, in an otherwise fascinating account of the significance of consumer choice embedded into wider social networks as an important theoretical tool for understanding diffusion, describes the process itself as the 'final stage' in the evolution of a technological system.[24] However, it will be argued in this thesis that the purchase of a technological option is *not* the end stage of development or 'evolution'. Instead, it is merely the point at which a technology's development is played out in a new arena. Rather than diffusion being a sign of its stabilisation or closure, the spread of technologies to new arenas and sites introduces even more opportunities for the negotiation and creation of heterogeneity: in other words, diffusion marks a shift in the nature of development. From the activities associated with 'systems builders'[25] or 'heterogeneous engineers'[26] located in very specific and specialised locations, diffusion marks the point at which the future of a particular technology is shaped by the activities of a whole new set of actors. These actors exist in the realm of daily practice: the home, the factory or the hospital. Thus, diffusion is not the end of a process but the junction where two forms of innovative activity meet. Schwartz Cowan's plea to focus attention on what she terms the 'consumption junction' is important, but not for the reasons she posits. What is interesting about consumption is not simply why people buy a certain technology (or why they do not) but what they subsequently do with it: how they make it work.

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[23] There are, of course, exceptions to this. See, for example, Latour, B., (1992), 'Where are the missing masses?'

[24] Schwartz Cowan, R., (1987), 'The consumption junction: a proposal for research strategies in the sociology of technology' in Bijker, W.E., Hughes, T.P. & Pinch, T.J., *The social construction of technological systems,* p.278.

[25] Hughes, T.P., (1987), 'Large technological systems'; *idem,* (1979), 'The electrification of America'.

[26] Law, J., (1991), 'monsters, machines and sociotechnical relations' in Law, J., (ed.), *A sociology of monsters,* pp. 50-63.; *idem*, (1987), 'Technology and heterogeneous engineering: the case of Portuguese expansion' in Bijker, W.E., Hughes, T.P. & Pinch, T.J., (eds.), *The social construction of technological systems,* pp. 111-34.

In this thesis it will be argued that innovation and diffusion are not mutually exclusive terms. Rather, they should be regarded as the dual dimensions of an inter-linked, dynamic process, which is continually on going. The introduction of obstetric ultrasound to each new hospital involved a learning process amongst those who used it and, importantly, the way in which new people and new locations adapted to it (and were simultaneously adapted by it) shaped the developmental path of the technology. New skills, new personnel, and new institutional arrangements represented new sites of interaction between people and ultrasound machines that resulted in the equipment being used in previously unimagined ways - stimulating further innovation.

Therefore, while in some circumstances it is necessary to draw a distinction between the original innovation of a new technology and its subsequent diffusion, it needs to be borne in mind that once the technology (and knowledge of it) has begun to spread to other areas and contexts the two processes become very closely interconnected. The initial diffusion of obstetric ultrasound, for example, did not automatically entail that it was a successful technology. Rather it was during its subsequent use in practice that its success emerged. This, of course, raises the obvious questions of what 'useful' means and by whose definition, but these questions are themselves part of the analysis and need to be regarded neutrally within each specific location and historical period. What is deemed a useful quality in a large urban teaching hospital may not be deemed so in a smaller, more remote local provider. This in turn might be related to where the machines are situated, who operates them and how they are used within the routine of antenatal provision. Each site, therefore, has to be regarded as a semi-autonomous unit before wider comparisons and generalisations can be made about the factors that affected the general success of ultrasound as a diagnostic tool.

The second major theme elaborated in this thesis concerns where the explanatory weight in accounts of technological development should be sought. As many of the more recent studies of technology have stressed, traditional accounts of technological change were oversimplified and reliant on uni-directional models of development.[27] In explaining why

[27] See, for example, Hughes, T.P., (1987), 'Large technological systems'; MacKenzie, D., (1996), *Knowing machines;* MacKenzie, D. & Wacjman, J., (eds.), (1999), *The social shaping of technology: 2nd edition,* Oxford UP, Oxford; Pinch, T.J. & Bijker, W.E., (1984), 'The social construction of facts and artifacts'.

certain technologies 'succeed' while others 'fail', authors traditionally fell into various forms of technological determinism. Even in its weakest form, such accounts relied on a teleological form of reasoning: certain technologies 'succeed' because they work, while others 'fail' because they do not. Thus the root explanation for the success of a technology rested solely on its technical capabilities. The only scope for social influence in such traditional accounts is unveiled through the distorted vision of hindsight. Social prejudice, lack of funding or commitment etc. can be used to explain the slow uptake of what will later emerge as a 'successful' technology, while the same types of vested interests can be used to explain why a technology which is later regarded as a failure is initially supported. Thus, as Pinch and Bijker note, while social factors were included in such accounts of technological development, they were used asymmetrically to account for 'anomalies' – departures from the 'ideal' model of technological development.[28]

More recent accounts such as SCOT, have adopted a more agnostic position in relation to the perceived 'success' or 'failure' of technological designs. In this respect, once again, SCOT took its lead from work within the sociology of science. The agenda that underpinned SSK (and particularly the Strong Programme of David Bloor and the 'Edinburgh school') was to uncover the social content of scientific theories.[29] Whereas earlier theories had emphasised and privileged the 'truth' and logic of science, SSK claimed instead that social structures and social relations provided the basis of scientific theory and that, therefore, all forms of scientific theory were inherently and primarily the product of social relations. Thus when applied to technology studies, the aim of SCOT was to deconstruct technical artifacts (such as the bicycle, the electric lightbulb, or the refrigerator) in order to expose their social roots.[30] To examine the history of obstetric ultrasound from this perspective would involve uncovering the social motivations behind its success. The analysis therefore would be focused on the various professional groups involved with ultrasound, or on the medical profession as a whole, or on the role of the state - depending on the level of analysis desired.

[28] Pinch, T.J. & Bijker, W.E., (1984), 'The social construction of facts and artifacts'.

[29] See Bloor, D., (1976), *Knowledge and social imagery*; Collins, H., (1982), *Sociology of scientific knowledge;* Collins, H. & Pinch, T., (1993), *The golem: what everyone should know about science,* Cambridge UP, Cambridge; Webster, A., (1991), *Science, technology and society: new directions,* Macmillan, London. For a critique of this approach see Pickering, A., (1995), *The mangle of practice*; Woolgar, S., (1981), 'Interests and explanation in the social study of science' *Social studies of science,* Vol. 11, pp. 365-94.

Thus, a social constructivist account would search purely in the realm of the social for answers to why ultrasound was created and why it took the form that it did.

However, through its prioritisation of the social, this perspective suffers from what could be termed 'social determinism'. An account which holds that it is the power relations in society and the workings of social influence which directly affect the development of ultrasound, appears to present the relationship between the social and the technical in a manner which is too simplistic.[31] Technologies like ultrasound are analysed as representing and reproducing the social relations which created them - as if the translation from social influence to technology was simple and direct. But is it always and necessarily as easy as this to get technical material to operate exactly as required? As Pickering has noted, technologies and material (or non-human) agents are not infinitely malleable; nor are their properties and abilities always predictable.[32] Rather, these emerge through interactions with social actors who 'tinker' with them to adapt the way in which they operate. Thus, while social influence may operate on the level of choice (in terms of which trajectories of research or practice are followed), this is an emergent and complicated process, in which 'choice' itself is as malleable in the context of what material agents do, as those agents themselves are.

Furthermore, over-reliance on social explanation can also lead to a conceptualisation of 'the social' as a static context which creates the world in its own image. In other words, social power and conflict (defined in terms of gender, class, ethnicity, professional self-interest, etc.) can appear to exist merely as stable causal explanations for other things - scientific facts or technical artifacts, for example. As Bernike Pasveer has shown in her study of radiography, stable social contexts do not always exist prior to the introduction of new technologies.[33] Pasveer's account of the development of radiology attempted to show that the content and context of that technology were both created simultaneously and inter-dependently. Thus at the same time as the technical content of the equipment and images were being constructed, a professional hierarchy with its own skills and knowledge was

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[30] Key papers here include the collected works found in MacKenzie, D. & Wajcman, J., (eds.), (1985), *The social shaping of technology*; Bijker, W.E., Hughes, T.P. & Pinch, T.J., (eds.), (1987), *The social construction of technological systems.*
[31] Pickering, A., (1995), *The mangle of practice.*
[32] *ibid.*
[33] Pasveer, B., (1992), *Shadows of knowledge*; *idem*, (1990), 'Knowledge of shadows'.

simultaneously emerging - a context within which the new form of practice could be enfolded. In this account of the development of x-rays, there was no stable social context in terms of a set of professional groups and interests, whose prior existence could be used to explain the emergence of the technology. In a slightly different vein, Bruno Latour's depiction of the power of the laboratory to reshape the wider world in his account of Louis Pasteur's attempts to reorganise French farming in order to reproduce the manipulation of the Anthrax bacillus made possible in the laboratory, also provides evidence of the malleability of social contexts.[34]

Thus traditional accounts of technology and social constructivist approaches view the relationship between technology and society from diametrically opposite perspectives. If a continuum were imagined between material reality and social reality, these perspectives would be placed at each end of that line. However, it would appear that neither of these approaches could really get to grips with what technologies are, with why they appear in the form that they do, or with their dynamic nature. As John Law insists, technology studies is a messy area in that the objects of inquiry do not fall neatly into any one of the traditional academic disciplines as a result of their 'hybrid' status as both social *and* technical objects.[35] Exclusively prioritising either the material/technical or the social as the main source of explanation, results in a perspective which is unable to analyse the interplay between the two. If instead, obstetric ultrasound is viewed not as the product of technical logic or of social influence, but rather as a form of practice which is essentially and necessarily composed of both material and social interactions, then the analysis can look in much greater detail at the way in which those interactions are carried out and at the way in which they produce change.

Therefore, in order to provide as comprehensive an account of technological development as possible, both technical, non-human factors and social factors must be analysed jointly.

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[34] Latour, B., (1993), *The Pasteurization of France,* (transl. Sheridan, A. & Law, J.), Harvard UP, Cambridge Mass. And London; *idem,* (1983), 'Give me a laboratory and I will raise the world' in Knorr-Cetina, K. & Mulkay, M., (eds.), *Science observed: perspectives on the social study of science,* Sage, London. For a critique of Latour's ideas in this area see Scott, P., (1991), 'Levers and counterweights: a laboratory that failed to raise the world' *Social studies of science,* Vol. 21, pp. 7-35.

[35] Law, J., (1991), 'Introduction: monsters, machines and sociotechnical relations'.

Concentration on inner technical logic alone, as has been demonstrated by the social constructivists, creates a lop-sided account which veils the social nature of man-made objects. However, prioritising the social aspects of technology and thus veiling the way in which the social is mutually dependant upon the material simply turns this lop-sided picture on its head.

One approach that has avoided the pitfalls of these two extremes is actor-network theory (ANT) which grew from the work of Bruno Latour and Steve Woolgar.[36] ANT makes use of a number of concepts such as delegation, enrolment and inscription, to characterise both technology and society as 'hybrid' entities which cannot easily or usefully be separated. That is to say, the human and the technical are enmeshed within large sociotechnical systems (or networks) and these networks form the basis of what is termed 'society'. Furthermore, according to Latour, technologies represent certain human actions and abilities which have been delegated to machines.[37] On the other hand however, when humans interact with machines, certain actions are demanded or 'requested' in order that technologies operate and function in a useful manner. Thus, what drives technological development for Latour, is the way in which technical solutions are continually sought to replace potentially unpredictable human action with predictable machinic action. In terms of the diffusion of obstetric ultrasound, therefore, such a perspective could be used to focus attention on the interactions between ultrasound equipment and new users in new locations.

Nevertheless, despite its overt emphasis on human/non-human interactions, and its attempt to provide a greater role for non-human (technical or material) actors in its characterisation of technological change, ANT falls short of a truly interactional account which preserves the key differences between conscious human action and technical or material action. As Pickering points out, by comparing machines with texts, Latour's approach analyses

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[36] Callon, M., (1987), 'Society in the making: the study of technology as a tool for sociological analysis' in Bijker, W.E., Hughes, T.P. & Pinch, T.J., (eds.), *The social construction of technological systems,* pp. 83-103; Callon, M., Law, J. & Rip, A., (eds.), (1986), *Mapping the dynamics of science and technology,* Macmillan, Basingstoke; Law, J. & Hassard, J., (eds.), (1999), *Actor network theory and after,* Blackwell, Oxford; Latour, B., (1996), *Aramis or the love of technology,* Harvard UP, Cambridge, Mass.; *idem*, (1992), 'Where are the missing masses?'; *idem*, (1987), *Science in action*; Latour, B. & Woolgar, S., (1979), *Laboratory life,* Sage, London & Beverly Hills.

[37] This aspect of Latour's work is most clearly elaborated in Latour, B., (1992), 'Where are the missing masses?'

technologies from a semiotic perspective (what is being asked of the user? what is the message conveyed? what competencies are required?). Furthermore, the concepts of delegation and inscription imply interchangeability between human and non-human forms of agency which does not always exist. It is manifestly the case that in a practical, material sense, technologies can perform actions which humans cannot. Ultrasound machines, for example, can turn inaudible sound into visual images, whereas humans cannot. Ultrasound machines can also 'see through' human skin, whereas humans cannot. There is, therefore, something qualitatively different about material, technical agency which needs to be maintained in any account of human/non-human interactions and technological change.

In *The Mangle of Practice*, Andy Pickering puts forward a more nuanced analysis of human/non-human agency in his account of the emergence of new forms of scientific culture.[38] The central metaphor in this work is the old-fashioned clothes mangle, used to squeeze excess water from wet clothes.[39] For Pickering, what goes into the mangle rarely looks the same as what comes out of the other end. Furthermore, how a garment will look once it has gone through this process is essentially unpredictable. The nature of the material, the shape and position of the garment, the skill of the operator, and so on, all interact to determine the eventual 'nature' of the post-mangle garment. Thus, as a metaphor for scientific practice, 'the mangle' represents the way in which the emergence of new forms of science (or the extension of scientific culture) is both inherently unpredictable and the result of the interplay of numerous factors. That is to say, scientific practice is not the result of either social influence or goals, nor the result of independent material circumstance. Rather, it emerges from a mutual 'mangling' of human and material agency which, in an intertwined and dynamic relationship with one another, mutually construct a particular scientific practice. There are, of course, alternative interpretations of the term 'mangle' that are more destructive in nature. Thus, to mangle can mean to destroy, mutilate, spoil, disfigure, and so on. Nevertheless, even within such definitions, the term continues to imply unpredictability, messiness and transformation, which are equally applied in Pickering's perspective on science.

[38] Pickering, A., (1995), *The mangle of practice.*
[39] The adequacy of the mangle as metaphor for scientific practice is, however, questionable. The human actor who turns the handle is ultimately in control of this technology.

Using the concepts of agency and emergent practice, this thesis will attempt to demonstrate that the process of diffusion, that the actual *practice* of obstetric ultrasound, was a constantly emerging phenomenon which created new forms of the technology in different areas and over time. Furthermore, using an approach which highlights the dialectic between the social and the material at the point of practice will allow the analysis to include the many diverse aspects of this complex technology. The various professional groups, ultrasonic waves, electronic gadgetry, computing systems, images, pregnant women, fetuses, hospital spaces, administrations and hierarchies are all important and inter-related dimensions of this practice, and therefore the role and relative prominence of each are at stake and open to re-negotiation in the emergent practices of obstetric ultrasound. In other words, these are the factors which are fed into the 'mangle' of obstetric ultrasound.

Adopting such an approach also provides a useful tool for examining the final theme which runs through the following chapters: the importance of spatial location and local contingent factors in the development of technology. Through a focus on the diffusion of obstetric ultrasound, subtle differences in the technology's adoption and development in different locations can be exposed. Thus the way in which the administration and organisation of specific clinical settings affected (and was affected by) the technology can be examined within the overall dynamics of diffusion. The changeover, for example, from its use in limited 'high risk' cases to its use as a universal screening technology occurred differently from location to location. Therefore, studying ultrasound's diffusion will provide an account of changes such as these *as they happened* in different locations and across time.

Indeed, the influence of spatial and geographical location on technological change is a factor which has been relatively neglected, particularly by the sociology of technology. This is often especially evident in the characterisation of professional groups, where there is a tendency to attribute a unified stance to a particular group, even when such unity does not exist. In relation to the development of ultrasound, for example, Edward Yoxen claims that while radiographers 'tend to be much more enthusiastic about the technology', midwives in some hospitals felt that performing scans would diminish their clinical skills.[40] However, he does not go on to investigate why the latter should be the case in only 'some' hospitals, but instead, goes on to make wider sociological comments about the receptiveness of midwives in general to ultrasound and therefore to imply reasons for the difference in attitude between midwives and radiographers. This type of analysis, however, excludes the influence of historical and site-specific developments in the relations between different professional groups with the technical realities of a new machine. That is to say, the specific historical and local space within which the social relationships between different professional groups are enacted is itself an important dimension of those relationships. For example, midwives who work within institutions where they are involved with the provision of ultrasound examinations point out the advantages of their wider professional knowledge of pregnancy in comparison with radiographers.[41] They consider themselves to have a more holistic approach, and note that women attending routine scans often want to ask questions relating to other aspects of their pregnancy.[42] When examined in the context of Yoxen's comments, it can be suggested that the attitudes expressed by midwives in relation to ultrasound can be distinguished on the basis of whether or not they are actually involved with the technology. Those who practice within institutions where midwives operate ultrasound express a different view from those who practice in hospitals where they do not. This can only be explained through an analysis of how ultrasound was developed in particular clinical settings in specific locations. Only then can wider generalisations be forwarded in a manner sensitive to local historical and institutional differences.

Methodology, or the 'heterogeneous engineering' of the historian

The early innovation of obstetric ultrasound was a Glasgow phenomenon carried out, initially, in two separate sites (the Western Infirmary in the city's west end, where Ian Donald and his team of co-workers applied the early prototypes, primarily using gynaecology patients, and the Royal Maternity Hospital in the east end, where Donald's

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[40] Yoxen, E., (1987), 'Seeing with sound: a study of the development of medical images' in Bijker, W.E., Hughes, T.P. & Pinch, T.J., (eds.), *The social construction of technological systems,* pp. 281-282. See also Yoxen, E. & Hyde, B., (1985), 'Seeing with sound: the development of ultrasound equipment in medicine' *Bulletin of the society for the social history of medicine,* No. 37, p.93.

[41] All three midwives in Aberdeen who were interviewed, and who provide routine ultrasound examinations, mentioned this. See Chapter 4.

[42] This is discussed in Chapter 4.

obstetric wards were located). In 1964, with the opening of the Queen Mother's Maternity Hospital in Yorkhill (only some 400 yards from the Western Infirmary) a further Glasgow location was added to the ultrasound map. The aim of this thesis is to track the further diffusion of the technology; to examine its adoption and use as a clinical tool in obstetrics in a variety of Scottish hospitals, from its commercial launch in 1963 to the beginning of the 1990s. What differences and similarities can be detected in the ways in which the technology was introduced, used and developed from location to location and through time? Who were the actors involved in transferring the technology and how did they achieve this? What transformations did the technology help to bring about in hospital and clinical organisation and, on the other hand, how did site-specific arrangements affect the development of ultrasound in each location?

In order to trace the nuances and diversity inherent in the diffusion of ultrasound in Scotland, a case-study approach has been adopted which traces the career of ultrasound in four separate hospitals. These are: the Queen Mother's Hospital; Aberdeen Maternity Hospital (which was the first Scottish institution outside of Glasgow to introduce ultrasound); Forth Park Maternity Hospital in Kirkcaldy, Fife; and the Lewis Hospital (later the Western Isles Hospital) in Stornoway on the Isle of Lewis. Other hospitals, such as the other Glasgow institutions mentioned above, or Ninewells Hospital in Dundee and Perth Royal Infirmary (which both played an early role in the diffusion of the technology) are mentioned where their contribution helps to shed light on events and developments within the four main case-study hospitals. These case studies represent the mixture of hospital provision available throughout this period, from large establishments located in major urban centres, to smaller hospitals located in small towns. The large urban hospitals provide tertiary referral healthcare as well as serving their own populations, and also provide teaching facilities for city universities. The smaller centres provide health care for the local community only. Furthermore, the mix of institutions included also allows the difference between urban and rural contexts to be examined. Ultrasound was not simply an urban phenomenon and the way in which local conditions shaped the nature of the technology's development in rural locations such as the Western Isles reaffirms the importance of examining this technology within its varied contexts. Thus an analysis of ultrasound's development within these different contexts should introduce enough variety to examine the effects of site-specific factors.

In *Science in action,* Bruno Latour makes a plea for researchers into scientific practice to 'follow the actors' - to listen to what actors have to say and follow their actions in the construction of scientific fact.[43] For Latour, the main advantage of this strategy is that it enables researchers to avoid the pitfalls of imposing or constructing grand narratives, which bear little relation to what scientists actually do and how they do it. Nevertheless, although such a research strategy is attractive, there are a number of problems associated with it. Firstly, as John Law notes, following actors too closely can present the danger of losing critical distance: of reifying the perspective of scientists as the only truth.[44] In other words, if only the accounts and actions of prominent scientists (or in this case doctors) are traced, the resulting narrative may only underline their power and importance. Thus, if the method employed is to 'follow the actors', care must be taken over which actors are chosen.

Furthermore, this form of methodology presents particular problems for the historian. Following actors is more easily achieved through an ethnographic approach where the researcher can observe interactions as they occur.[45] To access such interactions in the past rather than the present, the historian must rely on two main sources - written, archival evidence and oral testimony found in the memories of the actors involved. Both of these forms of evidence have slightly different advantages and disadvantages.

Much of the archival historical material used in this thesis was found in the Historical Collection of the British Medical Ultrasound Society (BMUS). This collection, which is currently held in the Queen Mother's Hospital, (although it is shortly to be transferred to the Greater Glasgow Health Board Archives) houses a wide variety of sources relating to ultrasound in medicine which would otherwise be scattered in a number of libraries and attics. It includes virtually complete runs of national and international journals devoted to the technology; a comprehensive collection of papers and correspondences by Professor Donald; advertising literature from manufacturers and retailers; a large collection of original images using various forms of equipment as well as a number of records relating to the use

[43] Latour, B., (1987), *Science in action.*
[44] Law, J., (1991), 'Monsters, machines and sociotechnical relations' pp. 11-12.
[45] Latour and Woolgar made particularly good use of such observational techniques in Latour, B. & Woolgar, S., (1979), *Laboratory life.*

of ultrasound at The Queen Mother's Hospital itself. To all of this can also be added the documents, correspondences and offprints of published papers donated by a number of prominent actors in the field of medical ultrasound. In addition, the BMUS Historical Collection also holds a number of ultrasound machines dating from the late 1950s to the 1980s, which are due to be transferred to the Hunterian Museum at Glasgow University. Thus, in essence, the BMUS archive itself exists as testament to the 'success' of this technology.

Nevertheless, the wealth of material collected in this archive cannot alone shed light on the diffusion of this technology. While it might help in accounting for the when and how of the diffusion of ultrasound, it cannot be relied upon to explain the why. Or, to phrase it another way, while the general pattern of ultrasound's diffusion can be traced using these sources, the nature and dynamics of that diffusion are not so obviously presented. What motivated individual hospitals to spend thousands of pounds on ultrasound equipment? What did they hope to achieve and were those hopes fulfilled? How did they interpret the meaning of the technology and did these interpretations change once it was put into practice? While it is possible to detect shadows (or echoes?) of these questions in, for example, reports of clinical cases submitted to specialist journals, or editorials, or letters to Donald, a full account cannot be attempted without including the perspectives of the wider group of actors who interacted with ultrasound.

Thus the material collected from the archival sources has been supplemented by the oral testimony of those involved with the introduction, use and development of this technology in each of the case study centres. In all over fifty interviews were conducted with obstetricians, radiologists, midwives, clinical physicists, engineers, general practitioners and radiographers as well as a number of women who received ultrasound during their pregnancies.

However, the pitfalls associated with the reliability of oral histories are legion.[46] Factors such as distortions of memory, hindsight, overelaboration of one's own role in what are later

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[46] See, for example, Perks, R., (1992), *Oral history: talking about the past,* Historical Association in association with the Oral History Society, London; Perks, R. & Thomson, A., (eds.), (1997), *The oral history reader,* Routledge, New York; Thompson, P., (1978), *Voice of the past: oral history,* Oxford UP, Oxford.

viewed as historical events, the tendency for events to be reconstructed afterwards as part of a more general life-long self narrative and so on, entail that evidence acquired through reminiscence and memory must be approached with caution. Furthermore, the methodology of collecting such testimonies presents its own potential problems including, for example, interviewer bias, the general power dynamics between interviewer and interviewee, and so on.[47]

Nevertheless, while acknowledging such potential pitfalls in the reliability of oral testimony, the fact remains that the memories of those involved with this technology provide a very useful and otherwise unattainable insight into how it was used and developed. As all historians are aware, any source - be it written, visual or verbal; contemporary or historical - is subject to any number of biases and distortions and thus all sources must be approached with caution. Therefore, while some of the forms of bias differ with the various types of resource used, the same critical perspective is nevertheless applied.

Furthermore, the nature of the research agenda itself shapes the type of approach taken to oral evidence. Social scientists who use qualitative methods often point to 'saturation' as the culmination of the research gathering process.[48] Thus, enough informants have been interviewed when the data collected shows clear evidence of the repetition of similar narratives - i.e. conducting more interviews does not yield more information. While such an approach might be regarded as ideal, it is nevertheless rarely possible with historical research. When attempting to reconstruct a past event by interviewing those involved there may be few potential interviewees to approach in the first place, or problems may be encountered in tracing relevant witnesses to events long after they took place, and thus a 'saturation point' is rarely achievable. Furthermore, this thesis is not a strict oral history but a reconstruction of events through the examination of a variety of sources. Interviewees were contacted using a 'snowball effect' (where each individual was asked to provide names of other potential interviewees) or through the tracing of actors mentioned in other places. To this oral testimony can be added the variety of other sources used – not only in written

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[47] Bryman, A., (1988), *Quantity and quality in social research,* Routledge, London; Dey, I., (1993), *Qualitative data analysis,* Routledge, London; Nachmias, C. & Nachmias, D., (1992), *Research methods in the social sciences, 4th edition,* Edward Arnold, Sevenoaks.
[48] Dey, I., (1993), *Qualitative data analysis*; Nachmias, C. & Nachmias, D., (1992), *Research methods.*

form but also in the form of visual images and physical artifacts. Thus specific events have been reconstructed (and deconstructed) from a variety of sources and therefore perspectives, reflecting the very heterogeneity explored in the narrative. In this way, the resultant narrative is itself the product of hybridisation - of the binding together of various pieces of evidence to construct a 'workable' account. If historical research can be compared with 'the mangle' in this scenario, then the historian is its 'heterogeneous engineer'[49].

Organisation of the thesis

In Chapter 1 the early development of obstetric ultrasound leading to its commercial introduction will be discussed. This chapter will focus on the activities of the group of clinicians and engineers based at Glasgow's Western Infirmary and the University of Glasgow's Department of Midwifery who successfully brought together industrial flaw detecting equipment and knowledge of the anatomy, physiology and pathology of the reproductive organs of female bodies to construct a medical imaging device for use in obstetric and gynaecological cases. The chapter will consider the number of social and technical modifications which were made and which culminated in a technology that 'worked': i.e., one that enabled clinical diagnoses to be made. In essence, this group of actors performed the role of 'heterogeneous engineers'[50] outlined by John Law in that they brought together various human and non-human elements in the construction of a new technology. Obstetric ultrasound, in other words, emerged from those activities but, crucially, was the outcome of both active human, social agency and the material agency of such diverse factors as the layout of the human body, the activity of piezo-electric crystals, mathematical calculations, physics and electronics.

Nevertheless, in order to 'succeed' ultrasound needed to find a place in the day-to-day organisation of obstetric medicine. Chapter 2 therefore examines the way in which ultrasound operators in different centres investigated the clinical potential of this technology and sought a practical role for its application in obstetrics. In this chapter it will be argued that a number of trajectories of research were taken. Here research is examined as a

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[49] Law, J., (1991), 'monsters, machines and sociotechnical relations'; *idem*, (1987), 'Technology and heterogeneous engineering'.
[50] *ibid.*

multifarious activity – in some cases 'research' meant organised, funded projects with clear research hypotheses and the end goal of publications. However, in other cases 'research' was a more *ad hoc* procedure, including, for example, 'tinkering' with equipment to produce better images. This chapter will also examine the way in which a 'community' of ultrasound workers began to emerge and at the way in which links and connections were made between like-minded individuals scattered in different locations. In essence, ultrasound workers in different locations attempted to act together to 'stabilise' ultrasound technology.

In the mid 1970s the nature of ultrasound scanning underwent a major transformation. One of the most notable aspects of this was the emergence of 'real-time' ultrasound equipment: forms of the technology that (through rapid image renewal) represented the movement of internal structures as well as their form. Another feature of change was the proliferation of types of scanner available and the increasing numbers of manufacturers and retail agents providing equipment. In Chapter 3 these developments are examined in the context of competing technological forms and consumer choices. New technology designs, some of which were developed in the clinic while others emerged from the research and development laboratories of commercial organisations, became increasingly available at this time and competed with one another in an ever-expanding ultrasound market place. The variety of equipment available and the number of small companies that emerged to produce and market them marked a definite watershed in the historical development of ultrasound. In this chapter the emergence of consumer choice in obstetric ultrasound will be explored by examining the heterogeneous factors that underpinned both consumer decision-making and subsequent usage. The qualities valued in the design of an ultrasound machine differed markedly from one context to another. Furthermore, many of these qualities did not emerge as important until after they were played out in practice. In other words, crucial technical attributes emerged at the point of practice – important features which were not necessarily related to the qualities which governed technological choices, but which nevertheless resulted in a new configuration of the technology.

Where Chapter 3 examines heterogeneity in the development of ultrasound, Chapter 4 considers a variety of strategies employed by ultrasound workers, government bodies and professional organisations whose goal was a greater standardisation of ultrasound practices.

Partly in response to the changing nature of the technology, and partly as a result of public debate over the technology's safety in the mid 1980s, various attempts were made to lay down guidelines and codes of practice for the training of operators and delivery of ultrasound services. Nevertheless, it will be argued that only very minimal standardisation was achieved and much of this existed simply as rhetoric. The reasons for this lay in the way in which the technology had been moulded to suit its working environments.

Finally, a coda to the main thesis has been included. Here the perceptions and experiences of thirteen women who received ultrasound at different stages in the technology's development will be presented. These accounts are intended to provide an alternative view of the history of this technology and thus are not directly related to the themes explored in the main body of the thesis. Nevertheless, in this section what will be stressed is that, just as ultrasound itself can be viewed as a heterogeneous and emergent phenomenon, so too the experiences of pregnant women can and should be regarded as multi-faceted and contingent. That is to say, for each woman exposed to ultrasound, a wide variety of social and technical factors shaped the nature of her experience. Factors as apparently diverse as previous obstetric history, attitude of operating personnel, position of the equipment in relation to the woman being scanned, accessibility of the clinic, the type of equipment used, and so on all contribute to the overall experience of an ultrasound scan. Thus while meta-narratives may appear attractive as aids for understanding the experiences of women (such as, for example, the medicalisation of the pregnant body, gender oppression in the field of obstetrics or the alienation of pregnant women in the face of the increasing technologisation of obstetrics), they nevertheless obscure the nature of those experiences more than illuminate them. Thus, as with technological development itself, heterogeneity should be embraced rather than glossed over, if an understanding of women's experiences with technology can ever hope to be achieved.

Contained within the following pages, therefore, is an account of the career of obstetric ultrasound in Scotland which emphasises the innovatory practices which are inherent in the technology's diffusion, and which strives to demonstrate the diversity and heterogeneity which existed in its adoption, application and reception.

Chapter 1

Heterogeneous engineering: from metal flaws to female bodies – the emergence of medical ultrasound in Glasgow

Introduction[1]

On July 21st, 1955, a strange experiment was carried out in the research department of Babcock and Wilcox - a heavy engineering firm based in Renfrew. Professor Ian Donald - obstetrician/gynaecologist and Regius Professor of Midwifery at the University of Glasgow - arrived at the factory with two cars laden with excised fibroids and cysts from his gynaecology patients.[2] The purpose of this visit was to see whether industrial flaw detecting equipment (used to locate flaws in metal welds) could distinguish between the different types of tissue. This equipment used piezo-electric crystals to create pulses of ultrasound. The sound waves would bounce off hidden structures and the returning echoes were displayed on an oscilloscope as a series of spikes. The height of the spike related to the intensity of the echo, while its position was measured by an on-screen time line.[3] The engineers at Babcock and Wilcox provided Donald with a large steak to use as a control and Donald was shown how to operate the equipment. The results, however, surprised even him:

> All I wanted to know, quite simply, was whether these various masses differed in their ultrasonic echo characteristics. The results were beyond my wildest dreams and even with the primitive apparatus of those days clearly showed that a cyst produced echoes only at depth from the near and far walls, whereas a solid tumour progressively attenuated echoes at increasing depths of penetration.[4]

In other words, with no prior experience of operating such equipment, Donald was able to distinguish one type of tissue from the other on the basis of the manner in which the ultrasound pulses were differentially absorbed and reflected. Fluid-filled cysts produced strong echoes only from the points at which fluid and membrane met, whereas tumours scattered the echo pattern – producing a number of 'blips' on the screen.

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[1] Some of the primary material on which this chapter is based was kindly made available by Dr Malcolm Nicolson, and was gathered as part of a Wellcome Trust project on the development of medical ultrasound in Glasgow (Nicolson, Fleming & Spencer, 'The development of medical ultrasound in Glasgow, 1954-1976', Grant award number 043174/Z/94). Any inaccuracies or erroneous conclusions are, however, my own and do not reflect the interpretations made by Nicolson *et al.* I would like to acknowledge my gratitude to the grant holders for allowing me to access this data.

[2] Donald's surgeon colleague, Mr. Wallace Barr, drove the second car.

[3] See McDicken, W.N., (1976), *Diagnostic ultrasonics, principles and use of instruments,* Crosby Lockwood Staples, London.

[4] Donald, I., (1974), 'Apologia: how and why medical sonar developed' *Annals of the Royal College of Surgeons of England,* Vol. 54, p.133.

The success of this first experiment encouraged Donald to investigate the potential of the technology in clinical diagnosis. In effect, this event marks the first link in a chain of events (equally influenced by luck, chance, effort and desire) culminating in the commercial production of the Diasonograph in 1963 – the world's first contact medical ultrasound scanner.

In this chapter, the evolution of ultrasound technology in Glasgow from flaw detection to medical diagnosis will be outlined. At the outset, it should be noted that Glasgow was not the only location where the possibilities of ultrasound's use in clinical diagnosis were investigated. From the late 1930s various attempts were made in a number of locations in Austria, Sweden, the USA and Japan, to image a number of biological structures. Accounts of these research activities are documented elsewhere.[5] However, the direct origins of the first form of *obstetric* ultrasound can be found in Glasgow in the late 1950s. There are already a number of publications dealing with the innovation of medical ultrasound in Glasgow which, taken together, provide a detailed reconstruction of the activities and experiences of Professor Donald and his colleagues.[6] The chronology and nature of the events which took place are thus already well-documented elsewhere and will not, in the main, be challenged here. Thus the intention of this chapter is not to simply (re)present the history of ultrasound's innovation, but rather to re-examine it from a slightly different perspective. Within the following pages, the complex and heterogeneous nature of

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[5] Blume, S.S., (1992), *Insight and industry: on the dynamics of technological change in medicine,* MIT Press, Cambridge Mass. and London, chapter 3; Woo, J., (accessed May, 2001), *A short history of ultrasound in obstetrics and gynecology, part 1,* (www.ob-ultrasound.net/history); Yoxen, E., (1987), 'Seeing with sound: a study of the development of medical images' in Bijker, W.E., Hughes, T.P. & Pinch, T.J., (eds.), *The social construction of technological systems,* MIT Press, Cambridge Mass. and London, pp. 281-303; Yoxen, E. & Hyde, B., (1985), 'Seeing with sound: the development of ultrasound equipment in medicine' *Social history of medicine,* No. 37, pp. 93-5.

[6] Blume, S.S., (1992), *Insight and industry*; Fleming, J.E.E. & McNay, M.B., (1999), 'Forty years of obstetric ultrasound 1957-1997: from A-scope to three dimensions' *Ultrasound in medicine and biology,* Vol. 25, No. 1, pp. 3-56; Levi, S., (1997), 'The history of ultrasound in gynecology 1950-1980' *Ultrasound in medicine and biology,* Vol. 23, No. 3, pp. 481-552; Nicolson, M., (unpublished paper), 'The experiment and the image: Ian Donald's first application of ultrasound to biological materials'; *idem.*, (unpublished paper), 'Ultrasound imaging and the anti-abortion debate: Ian Donald's clinical holism'; Nicolson, M. with Fleming J.E.E. & Spencer, I., (unpublished draft chapter), 'Ultrasound before Donald'; Oakley, A., (1984), *The captured womb: a history of the medical care of pregnant women,* Blackwell, Oxford, chapter 7; Woo, J., (accessed May, 2001), 'A short history of ultrasound;' Yoxen, E., (1987), 'Seeing with sound;' Yoxen, E. & Hyde, B., (1985), 'Seeing with sound'.

ultrasound's early innovation will be emphasised, by reconstructing the varied experiences of the clinicians and engineers involved.

In particular, the work of Ian Donald and his clinician colleagues will be compared with that of Thomas Graham Brown – the industrial engineer who formed part of the original three-man team of ultrasound workers in Glasgow. Brown was a young research engineer when, in 1956, he became involved with medical ultrasound. In the late 1950s and early 1960s he was chiefly responsible for the maintenance and development of prototype machines and thus played a prominent role in the technology's transformation into a clinical device. Nevertheless, Brown's contribution has been somewhat neglected in the accepted historical accounts, which have focussed far greater attention on the work of Donald. [7] Part of the reason for this lies in the fact that Donald's association with the technology is more widely known and, certainly within the medical profession, he is generally identified as its 'inventor'. Furthermore, as an eminent University professor, Donald had far greater opportunities to publish and present papers relating to his experiences than Brown. Thus much of the accepted account has been acquired through Donald's recollections. In presenting Brown's perspective on these events, it is not the intention of this chapter to cast doubt on existing versions of this narrative, but rather to augment them. Brown's account is different in that it focuses much greater attention on the engineering aspects of medical ultrasound, in comparison to the technology's medical dimensions. It therefore enables a more complex and multi-faceted reconstruction of innovation to be presented.

What will be highlighted is the way in which a variety of material agents were marshalled into relationship with one another by the innovative intentions of a number of human actors to create a 'working' practice. Furthermore, it will become apparent that this technology emerged from these activities in a manner not wholly envisaged by its human 'inventors'. In other words, through a process of trial and error, and through the interplay of material and human agency a new form of clinical practice emerged. In *The mangle of practice*, Andy Pickering characterises innovations of this nature as the outcome of what he terms a 'dance

[7] It is clear from reading Brown's interview transcripts and his written account of his role in the development of ultrasound, that he himself feels he has not been properly acknowledged as the 'inventor' of the compound sector scanner (or B-scanner as it became known). Nevertheless, this chapter should not be read as an attempt to argue Brown's case, but merely to present his perspective.

of agency'.[8] Human actors manipulate the technical or material dimensions of an existing technology or practice. They then wait and watch what occurs when the technology performs its part of the 'dance', before re-engaging to make changes and amendments in response. Thus, innovations in technique and/or technology are the emergent outcome of human and material interactions. The emergence of medical ultrasound in Glasgow between 1955 and 1963 can be characterised as the result of just such a 'dance of agency', with clinicians, engineers, and a variety of electronic, physical and biological components taking their 'turn' on the floor.

Furthermore, in their efforts to keep the medical ultrasound project afloat, the human actors involved developed a number of different skills and capabilities, and moved around in a variety of arenas. In these activities it is possible to spot resonances of what John Law describes as 'heterogeneous engineering'.[9] Operating in a variety of social and technical fields, the members of the Glasgow team facilitated the creation of a new entity: medical ultrasound. In other words, the technology that they created did not emerge in some pure sense from their social interests – it was not simply an embodiment or reflection of their goals, intentions and interests, *a la* Pinch and Bijker.[10] Instead, medical ultrasound *emerged* from a variety of technical and social interactions and activities, enacted in a number of arenas. Furthermore, the joining together of such disparate entities as sound waves, human pathologies, valves, electronic switches, oscilloscopes, etc., altered also the skills and capabilities of the human actors: they learned a new language and set of practices which had not previously existed, and which gradually emerged with the technology.

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[8] Pickering, A., (1995), *The mangle of practice: time, agency and science,* University of Chicago Press, Chicago and London.

[9] Law, J., (1991), 'Introduction: monsters, machines and sociotechnical relations' in Law, J., (ed), *A sociology of monsters: essays on power, technology and domination,* Routledge, London, pp. 1-25; *idem,* (1987), 'Technology and heterogeneous engineering: the case of the Portuguese expansion' in Bijker, W.E., Hughes, T.P. & Pinch, T.J., (eds), *The social construction of technological systems: new directions on the sociology and history of technology,* MIT Press, Cambridge, Mass., pp. 111-34. There are also a resonance between Law's 'heterogeneous engineers' and Thomas Hughes's 'systems builders'. See Hughes, T.P., (1999), 'Edison and electric light' in MacKenzie, D. & Wajcman, J., (eds), *The social shaping of technology: 2nd edition,* Open University Press, Buckingham, pp. 50-63.

[10] Pinch, T.J. & Bijker, W.E., (1984), 'The social construction of facts and artifacts; or how the sociology of science and the sociology of technology might benefit each other' *Social studies of science,* Vol. 14, pp. 399-441.

However, Donald's first experiment at the Babcock and Wilcox factory poses the question of what motivated him to apply a piece of industrial equipment to human biological tissues. Part of the explanation of how ultrasonic waves and human bodies first came into contact with one another in Glasgow, can be found in the influences of war, industry and medicine.

Following the sinking of HMS Titanic in 1912, a British meteorologist made the suggestion that sound waves could be used to detect underwater icebergs. Nevertheless, it was during the First World War that serious effort was made to develop a device to achieve this – although the primary 'target' had changed from icebergs to submarines. This work continued throughout the interwar period and during the Second World War major developments were made in the equipment used for what had now become known as sound navigation and ranging (SONAR). Within industry, it was Soviet physicist S.Y. Sokolov who first made the suggestion that reflected ultrasound waves could be used to image flaws within various materials in 1928.[11] It was not until 1945, however, that Firestone published his findings with the 'Reflectoscope' – the first commercially available A-scope metal flaw detector. Much of the innovation and early use of the Reflectoscope had been conducted as part of the US war effort and was therefore classified until the end of the war.[12] With post-war demobilisation in the 1940s, the skills and technical advances made during wartime were available to the industrial sector, further stimulating technological change.[13]

In addition to the work done in the military and industrial contexts, ultrasound technology had also begun to appear within medicine. In Austria during the late 1930s and the 1940s, the Dussik brothers created representations of the inside of the head by transmitting ultrasound through the skull. While their findings were later disproved (images produced by the Dussiks which claimed to display ventricles, were reproduced using empty skulls) their work did inspire others to investigate the technology's use within medicine.[14] By the early

[11] For a more comprehensive account of the early history of ultrasound see Blume, S.S., (1992), *Insight and industry*; Fleming, J.E.E. & McNay, M.B., (1999), 'Forty years of obstetric ultrasound;' Levi, S., (1997), 'The history of ultrasound in gynecology;' Yoxen, E., (1987), 'Seeing with sound'.
[12] Nicolson, M. with Fleming J.E.E., (unpublished draft chapter), 'Ultrasound before Donald'.
[13]This lends weight to Pickering's claim that the main developments in technoscientific culture occur in the overlapping dimensions of destruction and production. See Pickering, A., (1995), *The mangle of practice,* ch7; Pickering, A., (1995), 'Cyborg history and the World War II regime' *Perspectives on science,* Vol. 3, No. 1, pp. 1-48.
[14] Nicolson, M. with Fleming J.E.E., (unpublished draft chapter), 'Ultrasound before Donald'.

1950s Howry and Bliss in Denver, Colorado, Wild and Reid in Minnesota, Uchida in Tokyo, and Edler and Hertz in Sweden, were also investigating the technology's diagnostic potential.[15] Furthermore, a slightly different form of ultrasound had been used in therapeutics from the late 1920s. Unlike flaw detectors (which created images on the basis of reflected echoes of pulsed ultrasound), ultrasound therapy involved the continuous transmission of high frequency sound, which created heat in biological tissues. Thus the intention here was to effect change in tissue structures.[16]

However, the use of significant pieces of machinery within medicine was not without its precedents and ultrasound was by no means the first such technology to be used. Diagnostic radiology in particular could be regarded as a model for ultrasound – a diagnostic technique in which the body is exposed to radiation in order to create a shadow image representing the structures the rays encounter on their passage through the body.[17] In addition, it would appear that there was some scope for a new diagnostic device in gynaecology. The most commonly used method for diagnosing the presence of tumours or cysts was abdominal palpation. However, in obese patients this method was often inadequate. According to Donald this was one of the reasons for his interest in ultrasound, as a possible alternative to palpation.[18] Thus the context of ultrasound's military and industrial applications, the attempts being made by others to use ultrasound for medical diagnoses, as well as the use of other imaging techniques in medicine and the diagnostic problems associated with

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[15] Blume, S.S., (1992), *Insight and industry;* Fleming, J.E. & McNay, M.B., (1999), 'Forty years of obstetric ultrasound;' Woo, J., (accessed May, 2001), 'A short history of ultrasound;' Yoxen, E., (1987), 'Seeing with sound'. For a direct comparison of the work done by Howry and Bliss, and Wild and Reid, see Koch, E.B., (1993), 'In the image of science? Negotiating the development of diagnostic ultrasound in the cultures of surgery and radiology' *Technology and culture,* Vol. 34, pp. 858-893; *idem,* (1990), 'The process of innovation in medical technology: American research on ultrasound, 1947-1962' unpublished PhD thesis (University of Pennsylvania).

[16] Indeed, Donald's preference for the term 'medical SONAR' was motivated by his desire to distance his innovation from the potentially harmful effects associated with ultrasound therapy. Donald, I., (1969), *Practical obstetric problems: 4th edition,* Lloyd-Lukes (Medical Books) Ltd., London, chapter 28, p. 928; *idem,* (1976), 'The biological effects of ultrasound' in Donald, I. & Levi, S., (eds.), *Present and future of diagnostic ultrasound,* Wiley, New York and London, p. 21.

[17] See Wolbarst, A.B., (1999), *Looking within: how x-ray, CT, ultrasound, and other medical images are created, and how they help physicians save lives,* University of California Press, Berkeley, Los Angeles and London. See also Pasveer, B., (1992), 'Shadows of knowledge, making a representing practice in medicine: x-ray pictures and pulmonary tuberculosis, 1895-1930' PhD Thesis (University of Amsterdam), published by CIP-Gegevens Koninklijke Bibliotheek, Den Haag; *idem,* (1989), 'Knowledge of shadows: the introduction of x-ray images in medicine' *Sociology of Health and Illness,* Vol. 11, No. 4, pp. 360-81.

[18] Indeed, Donald claimed that obesity was especially prevalent amongst the women of Glasgow! Oakley, A., (1984), *The captured womb,* p.157.

palpation, render this early experiment understandable.

Nevertheless, in order to fully grasp how the apparently disparate entities of flaw detectors and female pathological growths came into contact with one in Glasgow at this particular time, a number of contingent and accidental factors need to be included. No small part of this rests with the unusual character of Donald himself.

Ian Donald was born in Cornwall in 1910 and was the third generation of a family of Scottish doctors.[19] Educated first in Scotland (at Warriston School in Moffat and Fettes College in Edinburgh) and later, after the family emigrated, in South Africa, he received his BA from Cape Town University in 1930. He then moved to London to train in medicine, going on to specialise in obstetrics and gynaecology in the 1940s. After two Readerships at St. Thomas's and Hammersmith's Hospitals in London, he arrived in Glasgow in 1954 to take up the Regius Chair of Midwifery at Glasgow University.

Donald appears to have had an active interest in mechanical devices and technologies since his childhood.[20] Indeed, prior to his research into ultrasound Donald had already become associated with various technical 'toys' – inventing a mechanical device for rinsing out bladders while he was a student, and working on a mechanical respirator for neonates with respiratory problems.[21] This predisposition marked Donald as an 'atypical' clinician in that his research was geared not toward the use of new clinical procedures or pharmaceuticals, but towards the utility of electro-mechanical equipment in his specialty. Indeed, Donald apparently was nicknamed 'Mad Donald' by some of his colleagues in London and caricatured as a crazy inventor.[22] In addition to Donald's technical predisposition, his experiences during the war also contributed to his later work with ultrasound. As a medical officer for the RAF, Donald did his service in the Azores, and on the island of Benbecula in the Western Isles, amongst other places. Whilst stationed on Benbecula, Donald was

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[19] A more detailed account of Donald's life and early career is being compiled by Nicolson, M., with Fleming, J.E.E., (forthcoming). See also Woo, J., 'A short history of ultrasound'.
[20] Nicolson, M., (unpublished paper), 'The experiment and the image: Ian Donald's first application of ultrasound to biological materials'.
[21] *ibid.*
[22] Willocks, J., (1996), 'Medical ultrasound – a Glasgow development which swept the world' *Glasgow University Avenue,* No. 19.

encouraged to perform additional duties. He thus became involved with the radar station and learned a technique that, while not identical to the operation of ultrasound, was nevertheless sufficiently similar to foster some familiarity. It was also during this period that the RAF was active in improving its sonar techniques and Donald was very much aware of these developments.

Nevertheless, the equipment that he initially used was a metal flaw detector rather than a military sonar device. In this respect, the socio-economic make-up of Glasgow itself comes into play. In the 1950s, the infrastructure of Glasgow was largely based on heavy engineering and shipbuilding. Thus the skills and technology that Donald would later help to integrate into medicine were very much present in the local area. Indeed, it was thanks to a grateful gynaecology patient, whose husband was an 'eminent' engineer at Babcock and Wilcox, that Donald was put in touch with that particular firm.[23]

One final event of significance occurred in London in the early 1950s when Donald was introduced to Dr John J Wild – who had already published his initial findings on clinical diagnoses using pulsed ultrasound.[24] This, it could be argued, created yet another link between ultrasound waves and human bodies in Donald's imagination.

It is clear, therefore, that even at this early stage in the history of the technology a number of factors (such as chance, personal interest, local infrastructure and industry, previous experiences, etc.) coincided to create the right circumstances for the development of medical ultrasound. Nevertheless, it is important to emphasise that this should not be read as an account of 'background' context, into which ultrasound can simply be slotted. Instead, such factors as Glasgow's industrial heritage should be viewed as one of the many influential factors that contributed to Donald's early experiment with ultrasound. Furthermore, the very fact that the experiment worked, that with little need for 'tinkering' the equipment produced a sufficiently clear distinction between different tissue types, played its part in carrying the enterprise forward. As Donald himself put it:

[23] Donald, I., (1974), 'Apologia'.

[24] Wild, J.J., (1950), 'The use of ultrasonic pulses for the measurement of biological tissues and the detection of tissue density changes' *Surgery,* Vol. 27, pp. 183-88. For an analysis of Wild's work see Koch, E.B., (1993), 'In the image of science?'

> Accident and good luck have combined at the right time to open up for our profession a new diagnostic dimension. No credit can be claimed for what is after all a coincidence...[25]

Creating a 'working' medical machine

There is a substantial difference between the direct scanning of excised cysts and fibroids, and scanning them while *in vivo.* Donald's next goal, therefore, was to acquire a machine that could be used in the hospital.

From Professor Mayneord in London, Donald was loaned a Kelvin Hughes Mark IIb 'supersonic' flaw detector. Mayneord, in conjunction with RC Turner had been experimenting with the device at the Royal Cancer Hospital (now the Royal Marsden), attempting to locate lesions and tumours in the brain by imaging the displacement in the midline echo.[26] These experiments had, however, been largely unsuccessful and Mayneord was somewhat disillusioned. Donald, on the other hand, was optimistic following his initial experience with the technology at Babcock and Wilcox. Nevertheless, his attempts to image the female body using the new equipment in The Western Infirmary were considerably less successful than his first experiment.

The most significant reason for this lack of success was that this machine was incapable of obtaining echoes from less than 8cms from the face of the transducer, which posed obvious problems for its use in both gynaecology and obstetrics. This was therefore a very important *material resistance* which Donald would have to accommodate. He could not simply apply the probe to the patient's skin and get it to perform for him - he had to find a way around the material realities of the equipment with which he was working.

In an attempt to accommodate the 'blind' 8cms, water-filled rubber buckets were employed to create a liquid barrier between the probe and the patient. Water is a good conductor of

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[25] Donald, I., (1974), 'Apologia' p.132.

[26] See White, D.N., (1988), 'Neurosonology pioneers' *Ultrasound in medicine and biology,* Vol. 14, pp. 541-61.

ultrasound,[27] and so the principle underlying this accommodation was to artificially extend the distance between the bodily structures of interest and the probe. However, the interface between gas and water is a strongly reflective surface. Thus Donald had to attempt to prevent air becoming trapped between the bucket and the surface of the skin. In addition, therefore, Donald experimented with a variety of gels and oils to couple the water barrier to the patient's skin, a rather more messy procedure in practice than in theory:

> It does not take much imagination to think of the bizarre situation of balancing a bucket with a plastic bottom and filled with water on top of a female abdomen smeared with coupling oil and then trying to interpret echoes using a probe dipped gingerly into the surface. Accidents resulting in wet beds were frequent and the echo information, such as it was, proved unintelligible.[28]

While this account might be somewhat amusing, it should be remembered that many of Donald's gynaecology patients were elderly women. Wet beds also entailed wet patients, for which Donald incurred the wrath of the Matron.[29] Donald experimented with other means of achieving a water 'stand-off' including water-filled balloons and, eventually, condoms. Purchasing the latter in bulk was not particularly straightforward in the late 1950s. One particular anecdote recalled by Donald is worth presenting in full:

> I was being visited in Glasgow at the time by my old friend the late Professor James Louw of Cape Town University and on passing the top end of West Nile Street he said he would run into one of those shops that sell rubber goods and buy me a collection, as he himself was not known in this town. However, to the astonishment of the person behind the counter who asked whether he wanted plain or teat ended condoms he said he did not know but would run out to the car and find out.[30]

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[27] It is interesting to note that this material property of ultrasound was not the spur for the development of the 'full bladder technique' - where the patient is asked to fill her bladder to provide a sounding tank for the ultrasonic waves. Rather, this technique was a discovery made years later and seemingly accidentally (see Chapter 2).
[28] Donald, I., (1974), 'Apologia', p.134.
[29] Donald, I., (1974), 'Sonar – the story of an experiment' *Ultrasound in medicine and biology,* Vol.1, p.110
[30] *ibid.*

At this time, Donald was receiving technical help from the medical physics staff of the hospital, who were also part of the Regional Physics Department. This department, which had been formed in 1953 by Professor John Lenihan[31], provided both on-site medical physicists and a wider network of specialists in the area. Thus Donald was provided with a physicist to assist in his endeavours to produce readable, understandable images with, however, little success.

It was at this point that luck and accident again played a part, with the arrival of Tom Brown. Thomas Graham Brown was a young research engineer at Kelvin Hughes, Ltd. – the company who had supplied Donald's flaw detector. Although Brown was only twenty three years of age, and still a trainee engineer, he had worked on the design of an automatic ultrasound scanner for industrial testing (to assess welds in metal structures) in 1953. However, in 1956, when he became involved in Donald's project, he was no longer working in the area of ultrasonics, but on what he terms a 'very lowly' project designing smoke detectors for factory chimneys.[32] Friends of Brown from Kelvin Hughes (who were installing an experimental shadowless lamp in Donald's operating theatre)[33] mentioned that the doctor there was 'using a flaw detector on people'.[34]

> Not knowing any better, I looked Donald up in the book, and telephoned him that evening. He was friendly and very courteous, but told me that he had all the technical help he needed from Dr. John Lenihan's 'Regional Medical Physics Department'. However I was welcome to come and see what he was doing.[35]

This is how Brown recollects the scene which confronted him when he arrived at the Western Infirmary to see Donald's machine in action:

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[31] Lenihan's PhD thesis was on acoustics, measuring the speed of sound using pulsed sound waves (Lenihan, J., (1948), 'The velocity of sound in air' unpublished PhD thesis (University of Glasgow). It was thus perhaps unsurprising that he should show at least some interest in Donald's endeavours.
[32] Brown, T., (unpublished paper), 'Development of ultrasonic scanning techniques in Scotland, 1956-1979: personal recollections of T.G. Brown' (British Medical Ultrasound Society (BMUS) Historical Collection).
[33] This also highlights the inter-relatedness of the industrial and clinical fields when connections between manufacturing firms and clinical departments are made. Nevertheless, the relationship between Donald's department and Kelvin Hughes would get more intimate over the next few years.
[34] Brown, T., (unpublished paper), 'Development of ultrasonic scanning' p.2.
[35] *ibid.*

> One of the things that was noticeable about it [the machine] was the front panel had a gaping hole in it where somebody had been at it with a hacksaw. Also sitting on the trolley was a big jar of Vaseline and a glass cylinder about 10 inches long and about two and a half to three inches diameter, open at both ends, and a large jug of water and plenty of towels. So the patient was wheeled in and the Professor in his best bedside manner pulled back the covers exposing this large abdomen. He picks up the glass cylinder and smears one end with Vaseline and sort of brings it on to the abdomen, picks up the jug of water, fills the cylinder up with water and then picks up the probe and sticks it in the end. ... [T]he real fun started when he tried to get the water back out of the cylinder and into the jug, which is why there was plenty of towels.[36]

Brown realised there and then why the clinician was having so much trouble creating images. First of all, although the flaw detector was a Kelvin Hughes design, it was not actually manufactured by the firm. It dated from the latter part of the war years and had been made by another company to Kelvin Hughes's specifications under a Ministry of Supply contract. More importantly, however, the Mark IIb had been designed to have two separate probes – one to produce the pulses of ultrasound and the other to pick up the returning signal. What Brown noticed was that at some point this particular machine had been modified (inadequately, by 'someone who should have known better'[37]) so that one probe could both transmit and receive the sound waves:

> ...[I]t had been 'converted' to a single-transducer operation by simply connecting the output of the transmitter pulser more-or-less directly into the amplifier input. This caused the amplifier, never designed for such insult, to go into complete paralysis for several hundred microseconds, before staggering back into some degree of normal function. ... Donald had to arrange some sort of water standoff to allow the amplifier to de-saturate before echoes started to come back from the patient.[38]

Not wishing to insult the physicist from Lenihan's department who was also present, by explaining what was causing the problem, Brown diplomatically offered to try and get

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[36] Tom Brown, interviewed by Ian Spencer, (courtesy of Nicolson, Spencer and Fleming).
[37] *ibid.*
[38] Brown, T., (unpublished paper), 'Development of ultrasonic scanning' p.3.

Donald a 'newer' machine – i.e. one which had not been tampered with. Again, Brown's account of how he 'acquired' a new machine is interesting, not just in terms of its historical significance, but also in terms of the expediency and luck involved in the event. The man for whom Brown had worked on the automatic flaw detector (Alex Rankin) was now based at Kelvin Hughes's main factory at Barkingside in London:

> So I phoned up Alex … and explained the situation to him. Alex never respected formalities so the next thing was I got a phone call, 'Tom, get yourself into Glasgow Central Station, you will find there is a package for you'. Here was a brand new Kelvin Hughes Mark IV flaw detector, £600 worth in 1956, (a lot of brass), in its original packing, brand new. It weighed a tonne.[39]
>
> I didn't drive then, but got that brute of an instrument out of the station and into a taxi, and up to the Western Infirmary, then onto a patient cart, and up to Donald's Gynaecology Unit.[40]

Thus, Donald was unofficially 'gifted' the latest model of flaw detector made by Kelvin Hughes and at the same time Brown was secured a position in the team. As it would turn out, despite the fact that the improvements which came with the new machine were considerable ('the results were as different as chalk and cheese'[41]), in the long term it would be the technical expertise which Brown brought to the team which was most significant about this event.

Brown's arrival, however, effectively drove a wedge between the ultrasound workers and Lenihan's department. In Brown, the team had the experience with ultrasound technology they had previously lacked and which, in that sense, superseded the expertise which could be offered by Medical Physics at that time. It must be remembered that the remit of Medical Physics extended to much more than simply the innovation of a medical ultrasound device and at this time Lenihan himself was busy building up his department, which was the first

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[39] Tom Brown, interviewed by Ian Spencer, (courtesy of Nicolson, Spencer and Fleming).
[40] Brown, T., (unpublished paper), 'Development of ultrasonic scanning' p.3.
[41] Tom Brown, interviewed by Ian Spencer (courtesy of Nicolson, Spencer and Fleming).

regional service of its kind in the UK.[42] The physicist from Lenihan's team who was previously involved in the project, Dr Greer, gradually disappeared from the scene as the young engineer from Kelvin Hughes increasingly upstaged him. It would appear that this caused something of a rift between Lenihan and Donald, which was not really reconciled until the late 1960s, when Lenihan's department began taking a much more direct and active role in the diffusion of ultrasound.[43]

On the other hand, as an engineer for Kelvin Hughes, Brown was able to provide a link between the medical workers and the commercial interests of his firm. Thus the arrival of Brown marked the start of a longstanding relationship between Donald's project and Kelvin Hughes which would last until the company finally ceased its activities in ultrasound in 1966.[44]

In addition to the new scanner, Brown was also able to 'scrounge' an oscilloscope camera, which could be used to record the scan on 35mm film. The different goals and intentions of the team members are nicely illustrated in their attitude to this extra 'acquisition'. For Donald, this camera was very significant indeed. Not only did it enable some form of record to be kept of the scan, it also meant that actual scan images could be printed in any published work. For him, publishing an account of his work in the appropriate peer review journals was a necessary prerequisite if his innovation was going to make it to a wider audience. As Latour has noted in the context of science, publications and the translation of scientific activity into textual representations are an important means of enrolling peer support for a new idea.[45] For Brown, on the other hand, it was simply another thing he had managed to illicitly obtain; he already had other concerns on his mind.

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[42] The fact that Scottish teaching hospitals were managed by Regional Hospital Boards, rather than individual boards of governors as they were in England, made the Scottish system more amenable to the development of such regional services.

[43] See Chapter 2. Brown attributes some of the apparent acrimony which developed between Lenihan's department and Donald's project team in this early period to his own over-enthusiasm and lack of diplomacy: 'unfortunately, I am about as tactful as a JCB in a hurry' (Tom Brown, interviewed by Ian Spencer, (courtesy of Nicolson, Spencer & Fleming)).

[44] Kelvin Hughes merged with Smiths Industries in 1961. The factory at Hillington was closed in 1966, after Smiths pulled out of Scotland. At this time the medical ultrasound interest was sold to Nuclear Enterprises. See Chapter 2.

[45] Latour, B., (1987), *Science in action: how to follow scientists and engineers through society,* Harvard UP, Cambridge, Mass., ch.1.

One group, two projects

It was at this time that the different backgrounds of the engineer and the clinician brought divergent goals and intentions to the fore. In a sense the ultimate goal remained the same – both Brown and Donald were aiming to produce clinically reliable images which could be repeated and used in actual practice for diagnoses. However, the way in which they approached this goal differed considerably.

Armed with his new and easier-to-use scanner, Donald set to work establishing the parameters of the images produced by the A-scope display. In other words, he sought a way of looking at the 'right' blips on the screen: interpreting the vast amount of information generated into adequate 'rules of thumb' for what type of echo display corresponded to what type of structure. It was at this point that Dr John MacVicar[46] joined Donald in these clinical investigations, completing the three-man team who co-authored the first publication in 1958.[47]

By 1956/7, Donald and MacVicar were building up considerable experience using the A-scope machine – scanning hundreds of cases (although not yet using the technology as a practical diagnostic tool). Nevertheless, their interest in, and enthusiasm for, the equipment was a source of mirth amongst some of their clinician colleagues. For example, according to MacVicar:

> Even after our first publication in 1958 an eminent gynaecologist summed up the use of ultrasound as only being of use to gynaecologists who were deaf, dumb and blind and had lost the use of their hands![48]

What particularly appears to have amused them was the technological complexity of Donald's approach to the differentiation of structures which, for them, could easily be

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[46] MacVicar was appointed as a Registrar in the Department of Obstetrics and Gynaecology in 1956. He remained in Glasgow (as Lecturer and then Senior Lecturer) until 1974.

[47] Donald, I., MacVicar, J. & Brown, T.G., (1958), 'Investigation of abdominal masses by pulsed ultrasound' *Lancet,* Vol. 1, pp. 1188-95.

[48] This was included in an obituary, written by MacVicar following the death of Ian Donald in 1987. BMUS, (1987), *Bulletin of the BMUS,* No. 46, September, p.6.

achieved through abdominal palpation. Indeed, this epitomises the difference between Donald's approach to his role as a gynaecologist/obstetrician and that of the majority of his fellow-professionals. Donald's predisposition towards technology and electronic equipment lay in stark contrast to the attitude of most other clinicians in his field at the time. In their view, twiddling with electronic equipment and so on was not what gynaecologists and obstetricians did and they did not see the benefit of using such equipment when the 'traditional' skills of their profession seemed perfectly adequate. In this respect, the difference between Donald's method and that of other obstetricians can be characterised as a conflict between the 'art' and 'science' inherent in 20th century medicine as identified by Chris Lawrence.[49] Donald and MacVicar's more 'scientific' approach was considered by some of their peers as unnecessary, given the skills and tacit knowledge of traditional practices. Thus Donald's activities were far from characteristic of his profession, which in part explains the mirth, and occasional hostility, which he received at the hands of certain of his colleagues.

An important breakthrough for Donald in this respect came when he and MacVicar successfully diagnosed a large ovarian cyst with their machine, in a patient who had been diagnosed (clinically - via palpation, and radiologically) with cancer of the stomach:

> My medical colleagues were gathered round to see the demonstration and I had explained that I expected to find bowel echoes floating up towards the centre. You can imagine my dismay when on applying the probe to the most protuberant part of the patient's abdominal wall there were no bowel echoes to be seen in this area but simply a large clear space presumably of fluid with a very strong echo at great depth almost off the screen. Just at this moment Dr. MacVicar came looking for me, poked his head over the screen and commented, 'Seems a large cyst.' I apologised, of course, to my medical colleages [sic] and modestly pointed out that the machine might not be working very well.[50]

[49] Lawrence, C., (1985), 'Incommunicable knowledge: science, technology and the clinical art in Britain, 1850-1914' *Journal of contemporary history,* Vol. 20, pp. 503-20.
[50] Donald, I., (1974), 'Sonar – the story of an experiment' p.111.

The fact that the diagnosis had been made by the Professor of Medicine, who was also present at this demonstration, added further significance to this event, as John MacVicar recalls:

> I remember Professor Donald kicking me under the bed-screen and saying, 'Not at all, it is a malignancy, the Professor of Medicine says so.' So I kept quiet after that.[51]

MacVicar, however, stuck with his interpretation. The woman was referred for a laparotomy and a large, mucinous ovarian cyst was removed. She duly recovered, and her recovery simultaneously provoked greater interest in Donald's research, both from the engineering firm of Kelvin Hughes and from colleagues. Here again the dialectics of the relationship between the technical and the social are very much evident. The success of this demonstration of his equipment (in terms of its ability to diagnose; to inform clinical treatment - in other words to do something which in its absence would not have been possible without surgery) caused a re-alignment and re-evaluation of outsider impressions of the technology. This was not brought about wholly by Donald's confident promotion of his machine or by the team's general enthusiasm regarding its potential. Rather the material properties of ultrasound were shown to 'work' in this demonstration and therefore those material/technical properties themselves also contributed to a change in attitudes.

The effect of Donald's poignant demonstration of his equipment's capabilities was two fold. First of all, in all likelihood, it boosted the Glasgow ultrasound team's confidence in the future of their work, providing them with renewed vigour. In addition, however, it effectively removed the very core of the weapon used to scorn the innovation amongst those not associated with the project - i.e. that it was of no clinical benefit. Had Donald's diagnosis been wrong, due to some hitch or problem in the mechanics of the machine, the weight that this may have added to the views of his sceptics might have proved difficult to overcome. Instead, the success of this demonstration may have added immeasurable impetus to the technology's development. At the very least, doubting colleagues would have been

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[51] Tansey, E.M. & Christie, D.A., (eds.), (2000), *Wellcome witnesses to twentieth century medicine, volume 5. Looking at the unborn: historical aspects of obstetric ultrasound,* Wellcome Trust, London, p.19.

forced to re-define the grounds of their objections to the technology; at most, to re-evaluate their stance.

This is not to argue, however, that opposition to ultrasound as a clinical tool was straightforwardly and simply overcome through the equipment's technical capabilities alone. As a number of authors have noted, controversies over new ideas, techniques or technologies are never closed as the result of one single factor.[52] Successful experiments or demonstrations are often refuted through an appeal to contingent factors, errors in experimental design, extraneous variables, etc. [53] Thus, even in the late 1960s, the clinical utility of ultrasound was still questioned:

> ...one of my alleged friends from the rival city of Edinburgh rewarded our hospitality by declaring to a hilarious group of students that in Glasgow we were employing a machine costing more than £10,000 in order to diagnose an ovarian cyst which he could feel with a two-penny glove.[54]

Rather, it would take several years of sustained promotion on the part of the Glasgow team through the training of future specialists; dissemination of knowledge about ultrasound and its advantages via the medical journals; and dispersal of pro-ultrasound clinicians from Glasgow to other hospitals, to convince the majority of fellow practitioners that the technology was a useful diagnostic instrument.[55] The foundation upon which such promotion was based (in terms of the knowledge and utility claims used) was interwoven with the emergence of the technology as artifact and practice.

While Donald and MacVicar worked on the clinical underpinning of the A-scope, Tom Brown was effectively working to supersede this form of imaging altogether. For Brown

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[52] Barnes, B., Bloor, D. & Henry, J., (1996), *Scientific knowledge: a sociological analysis,* Athlone, London; Mulkay, M., (1991), *Sociology of science: a sociological pilgrimage,* Open University Press, Milton Keynes; Pinch, T.J. & Bijker, W.E., (1984), 'The social construction of facts and artifacts'; Shapin, S., (1982), 'The politics of observation: cerebral anatomy and social interests in the Edinburgh phrenology disputes' in Collins, H., (ed.), *Sociology of scientific knowledge,* Bath University Press, Bath.

[53] In relation to experimentation, the appeal to extraneous factors to explain the 'failure of one's own experiment, or the 'success' of a rival's is also known as the theory of 'under-determination' or the Duhem-Quine principle. See for example the Pasteur/Pouchet debate in Collins, H. & Pinch, T., (1993), *The golem: what everyone should know about science,* Cambridge UP, Cambridge; Latour B (1987) *Science in action.*

[54] Donald, I., (1976), 'The biological effects of ultrasound' p.21.

[55] This process will be outlined in much greater detail in the following chapters of this thesis.

(used to the A-scan display in metal welds and structures) the differences between that and the images created by ultrasound in the human body were immense. First of all, in his view, there was too much information coming back in the echo pictures. Human bodies are considerably less uniform and predictable than metal structures. The sheer number of different tissue types, organs, fluids etc in the body created a whole variety of echoes of different magnitudes and sizes. Furthermore, with the long pulses generated by the quartz crystals any number of additional factors affected the resultant echoes: closely adjacent echoes would interact with one another, any movement of the probe would create more echoes, the normal movements of the body's respiratory and cardiac cycles etc., all affected the resultant images. Thus, the very wealth of information generated was regarded in itself as a problem for Brown.[56]

In essence, therefore, what Brown wanted to do was delineate 'fact' from 'artifact' in the image; to find some way to cancel out the echoes that were of no interest to him and only leave the ones that were. In doing this (deciding which echoes were important and which were not) he was effectively 'creating' a reality for the images – deciding on the basis of the clinical interests of this particular medical specialty which echoes were 'real' and which were 'not'.[57] In other words, he wanted to 'render' the image in a way which would be more useful for gynaecological diagnosis.[58]

Brown interpreted the problem as a mismatch between the way in which the echoes were displayed and the information required. The moving timeline of the A-scope provided the only indication of the whereabouts of the structure being imaged: the further along the timeline a 'blip' was, the deeper in the body it was located. While this was all that was necessary when scanning metal welds looking for flaws, it was totally inadequate for imaging humans in Brown's opinion. In other words, the image and the structures did not correspond closely enough. As David Bloor has highlighted, an enduring characteristic of

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[56] Brown, T., (unpublished paper), 'Development of ultrasonic scanning' p. 4.

[57] A similar account of such activities in radiology can be found in Pasveer, B. (1989), 'Knowledge of shadows'.

[58] For different analyses of the process of rendering images see Latour, B., (1986), 'Visualisation and cognition: thinking with eyes and hands' *Knowledge and society: studies in the sociology of culture past and present,* Vol. 6, pp. 1-40; Lynch, M., (1985), 'Discipline and the material form of images: an analysis of scientific visibility' *Social studies of science,* Vol. 15, pp. 37-66; Yoxen, E., (1987), 'Seeing with sound'.

scientific knowledge is the belief that the scientific method facilitates a closer correspondence between 'nature' or 'reality' and human knowledge than other forms of belief.[59] In this respect, Brown's intentions can be characterised as driven by the desire to present a more 'truthful' representation of the contents of the uterus. Ironically, however, to achieve this, the images were constructed using a greater degree of manipulation and technological sophistication – arguably shifting them further away from any 'true' representation.

There was, however, one further dimension to Brown's assessment of the equipment. As well as the mismatch he perceived between the echoes and the display, he also crucially saw this as involving a mismatch between the display and the human operator. Brown felt that the enormous wealth of information presented in the A-scope was unreadable because of the way in which humans visualise and perceive:

> In other words, and it is a theme I was to come back to time-and-time again in the rest of my career, there was a gross mismatch between the manner in which the data was being presented, and the perceptual faculties of the observer who had to utilise it.[60]

What is interesting about this is not only that Brown (unlike Donald and MacVicar) was thinking like an engineer, but also that, crucially, he was thinking like a non-clinician. When viewing the ultrasound images, Brown drew on his skills in engineering and compared ultrasonic representations of the human body with his industrial engineering knowledge of ultrasound representations of metal structures. The former he viewed as far more complex than the latter, rendering the image far too difficult to read in its current format. Donald and MacVicar, on the other hand, had a whole series of different skills with which to make sense of the information the images afforded. Their knowledge of human anatomy, their skills in palpation, their knowledge of the symptoms associated with various pathologies and so on, afforded them other avenues of meaning and interpretation that were different from Brown's.[61] That, of course, is not to suggest that these skills enabled them to interpret all of

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[59] Bloor, D., (1991), *Knowledge and social imagery,* Chicago UP, Chicago.
[60] Brown, T., (unpublished paper), 'Development of ultrasonic scanning' p.4.
[61] In other words, they could utilise both the 'art' (intuitive knowledge, experience, skill, etc.) and 'science' of their profession. See Lawrence, C., (1985), 'Incommunicable knowledge'.

the information in the scan. Furthermore, as demonstrated in the case of the misdiagnosed cancer described above, clinical knowledge could not be wholly relied upon to make sense of the ultrasound data. Nevertheless, it does mean that ultrasound could be compared and contrasted with a host of other technologies, practices and 'ways of knowing' to generate clinical meaning from the image. Thus the previous experience and knowledge of Brown, and of Donald and MacVicar led them to interpret the images in a subtly different manner. Nevertheless, the interactions between the two sets of actors, and their interactions with the new imaging modality of *medical* ultrasound, meant that engineering and medical knowledge and experience were brought together in a way which transformed both. Thus, while it is tempting to simply attribute Brown's 'interpretation' of the equipment to the fact that he was an engineer, it was also crucially shaped by his position as an engineer in a clinical environment.

In this example, the dual concepts of 'interpretative flexibility' and 'relevant social group' developed by Pinch and Bijker in their analysis of technological change are inadequate to explain Brown's activities.[62] Brown's approach was governed neither by his association with a certain group (engineers, engineers who work in ultrasonics, etc.) nor in a sense solely by his interactions with the technology itself. Instead, the way in which Brown interpreted medical ultrasound was shaped by both of these factors *and* by his relationship *vis à vis* another set of social actors, *and* by the nature of the environment in which he worked. Therefore, to explain how Brown formed his interpretation of the A-scope machine requires an account which is more nuanced and less simplistic than the concept of 'relevant social groups'.

The solution proposed by Brown to overcome the deficiencies he perceived with ultrasound in this particular medical context was to devise a way in which to plot or graph the position of the various echoes generated. In other words, he wanted to find some way to make the images into a two-dimensional 'picture' and the solution he proposed was to develop some kind of cross-sectional image.

[62] Pinch, T.J. & Bijker, W.E., (1984), 'The social construction of facts and artifacts'.

While this idea marked a radical departure from the approach currently being taken in Glasgow, it was not a completely new concept. In Denver, Colorado in the early 1950s, radiologist Dr Douglas Howry and electronics engineer Rod Bliss had developed a similar approach.[63] However, their technique (which involved immersing the subject in water tanks – the first of which was constructed from an old gun turret) was centred on producing single sector images by rotating the probe around the patient in a linear plane. What Brown eventually produced was something of a hybrid between the A-scope and the sector scans of Howry, producing a two-dimensional 'map' of the pelvic area. Brown, however, claims to have been unaware of this previous work and indeed, in hindsight, considers this to have been an advantage:

> One of the things that is often asked is this. Were we aware at that time, or was I aware at that time, of the work done by Douglas Howry? The answer is, curiously, 'no'. Perhaps we should have been. ... However, I think that had we been aware of what Howry was doing, and had set out our stall to improve on Howry's work, we would have been stuck with immersion scanning.[64]

Nevertheless, there are enough similarities between the approach taken by Brown and that taken by Howry, to make the fact that Brown was unaware of this work very intriguing. It is, of course, possible to argue that Brown's general sense that his contribution to the development of medical ultrasound has been undervalued, has led him to re-evaluate his role and, perhaps, over-emphasise the uniqueness of his work. On the other hand, Brown was not a medical physicist but an industrial engineer and, given that Howry and Bliss published their work in clinically oriented journals, it is entirely possible that Brown did not know of it. Brown's explanation was that no systematic literature search was carried out before the compound sector scanner was built. The project was not a traditional scholarly one, but an industrial feasibility study for Kelvin Hughes, which would be followed up at a later date by a thorough patent search.[65] Thus Brown's development of a two-dimensional

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[63] Howry, D.H. & Bliss, W.R., (1952), 'Ultrasonic visualisation of soft tissue structures of the body' *Journal of laboratory and clinical medicine,* Vol. 40, pp. 579-92. For more detailed accounts of the work of Howry and Bliss see Blume, S.S., (1992), *Insight and industry*; Yoxen, E., (1987), 'Seeing with sound'; Koch, E.B., (1990), 'The process of innovation in medical technology'.
[64] Tansey, E.M. & Christie, D.A., (eds), (2000), *Looking at the unborn,* p.18.
[65] *ibid,* (Footnote 41), p.18.

scanning system should be viewed as one which emerged from practice, from the problems encountered by himself (and Donald and MacVicar) in matching one-dimensional A-scope images to human bodies and their pathologies. It was, therefore, achieved through a process of interactive modelling and tinkering.

According to Brown, it was not easy to convince his clinical co-workers that two-dimensional scanning would provide better information. This he partly attributes to his own inability to describe in understandable terms what exactly he wanted to do, but again, divergent intentions can also be seen at work:

> I found it a bit difficult to fire Donald or John MacVicar with my 'dream'; or even make them understand it. I remember thinking that it would be much easier just to build the thing and show them. This is not really a criticism. They were, after all, only recently started into exploring the medical utility of quite an expensive, sophisticated and highly developed electronic package which had just come, fortuitously, into their hands. They had by no means exhausted its possibilities. Here was a young impatient who wanted, without any tangible resources, to rush off and radically change it all.[66]

In the quote above, it is possible to see the divergence between the clinical goals of Donald and MacVicar, and the engineering goals of Brown. Nevertheless, it is important to note the overlap between the two approaches to ultrasound – what is different here is the way in which clinical knowledge and engineering knowledge coincide differently in the actors involved. For Brown, the best way to improve diagnosis was to maximise the amount of information which could be displayed by creating a more 'picture-based' image. For Donald and MacVicar, the best way to achieve this same goal was through practice and increasing expertise with the technology in its existing form.

Despite any reservations he might have had, however, Donald agreed to approach Kelvin Hughes for more money to fund Brown's project. At the same time, Brown used his own contacts in the firm to do the same. In the end, the project was awarded £500 and Brown

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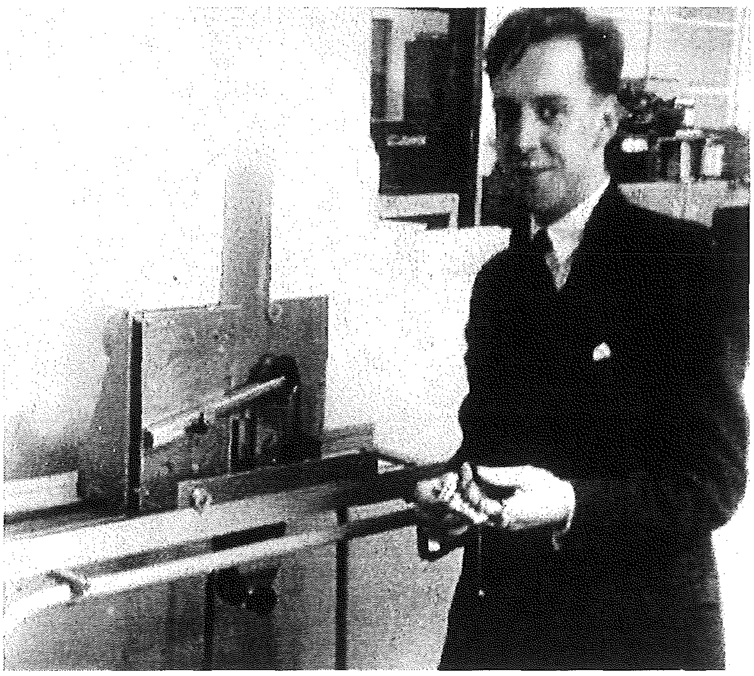
[66] Brown, T., (unpublished paper), 'Development of ultrasonic scanning' p.4.

was released from the factory for one afternoon a week to work in the hospital with Donald.[67]

The scanner built by Brown was a hybrid of industrial and medical parts. Brown reclaimed his experimental automatic weld-tester from the company's factory in Barkingside and pillaged it for its electronic cabinet and power supplies. He also managed to 'acquire' a slightly older Mark IV flaw detector from the company stores in Glasgow along with a cathode ray tube (which acted as the oscilloscope for the flaw detector). The most innovative aspect of his machine was its ability to plot the exact position of the echoes received through the use of a complex measuring grid. This was achieved through the use of a sine/cosine potentiometer used to calculate the position in space of the probe from the angle of its rotation. Again, Brown's ability to 'acquire' parts was crucial here: this was a very expensive component which alone would have cost more than his £500 budget. He managed to 'find' a discarded one which was slightly defective and which he then fixed. Finally, the entire machine was built on a hospital bed table which Donald borrowed from the Western Infirmary.

Figure 1.1: Mr Thomas Brown with the prototype 'bed table' scanner *circa* 1958

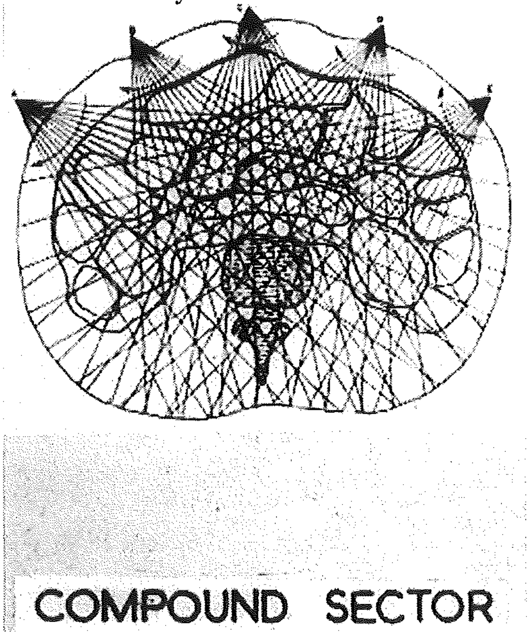


(Photograph courtesy of the BMUS Historical Collection.)

[67] Donald, I., (1974), 'Apologia' p.134.

The scanner worked by gradually building an image as the probe was manipulated back and forth and moved across the patient. The pulses of sound (at a frequency of 2.5 MHz) were generated by one element in the probe and received by an adjacent crystal. The oscilloscope and sine/cosine potentiometer then plotted the position of each echo in relation to the probe, building up a two-dimensional representation of the structure encountered. This type of imaging became known as compound sector scanning or B-scanning because, unlike the A-scope, it worked in two dimensions.

Figure 1.2: Representation of the process of building an image with the compound sector ultrasound scanner built by Brown.



(Photograph courtesy of the BMUS Historical Collection.)

In order to create images in this way, however, the probe had to be able to transmit and receive the sound pulses and echoes from positions other than purely vertical to the skin. This again, reintroduced the problem of air coming between the probe and the skin. Brown overcame this by providing a 'water-bag' into which the probe was placed. As Brown explains: 'what better container could I find than a condom?'[68] Nevertheless, despite this accommodation, the degree of reverberation was too great, and Brown abandoned the condom in favour of direct contact scanning. This however, presented further problems.

[68] Brown, T., (unpublished paper), 'Development of ultrasonic scanning' p.7.

Piezo-electric crystals generate ultrasound when they vibrate. Discs made of such crystals provided the main firing elements in medical ultrasound technology. However, the discs generated ultrasound in both directions – forwards (into the patient) and backwards (into the probe). Therefore some form of backing material was used to dampen the backward radiation and 'damp' the vibration of the disc to create a short pulse. This material was made of some form of metal powder, mixed with a fixing resin such as Araldite. During this process, tiny air bubbles became trapped in the mixture which prevented the backing material from being entirely uniform.

Again, while this was easily accommodated when uniform structures were being imaged using an A-scope, this represented a major obstacle to Brown. The 'non-uniform' structures of human bodies as well as his technique to produce compound scans, translated these tiny air bubbles into major artifacts in the image, producing echoes which appeared to represent structures within the body. Brown and his colleague at Kelvin Hughes (Clive Ross) experimented with a number of different materials in their attempt to overcome this problem. They also tried mixing the resin in vacuums and under compression. Finally, they conceded that whatever they did, they could not avoid trapping air in the wet mixture. What happened next was an interesting accommodation: instead of trying to prevent the formation of bubbles, they decided to help them to float out of the mixture using a high-speed centrifuge. Thus, in another example of Pickering's 'dance of agency' they improved their acoustic backing material by redirecting their goal to accommodate material resistance. They did not achieve an air-free mixture, but found a way to lessen its effects.

The bed table scanner went into operation in 1957 and the team began to use it as often as possible, and on as many suspected gynaecological conditions as possible. In order to keep track of the scans performed and their results, an elaborate file-card database was constructed. Each card contained information on the patient and her clinical history, as well as a number of boxes in which the details of up to 12 scans could be recorded. Polaroid photographs of the scan images were then attached to these cards using a stapler, after having first been painted with a protective varnish to 'fix' the image.[69] Then, using a system

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[69] Mrs Margaret McKee, who was employed in December 1971 as the receptionist for The Queen Mother's ultrasound service, recalls that much of her daily duties when she first took up her position involved applying this varnish to the images. (Interview with Mrs Margaret McKee, March 1998.)

of holes punched into the sides of the cards, patients with similar conditions could be identified quickly by passing a needle through the pack at the appropriate 'hole' and then shaking out the cases of interest. Although it may seem a rather inconsequential aspect of their work, this innovation (particularly in terms of the attachment of the Polaroid photographs, and thus the ability to directly compare similar images) was crucial in enabling the team to keep track of their progress.[70]

At this point Brown's 'heterogeneous' engineering activities became intertwined once more with the activities of Donald and MacVicar. In a sense, therefore, the interactions between the engineer and the clinicians can also be framed in terms of a dance of agency: Brown had made a new machine – it was now time to see how useful it could be to the clinicians. They, meanwhile, had been developing their skills in diagnosis using the A-scope equipment. While Brown was building the machine, Donald and MacVicar had been experimenting with ways of differentiating tissues by altering the frequency of the A-scope. Doing this, they discovered, allowed them to differentiate between types of solid mass by their 'transonicity' (ability to be penetrated by ultrasound).[71] At different frequencies, different tissues (such as tumours which were previously impenetrable) could be visualised. Thus Donald and MacVicar worked on finding the frequency which corresponded to the tissue, effectively increasing the sensitivity of their diagnoses. Nevertheless, while these activities gave them a greater familiarity with the A-scope, they now had to develop new diagnostic skills for operating the B-scan machine.

The joint efforts of Donald, MacVicar and Brown were made public in 1958, with Kelvin Hughes's patent application[72] and the publication of the team's first paper.[73] In this paper, 275 scans on 100 patients are described, with a variety of normal and pathological conditions imaged. Even then, according to Donald, 'our results at that time were crude and our successes infrequent'.[74]

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[70] This system continued to be operated until at least 1976 and a large collection of the original files has been kept at The Queen Mother's Hospital.
[71] Donald, I., (1974), 'Sonar – the story of an experiment' p.111.
[72] According to Brown, this patent covered all subsequent contact scanners. However, the financial troubles at Kelvin Hughes during this time meant that this patent was never really enforced until the mid 1960s. Brown, T., (unpublished paper), 'Development of ultrasonic scanning' p.8.
[73] Donald, I., MacVicar, J. & Brown, T.G., (1958), 'Investigation of abdominal masses'.
[74] Donald, I., (1974), 'Apologia' p.135.

One such 'success' however, was the first ever ultrasound diagnosis of pregnancy. The equipment was being used to examine a woman who had been clinically diagnosed with uterine enlargement due to fibryomata[75], but instead it was discovered that she was carrying a 14-week fetus.[76] Nevertheless, although this is the first case in which a fetus was imaged using ultrasound, it was achieved within the context of a gynaecological diagnosis, rather than an obstetric one. Donald, Brown and MacVicar's activities were guided by the intention of identifying pathological gynaecological conditions, and thus what was most important within this context was the machine's ability to enable them to differentiate between the normal condition of pregnancy and pathological growths. In other words, their interest was not initially motivated by a desire to monitor the fetus, or to investigate the pathologies associated with pregnancy. Investigations of this nature, however, did not take long to emerge.

Soon after the B-scan machine was put into operation in the Western Infirmary, and following Donald's accidental 'discovery' of its ability to image the fetus, the original A-scope machine was transferred to the Royal Maternity Hospital at Rottenrow. With the A-scope equipment a fetus produced a very distinctive triple 'spike' pattern – with two large spikes separated by a smaller spike midway between the two. These corresponded to either side of the fetal skull and a midline echo. This spike pattern was distinctive enough to differentiate a fetus from either fibroids or cysts. Dr James Willocks, who joined the team in 1958 and was later assisted by Tom Duggan from Professor Lenihan's department of Clinical Physics and Bio-engineering, worked on improving the A-scope's abilities to measure the head and on developing a model of fetal growth based on those measurements. Thus while Donald and MacVicar investigated the B-scan's capabilities (mainly on gynaecology cases) Willocks and Duggan began to investigate fetal development with the A-scope.

[75] Fibryomata, or uterine fibroids, are benign growths of mainly fibrous tissue. They can, however, cause complications if they are large or numerous. *Blackiston's Gould Medical Dictionary – second edition,* (1979), McGraw-Hill Publishing Company, New York.
[76] Donald, I. & MacVicar, J., (1963), 'Sonar in the diagnosis of early pregnancy and its complications' *Journal of obstetrics and gynaecology of the British Commonwealth,* Vol. LXX, No. 3, p.387.

One further potential use of ultrasound in obstetrics which was investigated at this time was its ability to demonstrate the exact position of the fetus. This 'discovery' however was not made by any of the clinicians, but by the Staff Nurse at the Royal Maternity Hospital, Miss Marjory Marr.[77] While doing his Friday morning obstetric rounds, Donald was surprised to find that the Staff Nurse could tell him in advance (before he had palpated the patient) where the fetus lay. He discovered that she had begun using the A-scope machine to determine fetal position (by locating the head) in cases where it was difficult to palpate (e.g. those perennial cases of obesity).[78] Thus where initially the scanner was used only to confirm pregnancy, Donald now began to use the information from the fetal head to determine its position in the uterus. Again, what needs to be underlined here is the chance nature of the emergence of this practice. The team were not initially interested in determining fetal positions but once they realised this could be done, attention was then focused in that direction and the possible benefits it may have for clinical diagnoses and medical management were investigated. Here therefore, it is almost as if the equipment revealed one of its potentials to them, and, in response, they altered the direction of their research to accommodate this: the dialectics in this case worked, initially, from the material to the social, rather than *vice versa*.

This widening of the technology's uses to include obstetric cases, and the fact that it began to be used to detect fetal position (rather than pathology), brought the issues of the technology's safety and potential hazard more clearly to the fore. Indeed, given the publication, in 1956, of Alice Stewart's influential work on the association between exposure to x-rays *in utero* and childhood leukaemia,[79] one might expect to observe a higher degree of caution in the way the technology was introduced in obstetrics. While this might be anticipated to have been the case with any new and innovative medical technology being applied to pregnant women at this time, ultrasound's similarity to x-rays – in that both were medical imaging devices – undoubtedly increased the need for such caution. While ultrasound was not a form of ionising radiation, it nevertheless introduced a foreign form of energy (pulses of ultrasonic sound) into the pregnant uterus. According to Tom Brown,

[77] Miss Marr later became Matron at the Queen Mother's Hospital.
[78] Donald, I., (1974), 'Sonar – the story of an experiment' p.112.
[79] Stewart, A., Webb, J., Giles, D., Hewett, D., (1956), 'Malignant disease on childhood and diagnostic irradiation *in utero' Lancet,* Vol. 2, p.447. See also Greene, G., (1999), *The woman who knew too much: Alice Stewart and the secrets of radiation,* University of Michigan Press, Michigan.

concerns over safety did directly influence the team's decision to concentrate their attentions at the outset on gynaecology rather than obstetrics.[80] Furthermore, the Glasgow team were aware of the use of power ultrasound in therapeutic applications, and thus knew that ultrasound energy *could* cause biological effects. Nevertheless, in their view, the type of equipment being used was unlikely to have any damaging effects as long as the intensity of ultrasound being emitted was kept to a minimum. Thus, in his modifications to both the A-scope and the bed table B-scanner, Brown took the initiative to operate using weak power output and high amplification to generate images. Furthermore, the *Lancet* publication in 1958 includes the results of an experiment carried out by Donald and MacVicar to test the safety of the procedure.[81] The brains of kittens were exposed to ultrasound for an hour with no obvious changes in tissue structure being observed.[82]

In the context of modern medical practice it may appear shocking that such a highly experimental procedure was being tested on hospital patients and pregnant women. Nevertheless, at the time, the actions taken to ensure the technology's safety were, perhaps, more than adequate. What must be remembered is that flaw-detecting equipment had been used in industry for over ten years, with no obvious side effects being experienced by those who used it. Furthermore, during Donald's initial visit to Babcock and Wilcox, he had observed the way in which the operators calibrated the equipment by testing it on their thumbs. Thus ultrasound was presented to Donald as a non-hazardous technology. In light of this, the experiments which were conducted and the decision to operate using a minimum of power were, in the context of the time, fairly good precautionary measures.

The automatic scanner and the 'Sundén' machine

For Tom Brown, the manifest inconsistencies of the bed table scanner were difficult to assess. As a young, male, medically unqualified engineer, in what he describes as the 'rather Victorian establishment of the Western Infirmary', he was not permitted to directly operate

[80] Tom Brown, interviewed by Ian Spencer, (courtesy of Nicolson, Spencer & Fleming).
[81] Donald, I., MacVicar, J. & Brown, T., (1958), 'Investigation of abdominal masses'.
[82] The issue of ultrasound's safety continued to be a feature of Donald's work and he carried out a number of small studies to demonstrate that it was unharmful. For a summary of these experiments see Donald, I., (1976), 'The biological effects of ultrasound'.

the hand-guided scanner on patients.[83] For this reason, he was somewhat frustrated by the lack of consistency in that he had no way of determining whether it was due to the machine itself or to the human operator. In his terms, he was unable to 'take control of the examination conditions'.[84] Thus, for Brown, the main ambition which underpinned the development of the next prototype (the automatic scanner) was to ensure that he could control directly the conditions of its use.

Donald, however, recalls events somewhat differently. For him, it was the clinical experiments which he and MacVicar were doing in an attempt to image hydatidiform moles[85] (which involved increasing the gain – or amplification – of the signals) that led to the development of the automatic machine:

> With high gain settings we were confronted with the danger of being deceived by 'electronic grass'. This danger now seemed so great that we decided to eliminate at least this error from over amplification and observer error by having an automatic scanner which would operate at a completely standardised speed.[86]

Again, these two explanations for the evolution of the automatic machine demonstrate the differences between the view of the engineer and that of the clinician. Brown's frustrations over 'examination conditions' lie at the heart of his account – and are thus, again, shaped by his position as an engineer working in a clinical field. Donald on the other hand is led to his assessment of the problems associated with the bed table machine by his clinical experience of its use. Nevertheless, the heterogeneity of the activities of both actors is also clearly evident. While Brown is in part speaking of a need to facilitate consistent and dependable diagnoses, Donald sounds less like a clinician and more like a clinician-engineer!

The net result was nevertheless the same and in 1958 Brown and his colleagues at Kelvin

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[83] Brown, T., (unpublished paper), 'Development of ultrasonic scanning' p.11.
[84] *ibid.* It is also very telling that Brown claims to have deliberately omitted to put identifying labels on any of the electronic controls, so that he would have to be present whenever the prototype scanner was used.
[85] A hydatidiform mole is produced through the abnormal development of a fertilized ovum, and consists of a mass of cysts found within the uterus. Walton, J., Beeson, P.B. & Scott, R.B., (eds.), (1986), *The Oxford companion to medicine – volume I,* Oxford University Press, Oxford.
[86] Donald, I., (1974), 'Sonar – the story of an experiment' p.113.

Hughes started work on the automatic scanner. This machine was an extremely complex affair involving, amongst other things, motors, pressure sensing switches and an over-bed gantry. The probe itself was mounted in a steel ball – similar in appearance to a steel soap dispenser. That was then connected to a column suspended from a gantry. Through a series of cranks the steel ball containing the probe rocked to and fro. When it was 30° from the perpendicular to the skin (sensed by what Brown describes as 'rather indelicate looking projections on either side of the ball'[87]) the motion was reversed and, simultaneously, the gantry supporting the column itself moved about 15mm, and the process was repeated. The fact that the probe was supported by a gantry, rather than a bed table, meant that scans could be done in the longitudinal plane – i.e. up or down the abdomen lengthways, rather than only across the width.

Figure 1.3: Professor Donald and Dr. MacVicar (in the background) using the automatic scanner.

(Photograph courtesy of the BMUS Historical Collection.) NB: Donald is setting the position of the probe using the joystick. The probe itself can be seen in the bottom left corner.

Complicated though this sounds, Brown added further complexity to the machine in an attempt to accommodate the variety of shapes and sizes of the female body. It has to be borne in mind that the body surface being imaged (the female abdomen) is a convex one. Furthermore many of the patient's to be scanned had swollen abdomens, either as a result of some form of pathology, or because they were pregnant, or because they were simply large

[87] Brown, T., (unpublished paper), 'The development of ultrasonic scanning' p.11.

women. The machine therefore had to be able to remain in contact with body surfaces of considerable variety. One way in which Brown accommodated this was through another motor which could drive the probe up or down as required. This coupled with a pressure sensitive switch, allowed the probe to stay in constant contact with the skin – however its surface might vary. Thus, the automatic scanner had two separate motors, one which operated in the horizontal plane, and one in the vertical. However, in order to operate on 'the steep flanks of often rather rotund ladies'[88], the scanner had to be able to sense whether the next movement required had to be horizontal (with sensitivity controlled in the vertical plane) or vertical. Thus, an elaborate switch over mechanism was designed to enable the machine to switch backwards and forwards between the two motors.

The final touch was a joystick. This was the only manual part of the actual scan itself and was used to position the probe at the start of the scan.[89] The 'auto' button was then pressed and the machine took over. When the scan was complete, the machine automatically switched itself off and a bell would ring to summon the operator. The whole process would take between 60 and 90 seconds.

What is remarkable about this scanner is that it was used fairly regularly for around six years to scan thousands of patients with what was generally regarded as a fairly high degree of consistency, and yet it is the only automatic machine ever built. This prototype never made it into production, and the team switched to a manually operated design for their next prototype. While it might be tempting to explain this in terms of professional, clinical resistance to an automatically operated machine (which would, as intended, lessen the significance and control of the human operator) it is clear that there were other contributing factors at work here. Firstly, with so many moving parts and valve-based electronic circuits, the machine was prone to breaking down, involving much 'tweaking' to get it working again. However, part of the reason, also lies in the team's need for funding, the complicated financial scrabbling they were doing, and the financial problems which were beginning to affect their main sponsor – Kelvin Hughes Ltd.

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[88] *ibid.*

[89] It is tempting to interpret the fact that this was done by joystick, rather than by directly moving the probe, as another demonstration of Brown's desire to make sure it was something he himself could do, i.e., it did not require the operator to touch the patient. However, the mechanics of the operation of this machine entail that there is also a material basis to the need for a joystick.

It seems clear that, despite the fact that much of this work was 'funded' by Kelvin Hughes, the Chairman and most of the Board were not aware of their support for medical ultrasonics. Brown's 'scrounging' and 'borrowing' was supplemented by the subversive tactics of the deputy Chairman of Kelvin Hughes, William Slater. According to Brown, Slater fed whatever money he could 'acquire' to the team and, at times, hid the whole project from the rest of the board. It was also Slater who facilitated the services of Brown to the Glasgow team on a regular basis and donated the £500 of company funds for the development of the bed table scanner.

Donald himself, however, was not averse to a little underhand wheeling and dealing. In 1959, for example, he hired the services of Tom Duggan, a physicist, to work on the ultrasound project. However, Duggan's salary was derived from a grant Donald received from the Scottish Hospital Endowment Research Trust for a study of neonatal respiration. This grant was awarded with the specific instruction that it was not to be used for ultrasound.[90] The early years, therefore, were characterised by these unofficial arrangements. It must of course be remembered that with the exception of Duggan none of the team were working on ultrasound on a full-time basis. Donald and MacVicar had their other clinical duties, while Brown was still working for other projects at Kelvin Hughes's factory. Nevertheless, this was a large-scale research project which lacked a properly defined funding programme. Things, however, were set to get still worse.

In December of 1959, Donald was called to see William Slater at the Kelvin Hughes factory. The original £500 Slater had given to the project had by this time stretched into several thousand pounds, and the company could no longer afford to help fund the project. At this time, Kelvin Hughes were beginning to have larger concerns to worry about which – ironically – were partly attributable to the automatic flaw detectors which Brown had helped devise in the early 1950s. While these were being redesigned at the company's main factory site in Barkingside, London, they were vigorously marketed all over Britain. Despite a large

[90] McNay, M.B. & Fleming, J.E.E., (1999), 'Forty years of obstetric ultrasound' p.10.

number of models being sold, few were actually being delivered and orders were beginning to back up. Problems with the design were also delaying the process.[91]

This meant, however, that Donald had problems of his own in funding the continued development of the automatic scanner. In solving these, Donald behaved very much in the role of 'systems builder' or 'engineer-entrepreneur' described by Thomas Hughes – networking and using the many contacts he had to save his project.[92] Donald's first stop was to the office of the Principal of Glasgow University, Sir Hector Hetherington.[93] From Hetherington he received £750, but he was also advised by the elderly Principal to approach the Advisory Committee of Medical Research and, again, the Scottish Hospital Endowments Research Trust. Following a 'lunch party' which Donald attended with William Slater from Kelvin Hughes, the Chairman of the Trust sanctioned a grant of £4,000. This was later supplemented after Donald's visit to London, where he worked his charm on the National Research Development Corporation, gaining an immediate £4,000, and a total of £10,000 over the next few years. 1960, in other words brought a greater degree of financial security to the project, which would last until at least 1965.

In Donald's search for funding at this time, it is important to note not only his networking skills but also the more personal qualities attributed to him. Virtually all interviewees who knew or encountered Donald, describe him as a very strong character – enthusiastic, motivational, occasionally strict, but above all, charismatic. He was also a tall man with that intangible quality known as 'presence'.[94] Furthermore, in the very traditional and class-ridden world of medicine in the 1950s and '60s, Donald was certainly one of the club. Professor at a prestigious university, he possessed not only the appropriate medical skills of his profession, but also the more unofficial 'character' and background of a man of his position. These personal characteristics were undoubtedly put to good use at times such as these.

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[91] Brown, T., (unpublished paper), 'The development of ultrasonic scanning'.
[92] Hughes, T.P., (1999), 'Edison and electric light'.
[93] Donald, I., (1974), 'Sonar - the story of an experiment' p. 112.
[94] For an attempt to integrate such characteristics into the sociology of science see Thorpe, C. & Shapin, S., (2000), 'Who was Robert J. Oppenheimer? Charisma and social organisation' *Social studies of science,* Vol. 30, No. 4, pp. 545-90.

What is also important about Donald's activities here is that they demonstrate the interconnection between innovation and diffusion – even at this very early stage of development. What Donald was doing was 'selling' his machine – or at least its potential, the promise it represented. Selling medical ultrasound to committees and bodies who could fund its development was essentially an exercise in diffusion of the *idea* of ultrasound. The team had already published evidence of its potential – this was simply another way of spreading the message. Furthermore, Donald at around this time embarked on a series of lectures in the US – again spreading the word about medical sonar. Brown also played his part in this respect. In 1960, he took the finished automatic scanner to London, to show it at Olympia.[95] These activities were as crucial as those occurring in the Glasgow factory and in the hospital, and indeed they were all interwoven. Both the clinical and technical developments in Glasgow were dependent on funds and therefore interest if they were to continue. Similarly, Donald would have nothing to 'sell' without the activities going on at home. Thus the innovation and diffusion of the early scanner was the emergent outcome of a whole host of activities in a variety of contexts and locations.

Donald also had one other source of income for the project. Around this same time a young Swedish obstetrician, Dr. Bertil Sundén, visited Glasgow on a quest to find a suitable research topic for his MD thesis. His interest aroused by the Glasgow research into ultrasound, Sundén decided to reproduce Donald's work – in other words, to verify his findings. Despite the fact that the automatic scanner was almost complete, Sundén wanted an exact copy of the machine which Donald had used to produce his first publications – i.e. the bed-table scanner – and offered to pay whatever was required.[96] What Sundén eventually got, almost two years later, and at a cost of around £2,500 was a hybrid between the manually operated bed-table machine and the automatic scanner. In other words, Sundén's money was used to build yet another prototype – which would become the basic model for the Diasonograph, the first commercially manufactured machine.

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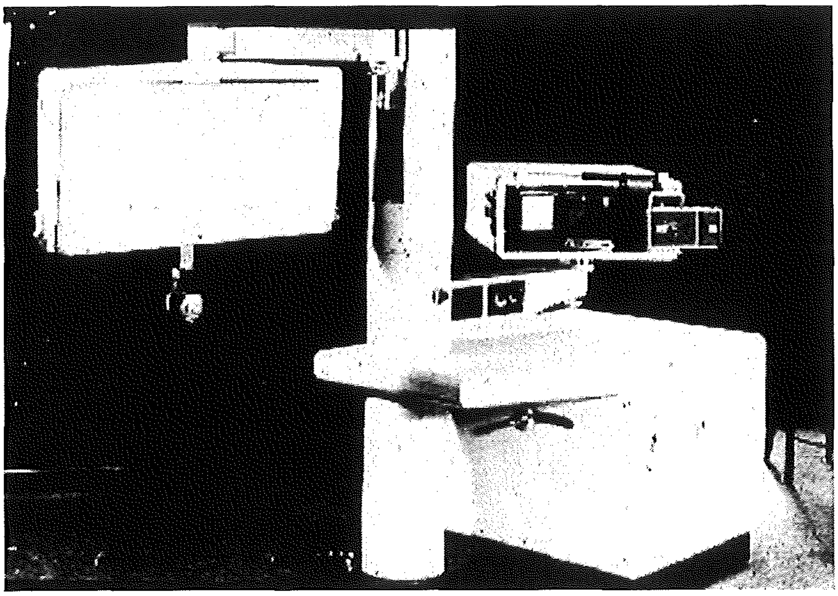
[95] Indeed, Donald makes reference to the fact that on this occasion Brown 'demonstrated his ability as a showman' (Donald, I., (1974), 'Sonar – the story of an experiment' p.114).

[96] Brown, T., (unpublished paper), 'The development of ultrasonic scanning;' Donald, I., (1974), 'Sonar – the story of an experiment'. See also Blume, S.S., (1992), *Insight and industry*; Fleming, J.E. & McNay, M.B., (1999), 'Forty years of obstetric ultrasound'.

Figure 1.4: The Sundén machine



(Photograph courtesy of the BMUS Historical Collection.)

The early 1960s therefore, saw the ultrasound project gain increasing momentum. This was further compounded in 1962, when Kelvin Hughes merged with Smith's Industries, an English based manufacturing firm. The resources which Smith's could muster added increased financial support. The team itself was also expanding: Brown and his colleagues at Smith's/Kelvin Hughes continued to work on the construction of the equipment, while Donald and MacVicar, now joined by James Willocks worked on clinical applications and Tom Duggan collaborated with Willocks on the development of electronic cursors for measuring fetal bi-parietal diameter (BPD). In 1962, their number expanded still further when John Fleming, a 28 year old electrical engineer, was appointed by Smith's as a Project Engineer for the Diasonograph.[97]

Furthermore, the diversity of the group's activities (evident almost since the start of the project), was further compounded by the number of models they now had available for use. Willocks and Duggan worked with the A-scope machine in their analysis of fetal measurements at the Royal Maternity Hospital; Donald and MacVicar continued to investigate a series of gynaecological and obstetrical conditions using both A-scope and B-

[97] Interview with John Fleming, September 1998.

scanner models.

In 1961, Sundén at long last received his newly re-designed ultrasound machine – making him the first customer of contact B-scan equipment – and set about reproducing Donald's work in Lund, Sweden.[98] There were, however, 'teething problems' associated with the purchase of a prototype, and one of John Fleming's first tasks on arriving in his new post in 1962 was to fly to Sweden to fix Sundén's machine.[99] Overall, much of this period was devoted to refining the scanner's design for commercial production. Fleming worked on the electronic circuits, Brown on the mechanical aspects and Dugald Cameron (then an Industrial Design student at Glasgow School of Art and later Principal of that institution) was engaged to develop the aesthetics of the machine. The end product – the Smith's Industries 'Diasonograph' went into commercial production in 1963, and in 1964 the first model was delivered to the soon-to-open Queen Mother's Maternity Hospital, in Yorkhill Glasgow.

Conclusions

In this chapter, the early development of medical ultrasound in Glasgow, which led to the production of the first medical scanner for use in obstetrics, has been examined. Throughout these developments it is clear that the research project on medical ultrasound was a collaborative one. Clinicians and engineers learned to move in each other's spheres, to understand each other's language and practices. Furthermore, their interaction with ultrasound led to the development of whole new forms of practice and language. In other words, in the wards of the Western Infirmary and the Royal Maternity Hospital, and in the factory of Kelvin Hughes, a new specialist area of practice and knowledge was beginning to emerge. Not only was this an extension of the existing cultures of engineering and medicine, it was also crucially a hybridisation between the two. The emergence of medical ultrasound brought together two separate communities of actors and forms of expertise.

[98] Sundén, B., (1964), 'On the diagnostic value of ultrasound in obstetrics and gynaecology' *Acta obstetrica et gynaecologica Scandinavica,* Vol. 43, (suppl. 6).
[99] Interview with John Fleming, September 1998.

Furthermore, the activities of the actors involved can be characterised as a form of 'heterogeneous engineering'.[100] In bringing together metal flaw detectors and female bodies in the emergence of a new technology, the actors played out multiple roles and interacted with a variety of material and social circumstances. It was as a result of all of these heterogeneous activities and interactions that ultrasound emerged in the form that it did. These activities were interwoven with one another. Sometimes the interactions in which Brown was engaged diverged from those of Donald and MacVicar, while at other times they converged and overlapped. Thus the interactions between the clinicians and the engineer are characteristic of John Law's conception of 'heterogeneous engineers' and Thomas Hughes' 'systems builders'.[101]

In addition, the actors' interactions with ultrasound itself present an example of Andy Pickering's 'dance of agency'.[102] Brown's activities, for example, in designing his various prototypes demonstrate the fundamental characteristics of human interaction with the material world. From probe design, to image display, to contact method and image recording, Brown 'tinkered' with and 'tuned' his machines. His activities were mirrored by the performance of the equipment. When a change was made, he would wait and see how it affected overall performance then would act again to make further changes. Thus, in Pickering's sense, his human agency was engaged in an interactive, dialectic relationship with the material agency of the sound waves, electronics, mechanical design, etc of the machine. However, at other times, both Brown and Donald interacted in different arenas – in their promotional activities to 'sell' their machine, or with one another to communicate in the hybrid they were creating between their two scientific cultures. The underlying point is that these activities were heterogeneous and it was the particularities of this heterogeneity that co-produced the technology and shaped its form.

What has also been emphasised in this account is the unpredictable nature of the development of ultrasound. Any overly deterministic account of the emergence of this technology (from either a technical or social perspective) would downplay – or ignore – the

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[100] Law, J., (1991), 'Introduction: monsters, machines;' *idem,* (1987), 'Technology and heterogeneous engineering'.
[101] Hughes, T.P., (1999), 'Edison and electric light'.
[102] Pickering, A., (1995), *The mangle of practice.*

importance of chance, luck, and accident. This story is riddled with such events from the first experiment at Babcock and Wilcox, to the eventual design of the Diasonograph. To ignore them would diminish the capacity to account for technological changes of this sort.

This chapter, therefore, has traced what is traditionally regarded as the 'innovation' stage of technological development from the building of prototypes to the construction of a commercial machine. Nevertheless, it is clear that even while prototypes were being developed and research into possible applications was being conducted, some forms of diffusion were already taking place. In their publications, in Donald's lecture tours, in their demonstrations of the machine to visiting medics such as Sundén and even in their negotiations with funding bodies, Donald and his team of co-workers were already diffusing the 'idea' of ultrasound and its potential. They were, in other words, already active in constructing a market for the technology. Thus even before the first machines were actually manufactured, sold and installed in new locations, medical ultrasound had already embarked upon the road of diffusion. Nevertheless, all of their activities were inter-related and co-dependant. It thus seems foolhardy to attempt to allocate 'innovation' and 'diffusion' to two separate stages of development in a way which would obscure the heterogeneity of activities of both kinds which are evident here. Furthermore, as will be outlined in Chapter 2, the diffusion of the Diasonograph as an artifact, and of obstetric ultrasound as a technology, in terms of its introduction into new locations, did not signal the end of innovation, but merely a change in its nature.

Chapter 2

‘Enrolment’: the early career of contact B-scanning in Scotland

Introduction

The preceding chapter outlined some of the activities involved in the early innovation of diagnostic ultrasound in Glasgow, leading to the construction of the Smith's Diasonograph. However, as Ruth Schwartz Cowan has noted with reference to technological development in the United States:

> If the landscape of American social history is cluttered with the remains of failed communes and cooperatives, the landscape of American technical history is littered with the remains of abandoned machines.[1]

British technical history is no less cluttered with prototypes that never made their way into production, or with commercial machines which did not sell. Thus the launch of the Smith's Diasonograph as a factory produced commodity did not, in itself, indicate the commercial 'success' of medical ultrasound. Its fate would instead be determined by the extent of its uptake and use by other actors in other locations. In other words, medical ultrasound needed to have a market – a set of actors willing to purchase the technology and use it in clinical practice. In this chapter the emergence of this market will be examined by an exploration of the uptake of obstetric ultrasound in Scotland during the 1960s and early 1970s.

Three related developments in particular characterise this period in the technology's history. Firstly, the 1960s marks the technology's 'coming of age' in both a commercial and clinical sense. The commercial production of Diasonograph machines (first by Smith's Industries and, later, by Nuclear Enterprises Ltd.) facilitated their wider uptake in other locations. In addition, other medical equipment manufacturers from mainland Europe (Siemens of Germany and Kretztechik of Austria) began to produce machines for use in obstetrics. While these manufacturers did not make a significant impact in Scotland (in terms of the number of machines adopted in Scottish hospitals, in comparison to the Diasonograph design) the increased commercial interest in obstetric ultrasound does provide evidence that the technology itself was gaining in prominence. Interwoven with these commercial developments, this period also saw the technology become established as a diagnostic tool

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[1] Schwartz Cowan, R., (1985), 'How the refrigerator got its hum' in MacKenzie, D. & Wajcman, J., (eds.), *The social shaping of technology: how the refrigerator got its hum,* Open UP, Milton Keynes, p.202.

in obstetric medicine. The number of conditions and pathologies which ultrasound could help diagnose increased while, simultaneously, it began to be used on a more regular basis.

Secondly, this period saw the emergence of what could be described as an 'ultrasound community' in Scotland: a set of workers scattered across the country whose activities in a variety of spheres fostered and developed the emergent technology. The early members of this community were those largely responsible for the technology's initial diffusion - actors who came into contact with the technology (or with Ian Donald's enthusiasm for it) and who were inspired to lobby their own institutions for the funds to purchase a machine, or junior doctors trained by Donald and the team to use the technology while resident at one of the Glasgow hospitals, and who subsequently took up employment elsewhere. On the other hand, there were also those whose entry into this community was a consequence of ultrasound's diffusion - those who were drawn into the technology because of the specialist skills they possessed (in, for example, engineering or medical physics) when a new institution acquired a machine and sought help in the construction of a working service. Thus, the emergence of this community was interwoven with the technology's diffusion, being both shaped by the spread of the technology to new areas, while also helping to foster this. Furthermore, the importance of this emergent community highlights that ultrasound's diffusion was not simply about the movement or spread of artifacts, but was also crucially related to the movement of actors with the knowledge and skills associated with the technology.

The final development which characterised this period in the history of ultrasound was its growing significance as an *obstetric* tool. Indeed, despite the fact that Donald's first investigations were in gynaecological cases, and that the Diasonograph had been designed for use in general abdominal examinations, it was primarily within obstetric medicine that ultrasound achieved its first commercial 'success' in terms of its diffusion to other areas. The aim of this chapter is to map out these developments by examining the 'career' of the Scottish-designed Diasonograph within obstetrics throughout the 1960s and early 1970s.

Much of the secondary literature on the development of diagnostic ultrasound has focussed on the nature of the social and professional relations between different sets of professional actors, or between the medical profession and the patient population. Ann Oakley, for example, explains the success of obstetric ultrasound in terms of the medical profession's desire to capture control over pregnancy from pregnant women themselves.[2] Obstetric ultrasound, according to Oakley, enabled clinicians to peer directly into the pregnant uterus and thus obtain information about pregnancy in a way that allowed them to by-pass the women involved. This, she argues, was a powerful motive for both the innovation and diffusion of the technology. Ellen Koch, on the other hand, concentrates on inter-professional comparisons in her study of the early work of Howry and Bliss on the one hand and Wild and Reid on the other, comparing the two groups of actors in terms of the different cultures of radiology and surgery.[3] From this, she argues that their respective specialist interests led them to pursue the development of ultrasound imaging in different ways. Howry (the radiologist) sought a technology to complement x-rays and one that would display a full map or topography of internal tissues and structures, while Wild (the surgeon) sought to immediately differentiate between malignancy and normal pathology. Similarly, Edward Yoxen explains the relative success and failure of groups of medical ultrasound innovators in terms of the nature of their adherence to professional socialisation.[4] For Yoxen, those actors who drew on their professional training and background as a resource (rather than a rigid determinant of activity) were able to approach innovation with greater flexibility. In turn, flexibility in interpreting professional background allowed the development of a 'technological frame' that encompassed the training of other actors.

While such approaches have produced some valuable insights into the study of ultrasound's development, they tend to suffer from an over dependence on a single explanatory variable: i.e. specialist interest. However, the very notion of a set (or sets) of actors with pre-existing interests in relation to a new technology is an assumption which is, itself, open to challenge. For example, in her detailed study of the development of x-ray diagnosis, Bernike Pasveer

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[2] Oakley, A., (1984), *The captured womb,* Basil Blackwell, Oxford.
[3] Koch, E.B., (1993), 'In the image of science? Negotiating the development of diagnostic ultrasound in the cultures of surgery and radiology' *Technology and Culture,* Vol. 34, pp. 858-893; *idem,* (1990), 'The process of innovation in medical technology: American research on ultrasound, 1947 to 1962' PhD thesis, (University of Pennsylvania). See also Blume, S.S., (1992), *Insight and industry: on the dynamics of technological change in medicine,* MIT Press, Cambridge Mass.
[4] Yoxen, E., (1987), 'Seeing with sound: a study of the development of medical images' in Bijker, W.E., Hughes, T.P. & Pinch, T.J., (eds.), *The social construction of technological systems: new directions in the sociology of technology,* MIT Press, Cambridge Mass., pp. 281-303.

questions the prior existence of such interests.[5] Her account of this technology traces the co-development of technical artifact, technique and professional hierarchy in the co-construction of the medical specialty of radiology. For Pasveer, the organisation and differentiation of different sets of actors (such as the emergence of a two-tier medical hierarchy of 'radiographers' and 'radiologists') were themselves the emergent outcome of the technology's development. In other words, 'specialist interests' did not exist *a priori* - suspended in some form of 'social limbo' - and for this reason the idea of stable social contexts which can be used to explain technological development is too simplistic. That is not to argue that social interests cannot and do not influence technological development and change, but simply to suggest that they themselves do not remain static or unchanged. Social interests such as those associated with specific medical specialties are as adaptable and malleable as technical artifacts and forms of practice - no more so, but also no less so.

In *Insight and Industry*, Stuart Blume traces out a more useful model of the way in which specialist medical interests influenced the development of diagnostic ultrasound.[6] Using a hybrid analytical account that looks simultaneously at organisational, social, epistemological and economic factors, he attempts to trace the comparative successes and failures of various ventures in diagnostic ultrasound in an international perspective. His account is also strengthened through a close examination of medical/industrial interconnections and relationships.

Blume compares the interests and activities of a number of medical specialties that investigated the clinical potential of ultrasound in their disciplines including cardiology, neurology, ophthalmology as well as obstetrics and gynaecology. What is different in Blume's account is that it explores a number of ways in which specialist interest affected not only the design of the technology, but also its comparative amenity to commercial exploitation. For example, Blume notes that research into ultrasound's potential uses within some specialties entailed only a slight modification to existing flaw detecting equipment in

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[5] Pasveer, B., (1992), 'Shadows of knowledge, making a representing practice in medicine: x-ray pictures and pulmonary tuberculosis, 1895-1930' PhD thesis (University of Amsterdam), published by CIP-Gegevens Koninklijke Bibliotheek, Den Haag; *idem*, (1990), 'Knowledge of shadows: the introduction of x-ray images in medicine' *Sociology of health and illness,* Vol. 11, No. 4, pp. 360-81
[6] Blume, S.S., (1992), *Insight and industry: on the dynamics of technological change in medicine,* MIT Press, Cambridge Mass. and London.

the form of the A-scope. Thus, at least potentially, existing firms could manufacture medical ultrasound for these specialties relatively easily. He also notes that such equipment meant that market entry barriers were significantly lower and thus new, small firms were able to gain a foothold in emerging markets. On the other hand, he notes that the protracted and complex nature of the development of abdominal scanners for gynaecological and obstetric investigations brought with it a much higher degree of investment, research and development before any commercial returns could be made. Thus (as outlined in Chapter 1) the degree of redesigning and technological complexity of the Diasonograph made it a major drain on resources and a long-term financial commitment with, at least initially, little obvious immediate return on investment.

Furthermore, although he does not pursue this point, within Blume's account it is possible to spot evidence of material agency playing a role in the differential development of ultrasound in diverse medical contexts. For example, in ophthalmology a simple 'snap-shot' picture was all that was required while, at the same time, the area to be imaged was relatively small. Furthermore, the physical makeup of the structure being imaged (for example the interference of the skull when imaging the brain, or the very subtle tissue density changes and lack of standardisation in the female breast) made technological design much more problematic for some specialties than for others. With obstetrics and gynaecology, the abdominal area of interest presented problems in terms of its large area and the number and complexity of organs and tissues present. Indeed, as Blume notes, the development of ultrasound for gynaecological and obstetric applications was, comparatively, one of the most protracted and complex: Brown's two-dimensional scanner was one of the most intricate developments from the original flaw detecting equipment which most researchers were using. It was not, in other words, simply the questions being asked of the technology within this medical specialty which accounts for its different development, but also the precise nature of the bodily parts being imaged: their make-up, their functioning and their position.

Thus while 'specialist interests' did shape the development of the various forms of diagnostic imaging, this was not done in a simple cause and effect manner. Instead, it was the interaction between such interests, the equipment being employed and the areas of the body being imaged which co-constructed new forms of the technology. What will be highlighted in this chapter, however, is that these issues continued to affect the development of obstetric ultrasound once it had begun to diffuse to other centres. In other words, there is no simple and straightforward division between 'innovation' and 'diffusion'. The questions being asked of the technology, the uses to which it was put, and the agency of the bodily material with which it interacted continued to shape its development as both a research and clinical tool. At this particular consumption junction[7] new actors, locations and circumstances introduced new demands that often required modifications or accommodations in terms of technical configuration and/or technique. What is significant about this is that issues and problems that arose with existing design could not have been predicted or anticipated in advance. Rather, it was users in their daily interactions with the technology that identified limitations in design, or indeed who redefined the purpose of certain design features.

Another useful concept which can help clarify this period in the history of obstetric ultrasound is Bruno Latour's 'enrolment'.[8] For Latour, the way in which actors come to support a new scientific idea or practice can be characterised as their enrolment into an actor-network – a set of human/ non-human relationships which, taken together, jointly constitute the technology. Thus the diffusion of obstetric ultrasound could be characterised as achieved via a process of enrolment in terms of the new actors, locations and circumstances which became associated with the technology. However, as Latour points out, enrolment does not simply mean that actors are enveloped within current practices - each new set of relationships and circumstances creates new opportunities for innovation in the nature of the interaction between users and machines. Thus it is not simply 'how' actors are enrolled, but also the nature of their subsequent interaction with the technology which is important.

This chapter, therefore, will examine the early uses to which obstetric ultrasound scanning equipment was put. What questions were asked of this equipment and what demands were

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[7] Schwartz Cowan, R., (1987), 'The consumption junction: a proposal for research strategies in the sociology of technology' in Bijker, W.E., Hughes, T.P. & Pinch, T.J., (eds.), *The social construction of technological systems,* MIT Press, Cambridge, Mass., pp261-280.
[8] Latour, B., (1992), 'Where are the missing masses? The sociology of a few mundane artifacts' in Bijker, W.E. & Law, J., (eds.), *Shaping technology/building society: studies in socio-technical change,* MIT Press, Cambridge Mass; Latour, B., (1987), *Science in action,* Open UP, Milton Keynes.

placed on it? What expectations were raised by its availability? Also, how exactly was knowledge about this technology spread from centre to centre and which types of actors were instrumental in its adoption and use? What will become clear is that in order to account fully for the initial uptake and use of ultrasound as a commercial technology in obstetrics, the search for explanation must move beyond simple inter-professional interests. This chapter will follow both actors and machines and examine not only their activities *vis à vis* one another, but also with other actors and other machines.

The commercial suppliers: another change in ownership

An important factor associated with the early career of the Diasonograph lay in the continuing complexities associated with the commercial side of the endeavour. Smith's Industries began the manufacture and sale of the Diasonograph in 1963. Three years later, however, the company withdrew from its activities in Scotland, including the medical ultrasound project, in response to financial difficulties being faced at the time. Thus Smith's themselves manufactured very few machines. According to John Fleming, who became chief engineer on the project following Tom Brown's departure to Honeywell Ltd. in 1965, Smith's only produced 12 machines commercially. Four of these models were sold to the Ministry of Health to be investigated for their clinical potential.[9] Donald, writing in 1974, indicates the destination of two of these - to University College Hospital, London and Bristol.[10] Unfortunately, there appears to be no available written record of the number, or fate, of the other machines, although one certainly went to the Queen Mother's Hospital and Fleming recalls another being shipped to Dubai.[11]

While the mounting cost of the medical ultrasound project undoubtedly contributed to Smith's financial problems at this time, most of the company's troubles related to a patent dispute over medical ultrasound rights. In 1958, before Smith's merged with Kelvin Hughes, patents had been applied for by the latter company in relation to the bed table scanner.[12] As far as Kelvin Hughes were concerned this patent covered all later forms of

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[9] Mr. John Fleming, *pers comm.*
[10] Donald, I., (1974), 'Sonar – the story of an experiment' *Ultrasound in medicine and biology,* Vol. 1, p.115.
[11] Mr. John Fleming, *pers comm.*
[12] Brown, T., (unpublished paper), 'Development of ultrasonic scanning techniques in Scotland, 1956-1979: personal recollections of T.G. Brown' (British Medical Ultrasound Society (BMUS) Historical Collection).

contact scanning – i.e. scanning in which the probe was applied directly to the body without the need for the patient to be immersed in water.[13] However, American firm Automation Industries (who worked in association with Floyd Firestone on a similar machine) claimed that their patent secured the commercial rights to medical contact scanning. This patent dispute was passed on to Smith's Industries and the associated legal costs proved to be a major financial drain. It is worth noting that the issue of patents can itself influence the development of technology by encouraging engineers to pursue certain avenues of research rather than others in an attempt to circumnavigate existing commercial rights and patents.[14] Indeed, according to Tom Brown, his attempts to develop a three-dimensional scanner in the late 1960s was specifically aimed at avoiding the patent problems associated with two-dimensional contact scanning.[15] In the early 1960s, however, the dispute over commercial rights affected the development of the technology by forcing Smith's Industries out of the market altogether.

The company's withdrawal left the project stranded and Donald's greatest fear was that their work would be taken over by one of the large American firms (such as Automation Industries) now showing an interest in medical imaging. Again Donald's willingness to operate in multiple arenas is evident in the various ways in which he attempted to save his research:

> Once again, I hied me to the Principal of Glasgow University, now Sir Charles Wilson, simply to ask the right to engage electronic engineers on a fee-for-service basis to keep my apparatus on its feet and working. Hawking the project around a variety of firms had produced no tangible results, only polite refusal to burn their fingers as Smiths and Kelvin Hughes before them had done.[16]

In the end, it was Nuclear Enterprises Ltd., an Edinburgh-based engineering firm involved with the very prestigious and burgeoning area of nuclear technology, which took over the

[13] *ibid.*
[14] A number of examples of the importance of patents for technological innovation can be found in accounts of the work of A.D. Blumlein, the inventor of phonic recording, or sound reproduction. See Alexander, R.C., (1999), *The inventor of stereo: the life and works of Alan Dower Blumlein,* Focal Press, Oxford; Burns, R., (2000), *The life and times of A.D. Blumlein,* Institution of Electrical Engineers in association with the Science Museum, London.
[15] Brown, T., (unpublished paper), Development of ultrasonic scanning '.
[16] Donald, I., (1974), 'Sonar – the story of an experiment' p.117.

commercial interests of the Smith's medical ultrasound project. It is here, however, that events became somewhat more complex. Firstly, the changeover from Smiths to Nuclear Enterprises split the Glasgow team. Donald's interview with the Principal of the University was more successful than he had hoped. The University facilitated the establishment of a University Department of Ultrasonic Technology whose role was both to continue to maintain the existing equipment and to undertake further research and development. Based at the Queen Mother's Hospital (and thus from the outset more associated with obstetric medicine than other abdominal applications) the new Department was operated by two engineers from the ultrasound team - John Fleming and Angus Hall. Brian Fraser, however, (and Tom Brown, who returned to the project for a short while) transferred to Nuclear Enterprises to work on the further commercial development of medical ultrasound. Research and development activities were therefore divided not only in terms of geography, but also in terms of focus. At Nuclear Enterprises in Edinburgh Fraser and Brown worked exclusively on technical development, while the Glasgow team's research focussed on clinical applications. Thus the inter-related engineering and clinical dimensions of ultrasound which so characterised the original team's work in the late 1950s and early 1960s became much more sharply delineated. However, the actors continued to interact with one another and, with Glasgow University directly employing two engineers to work on the development of medical ultrasound, the Glasgow group's activities do not appear to have been adversely affected by the new arrangements. John Fleming, for example, recalls that improvements which were made to the technology at the Queen Mother's were diffused to Nuclear Enterprises, while new prototypes from Edinburgh were often loaned to Donald and his colleagues to be tried out in practice.[17]

Having taken over Smiths interests, including the company's stock, Nuclear Enterprises continued to manufacture the original Smith's design, which they renamed the NE4101. Later models which incorporated major technical developments, such as solid-based transistor technology (as opposed to the valve technology of the Smiths' machines) and grey-scale imaging (which enabled tissue texture to be viewed) were given similar names - in these cases the NE4102 and NE4200, respectively. Such technical-sounding nomenclature can be viewed as an attempt to convey meanings associated with technical

[17] Interview with Mr. John Fleming, 20/09/98.

sophistication which is itself indicative of the general importance and authority accorded to science and technology within medicine in the late twentieth century. Nuclear Enterprises, as a company associated with the cutting edge frontier of nuclear technology and its translation into medicine were, arguably, more in touch with the rhetorical power of science and technology than Smiths had been, and thus more inclined to take every opportunity to use that rhetoric to their advantage. In addition, (as the Microsoft Corporation has clearly demonstrated in the computer software market) the use of numbers can act as a powerful marketing ploy, with a change in number clearly signalling that the model has been somehow 'updated'. Whether or not this strategy worked for Nuclear Enterprises is hard to determine as, in Scotland, its prominence in the field undoubtedly owed much to the work of Ian Donald and his co-workers in Glasgow. Nevertheless, despite these name changes, in common parlance all of these machines continued to be known under what had now become the generic term of 'Diasonograph' (later they were occasionally also referred to as 'Dinosaurographs' or 'Brontosaurographs' due to their size and bulk). Nevertheless, what is important is that when ultrasound first began to spread to other locations in Scotland, it was Nuclear Enterprises who benefited from the financial returns that accrued.

Research into obstetric applications in Glasgow

In 1964, with the opening of the Queen Mother's Hospital (QMH), Ian Donald's obstetric wards moved from the Royal Maternity Hospital on the south side of the city, to their new West End location, opposite the Western Infirmary. The construction of this new hospital itself was a feat in which Donald was intimately involved. He lobbied the Hospital Board and the university with the need for its creation but, more significantly, was instrumental in its very design. As a former colleague, Mr. Wallace Barr recalls:

> He went to the Principal and arranged that the University would provide so much money and then he went to the Hospital Board, they got so much money and virtually planned the place himself. He pored over these plans... and they incorporated several ideas into the building of the hospital.[18]

[18] Mr Wallace Barr, interviewed by Ian Spencer, 30/04/96 (courtesy of Nicolson, Spencer and Fleming).

One of these 'ideas', for example, was for the labour ward to have separate rooms for each woman, rather than large wards with screens to act as dividers.[19] This was radically different from the traditional layout of maternity hospitals. His influence however could also be seen in the more mundane and practical aspects of hospital management. In the canteen, for instance, there was no separate 'doctors' mess' to reinforce the distinction and hierarchy of hospital life. Donald, it would seem, did not approve of such affectations.[20] Even the hospital's name was chosen by Donald, who was a great admirer of Queen Elizabeth, the Queen Mother.[21]

More significantly, Donald's influence on the design of the new hospital meant that it was the first medical establishment to have a dedicated, purpose-designed, ultrasound examination room. This room was designed to accommodate the machine (requiring a floor strong enough to bear the weight of the one tonne gantry), and enough space to enable patients to be wheeled into the room on trolleys, and doctors and technicians to move freely around). A water supply was also installed for the removal of the messy contact gel, while a small reception and waiting area were included, adjacent to the main scan room. The requirements of ultrasound diagnosis were thus built into the very fabric of the hospital. Prior to the official opening of the hospital, a Smith's Industries Diasonograph, the very first production model to be made, was installed in its new home at the Queen Mother's.

Thus the number of hospitals operating the technology in Glasgow expanded to three - the Western Infirmary, the Royal Maternity Hospital at Rottenrow and the Queen Mother's itself. At the Western, gynaecological conditions continued to be examined using ultrasound. However, in the hands of the hospital's Consultant Radiologists, Ellis Barnett and Patricia Morley, new areas of investigation were pursued, including differential

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[19] Indeed, the labour rooms designed at Donald's request so accurately reflected the nature of obstetric practice in the 1960s that by the 1980s they were too small to accommodate the proliferating number of technologies and attendants associated with childbirth during later decades. (Dr Malcolm Nicolson, *pers comm.*)
[20] Mr Wallace Barr, interviewed by Ian Spencer, 30/04/96 (courtesy of Nicolson, Spencer and Fleming).
[21] *ibid.*

ultrasound diagnosis of pathologies of the urinary tract.[22] In the Queen Mother's, however, the focus was on obstetrics and Donald began to pursue new avenues of clinical use.

As noted in Chapter 1, investigations into ultrasonic diagnosis during pregnancy were already underway prior to 1964. Donald and MacVicar began to consider pregnancy in the late 1950s - looking first of all at the differential diagnosis of pregnancy from clinical, pathological conditions before turning their attentions to complications in early pregnancy such as hydatidiform mole.[23] This work was extended by Willocks and Duggan's investigations into the use of the modified A-scope to map fetal maturity via measurements of bi-parietal diameter (BPD).[24] In late 1963 however, a chance observation was made which would help spur the clinical investigation of the pregnant uterus and its contents via ultrasound.[25] One woman who had been kept waiting for her ultrasound examination presented with a full bladder. Donald discovered that the presence of a large quantity of urine in the bladder meant that the intestine and bowel were displaced slightly, allowing a clear view of the uterus through the ready-made liquid sounding tank of urine. The significance of this lay in the fact that prior to this point, ultrasonic imaging of the uterus

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[22] Dr Ellis Barnett became involved in ultrasound imaging in the late 1950s, when he became acquainted with Donald's work in the Western Infirmary. Following the relocation of Donald's obstetric wards to the Queen Mother's Hospital, Barnett continued to operate obstetric ultrasound at the Royal Maternity Hospital at Rottenrow, and for gynaecology patients at the Western. From the mid 1960s, however, and in collaboration with his radiology colleague, Dr Patricia Morley, he began investigating ultrasound's uses for other abdominal applications including the kidney, liver and gallbladder. (Interview with Dr Ellis Barnett, 27/08/99). Their early publications include Barnett, E., (1972), 'Ultrasound in abdominal conditions' *Radiography,* Vol. 38, No. 453, pp.233-41; Barnett, E. & Morley, P., (1971), 'Ultrasound in the investigation of space-occupying lesions of the urinary tract' *British journal of radiology*, Vol. 44, No. 526, pp.733-42; *idem.,* (1972), 'Diagnostic ultrasound in renal disease' *British medical bulletin,* Vol. 28, No. 3, pp.196-9; Morley, P., Barnett, E., Bell, P.R., Briggs, J.K., Calman, K.C., Hamilton, D.N. & Paton, A.M., (1975), 'Ultrasound in the diagnosis of fluid collections following renal transplantation' *Clinical radiology,* Vol. 26, No. 2, pp.199-207; Davidson, J.K., Morley, P., Hurley, G.D. & Holford, N.G., (1975), 'Adrenal venography and ultrasound in the investigation of the adrenal gland: an analysis of 58 cases' *British journal of radiology,* Vol. 48, No. 570, pp.435-50; Kyle, K.F., Deane, R.F., Morley, P. & Barnett, E., (1971), 'Ultrasonography of the urinary tract' *British journal of urology,* Vol. 43, No. 6, pp.709-17.

[23] Donald, I., MacVicar, J. & Brown, T., (1958), 'Investigation of abdominal masses by pulsed ultrasound' *Lancet,* No.1, pp.1188-1195; MacVicar, J. & Donald, I., (1963), 'Sonar in the diagnosis of early pregnancy and its complications' *The Journal of Obstetrics and Gynaecology of the British Commonwealth,* Vol. LXX, No. 3, pp.387-395.

[24] Willocks, J., (1963), 'Foetal cephalometry by ultrasound and its place in clinical obstetrics' MD thesis, (University of Glasgow); Willocks, J., (1962), 'The use of ultrasonic cephalometry' *Proceedings of the Royal Society of Medicine,* No. 55, p.640; Willocks, J., Donald, I., Duggan, T.C. & Day, N., (1964), 'Foetal cephalometry by ultrasound' *Journal of Obstetrics and Gynaecology of the British Commonwealth,* No. 71, pp.11-20.

[25] Donald, I., (1963), 'Use of ultrasonics in diagnosis of abdominal swellings' *British Medical Journal,* No. 2., p.1154.

could only be achieved if it was sufficiently enlarged as a result of pathology or pregnancy to be accessed through the abdominal wall. The full bladder technique (as it became known) thus enabled visualisation of uteri of normal size, facilitating the study of very early pregnancy. Donald and MacVicar's first success in this area occurred when they observed an early gestation sac in a woman who had not yet been diagnosed as pregnant.[26]

There are two points to note about the development of the full bladder technique. The first is its significance to the further development of obstetric ultrasound. As Donald put it:

> Now at last we could really study pregnancy from one end of its development to the other.[27]

This technique enabled the scope of obstetric ultrasound to be considerably expanded. Pregnancy could now be studied, observed and charted to a degree previously unimaginable. Conditions and pathologies associated specifically with early pregnancy could now be investigated, as could the gradual development of the embryo and fetus. In other words, the boundaries of possibility were significantly extended by this 'discovery' prompting yet greater activity on the part of those investigating ultrasound's clinical potential.

The second point to note is that this highly significant event was essentially a product of chance and circumstance. This technique did not develop as the direct result of deliberate investigation prompted by either anatomical knowledge of the body and the proximity of organs, or expertise in ultrasound and its characteristic behaviour in different physical media. Instead, this technique was the unintended, emergent outcome of diagnostic ultrasound's interaction with a woman kept waiting too long to be examined and who was either too polite, embarrassed or deferential to her doctor to ask to be excused for a toilet trip. Although a mundane and insignificant event in itself, its repercussions and impact on the development of this technology were enormous. Thus, a major advance in obstetric ultrasound emerged from a humble and unintentional circumstance.

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[26] Donald, I., (1974), 'Sonar, - the story of an experiment' p. 115.
[27] *ibid.*

Thus when the Queen Mother's Hospital was opened in 1964, the ultrasonic study of pregnancy was gaining momentum and the team's research activities were relocated to their new purpose-built location. Here the practice of obstetric ultrasound continued to expand. As Donald's reputation and knowledge of the work of the Glasgow team began to grow, a new generation of clinicians was trained in ultrasound techniques at QMH. Amongst them were figures such as Stuart Campbell, Usama Abdulla and Hugh Robinson. Like John MacVicar (and Bertil Sundén) before them, these young doctors became involved in the practice of diagnostic ultrasound because of its clear potential as a research topic for their MD qualification. Indeed, it is interesting to note that for some of these clinicians ultrasound appears to have been very much a means to an end. John MacVicar, for example, gave up obstetric ultrasound once he had acquired his MD, while Hugh Robinson, although he continued to employ the technology in his later professional career, did not undertake further research into ultrasound. Thus although the impact of both men on the field was considerable, they specialised in this area of their professional practice for only a short time. Others, however, continued to actively pursue careers in which obstetric ultrasound figured largely. Stuart Campbell, for example, worked as a research registrar in QMH from 1965 to 1968 when he took up a lectureship in obstetrics and gynaecology at Queen Charlotte's Maternity Hospital in London. There he continued his research into ultrasound, and indeed was responsible for introducing the technology into that institution. He became Professor at Queen Charlotte's in 1976, before moving to Kings College Hospital where he remained until 1996. In that year he moved once more to St. George's Hospital Medical School where he was Professor and Chair at the Department of Obstetrics and Gynaecology and the Fetal Medicine Unit.[28] Throughout this prestigious career, Campbell continued to both research and promote obstetric ultrasound, becoming one of the world's most respected authorities

[28] Tansey, E.M. & Christie, D.A., (eds.), (2000), *Wellcome witnesses to twentieth century medicine, volume 5. Looking at the unborn: historical aspects of obstetric ultrasound,* Wellcome Trust, London, p.29 (footnote 64).

on the subject.[29] Similarly Usama Abdulla, a contemporary of Campbell's at QMH from 1965, carried his interest in obstetric ultrasound to other locations. He moved to Queen Charlotte's in 1969, then to Chelsea Hospital. In the 1970s he helped establish ultrasound departments in Oxford and then Liverpool. Thus for young doctors taking the first steps in their career, new technologies (as ultrasound was in the 1960s) could either form a stepping stone into their new careers *à la* MacVicar and Robinson, or could play a more significant role in their future professional development. Furthermore, the nature of careers in specialist medicine, and particularly the high degree of geographical mobility which tend to characterise them, suggest that the MD research route is also a significant one for technological diffusion within medicine. On leaving Glasgow, Abdulla and Campbell took their research interests with them and were prominent in transferring the technology to new locations.

In 1965, however, Campbell was still a Research Registrar at QMH. His project was aimed at refining the measurement of BPD. The technique he developed involved the use of both the A-scope display and the B-scanner. Two-dimensional (B scan) imaging was used to locate the optimum position from which to achieve mid-line echoes, and then the machine was switched to the A-mode display for making the actual measurements.[30] This, in itself, required another modification to the Diasonograph in the form of a switch installed at the back of the machine to facilitate movement between the two types of display. That this modification was performed by one of the engineers from Nuclear Enterprises (and not by Fleming or Hall at the Ultrasound Technology Unit in the hospital), provides further evidence of the new forms of collaboration now being fostered between the clinical researchers in Glasgow and the commercial suppliers in Edinburgh.

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[29] Campbell's later publications include Campbell, S., (1977), 'Early prenatal diagnosis of neural tube defects by ultrasound' *Clinical obstetrics and gynaecology,* Vol. 4, pp.351-59; *idem.,* (1974), 'Fetal growth' *Clinical obstetrics and gynaecology,* Vol. 1, pp.41-65; *idem.,* (1970), 'Ultrasonic fetal cephalometry by ultrasound' *Journal of obstetrics and gynaecology of the British Commonwealth,* Vol. 77, pp.1057-63; Campbell, S. & Dewhurst, C.J., (1971), 'Diagnosis of the small for dates fetus be serial ultrasound cephalometry' *Lancet,* Vol. 2, pp.1002-6; Campbell, S. & Wilkin, D., (1975), 'Ultrasonic measurements of the fetal abdominal circumference in estimation of fetal weight' *British journal of obstetrics and gynaecology,* Vol. 82, pp.689-97; Campbell, S., Johnstone, F.D., Holt, E.M. & May, P., (1972), 'Anencephaly: early ultrasonic diagnosis and active management' *Lancet,* Vol. 2, pp.1226-7; Campbell, S., Diaz-Recasens, J., Griffin, D.R. *et al,* (1983), 'New Doppler technique for assessing blood flow', *Lancet,* Vol. 1, pp.675-77; Campbell, S., Warsof, S.L., Little, D. & Cooper, D.J., (1985), 'Routine ultrasound screening for the prediction of gestational age' *Obstetrics and gynaecology,* Vol. 65, pp.613-20.

[30] Campbell, S., (1968), 'An improved method of fetal cephalometry by ultrasound' *Journal of obstetrics and gynaecology of the British Commonwealth,* Vol. 75, pp.568-76.

Abdulla, on the other hand, worked with Donald in his investigations into the diagnostic possibilities of visualising the placenta. As they note in one of their first publications in this area, placentography was a different practice from localisation of the placenta.[31] Localisation often only entailed identifying whether or not the placenta was praevia, i.e. in a position that would obstruct normal delivery of the fetus, or be prone to detaching early and causing haemorrhage and miscarriage. Placentography, on the other hand, involved a more detailed survey of the size, nature, texture and position of the placenta. Alternative ways of achieving information about the placenta were either by direct imaging via soft tissue radiography, or by inferring the level of placental tissues present through various assays of maternal blood by thermography, artiography or radioactive isotopes. Thus the ultrasonic alternative forwarded by Donald and Abdulla was considered to be both safer than radiography, and more detailed and immediate than the others. This particular clinical use was given further impetus in the early 1970s when grey scale imaging facilitated more detailed analysis of this organ.

Again, however, it is clear that new clinical applications were accompanied by further technical modifications. Donald and Abdulla's research into the placenta was conducted on a Diasonograph purchased for the hospital by the Scottish Home and Health Department in 1965. Although the research project itself ran from 1965-68, Donald and Abdulla refer to the first year of the project as 'the experimental year'.[32] It is clear, however, that 'experimental' in this context refers not only to the new form of analysis being undertaken and object of enquiry being studied, but also to changes being made to the equipment being used. They state, for example:

> after some months of modification, calibration and adjustment, the number of cases investigated began to build up rapidly as experience and confidence mounted.[33]

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[31] Donald, I. & Abdulla, U., (1968), 'Placentography by sonar' *Journal of Obstetrics and Gynaecology of the British Commonwealth'*, Vol. 75, No. 10, p.993.
[32] *ibid.*, p.1000.
[33] *ibid.*, p.993.

The importance of these modifications is further underlined in the acknowledgements of this paper, which are almost entirely devoted to John Fleming and Angus Hall for their 'fresh electronic modifications and refinements'.[34] What is significant about this is the way in which innovation in clinical practice went hand-in-hand with innovation in technical design. Both were mutually shaped in a way which extended not only medical culture but also technological design. Neither practice nor technology acted as a stable context here which could be used to explain the emergence of the other. Rather, they were both moulded and shaped through their interconnection.

The mid 1960s also really marks the period during which ultrasound crossed the divide between medical research and medical practice - however fluid and ill-defined that divide may be. The growth in clinical uses is well illustrated by comparing Donald and McVicar's initial paper devoted to obstetrics, and Donald's later publication of 1969.[35] In the former, investigative paper, Donald and McVicar concluded:

> Sonar examination is useful in the diagnosis of pregnancy after 9 weeks amenorrhoea, to confirm the diagnosis of threatened abortion, to diagnose or exclude hydatidiform mole and to elucidate the type of tumour if one is found as a complication of pregnancy.[36]

Further, at this stage, each scan took from one to two minutes to be completed and a minimum of four scans were taken and recorded for each patient.[37] By 1969 the number of clinical uses for the technology had increased considerably. These included diagnosis of twins from seven and a half weeks' gestation; hydramnios, hydrocephalus and anencephalus; as well as the BPD fetal cephalometry and placentography mentioned above.[38] Thus research practices were gradually put into daily practice to aid the diagnoses of a number of clinical conditions and potential hazards associated with pregnancy.

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[34] *ibid.,* p.1006.
[35] MacVicar, J. & Donald, I., (1963), 'Sonar in the diagnosis of early pregnancy'; Donald, I., (1969), *Practical obstetric problems: 4th edition,* Lloyd-Luke (Medical Books) Ltd., London, (chapter 28, 'Ultrasonics in obstetrics').
[36] MacVicar, J. & Donald, I., (1963), 'Sonar in the diagnosis of early pregnancy' p.394.
[37] These early obstetric scans were performed using the automatic scanner developed by Tom Brown (see Chapter 1).
[38] Donald, I., (1969), *Practical obstetric problems.*

Furthermore, the time taken for each scan had by this time been reduced to around 20 seconds.[39]

Moreover, changing technical equipment and techniques led to changes in the way cases were determined and treated. For example, the ability of ultrasound to diagnose incomplete or missed abortions, meant that women admitted on suspicion of this were only given dilation and curettage (D and C) if the uterus was found to contain retained products of conception - i.e. if it was not empty.[40] Placental localisation and diagnosis also had a significant impact on clinical management. Prior to ultrasonic diagnosis of placenta praevia, for example, women with suspected cases (due to bleeding) would be detained in hospital for complete bedrest. While ultrasound did not directly bring about a change in management for this condition, it significantly reduced the number of women advised to remain in hospital for long durations by distinguishing those who actually had low-lying placenta from those who did not. As Dr Margaret McNay[41] recalls of the period before ultrasound's employment in such cases, many women remained in hospital needlessly:

> We would have three or four patients at any one time in the wards taking up beds. They might have had children at home, somebody else had to look after them [the children], you know, all the social implications of that.[42]

Furthermore, prior to the introduction of ultrasound, the method of diagnosing the condition in preparation for the management of labour was a considerably invasive and potentially hazardous procedure:

> In my training [if] you had a patient who presented with bleeding later in pregnancy and she remained in hospital from several weeks perhaps until she was 38 weeks and she was then examined under anaesthesia in theatre. So you examined with the finger in the vagina through the cervix and you felt whether or not there was placenta there. And if there was, you were all geared to doing a caesarean section, if there

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[39] *ibid.*
[40] Donald, I., (1974), 'Apologia' pp.136-7; Donald, I., (1974), 'Sonar – the story of an experiment' p.115.
[41] Dr Margaret McNay worked at the Queen Mother's Hospital from 1978 to 1996, where she became Consultant and Head of the Department of Obstetric Ultrasound.
[42] Interview with Dr Margaret McNay, 05/11/97. For an account of just such a confinement from the perspective of one former patient see the coda to this thesis.

> was no placenta there she was wakened up from the anaesthetic and she was allowed to labour.[43]

Thus ultrasound's ability to diagnose placenta praevia not only saved many women from the inconvenience and distress of remaining bed-ridden in hospital for many weeks (which also had a significant impact on hospital management and availability of maternity beds) but also meant that the more invasive vaginal examination was eventually dispensed with.

There were, however, other uses to which the technology was put. Donald, for example, often performed ultrasound scans on women seeking terminations of pregnancy with the express intention of dissuading them from pursuing this action. In particular, the scan images would be shown to these women, while the implications of what was displayed on the image was carefully pointed out by the eminent professor using emotive language. As Mrs Winnie Childs (who worked as a medical Almoner at the Queen Mother's) recalls:

> I always remember very clearly he used to use the ultrasound. [...] The mothers would come in to him and he was terrific with single parents... Then of course you would go and have an ultrasound done and show the mother the picture of this baby you weren't to murder. This all happened in a busy clinic on a Friday afternoon. So it was full of drama, you were pretty sure of having a couple of dramatic scenes in a Friday afternoon clinic.[44]

As a member of the Anglican Church, and High Church in his allegiance, Donald's opposition to abortion was founded on his religious beliefs and was well-known to colleagues and associates at the time. This was particularly evident in his somewhat antagonistic relationship with his professorial counterpart in Aberdeen, Sir Dugald Baird. Also a very eminent and well-respected Professor of Obstetrics, Baird was not opposed to the practice of abortion and lobbied for the 1967 Abortion Act. Donald, on the other hand, actively campaigned against the legalisation of abortion not only in the UK in the 1960s, but also in other European countries such as Italy in the 1970s.[45] As well as writing letters to the media, giving public addresses and so on, his activities in this respect included passing anti-

[43] *ibid.*
[44] Mrs Winnie Childs, interviewed by Ian Spencer, (courtesy of Nicolson, Spencer and Fleming).
[45] Donald's audience with Pope John Paul II in 1979 was prompted largely by his anti-abortion campaigning rather than his obstetric or ultrasound work.

abortion petitions around his obstetric wards.[46] Thus two of Scotland's most prominent obstetricians held opposing views on abortion which, although never manifest as open hostility, did create a general antagonism and rivalry between the two.

It is important to note that the passing of the Act had different implications in Scotland than in England. Prior to the 1967 Act, Scots Law did not regard the practice of abortion as an assault on an individual and thus the practice was not technically illegal in Scotland. Indeed, Professor (later Sir) Malcolm McNaughton, who occupied Glasgow's sister Chair in Obstetrics alongside Donald from 1970, performed many abortions while working under Baird in Aberdeen in the 1950s.[47] On the other hand, the powerful and privileged position of Scottish professors enabled them to influence the availability of elective abortions following 1967. Thus while the details of the Act ensured that the decision to carry out a termination of pregnancy remained a clinical one, women's access to clinicians willing to carry out the procedure were dependent on their geographical location. For example, Donald's influence over obstetrics in Glasgow ensured that women could not obtain such a procedure within any of the city's hospitals until the arrival of McNaughton in 1970.[48]

It is clear, therefore, that Donald's political and religious attitudes towards abortion directly affected the way in which he operated ultrasound in the Queen Mother's Hospital and, indeed, it continued to do so throughout his professional life.[49] Furthermore, it was widely known that terminations of pregnancy were not carried out in the Queen Mother's while Donald was in charge (other than in cases where the fetus was considered 'incompatible with life'). Thus the number of women scanned under such circumstances (both before and after the passing of the 1967 Abortion Act) indicates a collaboration amongst Donald and anti-abortion general practitioners to dissuade women from terminations - legal or illegal.

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[46] Interview with former Queen Mother's Hospital patient.

[47] Donald often referred to McNaughton as 'the abortionist in the East' i.e. in the east end of the city. Professor Sir Malcolm McNaughton, interviewed by Ian Spencer, courtesy of Nicolson, Spencer and Fleming.

[48] Professor Sir Malcolm McNaughton, interviewed by Ian Spencer, courtesy of Nicolson, Spencer and Fleming.

[49] The inter-relationship between Donald's anti-abortion stance and his use of ultrasound is further examined in Chapter 3.

Donald's opposition to elective abortion did not mean, however, that he was unsympathetic to the social consequences of pregnancy. Indeed the appointment of Mrs Childs as Medical Almoner for the hospital was made at Donald's insistence, in order to provide social work care for pregnant women and recent mothers. He worked closely with Mrs Childs in the provision of support and counselling of options for unmarried mothers. Nevertheless, he was also quick to realise the potential of ultrasound for dissuading those who might otherwise seek to end their pregnancies.

By the late 1960s, therefore, the Queen Mother's was thriving with ultrasound activity. As its reputation grew, the team scanned ever-greater numbers of women. These were not only in-patients at the Queen Mother's, but also referrals from other Scottish and English hospitals. The card file records of ultrasound examinations that have been kept at QMH detail patients referred from hospitals in Aberdeen, Perth, Dundee, Bristol and Newcastle, as well as those from smaller institutions in the Greater Glasgow area. Inter-personal relationships within the obstetric community and increasing awareness of the work being carried out in Glasgow prompted clinicians in other locations to send problematic and/or interesting cases to Glasgow to see what could be made of them. Thus, although ultrasound machines did not begin to diffuse outside of Glasgow until the late 1960s, their use in obstetric medicine was already more widespread than the number of machines might indicate. In studying the spread and uptake of this technology therefore, it is important to examine not only the movement of machines, but also that of patients. This has important implications for the study of technological diffusion. Studying the number of units sold or the 'dispersal' of the technology may not actually reveal a great deal about its diffusion. A technological artifact may be sold in relatively large quantities, but used in a very limited manner. On the other hand, as in this example, a technology may have a much wider usage than its adoption figures imply. This reiterates the importance of regarding technologies as more than merely machines and artifacts but, instead, seeing them as forms of activity. To evaluate diffusion by simply counting machines misses this important point and risks replacing a study of diffusion with a study of sales figures.

When these patient transfers are taken into account, it is possible to view the Queen Mother's Hospital at this time as the established focal point of the emerging technology. Indeed, so many cases were being examined that extra help was drafted in. First of all came

Mrs Ida Millar, who was appointed in 1964. Millar was the wife of a local general practitioner of Donald's acquaintance. Her exact role in the Department was somewhat unusual. Neither secretarially trained nor medically qualified she fulfilled a number of duties including the organisation of the scanning department and the operation of the equipment. She was thus the only non-clinician at this time in the hospital who was directly involved in scanning patients. The position Millar occupied, therefore, was both unique and created specifically in relation to ultrasound. Millar was, in essence, the first incumbent of the new occupational category of 'ultrasonographer' – a non-medically qualified person who performed ultrasound examinations but who was herself unable to make clinical diagnoses. Thus her role and position within the hospital were defined entirely in terms of her interactions with ultrasound equipment. For this reason, Millar's appointment indicates an important time in the technology's history. In the creation of her role can be seen the first signs of the emergence of a new hierarchy surrounding the technology, and thus of the way in which the practice of ultrasound was helping to shape the organisation of medicine in this location. Her lack of qualifications might appear yet more unusual in light of Tom Brown's comments about Donald's reticence to allow the engineer to deal directly with patients because of his lack of clinical training.[50] However, Brown's training and employment as an engineer entails that he already had a clearly defined role *vis à vis* the technology and thus could be easily 'allocated' in this emerging hierarchy. Millar, on the other hand, did not have a pre-determined relationship to ultrasound at all and thus Donald had greater flexibility with which to determine what tasks could be delegated to her. As a general practitioner's wife (a social role which often entailed unofficial supporting 'duties' within medicine, such as maintaining appointment books, filing records and so on), Millar's previous experience made her well-suited to her new job.

Millar was later joined by a dedicated secretary for the scan department. Thus, concurrent with the various research projects being undertaken, the Queen Mother's gradually evolved a working obstetric ultrasound clinic, institutionally integrated with the rest of clinical practice. The scan department was, in other words, not only a centre of emerging expertise and research, but also a fully functioning clinical service operated by obstetric clinicians and with its own dedicated engineering and support staff. Furthermore, as the department was

[50] See Chapter 1.

staffed by many of those responsible for its initial innovation, it enjoyed a privileged position *vis à vis* the technology's commercial suppliers in terms of technical collaboration and access to new technical developments.[51]

By the late 1960s, then, Glasgow's success naturally attracted imitation, and it soon ceased to be the only Scottish city which was equipped with ultrasound.

Introducing a new obstetric technology in Aberdeen

In 1967, Aberdeen Maternity Hospital took delivery of a Nuclear Enterprises NE4101 machine - the first of such models to be made by the Edinburgh-based firm. Located in a large hospital campus in the Forresterhill area of the city, Aberdeen Maternity Hospital (AMH) was in close proximity to both the main hospital (Aberdeen Royal Infirmary) and the children's hospital (Aberdeen Hospital for Sick Children). Furthermore, the entire Forresterhill site was also close to the University of Aberdeen, where the three hospitals served as medical teaching establishments. Thus the maternity hospital formed part of another university/hospital nexus, with all of the opportunities which that affords in terms of research, specialisation and funding opportunities. In addition to its association with the university (and also as a result of it) Aberdeen Maternity was also a tertiary referral centre for the Grampian region and thus was the main centre of expertise in one of the largest Health Board areas of Scotland.

It may appear natural that a hospital such as AMH should be the next to join the ultrasound 'bandwagon'. It was another large tertiary referral unit located in one of Scotland's four main urban centres. Nevertheless, several historically contingent factors brought this about. The first of these was a significant change in personnel - the retirement of Aberdeen's head of Obstetric Medicine, Professor Sir Dugald Baird.

Baird's replacement was Ian McGillivray. Trained largely in Glasgow where he received his MD in 1953, McGillivray had also spent a proportion of his career in Aberdeen where he served as Senior Lecturer in Midwifery during the late 1950s, before taking a Chair in Obstetrics and Gynaecology at St. Mary's in London. Thus on his return to Aberdeen in

[51] Interview with Mr. John Fleming, 20/09/98.

1964 he was already acquainted with the Scottish obstetric community and importantly also with Ian Donald. A few trips to Glasgow in 1965 appear to have convinced McGillivray that ultrasound was something with which Aberdeen should become involved. What is important to note about this is that the initial demand for ultrasound in this location came from obstetrics and gynaecology. The Diasonograph was not designed to be a tool used exclusively in this specialty: Donald hoped it would be taken up in more general medical applications.[52] Nevertheless, it was in gynaecology that Donald and his co-workers had first investigated ultrasound's potential and published their results. Furthermore it was through the close inter-personal connections in the related fields of obstetrics and gynaecology that the greatest degree of interest was fostered.

McGillivray, however, needed an ally to help him persuade the local Health Board to introduce ultrasound and he found this in the person of Professor John Mallard. In 1965, Mallard arrived in Aberdeen to take up the newly established Chair in Medical Physics at the University of Aberdeen's Department of Biomedical Physics and Bioengineering - the first such Chair to be established in Scotland. Mallard's main research interests up to that point were in the also newly emergent field of nuclear medicine. At the Hammersmith Hospital and, later, St. Thomas's in London he had worked on the development of radioactive isotope imaging using a gamma camera (an alternative to the Geiger-Müller counter, which was used to detect the path of radioactive isotopes once introduced into the body).[53] This was an activity which he continued after his move to Aberdeen[54] as well as

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[52] Interview with Dr Ellis Barnett, 27/08/99. This is also minuted in a report following a meeting attended by Donald on diagnostic ultrasound (Western Regional Hospital Board, 'Report of the working party on ultrasonics' August 1971).

[53] Mallard, J., (1996), 'The first century of hospital physics 1895-1995, the evolution of medical imaging 1945-1995, with Aberdeen's role 1965-1995' in Adam, A., Smith, D. & Watson, F., (eds.), *'To the greit support and advancement of helth': papers on the history of medicine in Aberdeen, arising from a conference held during the quincentenary year of Aberdeen University,* Aberdeen History of Medicine Publications, Aberdeen; Tansey, E.M., Christie, D.A. & Reynolds, L.A., (eds.), (1998), *Wellcome witnesses to twentieth century medicine, volume 2. Making the body more transparent: the impact of nuclear magnetic resonance and magnetic resonance imaging,* The Wellcome Trust, London. See also Blume, S.S., (1992), *Insight and industry,* chapter 6. There are a number of interesting parallels between the emerging fields of ultrasound and nuclear imaging. Both owe at least part of their origins to the military/industry nexus of World War II. Furthermore, both CT scanning (Computed Tomography) and MRI (nuclear magnetic resonance imaging) developed as ways of viewing the body via transverse 'views' in the same way as Brown's contact B-scanning machine. Some of these overlaps where relevant will be referred to in the course of this chapter, but a more detailed analysis of the dynamics between ultrasound and nuclear medicine would provide an interesting future study.

[54] Mallard, J.R. & Corfield, J.R., (1969), 'A statistical model for the visualisation of changes in the count density on radioisotope scanning displays' *British journal of radiology,* Vol. 42, No.499, pp.530-38.

beginning work on the development of another imaging modality - Electron Spin Resonance (ESR).[55] Thus Mallard arrived in Aberdeen with not only a pre-existing interest in new medical imaging technologies, but also a track record in 'tinkering'. Medical physics itself, of course, developed as a result of another form of imaging – radiography. Thus the fact that Mallard was interested in images is not unusual *per se*. The fact that he had an interest in new forms of imaging was.

Mallard was first approached by the Professor of Midwifery following his inaugural speech in 1966, when McGillivray suggested that they might jointly approach the University about acquiring a Diasonograph. Mallard, who was a consultant to Nuclear Enterprises through his work with the gamma camera, was also aware of Donald's work and the fact that the development of ultrasound had moved to Nuclear Enterprises under the guidance of Tom Brown. The two Aberdeen Professors therefore submitted a grant application to the Medical Research Council (MRC) for the funds to purchase a Nuclear Enterprises machine and investigate its clinical uses.

Whatever the particular, personal motivations of these actors may have been, the importance of having people in such prominent positions interested in procuring the technology is clearly significant. McGillivray and Mallard were able to access important funding bodies as well as actors higher than they in the University and hospital hierarchies. They were, in other words, powerful actors within their own administrative and organisational settings.

Nevertheless, the scanner was not put into use until 1967. The reason for this delay lies in the number of ways in which the new machine had to be accommodated. The minutes of the North Eastern Regional Hospital Board (which would later become Grampian Health Board) record that the cost of installing the Diasonograph was £3 200.[56] This however, was not the cost of the purchase of the machine but of the purpose-built room in which it was to be housed. The large size of the Diasonograph, but also (and more importantly) its weight entailed that this significant piece of medical equipment could not simply be placed

[55] Mallard, J.R. & Kent, M., (1969), 'Electron spin resonance in biological tissues' *Physics in medicine and biology,* Vol. 14, No.3, pp.373-96.
[56] Property & Works Committee Minutes, 28 November 1967, Minutes of the North-Eastern Regional Hospital Board (GRHB A1/1/10).

'anywhere' in the hospital. Instead a separate room was built to house the machine – situated alongside the antenatal theatre in the hospital. This part of the installation process was funded by the hospital's Endowment Fund, with the cost of the actual machine being met by the MRC.[57]

From the outset, therefore, the uptake of diagnostic ultrasound was a joint endeavour on two levels – it was jointly funded by both the MRC and the Regional Hospital Board and was shared between the Departments of Obstetrics and Gynaecology and Medical Physics. It was therefore, from the outset, perceived as both a significant research project *and* an addition to clinical practice. Nevertheless, the chosen location for the machine is interesting. As in Glasgow, obstetrics and gynaecology were located in different buildings, although both were on the same site at Forresterhill. Obstetric cases were located in the Maternity Hospital while gynaecological ones were treated at the Royal Infirmary.[58] Thus ultrasound was placed squarely within the geographical realm of obstetrics – not only in that it was placed in the Maternity Hospital but also that it was directly adjacent to the antenatal theatre. It is tempting to surmise that its location indicates a predisposition towards obstetrics rather than gynaecology, and sound reasons can be suggested for this. First of all, given that the investigation of the technology's use in obstetrics was more recent than in gynaecology, it can be suggested that obstetrics provided more 'uncharted terrain' for research purposes.

John Mallard, as a medical physicist (a profession which he views as central to the development of new medical technologies[59]) occupying a newly created Professorial Chair, had ample motivation to find new areas of ultrasound research in which he could become involved. Professor McGillivray, arguably, was similarly motivated. Sir Dugald Baird could not have been a particularly easy act to follow in Aberdeen. The eminent and well-respected Professor cast a large shadow over the Chair now occupied by McGillivray. Many of the clinicians who worked under Baird's leadership (affectionately known as 'Baird's Boys') went on to take up important Chairs in other Universities.[60] Furthermore, Baird was highly

[57] *ibid.*
[58] Levack, I. & Dudley, H., (1992), *Aberdeen Royal Infirmary: the people's hospital of the North-East,* Baillière Tindall, London.
[59] Interview with Professor John Mallard, 28/3/00
[60] Levack, I. & Dudley, H., (1992), *Aberdeen Royal Infirmary,* pp.127-28. One of 'Baird's Boys' was, of course, Professor Malcolm NcNaughton, 'the abortionist in the East'.

supportive of research work in a number of areas including cervical smear tests and infertility treatment. It is possible, therefore, to suggest that ultrasound provided an expedient way for McGillivray to both stamp his authority on his new role and become involved in a still highly innovative form of practice. Not only was there the opportunity to be involved at an early stage with a new obstetric technology, but also the chance to demonstrate that there was a new Professor in town by working with Baird's old adversary Ian Donald.

However, despite the fact that obstetrics may have provided greater opportunities for new research, McGillivray (in his contribution to the Annual report for the hospital board in 1967) provides evidence to suggest that both obstetrics and gynaecology were expected to benefit from the arrival of ultrasound:

> ...work has commenced on the provision of a room to accommodate an ultradiasonograph [sic.] which has been provided by the University. With this machine it is hoped that there will be a great reduction in the use of X-rays in pregnancy. This machine is also of great value in the detection of certain gynaecological conditions.[61]

Thus the siting of medical ultrasound in the maternity hospital was probably the result of more practical considerations. The accommodation available for gynaecology as a specialty was more limited than in the large and independently situated maternity hospital. Indeed, if the machine were to be installed in the Royal Infirmary, the obvious location would have been within the Radiology department. Radiology, however, were not involved in the funding applications for the Diasonograph, nor with its planned installation. Furthermore, the arrival of the machine occurred only a year after new facilities had been created at the Royal Infirmary for the Radiology department and thus the reorganisation and upheaval required to introduce ultrasound would not have been particularly desirable in any case.[62]

Nevertheless, despite McGillivray's comments recorded above, there is little evidence of the technology's use in gynaecology until the early 1970s – either from the oral testimony of

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[61] Annual Report of the Group Medical Superintendent for the Aberdeen Special Hospitals Board of Management for 1967, p.28 (GRHB B2/2/14)

[62] Levack, I. & Dudley, H., (1992), *Aberdeen Royal Infirmary,* Chapter 12.

those who used the machine or in their published papers. This in turn was probably a direct result of the location chosen for the machine which was not particularly convenient for the examination of gynaecology patients. Thus from the outset, the machine was used as primarily an obstetrical tool. It can be suggested therefore that in Aberdeen, diagnostic ultrasound was reconceptualised as an 'obstetric' technology, rather than a general imaging device, as a result of both practical and personal reasons.

However, the purchase of a new piece of machinery is barely half the story of technology transfer: staff was required to operate and work with the machine. Once more, the personnel who were eventually recruited reflected the joint nature of the project. The first, Dr Alexander [Sandy] McIntosh, was an obstetric registrar at the hospital who was looking for a suitable research project for his MD qualification and was guided towards ultrasound by Professor McGillivray. His route into ultrasound therefore was similar to that of James Willocks, Usama Abdulla, Hugh Robinson and Stuart Campbell in Glasgow and was as a result of his position in a large teaching hospital.

McIntosh was joined in his new post by Mr Alexander [Sandy] Christie, a young engineer who represented the Department of Clinical Physics in the endeavour. Christie's route into ultrasound was more unusual than McIntosh's, however, and is worth considering in some depth. A former pilot in the Royal Air Force, Christie had changed career in 1963. Although still with the Ministry of Defence, he moved into electronic engineering, working for a spell on the development of weapon guidance systems before taking up an appointment as lecturer in electronics at Bristol College of Science and Technology (now the University of Bath). Christie first became acquainted with ultrasound through one of his engineering colleagues at Bristol College who used metal flaw detectors in his work. More significantly, this colleague was also aware of its emerging application in medicine and particularly the work of Peter Wells at Bristol Royal Infirmary. Wells was a key player in the development of diagnostic ultrasound equipment from the early 1960s. His most widely known contribution to the field was his work on the development of Doppler techniques.[63] However, Wells also worked in a number of other key areas such as grey-scale imaging and dynamic focussing.[64] When Christie met him in the mid 1960s, he was in the process of developing an articulated-arm contact B-scanner for clinical use. His interest aroused, Christie paid a visit to the medical physicist, who in turn put him in touch with Ian Donald:

> Peter told me about Ian Donald and all the rest of it and I thought it sounded to me just quite fascinating - just one of those things you hear and you think, 'that's interesting' and so I started looking into it. Then I contacted, I think I wrote to Ian Donald about it and that is when he invited me to come up [from Bristol]. And I didn't know anything about it, I don't think I had ever been in a hospital, well, apart from when I was born![65]

Once again, the very active promotion in which Donald was engaged to increase awareness of medical ultrasound can be seen in this invitation. The Glasgow team appear to have been very much aware of the importance of enrolling other actors, of fostering interest wherever it might prove fruitful. In this case, meeting Donald and being infected with his enthusiasm led Christie to begin work on the design of his own scanner.

How exactly Christie became enrolled into the ultrasound project is recalled differently by the actors involved. According to Mallard, Christie responded to his advertisement for the post, attended an interview and was appointed on that basis. Christie, on the other hand, recollects meeting Mallard the summer before at a social event, where Mallard expressed

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[63] His publications in this area include: Wells, P.N., (1969), 'A nomogram for the calculation of Doppler frequency shift' *Ultrasonics,* Vol. 7, No. 1, pp. 18-19; *idem.,* (1969), 'A range gated ultrasonic Doppler system' *Medical and biological engineering,* Vol. 7, No. 6, pp. 641-52; *idem.,* (1970), 'Doppler range finding' *British journal of radiology,* Vol. 43, p.229; *idem.,* (1970), 'The directivities of some ultrasonic Doppler probes' *Medical and biological engineering,* Vol. 8, No. 3, pp.241-56; Atkinson, P. & Wells, P.N., (1977), 'Pulse-Doppler ultrasound and its clinical application' *Yale journal of biology and medicine,* Vol. 50, No. 4, pp.367-73; Clifford, P.C., Skidmore, R., Bird, D.R., Lusby, R.J., Baird, R.N., Woodcock, J.P. & Wells, P.N., (1980), 'Pulsed Doppler and real-time "duplex" imaging of dacron arterial grafts' *Ultrasonic imaging,* Vol. 2, No. 4, pp.381-90.

[64] Wells, P.N., (1975), 'Review: absorption and dispersion of ultrasound in biological tissue' *Ultrasound in medicine and biology,* Vol. 1, No. 4, pp.369-76; Wells, P.N., Halliwell, M. & Mountford, R.A., (1974), 'A method of display dynamic range expansion using system gain wobbulation' *Ultrasound in medicine and biology,* Vol. 1, No. 2, pp.179-81. For more detailed accounts of Wells' career see BMUS, (1987), *Bulletin of the BMUS,* No.44; Woo, J. *A short history of ultrasound in obstetrics and gynaecology,* www.ob-ultrasound.net/pwells, (accessed 12/8/99).

[65] Dr Alexander Christie, interviewed by Ian Spencer and John Fleming, (courtesy of Nicolson, Spencer and Fleming).

interest in Christie's attempts to construct ultrasound equipment. Following this, according to Christie, he received a phone call from the Physics Professor offering him a post in Aberdeen. Christie took up his position in August 1967.

Either way, his appointment in Aberdeen was both fortuitous and unusual. Christie had no background in medical physics and no clinical knowledge. Nevertheless, he was an electronic engineer who already had an interest in the physical principles of ultrasound and its uses in medical and industrial applications.

Christie's entry into medical ultrasound is therefore interesting for several reasons. Firstly, it demonstrates how novel this technology was in the medical context: that someone such as Christie who had no previous clinical experience should be invited to help run a new medical service suggests that personnel with the relevant skills could not be found within the existing medical establishment. It reinforces, then, that ultrasound did not yet have its own subset of qualified practitioners and so the skills to be drawn upon had to be sought from elsewhere - in this case engineering:

> I was unique in that nobody when I started up here in Aberdeen, nobody knew what ultrasound was, they couldn't spell it. [...] For that reason they just had to sort of say, 'Well, okay, you have to do it'.[66]

Furthermore, it could be argued that Christie's appointment demonstrates the way in which technologies which are transferred into new contexts (in this case from the military and industrial to the medical) provide opportunities for a whole range of actors from varied professional backgrounds. This implies that as technologies are transferred, so too are skills. However, just as the equipment itself is moulded by the new context in which it is placed, so too the skills that are appropriate to one field may be altered by a new one. Furthermore, the heterogeneity of the actors involved provides additional evidence that despite the fact that it was now a commercial product, diagnostic ultrasound was in no way a 'stable' technology, making its way through the 'final stage' of development. Rather it remained an open and actively negotiated territory, with no professional or occupational barriers to prevent actors from a variety of backgrounds becoming involved. In a similar way to the

[66] *ibid.*

early diffusion of x-rays, ultrasound pioneers were characterised by an enthusiasm for, and interest in, the technology.[67] Indeed, at this stage Christie could almost be viewed as an 'enthusiastic amateur', but he was enfolded within the technology because of the skills which he brought. Christie went on to spend the next 30 years specialising in obstetric ultrasound and became a prominent figure within the emerging 'ultrasound community' in Scotland. He also became something of an ambassador for ultrasound, lecturing across the world on the technology's uses.

Initially, a substantial part of the remit of the new scanning service in Aberdeen was evaluation - Christie and McIntosh attempted to assess the capabilities of the equipment and its clinical potential. This, however, is unsurprising: the novelty of the machine, the operators' lack of experience, and the unfamiliarity of the images meant that it would have been both foolhardy and unethical to jump straight into clinical diagnosis. One of Christie's earliest recollections of using the machine in Aberdeen gives some sense of the ontological distance that existed between machine and operator:

> We asked our first patient and I remember as I started to scan the thought that went through my head was, 'You've bitten off more than you can chew this time son!' I remember that very clearly, I thought, 'What am I doing?'[68]

Nevertheless, these early experiences with ultrasound should not be characterised as simply a human learning exercise – a case of learning the 'right' skills to operate the machine and read the images. Instead, what was being done at this early stage was a form of human/technical alignment - the new operators were learning the skills necessary to use the machine in a practical way, while the machine was being tested and modified to align it with its new operators. In other words, the technology was being shaped in order to make it 'work' in its new location. As in Glasgow, where, for example, technical modifications were made to facilitate the imaging of the placenta by Donald and Abdulla, or to allow Campbell to switch between imaging modes, the technology was also transformed in Aberdeen. In order to make practical use of it in this new setting, Christie and McIntosh had to make their own interpretations and definitions and, more importantly, had to develop

[67] Pasveer, B., (1992), 'Shadows of knowledge'; *idem.*, (1989), 'Knowledge of shadows'.
[68] Interview with Dr Alexander Christie, 10/12/97.

their own uses and practices. In other words they had to mould their own technology, using and developing their own skills and competencies and 'tinkering' with the machine in use.

Nevertheless, before any 'tinkering' to improve or modify the machine could be performed, the Aberdeen ultrasound workers had to get the equipment to operate reliably:

> We had a lot of breakdowns in those early days. If the thing worked for half a day you were lucky. Then you were calling up Edinburgh and they were coming up again to fix it and all the rest of it.[69]

Lack of reliability in the Diasonograph was a problem shared by the Glasgow group. As John Fleming recalls:

> Initially a lot of the work was improving the Diasonograph - we hadn't spent enough time on development in the factory so there were still quite a lot of problems with it. It was electronically unstable and would oscillate, and there were reliability problems. [...] Some of the potentiometers that measured angles etc. wore out and we had to find a replacement - they weren't up to the job of being waggled continuously.[70]

As the Aberdeen machine was one of the first to be made by Nuclear Enterprises, it was basically a Smith's machine, complete with valve-based electronics rather than semi-conductors. However, although similar obstacles were shared by both groups of ultrasound workers, the implications of a breakdown were more severe in Aberdeen as a greater amount of scanning time was lost waiting for an engineer from Edinburgh. Thus it was not the unreliability of the machine, nor the lack of experience of its new operators, which created problems in Aberdeen. Rather, it was the combination of the two. Christie and McIntosh could not call upon the services and expertise of actors like John Fleming and so were far more reliant on the suppliers for assistance.

Furthermore, it is important to note that problems such as this were defined as such during actual use. That is to say, they were not inherent to the innovation process but were revealed

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[69] Dr Alexander Christie, interviewed by Ian Spencer and John Fleming, (courtesy of Nicolson, Spencer and Fleming).
[70] Interview with Mr. John Fleming, 20/09/98.

as the machines began to be used by more and more people in more and more places. Thus it was only as and when problems such as this emerged that they could be dealt with.

As Latour has noted in his analysis of technology, all machines and technical tools *demand* something from those who interact with them.[71] Certain skills, competencies or knowledge are, in his terminology, *inscribed* within technologies and demand that human operators behave in a particular manner. In other words, they operate in such a way that they shape human behaviour. On the other hand, Latour also notes that technological change can itself be prompted by the way in which people overcome these inscriptions in an attempt to either side-step what is demanded of them, or to provide new inscriptions.[72] An alternative, and less abstract, way of conceptualising this is in terms of the way in which human operators occasionally find themselves performing in ways designed to overcome or accommodate the technical limitations they perceive in the equipment. In Aberdeen for example (when the ultrasound equipment did work), the operators found manipulating the equipment in order to achieve the results they wanted required them to physically compensate for the technical limitations of the Diasonograph:

> Your eyes would be sore because you were working in darkness, you would peer at a tiny little screen and your arm would be sore from trying to whiz the gantry backwards and forwards, because if you could keep contact and make it move fast enough you got a better picture with more scan lines and that meant moving it pretty fast![73]

Working in darkness was an accommodation to the display screen on the Diasonograph, while the physical strain associated with scanning was a direct result of using the equipment at speeds for which it was ill-suited.

In addition, as an imaging technology it was not only the operation of ultrasound which demanded certain human competencies and actions, but also the interpretation of its output - the images themselves:

> We didn't know at that time what we were looking at! We looked at it

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[71] Latour, B., (1992), 'Where are the missing masses?'
[72] Latour, B., (1992), 'Where are the missing masses?'
[73] Interview with Dr Alexander McIntosh, 18/08/99.

> and we saw something and I remember [Alexander (Sandy) McIntosh] said, 'Oh look,' he said, 'There's a round thing there,' he says, 'I wonder if that could be a head?'. And that more or less illustrates what we were doing at that time. We were looking at shapes and trying to relate them to some form of basic anatomy, very basic, so we were thrilled to bits if we [...] could actually see and recognise a head or something that moved. It was there one minute and gone the next. And then it was sort of, 'Oh well, if that's how we get a head [...] where's the body?' And then we'd try to put the body and the head together.[74]

The procedure for learning to read ultrasound images was similar to that in Glasgow. The images were constructed and compared with other forms of imaging and representation, as well as evidence from autopsies and surgery.[75] As in Glasgow, however, there were times when the ultrasonic findings did not match with other representations, from, for example, radiography. In such cases, a decision was required to determine whether what had been rendered was real or illusory. One such case occurred relatively early, when a scan appeared to show an anencephalic fetus:

> We were able to show we had a body, we had a lot of fluid - excess fluid - which was typical of anencephaly, and only a little bump in the bottom for a head. And then the patient was sent for x-ray and the x-ray wasn't terribly helpful because it was a very healthy fetus. [The] senior registrar at the time, he said, 'Well, I think the evidence points to the fact that it must be [anencephaly], it must be'. And we all waited with bated breath [while the pregnancy was terminated] but it was in fact anencephalic.[76]

Again, this can be regarded as not only a *learning* process but also a crucially constructive one. Determining in the images what was 'real' and what was the artifactual outcome of poor technique, interpretation or technical efficiency was the outcome of the active alignment of the new operators and equipment. As one obstetrician who worked with Christie in the early 1970s recalls:

> I can remember scanning and I would see there was a funny line there and Sandy [Christie] would say, 'Artifact!' These in fact were the

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[74] Interview with Dr Alexander Christie, 10/12/97.
[75] See Pasveer, B., (1989), 'Knowledge of shadows' for a similar account in relation to the construction of x-ray imaging.
[76] Interview with Dr Alexander Christie, 10/12/97.

> lateral walls of the ventricles we were looking at, and neither Sandy nor I knew what we were looking at. So we were looking at things for years before it dawned on somebody what they were. I always remember that ...because it kept on appearing on patient after patient and Sandy said, 'Artifact!'[77]

The images were also compared with other ultrasound pictures, either created by Christie and McIntosh themselves or by other actors in the field. Indeed Christie recalls sending Polaroids of images to Donald in Glasgow:

> I used to ring him up and I used to send him pictures and things like that and he would send me little notes saying, 'Well done, I agree the diagnosis, that's definitely a head'.[78]

This again demonstrates the difference in kind which existed between the two groups of actors. The expertise which had emerged along with the technology in Glasgow entailed that the Glasgow team had substantially moved along from identifying heads in images, and thus Donald was able to perform the role of instructor. In Aberdeen, on the other hand, the emphasis was on identifying what the machine could do, how it was operated and what the images displayed. This difference is also evident in the Aberdeen researchers' first major project, on placental localisation. In contrast to Glasgow's concurrent research into placentography and the detailed scans they were performing, Christie and McIntosh concentrated on localisation: identifying the position of the placenta ultrasonically, and comparing their findings with the post-operative placental location following caesarean section deliveries. They were therefore following the established scientific practice of assessing the reproducibility of the work of others: was ultrasound an efficient and reliable means of determining the precise location of the placenta? As McIntosh recalls, a large number of patients had to be scanned in order to ensure a statistically viable number of caesarean section candidates:

> I used to haunt the antenatal clinics and bully everyone and I got hold of every single patient I could think of who looked as though they might require a caesarean section. Previous caesar, small stature, elderly pregnant, whatever, and I would ask them if they minded having a scan. We would localise the placenta and note it. If they had a

[77] Interview with Dr Jack Crichton, 09/02/98.
[78] Interview with Dr Alexander Christie, 10/12/97.

> caesarean section it was put in the notes (the clinicians didn't know where the placenta was, we didn't report). The clinicians were then asked if the patient required a caesarean section would [they] kindly make a careful note of where the placenta was.[79]

In order to achieve their target sample of 100 cases (i.e. those who actually underwent caesarean section), Christie and McIntosh scanned around 1,000 women. These findings on the ability of ultrasound to detect the location of the placenta were presented at the first World Congress on Ultrasonic Diagnostics in Medicine in Vienna in 1969.

However, what is most significant about this research project was that it helped embed the technology within antenatal practice in Aberdeen. Following this research, Christie and McIntosh began to receive referrals from the hospital's obstetricians requesting scans for placental localisation.

Obstetricians could easily recognise the utility and practicality of a visualising modality which could tell them with a certain degree of accuracy where they would find the placenta if they were about to perform an invasive surgical procedure on a pregnant woman (such as amniocentesis or caesarean section). Thus the acceptance of this technology amongst the medical community in Aberdeen cannot be attributed solely to the culmination of a gradual learning process on the part of Christie and McIntosh. An equal if not greater contributory factor lay in the properties and abilities of the equipment - it was finally able to do what they wanted with the degree of accuracy which they desired.

Nevertheless, while Aberdeen's obstetricians began to adopt ultrasound images as part of clinical diagnosis, the attitude of the hospital's radiologists is much less clear. In light of the work being done at the Western Infirmary in Glasgow by Ellis Barnett and Patricia Morley[80], it might have been expected that the Aberdeen radiological staff would have shown some interest in the new imaging technology - even within obstetrics. This appears

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[79] Interview with Dr Alexander McIntosh, 18/08/99.

[80] Their publications from this period include Morley, P. & Barnett, E., (1970), 'The role of ultrasound in the diagnosis of pelvic masses', *British journal of radiology,* Vol. 43, No. 513, pp.602-16 and Donald, I., Morley, P. & Barnett, E.,(1972), 'The diagnosis of blighted ovum by sonar' *Journal of obstetrics and gynaecology of the British Commonwealth,* Vol. 79, No. 4, pp.304-10.

not to have been the case, although Christie and McIntosh diverge slightly in their recollections of the role of radiology during the early days of ultrasound's career in Aberdeen. According to Christie, the chief radiologist in Aberdeen was slightly interested in learning about the technology while the other radiologists were somewhat hostile:

> I had a reasonable relationship in Aberdeen with the chief radiologist who in fact saw that if he didn't sit down with me and learn something about it he might be left behind. However, he didn't do very much, but I mean he showed interest.[81]
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> The radiologist attitude that I found was I thought they were afraid of it. They didn't understand it, therefore they were afraid of it, therefore it was no good and therefore they weren't going to have anything to do with it. That was the attitude I found both in Aberdeen and Dundee.[82]

Thus it was Christie's view that the radiological staff did not become involved with the service at the time of its introduction because they were not particularly keen to learn about it or to become involved with its development. However, McIntosh recalls that:

> The radiology department initially said they would have regular meetings and you can show us your pictures and we will comment on them. What I think they had in mind was they would do the reporting and we would do the donkey work. ... It used to frustrate me tremendously and as I was quite young at the time I thought I couldn't say too much because I've got a career to think of but I think Sandy [Christie] used to get very irritated. I think it did come across from some that he was not a doctor.[83]

Thus in McIntosh's account, the radiological staff *were* interested in the ultrasound project - at least in so far that they attempted to oversee its running - but it was McIntosh and Christie who resisted this. As is the nature of oral history, it is extremely difficult to entirely unpick the past through reliance on the oral testimony alone. However, two tentative conclusions can be suggested. Firstly, it can be surmised that the radiology department did not become

[81] Interview with Dr Alexander Christie, 10/12/97.
[82] Dr Alexander Christie, interviewed by Ian Spencer and John Fleming, (courtesy of Nicolson, Spencer and Fleming).
[83] Interview with Dr Alexander McIntosh, 18/08/99.

formally involved in the project at this time, whatever the underlying reasons.[84] Secondly, reading between the lines of both accounts it could be suggested that even though the radiology department may have made some attempt to participate, this was only half-hearted and unsuccessful. It is important to note that, institutionally, the Department of Radiology at Aberdeen had no particular requirement to become involved with the project. They had not been involved in the purchase of the machine, the employment of the operators and the setting up of the project. There may, therefore, have been an institutional reason for their apparent lack of interest.

Despite the slightly different nuances in their recollections, what is interesting is that both Christie and McIntosh go on to draw on the nature of ultrasound images and the practicalities of diagnosis by ultrasound when discussing the relationship between the staff of the two imaging modalities. For Christie, ultrasound is used as a tool to explain the hostility of radiologists:

> When they did see [ultrasonic images], the pictures were not the standard slices that x-ray always was. [...] There was no standard here because there was literally an infinite number of planes that could be imaged that they had never seen before, that none of us had ever seen before. They couldn't figure it out at all because basically with the patient lying flat the views we were taking were slices in a direction they never took slices in, they had never seen slices that way.[85]

Thus, for Christie, the radiologists were resistant to the ultrasonic images because they differed so dramatically from the representations produced with x-rays: their prior knowledge of x-ray technology entailed that they were *disadvantaged* when it came to reading and interpreting ultrasound echo-images. This perspective lies in stark contrast to the general conception of the relationship between radiology and ultrasound and also appears odd in light of the high degree of involvement of radiologists in other hospitals. What is also noteworthy is the way in which Christie expresses the difference between ultrasound and radiology in the quotation above. He uses the word 'slice' to describe x-ray

[84] Indeed this is supported by the testimony of other interviewees who were involved in the scanning service at a later date. Interview with Dr Valerie Farr, 10/05/98; interview with Dr Norman Smith, 01/04/98; telephone interview with Professor Allan Templeton, 05/03/99.
[85] Dr Alexander Christie, interviewed by Ian Spencer and John Fleming, (courtesy of Nicolson, Spencer and Fleming).

images, which is inappropriate in this context. X-ray images are not visual slices (i.e. transverse views) in the same way that ultrasound images are. Thus Christie is using the language of ultrasound to describe a very different technology, demonstrating the way in which his own perceptions of an unfamiliar imaging modality is at least partly shaped by a familiar one.

In McIntosh's account it was the radiologists' unfamiliarity with the way in which the images were produced which was the problem, but which also provided an opportunity for McIntosh and Christie to resist control from that department:

> Sandy [Christie] and I could actually cook a picture to make it look like anything we wanted to and then laugh if they got it all wrong. You could manufacture a placenta on a picture if you wanted to just by twiddling the machine a bit. A still image like that is only one part of a total scan and we used to try and say to the radiologists, 'If you were asked to do a barium meal or enema would you report on a couple of films taken at random after swallowing the barium by your radiographer and say, "there's your barium enema and a couple of films now make a diagnosis"?'. You can't do that with ultrasound. It's a dynamic process and the diagnosis is made at the time you do the scan by the person doing the scan.[86]

In this way, both Christie and McIntosh have woven the images themselves and their production into their narratives. Relationships between themselves and other professionals have become expressed and explained through reference to ultrasound images and their construction: in other words, the practicalities of image construction and interpretation have become part of their social and professional boundary-drawing, demarcating them from other professional groups. Thus, while still in its infancy as a professional structure and specialty, ultrasound and the forms of knowledge which it had helped to produce were already emerging (at the level of discourse and narrative as well as the level of practice) as a distinct area of medical expertise in Aberdeen.

Indeed the inextricability of the social and the technical is further highlighted when McIntosh's comments above regarding the inability to diagnose from snapshot pictures is

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[86] Interview with Dr Alexander McIntosh, 18/08/99.

juxtaposed with the fact that the Aberdeen ultrasound team would often send pictures to Donald in Glasgow for confirmation of their diagnoses.[87] Such activities drew on shared knowledge and expertise based around the technology, and also (probably) on the social need for disparate groups of practitioners to maintain links and construct recognition with those at the forefront of the technology's development.

There is another significant point to be noted here. In the quotation above, McIntosh implies that the reason he and Christie were able to 'cook' a picture lay in the fact that the radiologists could not tell from which angle the image had been created. The machine itself, however, could. As noted in Chapter 1, one of the most important reasons for the large scanning frame of the Diasonograph design was that it enabled calculations to be made which could indicate the exact position of the probe in space. Thus, if the position of the probe could be determined, then the angle from which the scan was made could also be recorded. However, it is significant that this technical solution to orientation does not appear to have been in use in Aberdeen. Instead, the angle and direction of the image was being deduced on the basis of clinical, anatomical knowledge. Thus the same machine was being used very differently in Aberdeen from the way it was used in Glasgow. This provides further evidence of innovation in practice – the same intentions and goals were being pursued in both locations, and with the same type of machine, but with different methods.

To conclude this section, the introduction of obstetric ultrasound in Aberdeen highlights the complex and intricate way in which a new technology is made to 'work' in a new environment. Interactions between operators and equipment took two forms - the first was in the construction of ultrasonic images and the second in their interpretation. However, fundamental to these two kinds of interaction was their inter-relatedness: images could be altered by altering the scan process or the machine itself, while interpretations of images could lead back to further manipulation of the machine or changes in the way scans were conducted.

Furthermore, clinical utility was the negotiated outcome of these interactions. The main emphasis was on trying to find the best way (in terms of exposure time, probe position,

[87] See footnote 78.

frequency etc.) to get an image from the machine which then had to be deciphered by comparison with other representations of the inside of pregnant women's bodies. Furthermore, this process also crucially involved delineating 'reality' from 'artifact' (i.e. echoes in the image which were not considered to relate to actual physical structures, but to have been created by problems with the machine or double echoes etc.).

What this highlights, then, is the way in which the creation of clinical utility and practical reliability was contingent upon the mutual accommodation of the human, social and technical elements of ultrasound technology - the way in which various elements merged together created the emergent shape of the technology.

The further diffusion of ultrasound in the early 1970s

In the early 1970s new Nuclear Enterprises ultrasound machines were installed in a number of Scottish hospitals. As well as Scotland's other major cities such as Edinburgh and Dundee, smaller local providers also began to equip themselves with the technology. Thus by 1973, there were 25 ultrasound machines installed in hospitals across Scotland.[88]

As each machine was installed in a new location, the same mutual adaptation of new users to new machines and *vice versa* was undertaken. Whether the technology itself was by this time eight or ten years old was irrelevant to new users faced with ultrasound equipment for the first time. In Perth, for example, an obstetric ultrasound service commenced in 1973. Sandy Christie was principally responsible for the new service, having left Aberdeen in 1970 to take up a new post at Dundee Royal Infirmary (which was affiliated to the maternity hospital in Perth). Christie was assisted by an obstetrics registrar at the hospital – Dr Jack Crichton, whose recollections of his first experiences are reminiscent of those of Christie

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[88] Scottish Home & Health Department, (1979), *Report on the Future Development of Ultrasound in Scotland,* unpublished report, p9.

five years earlier:

> Nuclear Enterprises came along and put the Diasonograph in one of the side rooms in the gynae ward. It was sitting there and I was itching to get my hands on it and there was a girl associated with N.E. sales...and I sort of conned her into giving me an instruction book. I tried to scan oranges and balloons filled with water and things like that and was getting nowhere.[89]

Thus increasing familiarity with ultrasound through either the published work of others or from colleagues who had experience of the technology was entirely different from actually using the equipment itself. This reinforces the significance of the performative nature of technologies such as ultrasound. Furthermore, with such an interactive technology even an instruction manual would provide little assistance for the new operator: only by actually using the equipment, adapting to its capabilities and features and 'learning-by-doing' could familiarity with ultrasound be gained. In other words, substantial degrees of tacit knowledge and craft skill were associated with ultrasound imaging using the Diasonograph.

Furthermore, not all of the equipment being installed during this period was manufactured by Nuclear Enterprises. From around 1967 alternative models of ultrasound equipment appeared in the UK.[90] The first of these was the Vidoson, made by the German firm of Siemens and launched in that country in 1965. The Vidoson was a very early real-time, or rapid B-scan machine. Another potential competitor was Kretztechnik of Austria, who had entered the field of medical ultrasound in 1962 when they launched an A-scope machine for ophthalmology and for neurology. In 1965, in association with Dr Alfred Kratochwil, Kretz became involved in obstetric ultrasound using their A-scope machine, and by 1967 they had launched a B-scan machine on the market in Europe. Thus alongside the increasing diffusion of the Diasonograph design, the early 1970s also saw the embryonic beginnings of commercial competition the UK. In the context of new and emerging markets, it is important to note that Kretz in particular were able to gain entry by exploiting sales staff and organisational structures already in place in the UK. Kretz were well-established

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[89] Interview with Dr Jack Crichton, 09/02/98. Crichton was later involved with the development of obstetric ultrasound in the Western Isles - see Chapter 3.
[90] The emergence of competitive markets for obstetric ultrasound equipment is dealt with in Chapter 3.

manufacturers of non-destructive testing equipment and thus had sales staff already available to market and sell in the industrial sector. It was thus not too problematic for this sales team to widen their scope to include contacts within the field of medicine.

Nevertheless, in Scotland, Nuclear Enterprises dominated early ultrasound sales. It would not be until towards the end of the 1970s that a truly competitive market would emerge in Scotland, when smaller real-time portable units began to appear.[91] As late as 1977, for example, of the 38 B-scan machines in use in Scottish hospitals, Kretztechnik manufactured only six.[92] Still, it is worthwhile examining the introduction and use of one of these non Nuclear Enterprises machines in some detail as it provides further insights into the heterogeneity of ultrasound's development in practice.

In 1971, the Chief Radiologist for Fife hospital services, Dr Peter Aitken, purchased a Kretztechnic machine for use in Kirkcaldy's general hospital, The Victoria. The scanner was purchased with funds provided by the local police federation, who collected money for the hospital following the death of one of their members, Ms Maisie Douthwate, who died of leukemia in 1970 and who had been a patient at the hospital.[93] The main clinical rationale for acquiring this particular piece of medical equipment was to examine head injuries in order to better determine which cases should be transferred to Edinburgh for specialist treatment and which could remain in the smaller district general hospital. The imaging modality employed by this particular machine was known as a C-scan. This form of imaging created a scan image which was perpendicular to the position of the probe and at a constant pre-determined depth. Thus the transducer would be manipulated across the skull and only those echoes received from the desired depth would be displayed. This imaging modality, therefore, enabled clinicians to trace the midline echo of the brain – deviations in the echo indicated a shift in the midline associated with either blood clots or tumours in the brain. Thus according to Dr Aitken, it was the quality of images generated by this machine for this very specific type of examination which attracted him to this particular model.

However, having acquired such a machine, the radiologist was keen to extend its uses by

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[91] See Chapter 3.
[92] Scottish Home & Health Department, (1979), *Future Development of Ultrasound*, p1.
[93] Interview with Dr Peter Aitken, 22/2/99.

transforming it into a machine which could also perform B-scans. Such a modification was not, however, entirely straightforward - the hospital did not have the space to accommodate the large gantry frame associated with the Diasonograph (or with the Kretz-made equivalent). The solution proposed was to construct some form of hybrid using a mobile X-ray base:

> I said to them [the engineers from Kretz], 'look, can't we make this up as a mobile unit on a mobile unit X-ray base? Put the pantagraph on where the tube column would be and mount the A and the B scan on the mobile base?'[94]

In this way, the radiologist in Kirkcaldy, aided by engineers from Kretztechnic and GEC, effectively created an early version of a mobile ultrasound machine, which could be wheeled from ward to ward and thus did not require a dedicated room.

This example provides a neat illustration of the number of factors which can affect technological developments of this nature. Firstly, the type of scanner used was initially chosen for neurological examinations rather than obstetric or gynaecological ones, but was later adapted for more general abdominal examinations. It is thus significant that the man responsible for choosing the scanner was a radiologist rather than an obstetrician. His concerns and responsibilities did not rest with any one particular specialty, but rather was more generally related to visual diagnosis. In this instance, he was prompted in his choice of equipment by what he perceived as a pressing clinical need to provide an accurate triage system for head injury patients. More importantly, while this motivated his initial choice of machine, it also helped shape the development of scanning in this location. The hybrid unit built at the hospital performed a variety of scans and could be used to image various areas of the body. Indeed, the fact that this was a small general hospital, rather than a large specialist centre, also contributed to the shape of the technology here. An expensive piece of medical technology was adapted to perform a variety of roles, thus justifying its cost.

Furthermore, this example also demonstrates that innovative practices continue once the 'consumption junction'[95] has been traversed. In other words, buying a machine from a

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[94] Interview with Dr Peter Aitken, 22/2/99.
[95] Shwartz Cowan, R., (1987), 'The consumption junction'.

commercial company does not indicate the end of 'innovation', but merely the point at which different users begin to influence development. It is also important to note that the Kirkcaldy hospital was not a large specialist centre with dedicated research staff, access to funding bodies and an institutional agenda for research and development in clinical practice. Rather this is a very small-scale, local story both in terms of the funding of the machine's purchase and in terms of its development. Technological development was prompted by site-specific local concerns and practical problems. Thus technological transformations could and did occur when ultrasound was introduced to new circumstances and new locations.

With increasing numbers of hospitals acquiring ultrasound machines, and with its use beginning to extend to more and more applications (particularly within the field of obstetrics, but also with more general abdominal conditions) a distinct set of ultrasound practitioners was beginning to emerge by the end of the 1960s. Furthermore, with machines beginning to be manufactured by other companies located in Germany, the USA and Japan, ultrasound was beginning to be known and used in other areas of the world. Publications were thus being produced at an ever-increasing rate by the scattered groups of ultrasound researchers.

Until the end of the 1960s, aside from such communication in the published media, relations between ultrasound workers in Scotland remained largely informal in nature. Researchers, for example, would visit the Queen Mother's Hospital to see the Glasgow group's operation in practice, while letters noting interesting cases or unusual findings would be sent back and forth. The major exception to this informality was Ian Donald, who embarked on several lecture tours from the mid 1960s onwards. Nevertheless, it was not until 1969 that moves were made to create a more formalised ultrasound community.

The first layer of this community was created at the international level. A World Congress on Ultrasonic Diagnostics in Medicine was held in Vienna in 1969, to which those with an interest in medical ultrasound were invited. It was at this conference that McIntosh and Christie presented their findings on placental localisation, while papers were also delivered by some of the Glasgow group including Donald. During this meeting the decision was made to form an International Federation for Medical Ultrasonics, which would provide a forum for the interchange of ideas and innovations in the field. Thus the first formalised body to represent medical ultrasound was the product of international collaboration.

This was complemented at the UK level by the formation of the British Medical Ultrasound Group (BMUG) in December of the same year. Once again, the decision to institute such a Group was taken at a symposium in London on 'The Prospects for Future Developments in Ultrasonic Diagnostics'.[96] Interestingly, this symposium was called by two separate professional bodies - the British Institute of Radiology and the Hospital Physicists Association - who also undertook to set up the new Group. This in itself reflects the different development of ultrasound in England where, unlike Scotland, the obstetrics profession did not dominate the new technology to the same extent.

According to the first Bulletin of the British Medical Ultrasonics Group (which would become their journal), the purpose of the Group was:

> to stimulate communication on Medical Ultrasonics activities, to organise occasional scientific meetings and to represent UK interests in the proposed International Federation for Medical Ultrasonics.[97]

Furthermore, membership of the Group was open to all parties of whatever professional background who had a *bona fide* interest in ultrasound's uses in medicine. From the outset, therefore, this body was both a broad school *and* a specialised interest group with an initial membership of 'about 200'.[98] An advisory panel was formed which included Ian Donald and John Mallard to advise on Group policy. The BMUG, therefore, represented the emergence of an identifiable 'ultrasound community' in the UK - a collection of actors who shared a common interest in a new form of practice and who, in some ways, considered themselves slightly different from their traditional professional colleagues. From the outset, the group included obstetricians, radiologists, medical physicists, engineers, and so on. In forming such a Group, they were acknowledging their common position in relation to the new technology, while at the same time recognising that meaningful exchanges of

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[96] BMUG, (1970), *Bulletin of The British Medical Ultrasonics Group*, No.1, March. For the proceedings of the Symposium see *British Journal of Radiology,* Vol. 43, No. 507, (1970) pp.226-229.
[97] BMUG, (1970), *Bulletin,* No. 1, March.
[98] *ibid.*

information could better be achieved through communication with one another, than with colleagues in their own respective professions. The Group (which changed its name in 1978 to the British Medical Ultrasound Society) undoubtedly helped to promote the technology in the UK, and to foster an identity for ultrasound within medical practice.

This growing sense of community was also mirrored at the more local level. At the Queen Mother's Hospital, for example, *ad hoc* demonstrations for visitors were replaced in 1970 by formal training courses. These were co-ordinated from the Department of Clinical Physics and Bioengineering – led by Professor John Lenihan. Lenihan and Ian Donald put aside any differences they may have had prior to this[99] and began to discuss developing an ultrasound training course as early as 1967.[100] The first course was run in January 1970 by Norman McDicken, a physicist working in Lenihan's department, who had prepared a two-week programme of lectures and demonstrations. In addition, attendees of the course visited the Queen Mother's and the Western Infirmary to see ultrasound in practice. The new sense of community being fostered amongst ultrasound workers in the UK is illustrated by the fact that this course was announced in the second Bulletin of BMUG.[101]

Initially, the attendees were mainly clinicians, although by 1978 the department was offering separate courses for registrars and for radiographers.[102] Thus, partly in recognition of the growing interest in medical ultrasound, and partly through the increasing sense of ultrasound as an identifiable and specialist practice, training courses were formalised. This additionally helped to cement Glasgow as one of the main centres of excellence in the new technology and the centre of the emergent ultrasound community. Indeed, the first formal meeting of BMUG as a separate body was held at the Queen Mother's in December 1971[103] and in December 1972, Professor Donald was elected as the first President of the BMUG Committee.[104]

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[99] See Chapter 1.
[100] Fleming, J.E.E., (2001), 'Ultrasound: the Glasgow factor' in Wilson, D.B. & Geyer-Kordesch, J., (eds.), *Physics and physic: essays in memory of John M.A. Lenihan,* Wellcome Unit for the History of Medicine, Glasgow, pp.63-79.
[101] BMUG, (1970), *Bulletin of The British Medical Ultrasonics Group*, No. 2, July.
[102] BMUG, (1978), *Bulletin of The British Medical Ultrasonics Group*, No. 22, June.
[103] BMUG, (1971), *Bulletin of The British Medical Ultrasonics Group*, No. 3, January.
[104] BMUG, (1973), *Bulletin of The British Medical Ultrasonics Group*, No. 8, March.

Furthermore, in 1973, Lenihan's department took over responsibility for the maintenance of ultrasound equipment in the entire West of Scotland region. Two years earlier at a working party on ultrasonics called by the Western Regional Hospital Board, it was argued by Lenihan and Donald that commercial ultrasound manufacturers had not provided such a service, which was essential for the smooth running of a clinical service.[105] Following the formation of the Greater Glasgow Health Board, this recommendation was put into action and Mr Rowland Eadie was hired to maintain the, by then, ten machines in the Greater Glasgow area.[106] The uniqueness of this service needs to be noted. Rather than lobbying the commercial suppliers to provide a more adequate maintenance service, the Health Board were taking it upon themselves to fulfil this role. To some extent, this may be indicative of the nature of the relationship between ultrasound's innovators in Glasgow and Nuclear Enterprises who were, by far, the main commercial suppliers. Moreover, this service also provides evidence of the increasing diffusion of the technology and its growing prominence in medical practice.

Conclusions

In the first half of the 1960s, diagnostic ultrasound in the UK remained a Glasgow-based activity. By the mid-1970s, however, the technology had begun to appear across Scotland, not only in large research-oriented teaching hospitals, but also in smaller local district general and maternity hospitals. Thus in the twelve years or so after the launch of the Smith's Diasonograph in 1963 a market for the technology slowly began to emerge. Nevertheless, it is evident that the instalment of ultrasound machines to a growing number of individual hospitals was only one part of the process of diffusion. The purchase of ultrasound equipment was itself the outcome of a number of activities - from the publication of research papers demonstrating new uses for ultrasound in obstetrics, to the organisation of training courses for new users and the creation of forums in which those interested in the technology could communicate their experiences. In other words, the diffusion of ultrasound was constructed by those who took up the technology - as much as by the manufacturers who sold the machines. Through formal and informal demonstrations and communications,

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[105] Western Regional Hospital Board, 'Report of the working party on ultrasonics' August 1971.
[106] Fleming, J.E.E., (2001), 'Ultrasound: the Glasgow factor'.

published research papers and 'word of mouth' knowledge of ultrasound and its growing number of clinical uses spread to new actors in other Scottish locations. Furthermore, patient referrals to Glasgow from a wide range of locations demonstrate another aspect of this technology's diffusion which did not involve the actual purchase of equipment. Overall therefore it is evident that the diffusion of obstetric ultrasound was about a great deal more than simply the movement of artifacts or the number of units sold - also implicit here was the movement of people, ideas and knowledge.

Indeed, the type of research activities which went on in Glasgow were essential to the technology's diffusion - they provided a focal point for actors in other locations and diffused knowledge and awareness of the potential clinical uses of the technology. This was further reinforced with the collaboration of the Regional Medical Physics Department through training courses and through their role in servicing ultrasound equipment installed in hospitals in the region.

Furthermore, inter-personal communications between ultrasound operators in different regions of Scotland were facilitated by the emergence of an identifiable 'ultrasound community' in the UK with a strong Scottish contingent. Such associations provided a forum in which geographically separated groups of actors could share ideas and innovations in technique, and learn from one another. Nevertheless, this 'community' was given its *raison d'être* through its membership's relationship to ultrasound machines. In other words, what united those within this community, and what differentiated them from their peers and colleagues out with it, was their interaction with medical ultrasound. Thus while the emergence of the BMUG, for example, helped to foster a growing sense of this community, the Group itself was predicated on the increasing diffusion of ultrasound to new locations. In this way the emergence of an identifiable set of workers with a shared interest in the new technology was a phenomenon born of ultrasound itself. The very thing that gave its members - drawn from a wide range of disciplines and backgrounds - a common purpose was the technology itself.

Furthermore, the motivations which drove those in other locations to purchase and install an ultrasound machine were complex and varied. There is no over-arching, mono-causal factor which can explain why this technology was adopted in new places. In Aberdeen Maternity

Hospital, for example, personal motivations (such as the desire to establish one's reputation in research or to keep up with colleagues in other centres) merged with clinical objectives, funding opportunities, the creation of a new Chair and the appointment of new senior staff. At The Victoria Hospital in Kirkcaldy, on the other hand, the desire to make greater use of an ultrasound machine purchased to fulfil an entirely different clinical objective, also interacted with other influences. These included the growing awareness of the utility of such equipment in obstetrics and gynaecology through the work of the Glasgow group, a close working relationship with a manufacturer trying to make headway in Scotland and the location of obstetrics and gynaecology within the same institution. Thus the introduction of obstetric ultrasound in new places was the outcome of various factors, rooted in each location.

It is also clear that one of the main clinical objectives associated with the purchase of ultrasound equipment was for use in obstetrics. Although this was not universal (as the example from Kirkcaldy's Victoria Hospital illustrates) the fact remains that by the late 1960s obstetrics had emerged as the medical specialty most closely associated with diagnostic ultrasound. This relationship would be further reinforced over the next 10 years. Part of the explanation for this undoubtedly lies with the Glasgow group's publications throughout this period and their varied research projects on obstetric conditions. More significant still, however, might be the close-knit nature of the obstetrics community in Scotland. Tertiary referral centres in Scotland were located in only four locations – Glasgow, Edinburgh, Aberdeen and Dundee. By the end of the 1960s obstetric ultrasound was being used in three of these locations and thus clinicians who referred patients to these centres learned of the technology's capabilities and attributes in the field. Another significant factor is undoubtedly the availability of research and clinical 'material' associated with obstetrics. As a consequence of the centralised medical management of pregnancy, obstetric medicine has unparalleled access to a substantial proportion of the population of interest - including both 'normal' and 'abnormal' cases. Thus, for a technology in its infancy, the opportunities to extend current practice by finding new uses for the equipment were perhaps greater in obstetrics than in other fields.

The accidental discovery of the full-bladder technique was also a major influence here. As a result of this, ultrasound became the only technology of the time which could directly visualise early pregnancy providing opportunities to visually monitor the gradual maturation of 'normal' gestations. In this way, ultrasound created new forms of knowledge and practice and new ways of differentiating normality and pathology. Studying the form and texture of the placenta in the Queen Mother's, for example, created new categories of disease and possible pathology. Not only were these new forms of practice essentially born *of* the technology - they also created new and unexpected clinical advantages through which its necessity as an obstetric tool could be further established.

Nevertheless, the privileged access that the Queen Mother's had to expert technical and engineering assistance, through its Ultrasound Technology Unit as well as Lenihan's department, was unparalleled. Actors in other locations had to find the necessary skills and expertise on their own. Some of this was acquired through the appointment of new staff members possessing skills considered to be relevant and who were drawn from outside the medical establishment - such as Sandy Christie. In this way, actors were directly enrolled into the emerging ultrasound community. However, it is evident that whether an actor's skills were initially in engineering, obstetrics, radiology or medical physics, the main way in which the skills of obstetric ultrasound diagnosis were learned was through practice. Familiarity with obstetric ultrasound was achieved through hands-on experience, learning how to best move the probe to achieve a readable image, comparing ultrasound images with other representations of internal structures, learning to differentiate between 'fact' and 'artifact', etc. Such experiential knowledge acquisition is the essence of craft skill, and formed the basis of a 'working' technology in each location.

However, the acquisition of skill and hands-on experience went hand-in-hand with the emergence of a number of innovations in practice. Modifications in technique, in clinical use, and in technological function can be seen to have emerged in various locations and at various times. While the types of tinkering and tuning which went on in new centres such as Aberdeen and Kirkcaldy may not have been guided by exactly the same motivations which underpinned the work of Donald and his co-workers in the late 1950s and early 1960s, they were nevertheless geared towards adaptation to make the technology perform, to make it work. Thus while they may have been more limited in nature - technical modifications to adapt an A-scope machine to perform two-dimensional imaging for example, or alterations in technique to speed up image formation with a mobile fetus - they did nevertheless represent new ways of performing ultrasound. Furthermore, while the Kretz-hybrid constructed in Kirkcaldy may not have been replicated in other places or incorporated by Kretz into their machine design, it was nevertheless an innovation born of diffusion. Such innovations emerged from practice. It was actors' direct interactions with ultrasound in varied new contexts that shaped their perceptions of it.

Overall therefore, the early diffusion of obstetric ultrasound did acquire a certain momentum during the course of the late 1960s and early 1970s. This diffusion, however, was about more than simply the uptake of artifacts - it was also about the diffusion of ideas and knowledge and the movement of people - operators and patients. Furthermore, the way in which new actors were enrolled into obstetric ultrasound also varied - with a range of motivations, circumstances and contingencies based in each new location contributing to this. Thus the diffusion of obstetric ultrasound was a complex phenomenon. To reduce the early commercial success of the Diasonograph to a single explanatory construct - such as specialist interest, for example - obscures the emergent nature of the technology in practice and the way in which workers' interactions with it opened up new and unexpected avenues of development in technology and in medical practice, which then became new valued qualities to influence later adopters. Thus the early diffusion of obstetric ultrasound was inextricably bound with innovatory practices. For this reason diffusion should not be regarded as either a separate process from innovation, or as the final stage of technological development.[107] Rather, it marks the point at which a whole new set of actors in new locations interact with technology and thus provide opportunities to shape it.

[107] McKinlay, J.B., (1981), 'From "promising report" to "standard procedure": seven stages in the career of a medical innovation' *Millbank Memorial Fund Quarterly,* Vol. 59, No. 3, pp.374-411.

Chapter 3

Motion in ‘the mangle’: contextualising choice and technological change

The fate of facts and machines is in later users' hands; their qualities are thus a consequence, not a cause, of a collective action.[1]

Introduction

From around 1976, the market for ultrasound equipment in Scotland began to change. New machines manufactured by suppliers such as Siemens, Kretztechnik and Philips from mainland Europe, ADR and Diasonics from the United States, and Toshiba and Aloka from Japan began to appear in Scottish hospitals. By the beginning of the 1980s, Nuclear Enterprises had lost their dominant position as the main supplier of ultrasound equipment as a more open and competitive 'ultrasound market' began to emerge. Furthermore, the number of machines being operated in individual hospitals - particularly in the large research and teaching institutions - also began to increase. In the Queen Mother's Hospital, for example, there were two machines in operation in 1976 - both manufactured by Nuclear Enterprises. By 1983, however, there were eight machines in use, and only one of these was a Nuclear Enterprises model.[2]

Two developments in particular were associated with this shift in the nature of ultrasound's diffusion. One was the increasing move towards the use of obstetric ultrasound for the screening of all pregnancies. Such a strategy brought with it an obvious increase in the number of cases being scanned and thus also in the demands being placed on each piece of equipment. Furthermore, as with other screening strategies such as cervical smear testing, the universal application of ultrasound involved a triage system, with anomalies and problematic cases being followed up by yet more ultrasound examinations. Thus as the workload increased, so did the demand for ultrasound equipment. However, given that the introduction of universal screening policies was itself a fundamental transformation in the delivery of obstetric ultrasound services, and was associated with many more issues than simply technical changes in equipment, this aspect of the technology's development will be

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[1] Latour, B., (1987), *Science in Action,* Harvard University Press, Cambridge, Mass., Appendix 2, p.259
[2] From Fleming, J.E.E., Spencer, I.H. & Nicolson, M.A., (1997), '40 years of ultrasound', in Cockburn, F., (ed.), *Advances in perinatal medicine: proceedings of the XVth Eurpoean Congress of perinatal medicine Glasgow,* Parthenon Publishing Group, New York & London, pp.92-99.

examined in Chapter 4.

The second factor associated with the emergence of a more competitive ultrasound market lay in the technical differences between the various machines on offer. The most significant of these related to the way in which ultrasound images were created and displayed. Whereas the Diasonograph design was used to create gradually a compound image in the form of a static picture, the new models of ultrasound equipment which appeared in the mid 1970s used a radically different approach. Known at the time as real-time (RT) or fast B-scan equipment, these machines produced a virtually instantaneous image when the probe was applied. Furthermore, the image was constantly renewed at a speed fast enough to display motion. Thus, for example, the movement of the fetus could be directly observed on the scan image simply by maintaining the probe's position over the fetal echoes.

There were, however, a number of different ways in which such moving, real-time images could be created and displayed and different manufacturers specialised in one modality or the other. These differences were associated with diversity in a number of technical features from probe design to image display format. This in turn entailed that different RT imaging modalities also competed with one another - as well as with static compound scanners. During the late 1970s therefore, diversity and heterogeneity became a feature of ultrasound technology with a number of different imaging modalities and machine designs competing for market share. Thus, a period of heightened commercialism and commodification began to appear in the diffusion of ultrasound - presenting hospital administrators and clinicians with a large choice of technological options.

This chapter will trace the emergence of RT imaging in Scotland by examining, firstly, the various models on offer. What was different about each design in comparison to its competitors? What were the perceived advantages and disadvantages of each? The chapter will then go on to examine the introduction of RT equipment in the case study hospitals. What made particular models attractive and why were they chosen over their rivals? Furthermore, were there any obvious differences in the way RT machines were used from location to location? Were there also any obvious parallels and differences observable when RT machines were compared to earlier forms of the technology?

In investigating the introduction and uptake of RT ultrasound in different centres, it is important to note that the changes associated with the new mode of imaging were not purely technical. The production of RT images was associated with a subtly different form of activity. In other words, the practice of creating ultrasonic diagnostic images was itself crucially changed in the overall reconfiguration of the technology. Once more, therefore, in order to uncover the multifaceted aspects of technological change (i.e. its technical, social and cognitive dimensions[3]) it is useful to examine the technology 'in action'[4]. Such an analysis also provides an account that highlights the heterogeneous ways in which this form of imaging was accommodated at the local level. The development of RT scanning will thus be observed through a bifocal lens, which simultaneously examines both the impact of RT equipment on local practices, and the way in which the technology was moulded by local circumstances. In other words, in what ways were the forms of technical agency captured in RT scanners, and the forms of social agency and clinical arrangements which were in place in different locations 'tuned' to accommodate one another? What expectations were placed on the technology, what resistances (if any) arose to the fulfillment of those expectations and how were these overcome or accommodated? To borrow Pickering's metaphor, what effect did the introduction of moving RT imaging have on 'the mangle' of obstetric ultrasound practices?[5]

It should also be noted that a large proportion of this chapter is based on oral testimony collected from each case-study center. This evidence provides a large degree of detail - not only relating to actors' perceptions of the new imaging modality, but also in relation to more specific changes in practice, which rarely appear in the published literature of the time. Furthermore, in using such sources, a window is provided which allows the historian to glimpse into the varied motivations behind consumer choice in this context. Why did real-time scanning replace static B-mode ultrasound as the most popular form of ultrasound imaging? Was the revolutionary motion displayed on the screen ('revolutionary' both in terms of the rapid image renewal which made the appearance of movement possible, and in terms of its radically different form of image display in comparison to earlier machines)

[3] See MacKenzie, D. & Wajcman, J., (eds.), (1985), *The social shaping of technology: how the refrigerator got its hum,* Open UP, Milton Keynes, (editor's introduction).
[4] Latour, B., (1987), *Science in action.*
[5] Pickering, A., (1995), *The mangle of practice: time, agency and science,* Chicago University Press, Chicago, pp. 21-34.

more attractive to ultrasound workers than the wider and more detailed view provided by Diasonograph-style equipment? Or were other aspects of the newer machines perceived to be beneficial? To what extent were consumer choices conditioned by factors rooted in specific locational contexts? The oral testimony used within this chapter enables consumer choices and activities to be understood within the context of the circumstances, practices and arrangements of each location. This evidence is supported, where possible, by other primary sources, which either lend support to the oral evidence or add extra dimensions to the overall account.

Theorising competing technologies and 'consumer choice'

The analysis of competing technological forms has a long history and has been approached from a variety of perspectives. From the 1970s onwards a growing number of studies began to emerge, particularly from Marxist scholars, which challenged the modernist discourse that technological change could be explained solely through reference to increasing technical superiority and knowledge.[6] In their examination of the way in which non-technical forces such as social relations affected technological change, many of these studies paid increasing attention to the nature of relationships between producers of technology and consumers, and paved the way for less passive accounts of the latter. Harry Braverman for example, in his 'de-skilling' thesis, concluded that new workplace technologies (from the motorised conveyor belts of Henry Ford's Detroit factory of the 1920s, to the word processors of the modern office) were adopted specifically to achieve a social goal; the de-skilling of labour and transferral of greater power to management.[7] In this instance, company owners and their management representatives made consumer decisions regarding the purchase and implementation of technology on the basis of social interest and thus helped to shape the development of workplace technology in their favour. In the wake of Braverman's work, a whole host of labour process theorists examined the introduction of a

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[6] Rosenberg, N., (1982), *Inside the black box: technology and economics,* Cambridge UP, Cambridge; *idem,* (1976), *Perspectives on technology,* Cambridge UP, Cambridge; Thompson, P., (1989), *The nature of work: an introduction to debates on the labour process, 2nd edition,* Macmillan, Basingstoke; Wood, S., (1982), (ed.), *The degradation of work? Skill, deskilling and the labour process,* Hutchinson, London. See also Broadberry, S. & De Jong, H., (2000), 'Technology and productivity in historical perspective: introduction' *European review of economic history,* Vol. 4, No. 2, pp. 115-119 and the collected works in MacKenzie, D. & Wajcman, J., (eds.), (1985), *The social shaping of technology,* (part 2, pp. 67-172).

[7] Braverman, H., (1974), *Labour and monopoly capital: the degradation of work in the twentieth century,* Monthly Review Press, New York.

variety of technologies from this perspective.[8]

In a similar vein, feminist authors such as Ann Oakley and Ruth Schwartz Cowan have examined the influence of shifting gender power relations on the development of domestic, household technologies.[9] In these studies, consumer behaviour and choice was again located within a wider network of social relations, which were used to explain why women as the consumers of domestic technologies (or more accurately men, who as head of household often made the final decision regarding large financial purchases) chose to buy domestic appliances such as washing machines and vacuum cleaners.

Thus both the feminist critiques of domestic technology and the Marxist (and feminist) critiques of workplace technology highlighted two salient features relating to the adoption of new technologies. Firstly, they emphasised that consumers, or end-users, were not simply the passive recipients of technological innovation. More significantly, they also note that social aims and goals could potentially be a more powerful element in consumer decision-making than technical efficiency or superiority. Nevertheless, while such studies helped to provide an approach to technology that afforded a more active role for the purchasing consumers, the often mono-causal relationships they identified are too generalised to fully explain why certain technologies are chosen over others. There is also the danger of circular reasoning and functionalism here. Braverman, for example, is notorious for his reliance on management material in the formation of his account. His conclusions regarding the effects of the implementation of new technologies were thus extrapolated from management sources that outlined their intention! As Juliet Webster notes in relation to the introduction of information technology to secretarial work, intentions do not necessarily mirror outcomes.[10] Similarly, from the other side of this relationship, there is the danger of providing little more than a functional perspective if we deduce intentions from effects:

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[8]In particular see, Rosenberg, N., (1976), *Perspectives on technology*; Thompson, P., (1989), *The nature of work*; Wood, S., (1982), (ed.), *The degradation of work?*

[9] Oakley, A., (1985), *Sociology of housework: 2nd edition,* Blackwell, Cambridge Mass.; Schwartz Cowan, R., (1983), *More work for mother: the ironies of household technology from the open hearth to the microwave,* Basic Books, New York; Wajcman, J., (1991), 'Domestic technology: labour-saving or enslaving?' in Wajcman, J., *Feminism confronts technology,* Polity Press, Cambridge.

[10] Webster, J., (1985), 'Word processing and the secretarial labour process' in Purcell, K, (ed.), *The changing experience of employment,* Macmillan, Basingstoke; *idem.,* (1990), *Office automation: the labour process and womens work in Britain,* Harvester/Wheatsheaf, Hemel Hempstead.

technologies effectively de-skill workers, *ergo* that is why they were introduced. Such an account presents an almost God-like role for the adopters of technology, who can accurately foresee the exact outcome of their technological decision-making.

Another fruitful body of literature which examines how choices between different artifacts are made can be found in studies of the marketing of consumer products.[11] The power of advertising and marketing (and, more recently, branding) in shaping consumer preferences for one type of artifact over another has been examined from a variety of angles and with widely divergent observations on the nature of the relationship between producer and consumer. In essence, however, these studies have tended to fall into either of two separate characterisations. In the first, consumers are characterised as 'dopes', passively absorbing advertising rhetoric and using this as the basis for consumer decision-making.[12] Those companies, therefore, who are most persuasive in their marketing strategies will be the most influential in shaping consumer behaviour. In the second characterisation (associated with more postmodern perspectives within sociology) consumers are instead 'cultural heroes' - intelligent decision-makers whose ability to see past advertising rhetoric gives them a stronger role in their relationship with producers.[13] In this characterisation, companies must compete with one another to draw the attention of the sceptical consumer. In the context of new technologies therefore, potential purchasers are either easily persuaded through advertising rhetoric to buy a particular artifact (the first scenario), or represent a powerful social group exerting pressure on manufacturers to innovate technologies which will appeal

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[11] Corrigan, P., (1997), *The sociology of consumption : an introduction,* Sage, London; Goldman, R. & Papson, S., (1996), *Sign wars : the cluttered landscape of advertising,* Guilford Press, London and New York; Jhally, S., (1990), *The codes of advertising : fetishism and the political economy of meaning in the consumer society,* Routledge, London; Nava, M., (1997), *Buy this book: studies in advertising and consumption,* Routledge, London; Sinclair, J., (1987), *Images incorporated : advertising as industry and ideology,* Croom Helm, London; Sulkunen, P., (1997), (ed.), *Constructing the new consumer society,* Macmillan Press, Houndmills.

[12] See, for example, Klein, N., (2000), *No logo,* Flamingo, London; Jameson, F., (1984), 'Postmodernism or the cultural logic of late capitalism' *New Left Review,* Vol. 146, pp53-92; Adorno, T. & Horkheimer, M., (1972), *Dialectic of Enlightenment,* Herder, New York.

[13] Featherstone, M., (1992), *Consumer culture and postmodernism,* Sage, London; *idem.,* (1990), 'Global culture: an introduction' in Featherstone, M., (ed.), *Global culture: nationalism,globalization and modernity,* Sage, London; *idem.,* (1987), 'Lifestyle and consumer culture' *Theory, culture and society,* Vol. 4, pp.55-70; Tomlinson, A., (1990), 'Introduction: consumer culture and the aura of the commodity' in Tomlinson, A, (ed.), *Consumption, identity and style: marketing, meaning and the packaging of pleasure,* Routledge, London, pp.1-38.

to them (the second scenario).

Both of these characterisations are, however, far too simplistic and in reality the relationship between producers and consumers of new technology probably lies somewhere between these two extremes. Furthermore, this relationship will also itself be defined and shaped by the technological product in question. While all technologies are not the same, neither are all potential consumers. There are also problems associated with the very concept of the 'consumer' within the study of medical technologies such as ultrasound. As Jenny Stanton has noted, in a slightly different discussion of the applicability of the concept of 'configured-user' within medicine, identifying who the 'consumers' of medical technology actually are is less than straightforward.[14] If consumers are defined as those who purchase ultrasound machines then the definition is already a complicated one: as outlined in the previous chapter, machines may be purchased by hospitals, clinical departments, local health authorities or government agencies. In addition, the finance itself may come from a variety of sources such as government or research grants, or charitable donations. Further, the decision-making process itself can be complex with various actors, representing different departments and interests, negotiating the purchase of equipment.[15] Finally, to consume is also to use and thus the views and experiences of those who actually operate the equipment can play a significant role in decisions relating to future purchases.

Nevertheless, while the concept of 'consumer' may be problematic in its application to this technology, it remains a useful tool in the examination of choice within the context of competing technological designs and models. Thus, if the adopters of ultrasound equipment can be characterised as consumers who are neither passive in the diffusion process, nor its sole determinants, how exactly can they be perceived? An alternative approach is that provided by the social construction of technology (SCOT) perspective. Indeed, the development of RT scanning during the second half of the 1970s displays many similarities with that of the bicycle, the main illustration used by Trevor Pinch and Weibe Bijker in their classic early papers outlining this approach. For example, as in the development of the

[14] Stanton, J., (2002), 'Introduction: on theory and practice' in Stanton, J., (ed.), *Innovations in health and medicine: diffusion and resistance in the twentieth century,* Routledge, London, pp. 1-18.
[15] See for example the negotiations outlined in Chapter 4 regarding the purchase of new equipment for The Western Isles Health Board.

bicycle, a number of different forms of ultrasound imaging appeared around the same time, each with sometimes subtly, sometimes dramatically, different design features and in a situation where they competed with one another.[16] In Pinch and Bijker's study, subtle design features were hotly contested and different 'relevant social groups' drew different meanings from these various features. For the SCOT theorists, it was the outcome and resolution of these divergent perspectives, or 'interpretations', which shaped the direction of further research and the form of future design.

Within such an account therefore, 'consumers' are not simply regarded as the passive end users or recipients of technology, but are instead subdivided into groups of actors who influence technological change through the choices they make based upon their interpretations of artifacts. Nevertheless, although Pinch and Bijker's 'relevant social groups' are defined in relation to the technology (which presumably provides the yard stick against which their 'relevance' is judged), little is said in terms of exactly *how* they form their interpretations. One of the key characteristics that they stipulate to define 'relevant social groups' is homogeneity of perspective.[17] In other words, all members must view the technology in the same way. However, it is possible to suggest that a common view or interpretation may be formed from a multitude of very different reasons and circumstances and thus that homogeneity of perspective can mask heterogeneity of experience. For this reason, while accounts such as that of Pinch and Bijker demonstrate the role played by consumers and users in technological change, they do not pay adequate attention to the manner in which interpretations are formed. To do this, it is essential to locate both actors and machines within the historical and spatial context within which they interact.

There are, therefore, a number of precedents for analysing the influence of consumer choice on technological development in the context of competing technological forms. Nevertheless, while such studies may help explain why consumers buy the technologies they do, they shed little light on the fate of those technologies once purchased. Consumers do

[16] Pinch, T.J. & Bijker, W.E., (1987), 'The social construction of facts and artifacts: or how the sociology of science and the sociology of technology might benefit each other' in Bijker, W.E., Hughes, T.P. & Pinch, T.J., (eds), (1987), *The social construction of technological systems,* MIT Press, Cambridge Mass. See also Bijker, W.E., (1995), *Of bicycles, bakelites and bulbs: toward a theory of sociotechnical change,* MIT Press, Cambridge Mass., chapter 2.

[17] Pinch, T.J. & Bijker, W.E., (1987), 'The social construction of facts and artifacts'.

not, after all, only purchase technological machines; they also use them. Thus the intentions that may underlie the reasons for choosing a particular design may not be achieved in practice. Furthermore, technologies may be used in ways that they were not necessarily designed for. The purchase of a technology is after all only a small part of the relationship between consumer and machine. In Paul Rosen's study of the development of the mountain bike, for example, he notes the way in which one particular frame design (the Schwinn Excelsior) was considered the most suited to a novel form of cycling activity which emerged in California in the 1970s – riding down mountainsides at high speed.[18] The use of the Schwinn frame in this manner was essentially unpredictable, both for its original designers in the 1930s and for those consumers who purchased it at that time. Furthermore, the degree of direct technical rebuilding done on the Schwinn frame by the emergent 'mountain bikers' to increase its suitability for this new pastime emphasises that end-users and consumers can influence technological change in ways other than through their wallets.

Rosen's study further relates to a second gap in many studies of the consumer's role in technological change. While many such studies have sought to locate consumer decision-making within wider social relations and networks, much less attention has been paid to the way in which local context affects this process. That is to say, macro-level analyses of why social actors choose to adopt the technologies they do, have not been complimented by more micro-level studies which look at decision-making and consumer choice within specific historical and spatial contexts. Even Rosen's study, which notes the emergence of a new 'relevant social group' of mountain bikers in 1970s California, does not directly examine what affect the locality itself played in the emergence of this new activity. Nevertheless, his study provides evidence of a number of site-specific social and technical factors which contributed to the emergence of the mountain bike - from the local terrain itself to the pick-up trucks used to carry rider and bike up the steep hills in the first place. The development of the mountain bike could thus be examined as the emergent outcome of the location-specific interweaving of a number of social and material elements.

One way of conceptualising the role of local context is by adopting some of the theoretical

[18] Rosen, P., (1993), 'The social construction of mountain bikes: technology and postmodernity in the cycle industry', *Social studies of science,* Vol. 23, pp. 479-513.

tools used in biological theories of evolution. A certain degree of caution, however, should be maintained when transferring conceptual tools from one distinct area of study to another. As with technology transfer itself, the change in context can alter the dimensions and characteristics of the tool in question. Nevertheless, there are precedents for such developments (including the SCOT approach[19]) and certain epistemological constructs within evolutionary theory appear to lend themselves quite readily to the study of technological change. Indeed, the SCOT concepts of technical change through 'an alternation of variation and selection' are distinctly Darwinian. George Basalla, however, in a wide ranging critique of theories of technological change predicated on 'technical superiority' and 'Progress', provides a more focussed account of the applicability of Darwinian ideas to explanations of technological diversity and change.[20] In his account, the world of artifacts evolves as human ingenuity, goals and intentions interact with changing social and cultural contexts. Thus as in Darwinian terms species evolve through their interactions with one another in a given environment, so too do technologies. What is useful about this idea is that the environment itself is changeable through its dialectic relationship with the species within it, and thus the relative 'success' or 'failure' of an individual species or mutation *cannot be predicted.* That is to say, the process of evolution is historically contingent and emerges from a variety of factors. The implications of such an approach for examining the history of technology are obvious.[21] Nevertheless, this type of theoretical construct can only provide a limited metaphor for the complex and messy nature of technological change. As Basalla himself notes, what distinguishes the evolution of species from the evolution of man-made artifacts is that the latter are influenced by conscious, wilful human action.[22] Furthermore, this human action is goal-oriented and enacted in specific historical and cultural settings.

Thus previous studies of competing technologies can provide points of comparison and theoretical tools with which to study the development of scanning in the 1970s. What makes

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[19] Many of SCOT's theoretical constructs were adapted from those used within the sociology of scientific knowledge. See Pinch, T.J. & Bijker, W.E., (1987), 'The social construction of facts and artifacts'.
[20] Basalla, G., (1988), *The evolution of technology,* Cambridge University Press, Cambridge.
[21] Other writers on technology have taken up this theme. See, for example, Mokyr, J., (1996), 'Evolution and technological change: a new metaphor for economic history?' in Fox, R., (ed), *Technological change,* Harwood Academic Publishers, Amsterdam, pp63-83.
[22] Basalla, G., (1988), *The evolution of technology,* p.208.

the changes in scanning in this period more complex and interesting is that competition between different technological forms occurred on three levels. On one level, there was the competition between static B-mode scanners (i.e. the Diasonograph design) and the newly emerging real-time machines as a collective group. However, there were also very significant differences between the different types of RT scanners and, importantly, different companies coming into the ultrasound market from different backgrounds and routes, tended to manufacture and supply only one of these forms. There was, therefore, considerable competition in terms of the different methods of producing real-time images. Finally, each company obviously produced different models, with subtly different features, from their rivals and thus there was also competition between designs using the same imaging method. All of these forms of competition coalesced during the mid to late 1970s, to produce a time of rapid technical development. That is to say, the dynamic relationship between innovation and diffusion became much more closely and immediately connected, as well as being more obviously and identifiably related to the performance of different design features and modalities at the point of clinical practice. Furthermore, the very clearly interwoven relationship between innovation and diffusion in terms of technical development was mirrored in terms of clinical and cognitive developments: Here too it appears almost as if events were speeded up - in a way eerily akin to the underlying principle of real-time imaging itself.

In the following analysis of the uptake and use of new forms of ultrasound imaging in Scotland, a conscious attempt will be made to highlight the way in which the choices made between different designs can be contextualised by reference to local, site-specific factors. Further, the chapter will also examine ultrasound workers' interactions with their new machines within those same local contexts and thus will attempt to firmly place new forms of ultrasound imaging within specific historical and spatial locations.

Competing modalities of moving images

Before examining the different forms of dedicated ultrasound equipment that emerged during this period, it is important to note that Nuclear Enterprises B-scan equipment could itself be used to create moving images. Dr Hugh Robinson, for example, began using a standard Diasonograph to create moving images of the fetal heart in the early 1970s.

Robinson, like Campbell and Abdulla before him, became involved with obstetric ultrasound at The Queen Mother's Hospital as part of his training and career development as a clinician.[23] The technique he developed made use of the A-scope probe of an NE4102 to first detect the fluttering spikes associated with the fetal heart, before switching the machine to what was known as M-mode, or time-motion display. This type of display produced a trace of moving structures - the baseline of echoes moved relatively slowly across the screen and the fetal heart movements were visualised as a wave pattern. Thus by measuring the number of waves displayed in any given time frame, the fetal heart rate could be determined. This information could then be used to assess fetal well being and detect possible signs of fetal distress.

Prior to the work of Robinson, M-mode scanning itself had been more commonly used in cardiological applications, although the first recorded use of this method to detect and trace the fetal heart rate occurred in 1964 in China.[24] Robinson's contribution was to adapt this technique to the Diasonograph design. Without changing the set-up of the machine, Robinson developed a different technique of using the probe which 'showed' the movements of the beating heart.[25] Essentially, therefore, Robinson's technique enabled ultrasound equipment to operate as an ultrasonic fetal heart monitor, which could be used to determine the pregnancy's on-going status (i.e. that the fetus had not died *in utero*) and to detect 'fetal distress'. Figure 3.1 shows a static 'snap-shot' of the type of image produced.

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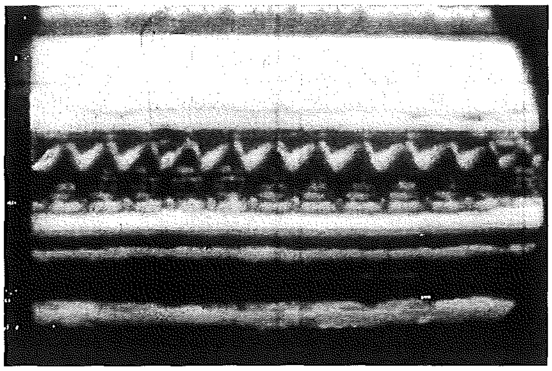
[23] Robinson completed his MD at Glasgow University in 1978. Robinson, H.P., (1978), 'The evaluation of early pregnancy and its complications by diagnostic ultrasound' MD thesis, (University of Glasgow).

[24] This study was undertaken by Professor Xin-Fang Wang and his team of co-workers from the Wahun Ultrasound Research Group, and was published in the Chinese Journal of Obstetrics and Gynaecology ('The application of ultrasound in pregnancy - the study of the fetal heart') in 1964. See Woo, J., (accessed 14/2/00) *A short history of ultrasound in obstetrics and gynaecology, Part 2,* http://www.ob-ultrasound.net/history2.html

[25] See Robinson, H.P., (1972), 'Detection of fetal heart movement in first trimester pregnancy using pulsed sonar' *BMJ,* Vol. 25, No. 4, pp. 466-8; Robinson, H.P., (1973), 'Early detection of fetal heart movement by sonar' *Ultrasonics,* Vol. 11, No. 2, pp. 52-4; Robinson, H.P. & Shaw-Dunn, J., (1973), 'Fetal heart rates as determined by sonar in early pregnancy' *Journal of obstetrics and gynaecology of the British Commonwealth,* Vol. 80, No. 9, pp. 805-9.

Figure 3.1: An early M-Mode display



(from Woo, J., (accessed 14/2/00), *A short history of ultrasound, part 2*)

Another technique for representing movement which developed in the Queen Mother's involved rapidly 'twiddling' a B-scan probe. A number of the hospital's ultrasound operators in the mid 1970s (including Hugh Robinson) employed this technique, while those from other centres recall observing it in practice:

> a girl called Valerie Hood [...] was a senior registrar doing scanning at the Queen Mother's and she developed a system where you had a single transducer and she would make it vibrate and I remember watching her wiggle it backwards and forwards and by making it go backwards and forwards quite quickly you got the impression of real-time.[26]

However, despite the fact that other actors observed both these techniques at the time, and that Robinson's work with M-mode was published in the journals used by obstetric ultrasound workers, neither practice was put into use in other Scottish centres. Part of the reason for this lack of diffusion can be attributed to the fact that the level of skill associated was difficult to transfer and perhaps reproduce. With M-mode fetal heart tracing, the operator needed to be adept enough with the machine to locate the heart in the first place. Then, once the machine was beginning to trace out the heart rate, the operator had to maintain the position of the probe over the heart – not a particularly simple task with a mobile fetus. The 'twiddle' technique similarly required substantial skill to keep the probe moving at considerable speed without losing contact with the abdominal surface. Thus the level of skill and experience demanded by these techniques helped to limit their diffusion in those centres who were only beginning their involvement with the technology.

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[26] Interview with Dr Jack Crichton, 09/02/98.

Furthermore, the arrival of dedicated RT machines and transducers effectively replaced both techniques. With an RT machine, the moving fetus could be viewed without the need to manipulate the transducer and the beating heart could be directly observed. RT machines thus represented a much more complex technology which was, however, easier to use. In this way, many of the skills required of the operator to perform this type of examination were 'delegated'[27] to the technical capabilities of the equipment. This, however, raises another noteworthy point. Although Robinson's M-mode trace required substantial skill and expertise, it nevertheless produced what could be termed 'objective' data, i.e. a continuous stream of information from which a precise heart rate could be calculated. RT machines, on the other hand, were used to provide a more 'subjective' assessment of fetal heart activity. Although the heart could be directly viewed, it was virtually impossible to accurately 'measure' a precise heart rate from observing the very rapid, fluttering movements of so small a structure. Furthermore, early RT machines had no means to record the images for later analysis. Thus assessments of 'normal' and 'abnormal' heart movements were made largely on the basis of tacit knowledge acquired from experience. In this instance, therefore, a more 'objective' measurement of fetal heart activity was essentially replaced by a more subjective one.

To recap, the 'twiddle technique' and M-mode scanning emerged from adaptation in the way in which a conventional static scanner was used in order to gain a different kind of information. In this way, it was the operator's interaction with the machine (the technique) which was altered rather than the make-up of the equipment itself. It could be argued, then, that such representations of movement were the product of the research culture of the Queen Mother's itself. This culture, centred as it was on the Diasonograph and dominated by techniques of static scanning, led to extensions of existing features of that culture. In other words, the type of research being conducted in the Queen Mother's followed a certain path or trajectory which was influenced by the considerable experience which had accumulated around static B-mode scanners.

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[27] Latour, B., (1992), 'Where are the missing masses? The sociology of a few mundane artifacts' in Bijker, W.E. & Law, J., (eds.), *Shaping technology/building society: studies in socio-technical change,* MIT Press, Cambridge Mass, pp225-58.

Thus, the first forays into real-time which were made by prominent Scottish actors in the field involved adapting the technique of scanning in order that motion could be represented using existing B-scan equipment. However, during the second half of the 1970s an alternative way to represent movement appeared in the shape of dedicated RT scanners, which involved a radical re-conceptualisation of the way in which ultrasound images could be constructed and presented. In other words, RT images were achieved through technical reconfiguration. Nevertheless, modifications to the technical dimensions of ultrasound also went hand in hand with modifications of the performance of scanning.

Initially the most successful form of RT scanner (in terms of its uptake in Scottish hospitals) was the linear array. In 1965, Werner Buschmann in association with Kretztechnik developed a linear array with a curved surface.[28] This transducer was designed for use in ophthalmology, and had an array small enough to be fitted directly over the surface of the eye. However, it is Professor Nicolaas Bom who is widely accredited with being the main innovator of this type of scanning, developing a machine in Holland for cardiographic applications.[29] Bom's original scanner made use of a long, hand-held, probe with 20 individual crystal elements each of which, in sequence, would transmit and receive a pulse of ultrasound. This created a scan frame of 20 vertical lines which was renewed at a rate of 190 frames per second. Electronic circuit boards located at the back of the unit controlled the sequential firing of each element in the array. It was the speed of the renewing scan frame which created the cine-film effect allowing motion to be represented.

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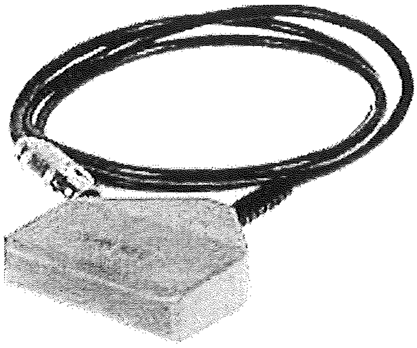
[28] His earliest publications in the English language were: Buschmann, W.H., (1966), 'Diagnostic ultrasonography in ophthalmology' *Journal of the All-India ophthalmological society,* Vol. 14, No. 3, pp.105-16; Buschmann, W. & Hauff, D., (1967), 'Results of diagnostic ultrasonography in ophthalmology' *American journal of ophthalmology,* Vol. 63, No. 5, pp.926-33. See also Woo, J., (accessed 10/9/02), *A short history of ultrasound, part 2.*

[29] His first publication appeared in 1971, Bom, N., Lancee, C.T., Honkoop, J., Hugenholtz, P.G., (1971), 'Ultrasonic viewer for cross-sectional analysis of moving cardiac structures' *Biomedical engineering,* Vol. 6, pp.500-503.

Figure 3.2: Bom's original linear array transducer



(from Woo, J., (accessed 14/2/00), *A short history of ultrasound, part 2*)

However, it is important to note that the representation of motion was not the initial aim of this type of scanning. Rather, the main research problematic underlying the development of the linear array, was to find a way to create two-dimensional images of the adult heart. Conventional static B-scan equipment was not ideally suited for this part of the body: the spaces between the bones of the rib-cage allowed only very narrow 'windows' through which to access the heart while the characteristic long sweeping action used to construct compound static images were also impeded by these bony masses. Furthermore, the close proximity of the air filled lungs (and their regular motion) disrupted the clarity of the slowly constructed static images. Thus the Diasonograph (designed as it was to image the large abdominal area) was ill-suited to scan this part of the body. The linear array was conceived with these problems in mind: the presence of multiple elements in a straight-line probe meant that the transducer did not have to be swept over the body, could fit between the ribs and could generate images fast enough to overcome the problem of artifacts arising from the motion of heart and lungs. However, the emergent outcome of this design and its speed of image construction was that this type of machine was able to represent motion.

Furthermore, due to the fact that this system did not produce compound sector scans but a single sector from a single angle, it did not require the large gantry associated with the Diasonograph. Each scan frame was constructed from an array of transducers at fixed distances from one another and in a straight line, therefore the relative position of each line on the display corresponded with the distance between each element in the array. Thus images could be achieved seemingly instantaneously and by applying the probe directly onto the patient by hand. These characteristics, as will become evident, turned out to be highly significant in the success of this form of imaging in obstetrics.

It is telling that the most dramatic way in which Bom's findings were diffused was not through his journal publications but through demonstration of his images. The following comments, for example, relate to the recollections of Dr Tony Whittingham[30] (who played a significant role in the later development of linear array scanners in the UK) on first seeing Bom's scan images of the adult heart:

> I think it was in 1971 that I was at a meeting of the British Medical Ultrasound Society in Glasgow. Bom was unable to attend to present his work, but he sent a film. I remember to this day the excitement when the film was shown of his 20-line image. The audience stood up and applauded the celluloid, because Bom wasn't there to receive the accolade himself.[31]

There is reason to suggest that the powerful impact of moving images (unrelated to the quality of the diagnostic image contained within them) was one of the technical qualities of this form of scanning which created a great deal of the impetus to its future development within obstetrics. The fact that they could produce moving two-dimensional images of hidden bodily structures had, it could be argued, an immediate appeal beyond the clinical. Never before had the possibility existed to observe the fetus *in utero* – to watch its movements and activities in an instantaneous moving image. The next step (as Tony Whittingham was quick to realise) was to improve the resolution to a level at which they could display diagnostic information.

There is some controversy over which company was first to introduce this type of scanner on a commercial basis with the credit going either to Organon Technica (who collaborated with Bom on the early innovation of the linear array) or to the American company ADR

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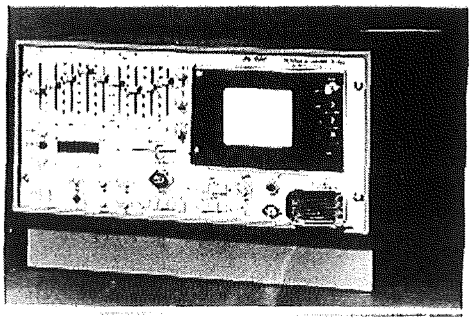
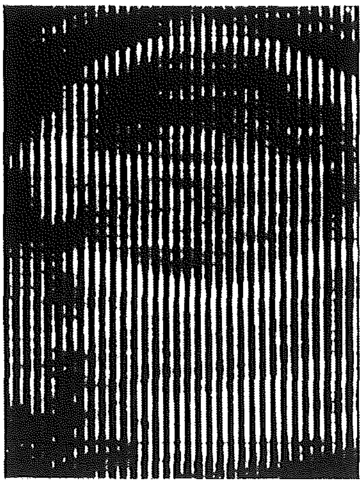
[30] Dr Tony Whittingham was a medical physicist, and Head of the Ultrasonics Section of the Northern Regional Medical Physics Department at Newcastle General Hospital from 1972. Much of Whittingham's work in the early 1970s concentrated on ways to introduce more scan lines into the RT image. See Tansey, E.M. & Christie, D.A., (eds.), (2000), *Wellcome witnesses to twentieth century medicine, Vol 5. Looking at the unborn: historical aspects of obstetric ultrasound,* Wellcome Trust, London, p. 38, footnote 98.
[31] Tansey, E.M. & Christie, D.A., (eds.), (2000), *Looking at the unborn*, p 39.

(Advanced Diagnostic Research Corporation) based in Arizona.[32] Nevertheless one of the first companies to produce this type of RT equipment in the UK was Diagnostic Sonar, a small Scottish company based in Livingston. More importantly, this company was initially the most successful supplier of RT machines to hospitals in Scotland. For example, three out of the four hospitals in this study acquired early machines from this company in the late 1970s.[33] Diagnostic Sonar's original model was the 'System 85', so-called because the transducer contained 85 individual transducer elements.[34] The scanner itself weighed around 32 kilograms, and was thus significantly smaller and lighter than static B-scan equipment. The transducer was located at the end of a long, flexible (although apparently somewhat unwieldy[35]) cable attached at the rear of the machine.

Figures 3.3 & 3.4: The Diagnostic Sonar 'System 85' and an example scan image of a fetal head





(both pictures courtesy of Blackwell, R.J., (1980), 'The basic physical principles of real-time ultrasound scanning,' in Bennett, M.J., & Campbell, S., (eds.), *Real-time ultrasound in obstetrics,* Blackwell Scientific Publications, Oxford, London & Edinburgh, p.3)

Two former Nuclear Enterprises workers; Duncan Cairns, a design engineer and Hans

[32] Actors involved with ultrasound during the 1960s and '70s diverge on which of these companies' linear arrays preceded the other. There was also another early British development by GEC Medical called RITA (real-time imaging transducer array) - a linear probe which could be attached to existing B-scan equipment and some actors claim this to be the first. (See Tansey, E.M. & Christie, D.A., (eds.), (2000), *Looking at the unborn*, pp.60-61.

[33] The only case-study hospital which did not acquire this make of machine was Aberdeen Maternity Hospital. However, as will be highlighted in the next section, Aberdeen did not develop its ultrasound services to any significant extent during the 1970s and did not actually purchase an RT machine until 1980.

[34] John Fleming recalls that the name emerged during a demonstration of the prototype at the Queen Mother's Hospital, following a discussion between himself and the two company directors. (Interview with John Fleming, September 1998).

[35] 'Evaluation of real-time ultrasonic scanners – first report' *Health equipment information,* No. 81, August 1979, (BMUS Historical Collection).

Gassert, an NE salesman, formed Diagnostic Sonar. Gassert and Cairns regarded the developments on the Continent in RT imaging as the next developmental stage in scanning and tried to persuade Nuclear Enterprises to invest in research and development in this area. Nuclear Enterprises, however, were not interested in doing so. Much of the explanation for this undoubtedly lies with the economic costs of research and development - a relatively small company division, the NE ultrasound division was only just receiving the return on the investment it had made into static scanning, and thus were reticent to channel those profits into the development of a different form of the technology. Furthermore, it is also possible to suggest that Nuclear Enterprises were confident in the superiority of their form of ultrasound imaging. The images created using linear array equipment were small, fuzzy and the structures contained within them difficult to discern, in comparison to the clearer, more detailed and panoramic views provided by static B-scan equipment. However, as both Ruth Schwartz Cowan and David Noble (amongst others) have demonstrated, technological superiority does not guarantee survival.[36]

Gassert and Cairns, convinced that RT would be the major growth area in the next few years, left NE in 1975 to start their own company in the early part of 1976 with very humble beginnings - renting a house in Livingston and using the kitchen as a lab.[37] Although outside the remit of this thesis, it is poignant to note that the difficulties faced by small companies such as Diagnostic Sonar in innovating new products were indicative of the UK's poor state support for innovation and research and development at this time.[38] The result, in terms of the expansion of the market in ultrasound equipment during this period, was that very few British companies emerged with competitive products, and fewer still survived into the 1980s.

The development of linear array RT scanning probes in the mid 1970s did eventually stimulate varying degrees of response from manufacturers of static B-scan equipment.

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[36] Schwartz Cowan, R., (1985), 'How the refrigerator got its hum' in MacKenzie, D. & Wajcman, J., (eds.), *The social shaping of technology: how the refrigerator got its hum,* Open UP, Milton Keynes, pp202-218; Noble, D., (1985), 'Social choice in machine design: the case of automatically controlled machine tools' in MacKenzie, D. & Wajcman, J., (eds.), *The social shaping of technology, pp. 109-124.*

[37] Interview with John Fleming, September 1998.

[38] Edgerton, D., (1996), *Science, technology and the British industrial 'decline', 1870-1970,* Cambridge University Press, Cambridge; Lundvall, B., (ed.), (1995), *National systems of innovation: towards a theory of innovation and interactive learning,* Pinter, London.

Norman McDicken, who had moved to Edinburgh University in 1974 from the Department of Clinical Physics and Bioengineering in Glasgow, developed a mechanical scanning probe that could be used on the Diasonograph. His main research interest at this time was geared towards the improvement of the quality of B-scan images by developing their grey-scale resolution. Grey scale or dynamic ranging was developed by Kossoff in Australia, and was essentially a technical improvement to increase image resolution by enabling weaker echoes to be imaged without distorting stronger ones.[39] In effect, grey scale enabled greater tissue characterisation to be displayed as a result of the way in which each 'dot' on the screen was represented. To improve the grey-scale capabilities of Nuclear Enterprises machines, McDicken concentrated on the quality of the materials used to create transducer elements. Thus ultrasound workers such as McDicken were actively engaged in improving the image quality of static B-scan equipment when RT machines appeared. This in turn had a tangential effect on some of those workers' impressions of early RT images. As they were actively engaged in improving the amount of detail they could gain from weaker echoes, their criticism focused on the poorer quality of the RT pictures, leading to an under appreciation of the importance of RT's other contribution - the representation of movement.[40]

Nevertheless, when the linear arrays appeared, McDicken felt that with the quality of transducers they had for the Diasonograph, they could perhaps get better RT images than those on offer if they could have them move fast enough. The Edinburgh team therefore placed four transducers on a wheel, with the face of each transducer lying flush with the wheel's edge, creating a seamless surface. The whole assembly would spin round, with each transducer being energised to emit ultrasound pulses and receive back the echoes as it swept round in the lower half of the wheel's rotation.

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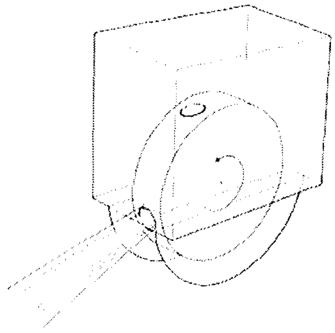
[39] See, for example, Kossoff, G., Garrett, W.J. & Radovanovich, G., (1973), 'Grey scale echography in obstetrics and gynaecology' *Australasian Radiology,* Vol. 18, pp.62-111. See also Wells, P.N., (1975), 'Review: absorption and dispersion of ultrasound in biological tissue' *Ultrasound in medicine and biology,* Vol. 1, No. 4, pp.369-76; Wells, P.N., Halliwell, M. & Mountford, R.A., (1974), 'A method of display dynamic range expansion using system gain wobbulation' *Ultrasound in medicine and biology,* Vol. 1, No. 2, pp.179-81.

[40] See for example Tom Brown's comments in Tansey, E.M. & Christie, D.A., (eds.), (2000), *Looking at the unborn*, p42.

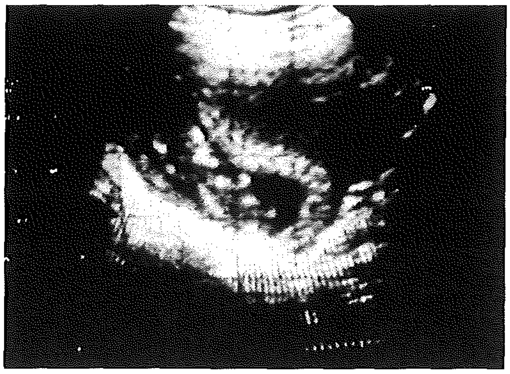
Figure 3.5: A diagram representing the operation of the EMI 'Spinner'



(from Blackwell, R.J., (1980), 'The basic physical principles of real-time,' p.23)

Unlike the linear array, the different angles of the transducers as they rotated around the wheel gave the resultant image display a characteristic 'pie' or 'fan' shape (see figure 3.6 which shows an image of an 18 week fetus facing the placenta).

Figure 3.6: Image of fetal head created by EMI 'Spinner'

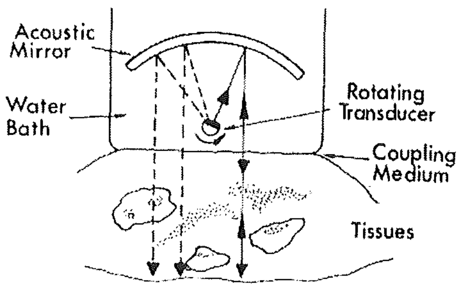


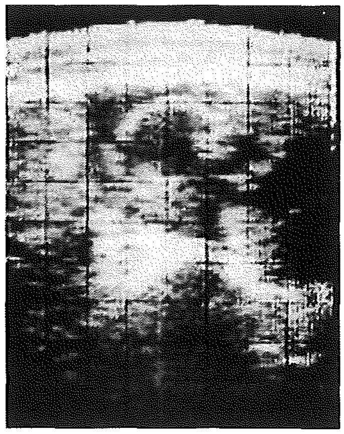
(From Blackwell, R.J., (1980), 'The basic physical principles of real-time,' p.23.)

McDicken and his team sold their spinner to Electrical and Musical Instruments (EMI) in 1977, shortly after that company had taken over Nuclear Enterprises. Thus with an NE (or EMI) machine, ultrasound operators could have both high quality static B-scans and an RT probe.

When examining the development of the 'spinner' in the mid 1970s there is a temptation to relate it to a much earlier design of RT scanner, which was commercially produced by Siemens in the mid 1960s, and attribute a straight developmental trajectory between the two. In reality, however, the similarities between the two imaging methods provide more evidence of the heterogeneity of technical development, rather than an example of a single 'technological trajectory'. The Siemens 'Vidoson' worked on the principle of a single crystal element that rotated at the focus of a parabolic mirror.[41] Both element and mirror were housed inside a water bath with a thin membrane, which would be coupled to the patient's abdomen with oil or gel. As it rotated, the transducer would emit pulses of ultrasound which would be reflected by the acoustic mirror, and into the patient (see Figure 3.7). Thus, despite the rotation of the element, the ultrasonic waves would enter the patient in parallel lines and the resultant echoes would return in the same form. Figure 3.8 shows a typical image created by the original Vidoson, this example being of a fetal face and head.

Figures 3.7 & 3.8: Diagram representing operation of Siemens Vidoson, and image of fetal face and head





(Fig 3.7 from McDicken, W.N., (1976), *Diagnostic ultrasonics: Principles and uses of instruments,* Granada Publishing Ltd, London; Fig 3.8 from Woo, J., (accessed 14/2/00), *A short history of ultrasound, part 2.*

The 'Spinner', like the Vidoson and unlike the linear array design, also created moving images through the motion of the elements themselves, although the former used a number of transducers rather than the single element of the Vidoson. Indeed, both designs became known as 'mechanical sector scanners' because it was the actual mechanical movement of the elements which created the image, rather than electronic sequential firing as with the linear array design. Thus it might appear tempting to reintroduce the Vidoson as the predecessor of the spinner and thus create a more tidy and linear developmental trajectory for the rotating head type scanner. The situation, however, is more complex than this would

[41] For a more detailed account of the physical principles of RT scanning see McDicken, W.N., (1976), *Diagnostic ultrasonics: Principles and uses of instruments,* Granada Publishing Ltd, London pp196-97 & 209-215; Blackwell, R.J., (1980), 'The basic physical principles of real-time ultrasound scanning' in Bennett, M.J., & Campbell, S., (eds.), *Real-time ultrasound in obstetrics,* Blackwell Scientific Publications, Oxford, London & Edinburgh, pp1-26; Woo, J., (accessed 14/2/00), *A short history of ultrasound in obstetrics and gynaecology, Part 2,* http://www.ob-ultrasound.net/history2.html

make it appear.[42] McDicken and his team did not modify the Vidoson or use the technical development of the Vidoson as their starting point: Rather, they proceeded from a different socio-technical culture – the technical developments of grey-scale and dynamic ranging with the static B-scanner, coupled with the desire to create moving real-time images of better quality than the linear arrays. Thus, the fact that parallels can be drawn between the Vidoson and the EMI spinner, further demonstrates the way in which the developments of a scientific and technological culture interact with, and are extended by, new and old forms of technical design. The Vidoson only became drawn into the story of the development of scanning in Scotland when a new set of circumstances had arisen. Thus the temptation to 'tidy up' the account of the innovation of real-time scanners by obscuring the heterogeneity of their development should be avoided.[43]

Indeed, it is worth noting that despite the fact that the Vidoson was the first commercially available RT scanner, and that it was fairly widely used in Europe in the late 1960s, it was never installed in a UK hospital. A number of factors can help explain this relative lack of commercial success. Firstly, as Chapter 2 demonstrated, the uptake of the Scottish designed Diasonograph did not itself occur until the late 1960s and thus knowledge of ultrasound's potential uses within obstetrics during this period was only just becoming more widespread. Thus the relative youth of the medical ultrasound market and the relatively small number of hospitals who acquired machines during these years, provided little incentive for Siemens to invest in any supply-push marketing of its product.[44]

Furthermore, the interest that was beginning to emerge in Scotland was centred on gynaecological and obstetric applications, following the work of Donald and the Glasgow group. In terms of this area of medicine, the ability of the Diasonograph to image the entire abdominal area was of more immediate advantage than the moving images of a smaller area produced by the Vidoson. Nevertheless, the technical differences between the two designs cannot alone shed light on the Vidoson's fate in Scotland: it was, after all, used quite widely in other countries for obstetric applications.

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[42] For a good account of the theoretical benefits of using non-linear developmental models see Bijker, W.E., (1995), *Of bicycles, bakelites and bulbs*.
[43] An example of such 'abridged' versions of development can be found in Blackwell, R.J., (1980), 'The basic physical principles of real-time ultrasound scanning'.
[44] John Fleming, *pers comm.*

One important factor must surely be the strong inter-personal connections between clinicians active in the field in Scotland and their relationship with the Glasgow team and Smith's Industries/Nuclear Enterprises. The role of actors such as Ian Donald, Stuart Campbell, Norman McDicken and Alexander (Sandy) Christie should not be underestimated in the diffusion and spread of ultrasound scanning. It could be argued that the Glasgow hospital had an institutional commitment to the Diasonograph which was, in a sense, passed on to those around them - those with whom they worked, as well as those who came to the Queen Mother's to learn the new technique.

Related to this, it is possible to argue that a considerable expertise was being established in the UK around static scanning using the Diasonograph. An obstetrician or radiologist who wanted to establish an ultrasound service in another part of Scotland could, if he chose a Diasonograph, become part of a wider network of practitioners with whom he could correspond for advice and technical/clinical support. In addition to this, the role of Professor Lenihan's Clinical Physics Department in Glasgow, in terms of their services and support for static scanning, also helped to glue together a network of actors clustered around this innovation.

A variety of factors, therefore, probably contributed to the fact that the Vidoson was never a commercial success in Scotland. Furthermore, the lack of a commercial market for the Vidoson in the UK provides further evidence to support the contention that a whole range of contextual and historically specific factors are implicated in the translation of new innovations into successful commercial products. In other words it is neither the 'technical superiority' nor the actions of interested parties which alone determine an artifact's fate, but rather a more complex and messy variety of circumstances, activities and outcomes. For this reason, the 'fate' of an artifact *does* lie in the hands of later users[45], but it also importantly lies in the general context within which those users operate, and the way in which this context will affect the artifact cannot always be accurately predicted.

To sum up, new forms of ultrasound imaging began to appear in the second half of the

[45] Latour, B., (1987), *Science in action.*

1970s in the form of linear array machines and the mounted spinning transducers. These innovations evolved from within the context of different circumstances. The linear array originated in the context of cardiology and ophthalmology, while the spinner emerged from improved transducer design. For the first time in Scotland, hospitals and ultrasound operators were faced with an array of technical choices – static or moving images, mechanical sector scanners or linear arrays, Diagnostic Sonar, ADR or EMI? Given the different modalities of producing RT images, and the fact that these were also competing with a more established form of diagnostic ultrasound in the shape of the Diasonograph, what factors influenced the purchase of individual machines? Why were certain models chosen over others and why were relationships developed between certain clinical establishments and companies? In other words, what 'consumer choices' were made and what role did such choices play in the further development of ultrasound? In order to answer these questions, it is necessary to examine the introduction of RT ultrasound in Scottish hospitals and the early uses to which it was put.

First impressions in practice: using real-time ultrasound at the Queen Mother's and Aberdeen Maternity Hospital

There is some degree of ambiguity relating to what type of RT machine was first introduced to the Queen Mother's Hospital and when. In 1978 the hospital participated in a multi-centre (and multi-discipline) assessment trial of new RT equipment on behalf of the Scottish Home and Health Department (SHHD) and the Central Services Agency (CSA).[45] During this assessment a total of eight new machines was circulated around seven Scottish hospitals, the Department of Clinical Physics and Bio-Engineering in Glasgow and the CSA in Edinburgh where they were tested for (amongst other things) safety, technical performance and ease of use. At the end of the trial, the machines were then distributed amongst the participating hospitals and thus the Queen Mother's acquired two machines (a Roche Axiscan and a Diagnostic Sonar 'System 85') in 1979. However, there is reason to suggest that the Queen Mother's had bought a Diagnostic

[45] For the findings of the assessment see 'Evaluation of Real-time ultrasonic scanners - first report' *Health Equipment Information*, No. 81, Aug 1979.

Sonar machine earlier than this - although the documentary evidence to support this is somewhat scant.[46] Beginning in the early 1980s (probably in response to the increasing number of machines being used in the Queen Mother's) John Fleming began a file in which he recorded details of machines and their location in the hospital.[47] In this file, a Diagnostic Sonar 'System 85' is recorded as having been installed in 1977/78. The file also notes that it was 'probably' acquired from an evaluation trial and purchased via the Medical Research Council.[48] This entry was not made at the time of the machine's acquisition, however, and the details of its purchase and installation are sketchy in comparison to the other entries in the file, which record exact purchase price, dates of installation and delivery.

This scanty evidence can be tentatively supported by a letter written by Hans Gassert (one of the directors of Diagnostic Sonar) to John Fleming in the mid 1980s.[49] In it (undoubtedly as part of a subtle sales ploy) Gassert mentions that the Queen Mother's were Diagnostic Sonar's first customer and the centre to which they sold their first machine. Furthermore, John Fleming recalls Gassert and Duncan Cairns (Diagnostic Sonar's other director) bringing their prototype machine to the Queen Mother's - probably to assess its use on obstetric patients.[50] This early involvement may have led the Glasgow hospital to buy a machine at an early date. It is thus possible to suggest strongly that the Queen Mother's was the first Scottish centre to purchase a Diagnostic Sonar linear array real-time scanner and that this occurred around 1977/78.

Nevertheless, in terms of routine clinical practice it would appear that the hospital continued to rely solely upon its static compound B-scanners until at least 1979. Dr Margaret McNay, for example, began working with ultrasound in the Queen Mother's in 1978 and recalls using only

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[46] None of the interviewees for the Glasgow case study could recall clearly what RT machine they first used.
[47] Ultrasonic Equipment Index, BB4, (BMUS Historical Collection).
[48] The entry also notes that the machine was later loaned to the Glasgow Veterinary School.
[49] Letter from Hans Gassart to John Fleming, July 1983, BMUS Historical Collection, Manufacturers folder.
[50] Indeed, according to both John Fleming and Charles Whitfield, Ian Donald in particular was very good at getting machines from manufacturers on 'extended loan' - i.e. the QMH would agree to take the machine for a trial period to assess its use, and then the company 'had to come looking for it to get it back' (Interview with Professor Charles Whitfield, 24/8/99).

the static scanners initially.[51] It is tempting to suggest that the machine was not at first used for clinical work but only for research/assessment, and, indeed, in 1978 the Glasgow group published a paper comparing BPD measurements done using real-time and static B-scan equipment.[52] Furthermore, it could be suggested that, while not put into daily clinical use in the Queen Mother's itself, the scanner was still used for both research and clinical purposes in one of the hospital's peripheral clinics. For example, John Fleming's 'Ultrasonic Equipment Index' records that in 1980 the Diagnostic Sonar machine, which was acquired from the SHHD/CSA trial, was updated using money from a project grant to assess the effectiveness of such a machine in a clinic situated in a poor inner-city area.[53] Its portability, its relatively low cost and its ease of use would have made it suitable for such a purpose. Furthermore, it was quite possible to support the idea that while a particular scanner may have been regarded as inferior and of poorer quality compared to static compound scanning machines (and therefore unsuitable for an important tertiary centre such as the Queen Mother's), that it was still perfectly adequate for a smaller peripheral clinic. According to Margaret McNay, for example:

> I used to think of it like cars - you get your Mini which is perfectly good for getting you from A to B, and they are reliable, small, portable equipment. Then you've got your Rolls Royce that can do everything. But not every unit needs a Rolls Royce ... only half a dozen or so really experienced units, of which the Queen Mother's was [one]. These units need the very sophisticated, the Rolls Royce type equipment, but for the vast majority of work the middle of the road scanner is more than adequate and for outlying clinics, certain rural areas, etc., then your Mini equivalent is quite adequate.[54]

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[51] Interview with Dr Margaret McNay, 05/11/97.

[52] Adam, A.H., Robinson, H.P., Fleming, J.E.E., Hall, A.J., (1978), 'A comparison of biparietal diameter measurements using a real-time scanner and a conventional scanner equipped with a coded cephalometry system' *British Journal of Obstetrics and Gynaecology,* Vol. 85, pp. 487-91.

[53] The update was the addition of a freeze-frame facility costing £3000, and the research project title was 'Evaluation of routine ultrasound in detecting IUGR at peripheral antenatal clinics in socially disadvantaged areas'. Ultrasonic Equipment Index, BB4, BMUS Historical Collection.

[54] Interview with Dr Margaret McNay, 05/11/97. The car metaphor appears very often when ultrasound workers try to explain their equipment and the changes between them. Sandy Christie, John Fleming and Valerie Farr, for example, all made use of this metaphor in explaining the differences between machines.

Thus the fact that the early RT machines were not regularly used for clinical practice in the Queen Mother's itself does not necessarily suggest that the ultrasound workers in that institution saw no value in the new forms of imaging. Further, McNay's comments might help to explain the fact that although the Queen Mother's owned three RT scanners by 1979 (the two Diagnostic Sonar machines and the Roche Axiscan), they nevertheless continued to rely on the large static compound B-scanners for all of their clinical work.

Another possibility, however, was that the static scanner was, at the time, simply preferred because of an institutional commitment to this form of imaging. By the mid 1970s the Queen Mother's Hospital could be characterised as the centre point of a large socio-technical web based around the practice of compound static scanning. In 1976, for example, eight new B-scan machines were installed in Scottish hospitals in Lanarkshire, Tayside, Fife, Greater Glasgow and Grampian bringing the total number of B-scan machines now being used in Scotland to thirty eight.[55] Each new machine strengthened Glasgow's position as the centre of expertise in this technology. For example, the ultrasound training courses offered by the Department of Clinical Physics and Bioengineering, which began in 1970, proliferated substantially as personnel from other hospitals sought expert training in the technology. By the middle of the decade there were a number of courses on offer - geared as separate endeavours for clinicians and technical staff. In November 1979, for example, courses in general ultrasound were advertised in the BMUS Bulletin with a ten day course for clinicians and senior registrars, and a five day course for radiographers on offer. Both these courses were run four times a year. [56] In addition, the Queen Mother's also offered its own specialist 'ultrasound in obstetrics' courses, open to all grades of staff and run three times a year.[57] Furthermore, in its capacity as a regional service, the Department of Clinical Physics and Bio-engineering continued with their

[55] Scottish Home and Health Department, (1979), *Report on the future development of ultrasound in Scotland,* unpublished report, p.9.
[56] BMUS Bulletin, No 25, November 1979.
[57] The QMH courses lasted 3 days and were operated twice a year. They also appear to have been largely open to all grades of staff from clinicians to technicians and were, obviously, confined to obstetric applications (see BMUS Bulletin, No 25, Nov 1979).

maintenance and servicing role for the ultrasound machines (of which there were 17 by 1976) now scattered through the hospitals in Glasgow and the west of Scotland.[58] The number of cases referred to the Queen Mother's had also increased - with patients being sent from all over Scotland, and occasionally also from England. In the Ultrasound Technology Centre based in the hospital, Hugh Robinson and John Fleming continued to develop the hospital's research output on static scanning - working on estimations of fetal weight using fetal measurements.[59] Thus in terms of both research and clinical practice, the Glasgow hospital had established itself as a centre of excellence in the area of compound scanning. Through these activities, building on the work done by Donald over twenty years, the QMH had a demonstrable commitment to static scanning. Thus, if there was to be any centre that might react negatively to the 'new kid on the block' – i.e. real-time ultrasound – the Queen Mother's might be a likely candidate.

According to one prominent actor in the field, there was a general perception that this was indeed the case, and that the ultrasound workers in the Queen Mother's were very cynical about the potential of the new modalities.[60] This impression, however, is contradicted by, amongst others, John Fleming:

> I think I was quite keen on it. I can't really remember what my reaction was. It might have been a bit of the 'not invented here' feeling as well, 'I wish I'd thought of that first'. But Angus [Hall] and I weren't trying to compete in that area.[61]

Nevertheless, Fleming also recalls that the resolution and small scan-frame size led many workers in the field to either dismiss or resist the new machines:

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[58] Scottish Home and Health Department, (1979), *Future development of ultrasound in Scotland,* p.8.
[59] For example, Fleming, J.E.E., Hall, A.J., Robinson, H.P., Wittman, B.K., (1978), 'Electronic area and perimeter measurement of ultrasonic images' *Journal of Clinical Ultrasound,* Vol. 6, pp. 379-84.
[60] Anon. pers. comm.(with respect to the wishes of the interviewee).
[61] Interview with Mr John Fleming, 20/9/98.

> Having got it I think people realised the limitations at that stage. The pictures were pretty awful. ... You got a picture with a lot of lines, the resolution was poor and you only got a picture of a section. With a Diasonograph you could scan over the whole length of a very large lady and get it all in one image so you could see the whole thing. So confronted with a silly little image that wasn't very good, there was quite a bit of resistance from some people.[62]

Thus from Fleming's recollections, it could probably be suggested that, rather than regarding the new imaging technique with hostility, his response to the 'System 85' could be characterised more correctly as 'ambivalent'. As an engineer he appreciated the ingenuity of the linear array, but having worked with static scanners since 1962 he similarly recognised the scanner's technical limitations. As a result of its reputation and experience with obstetric ultrasound, the Queen Mother's ultrasound team scanned a large number of complicated cases and pathologies referred from other hospitals. Thus the demands placed on ultrasound - in terms of the image quality they desired - entailed that the inferiority of the early RT images in comparison to those produced by static B-scan machines informed their impressions of the new imaging modality.

Nevertheless, although the new RT machines may have produced images of poorer quality and resolution, their ability to display motion could be viewed as an extremely important attribute, although not necessarily for clinical reasons. For example, Ian Donald saw in real-time scanners a way in which the power and immediacy of moving images could be used for anti-abortion purposes. According to Donald's wife (Mrs Alix Donald):

> In Dallas, Texas, Ian was shown the first real-time scanning machine brought from Phoenix, Arizona, by some talented young men. Ian was, of course, wildly excited.[63]

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[62] *Ibid.*

[63] Tansey, E.M. & Christie, D.A., (eds.), (2000), *Looking at the unborn,* p. 70. The machine to which Mrs Donald was referring was one of the first commercial linear arrays produced by ADR (Advanced Diagnostic Research Corporation) in the US. Their first model appeared in 1974, although a more successful model was marketed in 1976. This later machine was probably the one Donald first saw.

Part of the reason for Donald's excitement lay in the potentially strong emotional connection which could be made between women considering a termination of pregnancy and the fetus. Thus during the late 1970s in the on-going campaign against the 1967 Abortion Act, Donald used very early real-time images of first trimester pregnancies to demonstrate the 'humanity' of the fetus. The following, for example, is part of a speech which Donald made to a lay anti-abortion audience after showing a real-time film of a 12 week pregnancy:

> Anybody who says this is not alive is talking through his neck. It is a lie, which is intolerable and *seeing is believing...* And one of the things that this film has done *if it has done nothing else*, is to kill forever the lie of the pro-abortion lobby that there's nothing there just a potential human being ... That baby is as human as an old man ... the same individual from conception to grave...[emphasis added][64]

Thus, even for a clinician with a demonstrated commitment to the diagnostic use of ultrasonic images, the clinical potential of RT imaging alone was not its only quality. For Donald, RT's ability to display the movements of the fetus strengthened his arguments in relation to fetal life and personhood and this, in turn, shaped his perceptions of the technical attributes of this form of equipment. Despite this enthusiasm, Donald's retirement from clinical practice in September of 1976 meant that he did not play a significant role in the uptake and development of this type of scanning in the Queen Mother's Hospital. Nevertheless, what is evident from this example is that actors' perceptions of a new technical artifact may be shaped by a number of factors and circumstances, which are perhaps not immediately obvious. In this example, Donald saw in the moving images of RT ultrasound a quality which would not have been immediately apparent (or valued) by other clinicians who did not share his political views. Furthermore, the qualities perceived by the innovators and manufacturers of a technology such as RT ultrasound might not be identical to those perceived by later users.

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[64] From Nicolson, M., 'Ultrasound imaging and the anti-abortion debate: Ian Donald's clinical holism' (unpublished paper).

Despite the fact that ultrasound workers in the Queen Mother's like John Fleming and Margaret McNay were somewhat lukewarm in their perceptions of the early RT machines, there were aspects of the technology which emerged as significant in the delivery of antenatal services. The most obvious of these related to the way in which amniocenteses were performed. Since the late 1960s, compound scanning had been used to 'guide' the practice of amniotic fluid sampling.[65] An examination would be performed to locate the placenta and fetus and then a mark would be made on the patient's skin (usually a small 'x') to indicate where the needle should be inserted. The main rationale behind the sonogram was to minimise the risk of gaining what was termed a 'bloody tap' - an impure amniotic sample containing traces of blood from contact with the placenta.[66] Furthermore, piercing the placenta was thought to increase the risk of spontaneous abortion as a result of the procedure - endangering both pregnant woman and fetus.[67] However, as the scan was often performed some hours before the actual amniocentesis (in some cases the evening or day before), the ultrasonic findings could not be entirely relied upon to provide a definitive location for the placenta at the time in which the procedure was to be performed, let alone the mobile fetus.[68] In particular, an increase of fluid in the bladder would often alter the position of the uterus and placenta. Thus amniocentesis, in the age of the static scanner, required the use of ultrasound *in conjunction* with one of the techniques which in other procedures (such as the estimation of fetal age) it had come to supersede – i.e. abdominal palpation. Clinicians performing this test (and at this time amniocenteses were undertaken almost exclusively by clinicians) still relied predominantly upon their clinical skills to locate the fetus and placenta.

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[65] See, for example, Durtis, J.D., Cohen, W.N., Richerson, H.B., White, C.A., (1972), 'The importance of placental localization preceding amniocentesis' *Obstetrics and gynaecology,* Vol. 40, No. 2, pp. 194-8.

[66] For assessments of ultrasound's success in preventing such occurrences see Kerenyi, T.D. & Walker, B., (1977), 'The preventability of "bloody taps" in second trimester amniocentesis by ultrasound scanning' *Obstetrics and gynaecology,* Vol. 50, No.1, pp. 61-4.

[67] See Harrison, R., Campbell, S. & Craft, I., (1975), 'Risks of fetomaternal hemorrhage resulting from amniocentesis with and without ultrasound placental localization' *Obstetrics and gynaecology,* Vol. 46, No. 4, pp. 389-91.

[68] It is also worth noting that the scan was often undertaken in an entirely different location. In Kirkcaldy, for example, prior to the opening of the ultrasound department at Forth Park, scans were performed at the Victoria Hospital the day before an amniocentesis was carried out at the maternity.

Beginning in the early 1980s the Queen Mother's team were using real-time ultrasound *during* the performance of amniocentesis – relying much more directly on the imaging technology to guide their activity. Once again, however, the dialectics of resistance and accommodation came into play in making this practice 'work'. Two technical resistances in particular were associated with amniocenteses under direct ultrasound guidance. Firstly there was the problem of maintaining an aseptic environment - both in terms of the actual point of contact between the transducer and abdomen and in terms of the general suitability of the scan room. Ultrasound was not initially developed to be used in conjunction with invasive procedures such as amniocentesis and thus the need to maintain asepsis had never before been an issue. In some centres, for example, it was felt that the scan room itself was inadequate for the performance of such procedures and thus if the scanner was not a mobile unit, they continued to rely on techniques of palpation (see the following section on Aberdeen). However, in other centres such as the Queen Mother's, where it was felt the room could be made suitably sterile a resistance remained in terms of the cleanliness of the equipment. Ultrasonic probes, for example, had not been designed with ease of sterilisation in mind, while contact gels were all initially non-sterile oils.

A range of strategies was developed to accommodation such resistances. In their 1983 publication Hobbins, Winsberg & Berkowitz, for example, advocated that most centres should not attempt to use ultrasound to visualise the actual needle insertion, but that, by placing their finger beneath the part of the transducer which showed the optimal entry point, they should create an acoustic shadow indicating the preferred angle, before marking the abdomen. The scan image was then to be displayed on screen using a freeze-frame facility (which, of course, again provided further avenues of innovation for ultrasound manufacturers). The amniocentesis would then be performed using this frozen image to guide the needle insertion, but only after the contact gel had been removed using acetone.[69] For those centres who were in a position to directly image the needle insertion, the transducer should be gas-sterilised or placed within a

[69] Hobbins, J.C., Winsberg, F. & Berkowitz, R.L., (1983), *Ultrasonography in obstetrics and gynaecology - second edition,* Williams and Wilkins, Baltimore & London, p. 174.

sterile plastic bag.[70] At a later date, innovations began to appear from manufacturers of ultrasound equipment and other medical suppliers in the form of contact gels aimed specifically at the practice of invasive procedures using ultrasonography.[71]

Using these various accommodation strategies to overcome the need to protect the patient against possible infection, RT ultrasound began to be used in conjunction with invasive techniques such as this. Again it was real-time's fast speed and immediacy of image creation which were the forms of technical agency harnessed and put to use during this activity. Furthermore, for the purposes of amniocentesis, the linear array RT modality emerged as the most practicable and useful. However, this was not as a result of anything integral to its method of image creation - rather it was the fact that the linear arrays were all hand-held transducers which was important. This enabled clinicians to have the freedom of movement to easily position the transducer on any part of the abdomen in such a way that it could image the precise area in which they were working but was convenient enough for them to be able to perform the biopsy and manage the transducer. Thus again, a simple design feature emerged during this form of practice to be an important advantage over its rivals.

This is not, of course, to argue that amniocenteses could not be carried out under the direction of other types of RT imaging, such as 'the Spinner'. Rather, the suggestion is simply that using different machines with different characteristics meant that the operator in these circumstances made slightly different movements and the procedure was performed in subtly different ways. On the part of the operator, a different type of interaction and behaviour was required to carry out the test. With a linear array machine, the slightly clumsy transducer had to be operated with one hand while the needle was guided into the uterus. This operation required a relatively high degree of manual dexterity - two types of technique were applied simultaneously, and at the

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[70] Hobbins, J.C. *et al,* (1983), *Ultrasonography in obstetrics and gynaecology.,* p. 174

[71] Indeed, the increasing use of ultrasound during such procedures helped to create a lucrative niche market in products such as contact gels, with a proliferation of products designed with particular forms of scanning in mind. The emergence of this buoyant market can be easily seen in the advertisements in the BMUS Bulletins throughout the 1980s.

same time the operator was required to keep an eye on the biopsy needle, as both a direct physical presence and as an ultrasonic representation, as well as monitoring the reactions and movements of the fetus. Thus the new interactive relationship between operator, ultrasound equipment and biopsy needle became stabilised in a way which altered the practice of amniocentesis.

Furthermore, this new form of practice also extended practitioners' conceptual knowledge of fetal life. The simultaneous use of ultrasound imaging and a technique which introduced a foreign body into the uterus, provided another opportunity to observe the actions and reactions of the fetus during such circumstances.[72] Once again, this extension of medical knowledge has to be seen as an emergent outcome of the alteration in the practice of amniocentesis under ultrasound guidance.

The changes which RT ultrasound facilitated in the performance of amniocenteses demonstrate an important aspect of how perceptions of the qualities of the new machines were formed. Whilst the poorer quality and smaller view provided by RT ultrasound led the machines to be considered as inferior by the staff of the Queen Mother's, this perception was modified somewhat when an alternative use was found for this equipment. While RT was considered inferior for the detailed examination of the uterus and its contents (placentography, fetal anomalies, etc.), the way in which it constructed and displayed images was considered advantageous for invasive procedures. First impressions, therefore, did not dictate future usage. As medical practices changed - through interactions with the technology and growing familiarity - so too did perceptions of the qualities contained in this design. Thus what was expected of such machines, what it was asked to do and how it was used did not remain static. For this reason, the evolving nature of the context of ultrasound's usage influenced perceptions of the technical design of different machines. An RT scanner considered as a direct alternative

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[72] See, for example, Gennser, G. & Marsal, K., (1979), 'Fetal breathing movements monitored by real-time B-mode ultrasound: basal appearance and response to challenges' *Contributions in gynaecology and obstetrics,* Vol. 6, pp. 66-79; Neldam, S. & Pedersen, J.F., (1980), 'Fetal heart rate response to amniocentesis in early pregnancy'

to a static B-scan machine was disappointing; one viewed as an aid for invasive procedures was not.

From the early 1980s, therefore, these were the types of practices being carried out in the Queen Mother's Hospital by the ultrasound team. Furthermore, during the mid 1980s other invasive procedures such as chorionic villus sampling (CVS) and fetal blood transfusions also began to be performed in conjunction with ultrasound. The fact that such activities became defining features of ultrasound in this hospital, relates to the prominent position the Queen Mother's staff had acquired over the previous 20 years as an important tertiary hospital and a centre of expertise with this technology. This was not, however, simply based on a past reputation - their prominent position gave them access to problematic cases through referrals from other centres, thus giving them the opportunity to try out new procedures and increase their expertise in the area. Furthermore, their closely intertwined roles as University Department and NHS service gave them greater access to new equipment through their ability to draw on research grants. Thus, the way in which RT ultrasound was received and implemented in the Queen Mother's was largely shaped by the nature and position of the institution itself. Nevertheless, although tempting, it is too simplistic to suggest that the same experiences were replicated in other, similar institutions. To this end, it is worth briefly considering the reception and use of RT in the other large tertiary centre in this study – Aberdeen Maternity Hospital. While actors in this hospital shared many of the same perceptions of the new form of imaging with their counterparts in Glasgow, the way in which this translated into their interactions with the technology differed. In essence, RT received a lukewarm reception amongst the staff who operated obstetric ultrasound in Aberdeen. In order to explain this, it is first necessary to examine some of the events that occurred just prior to its introduction.

In the early 1970s a number of departmental shifts took place which altered the organisation of the small ultrasound department. Initially, the original Nuclear Enterprises machine (and the

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NE4102 which replaced it) was owned and run jointly by the Department of Medical Physics.[73] However, in the mid 1970s (very much against the wishes of the Chair of Medical Physics, Professor John Mallard) Dr Valerie Farr was placed in charge of the service. Although trained as a paediatrician, Dr Farr first became involved with ultrasound in the late 1960s when she headed the maternity hospital's intensive care unit. Much of her remit involved antenatal monitoring, which brought her into contact with Alexander (Sandy) MacIntosh and Alexander (Sandy) Christie's work with ultrasound. Her knowledge of the technology led to her appointment to the Aberdeen ultrasound team following the departure of Sandy MacIntosh in 1970. According to Farr, she was the obvious choice and 'just drifted into it'.[74]

Placing a clinician such as Farr in overall charge of the project, effectively laid control over the use and future development of the technology firmly in the hands of clinicians, reducing the role of their colleagues in Medical Physics. It would appear that the main rationale underpinning this decision was a difference in focus and approach between the two specialties, which is neatly summed up by John Mallard:

> I always used to argue, 'How can we [medical physicists] know how to improve this technique if we are not actually working with the patients and seeing what we cannot image?' On the other hand, the medics argue, 'We know all about anatomy, we know the condition that we think the patient has and we know what to look for in the image to show whether or not the patient has that condition.'[75]

Thus, by the middle of the 1970s it is possible to suggest that the Aberdeen obstetricians felt that ultrasound should be centred more fully around patient care and use than technical development and investigation. The technology had now been in use in the hospital for several years and, arguably, it was now felt that an ultrasound-experienced clinician was better suited to oversee its general use than a medical physicist, whose knowledge of the pathologies of

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[73] See Chapter 2.
[74] Interview with Dr Valerie Farr, 10/05/98.
[75] Interview with Professor John Mallard, 28/3/00.

pregnancy was confined to his or her knowledge of imaging techniques. Indeed, John Mallard's perception was that this often occurred in the relationship between medical physics and new technologies:

> As the years go by, usually it's the physicists that develop the thing, set it up, get it working, prove that it's clinically useful, and then gradually they get pushed out as the medics and the radiographers etc. take over. Then the physicist is the one that looks after the machine and repairs it. It's a sad business.[76]

This lament, of course, does not strictly apply to the development of diagnostic ultrasound in general, where the involvement of a number of clinicians such as Ian Donald was always apparent. Nevertheless, in Mallard's opinion, this was exactly what occurred with obstetric ultrasound in Aberdeen in the late 1970s, when the relationship between medical physics, obstetrics and the ultrasound scanning service was reconfigured. Mallard's department, however, continued their developmental work with ultrasound, but in areas other than obstetrics and gynaecology. Thus, through the Department of Medical Physics, Aberdeen continued to play host to developments in ultrasound and played an active role in assessments of the potential of real-time scanning. Indeed Mallard's Department was one of the first European centres to build a phased array transducer.[77] On the other hand, however, the obstetric scanning service based in the maternity hospital appears to have remained relatively unchanged throughout the late 1970s and into the 1980s. The staff remained relatively small – one secretary who would book-in patients and type up notes, Dr Farr and two assistants (one medical technician and one radiographer). The department of Medical Physics which had played such a pivotal role in the establishment of ultrasound in Aberdeen continued to provide support for the maintenance and upkeep of the hospital's static scanners.

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[76] Interview with Professor John Mallard, 28/3/00.

[77] Selby RDS, Hutchison JMS, Mallard JR, (1980) 'The Aberdeen phased array: A real-time ultrasonic scanner with dynamic focus' *Medicine and biological engineering and computing,* Vol 18, pp. 335-343.

Nevertheless, the shifting relationship between ultrasound and medical physics was not the only significant aspect of Farr's appointment. Unlike her predecessors, Val Farr was not an enthusiastic supporter of the technology. Her perceptions of its limitations were integrated with a general belief that medical technologies should be used to support clinical decisions, rather than the reverse, which she saw as the overall reality. In 1973, for example, she collaborated on a paper critical of the increasing reliance on measurements of biparietal diameter for calculating gestational age,[78] for which she received a few years of 'cold shoulder treatment' from Professor Donald.[79] In addition, she did not support the trend towards the use of the technology for universal screening (see Chapter 4) and felt that even by the late 1970s there was something of an over-reliance on the technology to the detriment of clinical diagnostic skill.

With a sceptic at the head of a virtually independent obstetric scanning team (whose only other two operators were lower grade staff) it is perhaps unsurprising to find that the new imaging modality of real-time was not received particularly enthusiastically. The first dedicated RT machine to be used was a linear array costing £35 000, which was purchased in 1980.[80] As might be expected, Farr's first impressions of the new piece of equipment were not particularly positive:

> It was terrible. The pictures were no better than the Diasonograph. You were used to the Diasonograph and knew what to expect and when you get a new machine you don't know its limitations at all.[81]

Nevertheless, these sentiments echo those expressed by actors such as John Fleming and Margaret McNay at the Queen Mother's. The difference, however, lay in the way such sentiments were translated into action. In the Queen Mother's, initial impressions of RT were

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[78] Davison, J.M., Lind, T., Farr, V., Whittingham, T.A., (1973), 'The limitations of ultrasonic fetal cephalometry' *Journal of obstetrics and gynaecology of the British Commonwealth,* Vol. 80, No. 9, pp. 769-75.
[79] Interview with Dr Valerie Farr, 10/5/98.
[80] Unfortunately, it has proved impossible to trace the make and model of this first machine - although from Dr Farr's description it was certainly a linear array.
[81] Interview with Dr Valerie Farr, 10/5/98.

overcome as the potential benefits of the new equipment were investigated - from its uses in small peripheral clinics, its ability to display fetal movements, and the advantages it provided in terms of amniocenteses performed under direct ultrasound guidance. In Aberdeen, on the other hand, negative first impressions led to inaction - staff continued to rely on their static B-scan machine and when, eventually, they did begin to use the RT equipment, it was simply regarded as another machine to be used in tandem. Amniocenteses, for example, continued to be performed after ultrasound examination, rather than being guided by direct ultrasound visualisation, and patients continued to be examined in the scan room, despite the RT machine's ability to be used at the bedside. In other words, the particular benefits and advantages that RT brought with it were not investigated, while its disadvantages continued to lead to its relegation as a poor substitute for the static B-scan machine.

This raises the obvious question of why the hospital would bother to spend £35 000 on a machine its own operators regarded as inferior. However, it is also possible to see here the growing divide between the obstetric scanning team and the Department of Medical Physics. The latter, in their role as the maintainers of, and experts in, such pieces of medical equipment had a strong voice in purchasing decisions. Their work on the development of phased arrays demonstrates that they did not share the same perception of RT as Farr and suggests that they played a significant role in introducing this form of the technology to Aberdeen.

Furthermore, it would also seem that obstetric staff who were not themselves ultrasound users were becoming more and more acquainted with the technology and its uses - mainly via the medical journals. Indeed, Farr felt this led to a lack of awareness on the part of consultants in respect of the equipment's limitations and capabilities:

> It's like all new things. People don't publish the bad things - only the good. Everybody's expectation is higher than what we can deliver. A lot

> of time was spent educating the staff as to what we could and couldn't do.[82]

Thus with both a Medical Physics department keen to try out and extend new developments in ultrasound technology, and with a growing number of the hospitals obstetricians keen to employ ultrasound assessments in their clinical decision-making, it was probably inevitable that real-time ultrasound would arrive in Aberdeen, whatever the wishes of Val Farr.

To sum up, it is possible to discern that, initially, RT imaging in Aberdeen, while greeted with some ambivalence on the part of its operators, was nevertheless gradually woven into the fabric of the delivery of obstetric ultrasound - but without altering or extending its nature. The altered relationship between medical physics and obstetric ultrasound, entailed that while research and development of RT was undertaken, it was done only by medical physics working in conjunction with other specialties. In obstetrics, despite the department's early involvement with the technology, ultrasound was in a sense reconfigured as a purely clinical service with no research commitment. Even within this remit, the sceptical attitude of the team leader led to little innovation in this direction once RT had been put into use. Although this scepticism towards the usefulness of ultrasound conditioned her approach to the technology, it should be viewed as an outcome of her interactions with it. In particular, it cannot be argued that Farr's attitude to ultrasound was the result of some prior and personal anti-technology sentiment. In the 1960s, for example, she had been heavily involved in the practice of intrauterine blood transfusions in rhesus cases - operated under x-ray.[83] Her involvement in the development of this very technologically invasive procedure demonstrates that she did not view medical technology *per se* in the same way that she viewed ultrasound. This, therefore, strongly suggests that her view of ultrasound was not the result of a reactionary/anti-technology stance, but rather the result of her experience with ultrasound. In the case of ultrasound-guided amniocentesis, for example, she did not feel that the image quality was sufficient, and saw little

[82] *ibid.*
[83] *ibid.*

advantage to be gained over the methods of abdominal palpation.[84] Thus it would appear that the new imaging modality of RT was valued purely on the grounds that it was an additional machine which could be used for clinical examinations. The new technology was simply enveloped within the existing practice of obstetric ultrasound - bringing about no noticeable change.[85]

In short, therefore, while there are many similarities between the Queen Mother's Hospital and Aberdeen Maternity Hospital in terms of their size and institutional position, the use of new RT scanners in each was markedly different. Nevertheless, this difference did not lie in either the reasons that motivated each centre to purchase RT, or in initial assessments of its qualities. Instead, what was different was the way in which the technology was actually used in practice in each centre. In the Queen Mother's, the use of the machine altered perceptions of its advantages, disadvantages and uses - in Aberdeen Maternity Hospital it reinforced an initial negative assessment. If actors such as Farr, Fleming and McNay can be characterised as 'consumers' of obstetric ultrasound in this example, their 'consumer choices' were not the only factors which shaped the general development of the technology in each centre. Of equal significance were their subsequent interactions with the chosen artifact.

In addition, the difference in RT's reception between these two institutions can only be understood by examining the technology in each individual local context. For example, the close working relationship between clinically-trained ultrasound users and the Ultrasound Technology Unit at the Queen Mother's meant that the clinical and technical qualities of the new machine designs were examined collaboratively. At Aberdeen Maternity Hospital, on the other hand, no such close collaboration existed. The small obstetric ultrasound team were effectively distanced from the Department of Medical Physics - who provided only technical

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[84] *ibid.*

[85] The role of ultrasound in obstetrics was re-evaluated in Aberdeen in the mid 1980s when a number of new, pro-ultrasound, staff took up prominent posts within the Obstetrics Department. The way in which this affected the development of ultrasound is considered in Chapter 4.

'support'. The same culture therefore did not exist. Mallard and his staff worked in isolation on the development of the technical aspects of the technology, while Farr and her small staff used the new machines to keep up with increasing clinical demand. Thus despite the similarities between the two institutions, the nature of their respective local research cultures and inter-departmental relationships led to significant differences in the way new forms of imaging were perceived and used.

Nevertheless, local context could also affect the technology in a much more direct manner. One example of this can be found in the innovative way in which RT ultrasound was used in the Western Isles to overcome difficulties associated with the social geography of the area. To this end, the following section will examine the reception of RT ultrasound in the smallest and most remote of the hospitals in this study - the Lewis Hospital in Stornoway.

Portability in the periphery: the emergence of a valued 'quality' in the Western Isles

The Western Isles (or Outer Hebrides) are situated about thirty miles off the West Coast of Scotland. Basically a collection of islands, they cover a very large area, spread in an arc of more than 150 miles in length. Outside of the largest town of Stornoway (on the Isle of Lewis) the social geography of the isles is composed of small, scattered, remote communities. In 1978, the entire population stood at 29,665[86] and this figure only increased by around 1000 to 30,660 by 1990.[87]

The main clinical provider for the region was the Lewis Hospital in Stornoway, itself a comparatively small district general hospital.[88] For example, throughout the 1970s and '80s, there was only one obstetric consultant based in the hospital, accompanied by a core staff of

[86] Registrar General, (1980), *Annual Report of the Registrar General for Scotland, 1978,* General Register Office, Edinburgh.
[87] Registrar General, (1991), *Annual Report of the Registrar General for Scotland, 1990,* General Register Office, Edinburgh.
[88] In 1992, the hospital was relocated to new premises in the town and renamed the Western Isles Hospital.

only three midwives. However, it has to borne in mind that this small group of professionals were dealing with a relatively low number of hospital births. Not all of the women of the Isles were delivered in the hospital (many choosing to go to mainland hospitals or to be delivered at home), while the small size of the population entailed a relatively low absolute number of births (417 live births in 1978, declining steadily to 345 by 1990).[89] Nevertheless, the absence of junior doctors and the solitary nature of the clinician's post, did create organisational resistances which effected the delivery of ultrasonic services - as will be outlined below.

In terms of pregnancy and childbirth, the organisation of hospital services in the Western Isles Health Board area was rather unusual and complicated. The sheer size of the area and the remoteness of its communities meant that for the women of the southern isles, it was as easy, if not more so, to travel to one of the hospitals on the mainland, rather than the smaller hospital in Stornoway. Furthermore, Loganair (who operated all flights between the isles) banned pregnant women from using their services after 37 weeks gestation.[90] Thus many women found themselves having to travel to the area where they intended to be delivered weeks before the baby was due. It was therefore, more sensible for them to be delivered in areas where they had relatives, rather than travel to Stornoway and be accommodated in a bed-and-breakfast establishment. For these reasons, the women of the Isles often opted to be delivered in various mainland hospitals - mainly in Glasgow or Inverness, but also sometimes Aberdeen or Edinburgh. This, then, entailed trips to the mainland for booking clinics, where many may have received a routine ultrasound examination - if that was the policy of the particular hospital in question. However, aside from these women, and others who were referred to the tertiary centres of Glasgow, Edinburgh or Aberdeen with suspected anomalies or complications, the majority of women in the Isles did not receive ultrasound as part of their antenatal care.

[89] Registrar General, (1980), *Annual report, 1978; idem.*, (1991), *Annual report, 1990.*
[90] Although, often with the complicity of their local GP, many women managed to 'manipulate' this regulation (anon. pers. comm. – with respect to the wishes of the interviewee).

In 1979, the Lewis Hospital became another in the growing number of Scottish hospitals to introduce an obstetric ultrasound service. The first piece of equipment to be purchased was a linear array RT machine - a Diagnostic Sonar 'System 85'. The main influence on the development of an obstetrics and gynaecology scanning service was the arrival at the Lewis Hospital of Dr Jack Crichton in 1978. Crichton had previously been involved in the creation of ultrasound scanning services in Perth and Dundee in the early 1970s, where he worked alongside Sandy Christie. From there, he had made use of his dual citizenship and taken up a post as consultant obstetrician/gynaecologist with the Canadian Royal Air Force in Germany. On his return to the UK, Crichton initially applied for a Consultant position in Perth, but this went to an obstetrician from the Lewis Hospital in Stornoway. Therefore, Crichton wisely applied for, and was appointed to, that newly vacated post.

Although no ultrasound machines were available to him when he arrived in the Isles, Crichton's interest in the technology was known. Almost a year later, in 1979, an under-spend in the Western Isles Health Board's capital budget provided the opportunity for a new piece of medical equipment to be purchased and it was decided that an ultrasound machine for the obstetric department should be funded. The exact amount of this under-spend dictated the model chosen. The 'System 85' was at the time the least expensive model available and the Health Board simply purchased the only machine they could afford.[91] In this case, therefore, choice was circumscribed and not made on the basis of favourable comparisons with other designs, but on purely financial criteria.

Having worked exclusively with Diasonograph-style static B-scanners up to this point, Crichton had to learn new skills and get to know the features and idiosyncrasies of his new machine. Initially, therefore, he proceeded with some caution and his recollections of his impressions of the Diagnostic Sonar machine echo the sentiments expressed by those in other centres:

[91] Interview with Dr Jack Crichton, 09/02/98.

At first that little System 85 machine, the power of that machine, as my father would say, 'wouldn't pull the skin off a rice pudding'. It wouldn't penetrate... you were not getting the depth that you wanted. It didn't have the power to get down with the ultrasound and process it properly.[92]

However, what is particularly interesting is the way in which Crichton attempted to accommodate the perceived poorer quality of his new machine. Firstly, it significantly affected his decisions and plans when it came to establishing a routine service. Despite the fact that many other centres (including Perth and Dundee with which he kept in contact through his association with Sandy Christie) were operating late first trimester scans in order to gain accurate dates, the routine which Crichton introduced was a scan at 16 weeks gestation.[93] It would appear that the reason for delaying scanning times was directly as a result of his assessment of his machine:

The quality of the scanners in those days...determined routine scanning. If one tried to do scanning earlier...you could say "Oh, I see a heart beat" or "I see a little fetus". ...But if the average person wanted to be reasonably certain it was best to delay scanning until 16 weeks when the baby was big enough and it would be easy to spot twins and where the measurement of the baby was reasonably accurate.[94]

It is important to note, however, that there was a precedent for scanning at these times. Stuart Campbell, for example, was at the time advocating routine scans at 16-18 weeks and 32 weeks - especially if the scan was performed using a real-time machine.[95] Nevertheless, Crichton would appear to have made this decision on purely practical grounds – in other words, he altered the clinical and social organisation of his examinations to accommodate the technical and visual particulars of his equipment. Unlike other actors in centres such as the Queen Mother's and Aberdeen Maternity, Crichton did not have access to any other type of equipment - he could not

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[92] Interview with Dr Jack Crichton, 09/02/98.
[93] A second routine scan at 30 weeks was introduced a few years later (see Chapter 4).
[94] Interview with Dr Jack Crichton, 09/02/98.
[95] Campbell, S. & Little, D.J., (1980), 'Clinical potential of real-time ultrasound' in Bennett, M.J. & Campbell, S., (eds.), *The basic physical principles of real-time ultrasound scanning,* pp.34-35.

pick and choose which scanner to use for which procedure. Instead, he was completely reliant on the only machine he had at his disposal and had to find ways to make best use of it. Thus he altered other aspects of the way in which the machine was used (in this case the times at which scans were operated) in order to achieve better results in terms of what could be detected/diagnosed. Indeed, he went so far as to change the time of first booking for maternity patients from 12 weeks (which it had been previous to the introduction of ultrasound) to 16 weeks (when he conducted his first ultrasonic examination).

From this example of a change in clinical organisation and practice it can be seen that not only was Crichton having to accommodate material/technical resistances which he perceived in his equipment, he was also, importantly, altering his decisions to accommodate the material and social realities of the Western Isles. Travel on and between islands was not quite as simple as on the mainland. Transport between the isles was facilitated by ferry services supplied by Caledonian McBrayne and air travel by Loganair.[96] These transport links, however, were dependant on weather and tidal conditions. The latter also affected air transport as most of the small islands had no runway and planes took off and landed on the beaches. Furthermore, travel between communities on the same island was also slow, as most roads were single track with passing places, even on Lewis itself. Thus, by changing the date of booking patients to coincide with their first scan, pregnant women would not be required to make an extra trip to the hospital. In this way, the very organisation of obstetric services in the Lewis Hospital were 'tuned' to fit Crichton's perceptions of the material and technical attributes of the technology that he used.

Nevertheless, while the reorganisation of booking times demonstrates one way that the technical disadvantages of this machine were accommodated in the Western Isles, this artifact did turn out to have at least one 'advantage' over its competitors which was to be of considerable significance in this location - portability. Once again, however, it is evident that

[96] British Airways also provided airlinks to the mainland, with regular flights from Stornoway to Glasgow and Inverness.

portability emerged as a quality because of the way in which the machine was used, and because of the peculiar local arrangements of the Isles.

As the only Consultant in obstetrics and gynaecology in the entire health board area, Crichton also had another clinic, held once every six weeks, on the Isle of Benbecula (some 70 miles from Stornoway) where patients from Barra, Benbecula and South Uist could be seen.[97] The reason Benbecula was chosen for these clinics was because of the advantageous facilities on the island, which were provided at a large military base dating from the Second World War. Despite the continuing backdrop of Cold War tensions, the military presence on Benbecula was comfortably integrated with the local community. One feature of this was that the runway at the base was also open to use for civilian air travel, which facilitated Crichton's trips to the island. Furthermore, his clinic itself was held within the Medical Reception Station on the base and here Crichton saw not only women from the local community but also the wives of military personnel. Very soon after acquiring his ultrasound machine Crichton decided to begin taking it with him on these monthly visits. This meant that women from the southern isles could be offered ultrasound examinations without having to travel the considerable distance to Stornoway. However, it also entailed the regular transportation of ultrasound equipment by plane, which was, in itself, no small task:

> I took it down with me and by the time I had the scanner and my case of goodies and my case-notes it was quite a feat to move the stuff and it was a fair old way.[98]

It should be emphasised that it would have been technically impossible to transport a static B-scanner in this way. The concept of 'portability' did not emerge in relation to ultrasound

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[97] Initially this service was limited to gynaecological examinations - the six week intervals between clinics on Benbecula were of too long a duration for any suspected obstetric anomalies. Such cases were, therefore, either dealt with at the Hospital in Stornoway or one of the mainland hospitals - depending on the nature of the suspected condition.

[98] Interview with Dr Jack Crichton, 09/02/98

technology until the advent of the smaller and lighter RT units during this period. Nevertheless, it is clear from the advertising literature of RT ultrasound manufacturers like Diagnostic Sonar that their definition of 'portability' differed considerably from the level of portability being asked of this equipment in the Western Isles. For Diagnostic Sonar, portability simply entailed the ability of the scanner to be moved from ward to ward on its own trolley.

Figure 3.9: Diagnostic Sonar advertisement literature c1979

(picture courtesy of BMUS Historical Collection)

Crichton, therefore, was making use of this scanner in a way which was unanticipated by the designers: in the new hands of Jack Crichton the Hebridean doctor, the scanner was asked to perform a novel role of 'flying' ultrasound machine. Thus the interpretation which Crichton formed of the machine was shaped by the nature of the location within which he used it. In this case the 'interpretative flexibility' of the artifact was directly affected by local contextual factors.

Nevertheless, the translation from actor's interpretation of this artifact to actual practice was not necessarily straightforward. Such an enhanced level of portability did not simply materialise on demand, but was achieved through modification in the face of material resistance from the equipment. For example, aside from the problems associated with the weight and bulk of the machine, Crichton was also concerned about possible damage to the unit on these monthly flights between the islands. In order to protect his machine, Crichton contracted the tent-making firm of 'Blacks' to make a special padded case. However despite this, the first time the doctor used the machine at his Benbecula clinic it stopped working after he had scanned only two patients. As it turned out, the problem and its solution were relatively straightforward and simple. The engineer from Diagnostic Sonar found that the vibrations of the plane had loosened large pins in the electronic circuit boards at the back of the scanner and so he designed a metal plate which was screwed over these pins to keep them in place.

It is easy to dismiss this particular instance as simply lack of knowledge and argue that, had Crichton been an engineer, he could have fixed his scanner in such a way as to prevent this from occurring. However, such an argument would be both misleading and unrealistic. The machine was being asked to perform a role for which it had not been designed and the way in which it acted in such circumstances could not have been anticipated in advance. A modification as simple as a panel screwed to the back was required in order that the machine be able to perform its new role in the Western Isles, but such a modification could only be made in response to the way in which the machine behaved in such circumstances. Thus the novel demands placed on the scanner by Crichton provoked new responses from the machine, which then had to be accommodated by the engineer.

Despite the emerging significance of the Diagnostic Sonar machine's portability, it was not purchased specifically *because* of this - as noted earlier the over-riding reason for choosing this particular machine was that it was the only one they could afford. Therefore, portability was an added feature of the machine which the Lewis Hospital bought. It seems clear then that Crichton's intentions (in terms of his decision to move the scanner around) were formed *through* his interactions with the technology - he didn't enter into a relationship with the technology with his intentions already formed:

> ...I didn't get the real-time scanner to go charging around the islands. I have to be honest, it was there and I was using it and these patients had to fly up to Stornoway to get a scan and I thought, 'Now, surely, we could do something', so I started to take it down [to Benbecula]. I didn't have a brilliant idea all worked out in my head beforehand, it evolved slowly over the years as being the way to do things.[99]

In a sense therefore, where portability may have been insignificant for medics working in different areas, in the Western Isles (characterised by the remoteness and geographical spread of its population) it emerged as a pivotally important factor in the creation of their scanning service. In other words, it was an aspect of the scanner Crichton could use, and manipulate, to improve his service. Once again, therefore, it is only by examining the technology in use that perceptions of its 'qualities' and 'value' can be assessed.

Indeed, the idea that portability became regarded as a central requirement of ultrasound equipment in this region is reinforced when the details of the next machine purchased for the Consultant are considered. In 1984 a new scanner was bought for the obstetric department. What motivated both the purchase of an additional scanner, and the specific choice of model, was Crichton's desire to extend the services provided at the peripheral clinic by offering routine obstetric ultrasound. High on the list of desirable attributes in the new scanner, therefore, was portability. The Consultant's experience with the Diagnostic Sonar machine in the context of this remote location taught him to value the portability of his chosen equipment and, crucially, led to new avenues of development in the way he organised and carried out his medical practice.

To establish such a routine service, however, Crichton needed more than an additional machine. As a lone consultant it was impossible to increase the frequency of the trips to the peripheral clinic in order to scan greater numbers of patients on a more regular basis. Crichton had

[99] *ibid.*

therefore to seek assistance. A local general practitioner (Dr Louise Hodgson), based on the same island as the peripheral clinic, was employed by the Health Board to operate the new screening service.[100] Although unusual, employing a GP as sonographer did have a precedent in other remote areas of Scotland where scanners had been purchased and situated in GP-run hospitals.[101] Furthermore, in remote areas like this it was not unusual for general practitioners to undertake duties that would otherwise be considered within the remit of specialist medicine.

The ultrasound and associated examinations performed by the GP were relatively simple and straightforward. She performed two routine examinations on each pregnant woman (at 16 and 32 weeks gestation) in which biparietal diameter measurements were made, fetal presentation and placental localisation were recorded, while any gross abnormalities or multiple gestations were looked for. Any unusual or suspect indications from either of these scans would be brought to the attention of the Consultant Obstetrician and the patient referred either to the local district general hospital, or to one of the larger tertiary hospitals on the mainland. The basic nature of the scans performed was a direct consequence of the way the service was organised. The GP had no on-site specialist support and was routinely scanning relatively low numbers of women (compared to sonographers located in more densely populated areas). These factors were thus taken into account in terms of the duties that she performed.

More importantly, the machine itself was chosen specifically with these issues in mind. As Dr Hodgson recalls:

> A lot of machines were coming on to the market, some aimed at hospitals which were enormous things and some aimed at adventurous private obstetricians which were very flashy machines that did all sorts

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[100] Dr Hodgson was paid on an hourly rate as a clinical assistant for her ultrasound sessions. She attended two separate training courses in Glasgow and London, and was given additional practical training by the Consultant Obstetrician at the local hospital. (Interview with Dr Louise Hodgson, December 1998.)
[101] Scottish Home and Health Department/Scottish Health Service Planning Council, Obstetric Ultrasound in Scotland: Report of the Ad Hoc Group appointed by the Specialty sub-committee for Obstetrics and Gynaecology of the National Medical Consultative Committee, Edinburgh, Her Majesty's Stationary Office, 1988.

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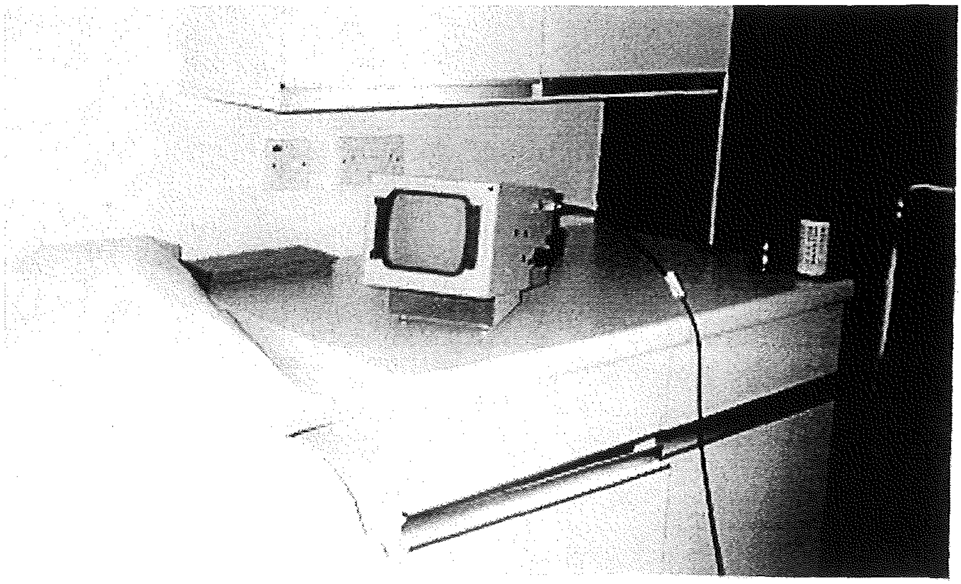
in this manner. Although he experimented with this, Crichton concluded that the images achieved in this way were inadequate for making accurate fetal measurements. Instead, at an additional cost of around £500, an extra monitor was purchased. Thus one single scanner had two monitors; one located in the hospital, and the other at the peripheral clinic. In this way, only the scanner moved between the two centres and was plugged into the monitor on arrival, thus minimising potential damage.

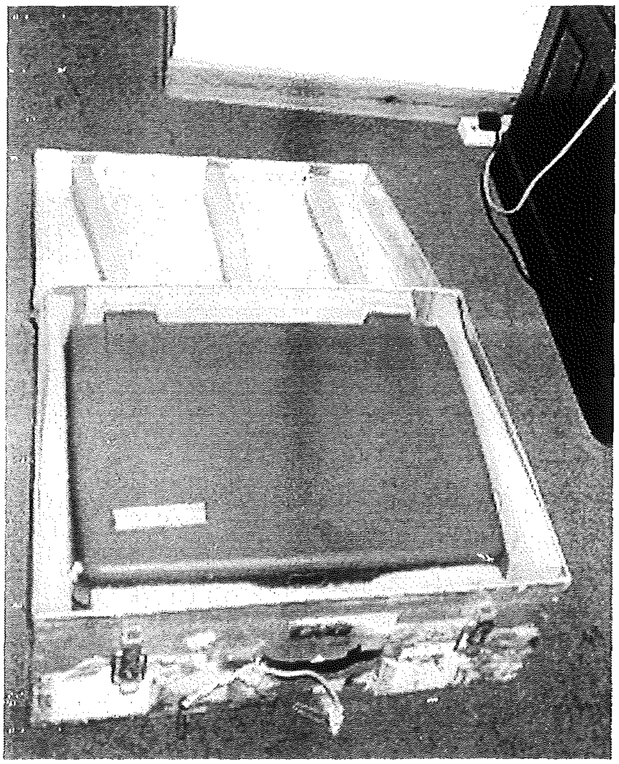
Figure 3.11: One of the detachable monitors used with Pie Data machine in the Western Isles.



(Photographed in Ness, Isle of Lewis by the author)

Furthermore, without the screen, the scanner could be more easily packed away and carried from place to place in its own case. The case itself was made from hard plastic and was supplied with the unit. However, while the protection and portability it afforded might be sufficient for journeys in the boot of a doctor's car,[103] previous experience with the Diagnostic Sonar machine highlighted the need for extra precautions when it came to island-hopping flights. Furthermore, the Consultant no longer accompanied the scanner on its trip: the machine was taken to the airport by a member of the hospital's maintenance staff, transported in the plane's hold, and collected by army personnel on Benbecula. The involvement of so many untrained 'hands' and the potentially damaging dangers of regular flights in an aircraft's hold led Crichton to have yet another case made, this time from foam-lined steel, into which the scanner, inside its manufacturers case, could be secured.

Figure 3.12: Custom-made steel protective case, used to transport Pie Data machine



(Photographed in Castlebay, Barra by the author)

[103] Scanners were, by the late 1970s, being transported in this way by obstetricians when attending sessions at peripheral clinics (see, for example, R.P. Balfour, 'Use of a real-time ultrasound scanner in district antenatal clinics', *British Journal of Obstetrics and Gynaecology,* 1978, Vol. 85, pp. 492-494). This again demonstrates that the way in which scanners were used in clinical practice, filtered back to manufacturers and were built into the design of new models.

The new screening service began on February 13th 1986.[104] Once a fortnight, the scanner would be packed up by the Obstetric Consultant and sent, unaccompanied, to the neighbouring island. At all other times, the scanner was based in the main hospital. The following year, the peripheral service was extended to another GP practice on the island of Barra - the most southerly of the populated Isles - and in 1988 a further GP in Ness at the northern tip of Lewis joined the fray. Each of these locations was also given separate monitors to use. A rota was drawn up which worked on a fortnightly cycle. In the first week the scanner would be taken by car to Ness (by a local shopkeeper who happened to work in Ness but live in Stornoway) and returned the following afternoon. In the second week it would be flown to Castlebay in Barra and, after being used there, would be taken by taxi to the ferry terminal at the north of the island and transported to Benbecula. The following day it would be flown back to the hospital in Stornoway. By the summer of 1988 then, the single portable Pie Data unit packed in its special metal box was being flown, ferried and taxied between four different sites on three different islands. Such a system was highly innovative. Its devolved nature, with obstetric scanning being carried out in the community by local GPs, was facilitated by stretching the concept of portability - the scanner was travelling over 250 miles every fortnight by plane, ferry and car. Nowhere else in the UK at that time (or subsequently) had such a system evolved to overcome the geographical and institutional barriers of a remote and scattered population such as this.

In the Western Isles, therefore, portability emerged as an important feature in ultrasound equipment and thus as a significant advantage of linear array RT equipment over static B-scanners. Following his experiences with the Diagnostic Sonar machine, portability became a pre-requisite for Crichton when later purchases of ultrasound equipment were discussed. Thus, the most important observation to be drawn from the early implementation of ultrasound in this remote Scottish region was that the features of greatest importance in terms of the design of the equipment emerged from actual practice - from the way in which Crichton used the machine.

[104] Correspondence, 5 Feb 1986, between Dr Jack Crichton and Dr Louise Hodgson, (JC correspondence, Western Isles Box, BMUS Historical Collection). Between the time of the machine's purchase and its use in the peripheral clinic, the equipment was used at the Lewis Hospital.

The very nature of what was valued - what was sought in machine design - was the outcome of previous experiences of ultrasound in the context of this particular location. Thus the way in which the technology was used in the Western Isles altered the nature of later practice and helped to shape the qualities valued in later purchases. In this way, the nature of 'choice' was neither fixed nor predictable - it was formed and altered through practice. Furthermore, the technical deficiencies (or negative qualities) perceived in the equipment shaped the timing of the services provided by the local consultant, which amounted to the moulding of practice to suit the machine. In this example, therefore, both the technical and organisational dimensions of obstetric ultrasound were mutually shaped through practice.

The problem of delegation: techno-social relations in the context of medical hierarchy

In Kirkcaldy a different quality again emerged as important when choices of equipment were made. The town's general hospital (the Victoria) had operated an ultrasound scanning service for both obstetrics and gynaecology since the early 1970s using an adapted Kretz A-scan machine.[105] However, the first foray into RT scanning coincided with the transfer of obstetric ultrasound services from the Victoria to the maternity hospital at Forth Park. This hospital purchased a Nuclear Enterprises static scanner in 1975 which was updated by the addition of a 'spinner' RT probe in 1977. Only two years later, however, a Diagnostic Sonar linear array scanner replaced this machine. In order to understand why particular models were chosen at particular times, it is again necessary to consider how site-specific arrangements and circumstances shaped consumer decisions and choices.

Opened in 1935, Forth Park Maternity Hospital was established by Kirkcaldy Town Council and replaced the existing maternity home in Stanley Park. A large granite building set inside its own grounds, Forth Park was gradually extended in order to facilitate the increasing scope of maternity services and the rising number of patients. It was one of these extensions (the

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[105] See Chapter 2 for a discussion of the development of ultrasound at Kirkcaldy's Victoria Hospital.

building of a new hospital wing, opened in 1977) which enabled the ultrasound scanning service to be relocated to the maternity hospital, where, initially, it became part of a newly established radiology department within the hospital. Thus, despite the fact that the transferral of the service placed it for the first time within the geographical realm of obstetric medicine, the service remained under the control of the department of radiology.[106]

It is evident that the very timing of this major investment had a direct affect on the choice of ultrasound equipment. The decision to add a new wing to the hospital was taken in 1975 and, given the nature of such capital expenditures, the cost of any new equipment to be introduced was budgeted for and included as part of the overall expansion costs. More than this, however, the new ultrasound machine was actually bought at that time - almost two years before the opening of the new wing in which it was to be housed.[107] The chosen machine was a Nuclear Enterprises compound scanner - an NE 4200 - which is unsurprising given that in 1975 that company still had the largest share of the Scottish market and the new, smaller RT machines had not yet begun to appear. As with the opening of the Queen Mother's Hospital in 1964, the perceived sociotechnical requirements of obstetric ultrasound as it was practised at that time (in terms of space and facilities) were built into the very fabric of the new wing. For example, a dedicated scan room was designed which was large enough to house the machine's large scanning frame and which had strong enough foundations to bear its weight. Furthermore, prior experience with obstetric scanning at the Victoria hospital - particularly with regard to both the full bladder technique and the messiness of the contact gels in use - led to the inclusion of patient toilet and shower facilities close to the scan room itself.

Nevertheless, almost two years separated the formulation of these plans, along with the purchase of the equipment, and the actual opening of the new wing. Given the shortage of space

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[106] Indeed, it is perhaps indicative of the widening scope of obstetric ultrasound in the 1970s that, according to Dr Aitken, 'the x-ray department ceased to be of any great use, as it turned out' (Interview with Dr Peter Aitken, 22/02/99)

[107] Interview with Dr Michael Hill (current Senior Obstetric Consultant at Forth Park), 15/7/96.

which the new wing was intended to remedy, there was no room large enough to accommodate the equipment until the new extension was opened. Thus, the scanner was left, unused, in the hospital's basement until the extension was completed, and women referred for scans continued to be sent to the town's general hospital, where they would be scanned by radiological staff using the Kretz-hybrid machine.[108]

Thus the gap between the purchase of the NE4200 in 1975 and its introduction into practice in 1977 straddled the appearance of the new linear array RT machines and the concurrent blossoming of the ultrasound equipment market. Furthermore, EMI (who had taken over Nuclear Enterprises in October of the previous year) had launched their own RT probe - the 'spinner'. What was significant about this probe for the Kirkcaldy hospital was that this transducer could be added to Nuclear Enterprises' (now EMI's) existing static compound scanners. In other words, it was not necessary to buy a whole new machine in order to gain the capacity to scan in real-time and display movement. Thus, although Forth Park planned for and purchased a static scanner for their new department, by the time it was installed it was a machine with RT capabilities. Therefore both the timing and nature of the building of a new hospital wing and the creation of a new ultrasound service in Kirkcaldy, effectively shaped the choice of RT ultrasound. Having purchased an, as yet unused, new piece of equipment - it was more sensible and cost effective to update this machine than to replace it with a new one.

In the 'spinner' therefore, EMI were not only able to sell complete units with RT probes already attached - they could also tap into a distinct market of their own by retrofitting machines which were already in use. Furthermore, unlike the producers of linear array equipment, EMI were able to offer their customers *both* the superior imaging capabilities of compound static scanning (with the wider image view and better detail) as well as real-time imaging. For hospitals such as Forth Park Maternity, the attraction of this lay in the desire to have the latest, most up-to-date equipment in their newly opened accommodation. The most recent innovation in ultrasound

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[108] See Chapter 2 for a more detailed account of this machine.

technology could be gained at a substantially smaller cost than would be required for the purchase of a complete new unit, whilst they could also claim to possess what was regarded as the most superior form of ultrasound in the field.

Nevertheless, while the purchase of a real-time probe may have been motivated by the desire to keep abreast of developments in the field, a completely different 'social interest' underpinned the choice of the next machine to be purchased. After only two years of use, a Diagnostic Sonar linear array machine effectively replaced the EMI one. In order to understand the reasons for this, it is necessary to consider how obstetric ultrasound was organised and operated in the Fife hospital.

The transferral of obstetric ultrasound from The Victoria Hospital to Forth Park Maternity also involved a reorganisation of operating personnel. The Chief Radiologist (Dr Peter Aitken) in association with Forth Park's Senior Obstetric Consultant (Dr Ian Duthie) made the decision to engage a radiographer to operate the new service. The person eventually chosen was Mrs Eleanor Young, who had previously been engaged as a radiographer in the Victoria Hospital's X-ray department. Mrs Young was trained to operate the technology by Dr Aitken, using the Kretz machine at the Victoria and was also sent to the Queen Mother's to undertake the 'ultrasound in obstetrics' course. Once in-post, the radiographer was solely responsible for scanning, calling for clinical assistance from Dr Duthie when required. In effect, therefore, despite the fact that the only full-time operator was employed by Radiology, that the service was under that department's jurisdiction, and that it was positioned within the maternity hospital's new x-ray department, clinical supervision of the scanning service, nevertheless, rested entirely with the specialty of obstetrics.

Thus the introduction of RT scanning to Kirkcaldy coincided with an important change in personnel - it was no longer medically trained specialists in obstetrics (Dr Duthie) and radiology (Dr Aitken) who performed ultrasound examinations, but a radiographer.[109] Indeed, this was the way in which the organisation of scanning continued in Forth Park, with yet more radiographers being drafted in during the 1980s to deal with the increasing workload.

It is important however to avoid concluding that the downgrading of operating personnel was a direct consequence of the introduction of the new form of imaging.[110] Indeed, when the plans for the new obstetric service were formulated, and Mrs Young appointed, real-time machines and probes had not yet appeared. Instead, the change in personnel would appear to have been the result of the accommodation of a number of factors. The geographical distance between the two hospitals (and thus between the main Radiology department and its new off-shoot obstetric service) coupled with the declining use of x-rays in obstetric cases, entailed that there were no radiologists permanently on-site. On the other hand, while some of the hospital's obstetricians (such as Dr Duthie) were keen to scan their own patients, the service needed a more permanent operator to handle the number of cases in which a scan was felt to be useful. Thus it made more sense to use the services of a technician, with clinical support provided by an obstetrician with some experience of the technology, and who was already based in the hospital. However, in coming to this decision it is clear that Dr Aitken felt there was a qualitative difference between obstetric scanning and other forms of ultrasound:

> I felt it was a sonographer that was all that was required because they were getting most of the things they wanted. It was a different story when you were dealing with gynaecology and abdominal scanning for

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[109] The wider implications of the increasing use of lower-grade staff to operate routine ultrasound examinations are discussed in Chapter 4.

[110] Real-time ultrasound has often been attributed by actors in the field with causing a general shift in the division of labour around ultrasound because the equipment was much easier to use than static B-scanners. This claim is made, for example, in a 1984 Royal College of Obstetricians and Gynaecologists report on routine ultrasound scanning, chaired by Professor Stuart Campbell, and in an outline of future training requirements for ultrasound personnel, written by Professor Charles Whitfield (RCOG, (1984), 'Report of the RCOG working party on routine ultrasound examination in pregnancy' The Chameleon Press Ltd., London, pp. 2-3; Whitfield, C.R., (1992), 'Training in ultrasound in obstetrics and gynaecology' in Chervanek, F., Isaacson, G. & Campbell, S., (eds.), *Ultrasound in obstetrics and gynaecology,* Little, Brown and Co., Boston, Mass.). While the design of the technology did undoubtedly contribute to this a number of other factors, such as the introduction of ultrasound screening, also played a role. This is discussed in Chapter 4.

> surgery and medicine and things like that. As far as the obstetrics were concerned I felt that the obstetrician and a sonographer were capable of doing all the scanning and it was a big part of the workload.[111]

Therefore, at least in part, the staffing decisions which were made for the new scanning service were the outcome of the actual practice of ultrasound in this particular area of medicine. The Consultant Radiologist's perception of the relative ease of acquiring such things as fetal measurements and assessments of the pregnancy's on-going status (gained through his own experience with the technology), informed his plans regarding the organisation of the service. Furthermore, this view or perception of obstetric scanning was itself the outcome of local circumstances and arrangements. The fact that the Radiology Department operated all forms of ultrasound imaging; that obstetric scanning was located on a separate site from the main department; that of the high number of scans performed in obstetrics, the majority would be 'normal'; that resources were finite; and that obstetric scanning was 'a big part of the workload' all informed the Consultant Radiologist's view that this form of imaging could be delegated to other staff. In other words, while there is nothing *essentially* easier or more straightforward about the technology's use in obstetrics in comparison to other medical fields, in this particular context it was more straightforward in practice.

Nevertheless, while the appointment of lower-grade staff was the result of a variety of site-specific circumstances, it had a significant effect on the way ultrasound was perceived, and on the qualities valued in machine design. The division of labour implemented in Kirkcaldy was similar to that employed with x-ray technology where radiographers performed the role of image constructers whilst clinically trained radiologists are responsible for interpreting the images to form diagnostic opinions.[112] Thus, effectively, Aitken was transferring the organisation of one technology to another. There were, however, key differences between the

[111] Interview with Dr Peter Aitken, 22/02/99.

[112] This hierarchy was, of course, itself the outcome of the development of x-ray technology over time. See Pasveer, B., (1992), *Shadows of knowledge, making a representing practice in medicine: x-ray pictures and pulmonary tuberculosis, 1895-1930*, CIP-Gegevens Koninklijke Bibliotheek, Den Haag.

two forms of imaging. In particular, the standard views created during x-ray imaging were very different from the multiple sections that could be imaged using ultrasound.[113] When viewing a still ultrasound image created by another actor, a clinician would need to know where exactly the probe had been placed to produce the picture, entailing that, without actually watching the scan being performed, it was more difficult to translate and make sense of the resultant image.

Moreover, the introduction of RT imaging compounded this mismatch between the technology and such a division of labour as diagnoses would not always be necessarily apparent from a still snapshot picture. The beating of the fetal heart, for example, could not be observed on a frozen image from an RT scan. Thus with RT the locus of diagnosis had become even more intimately centred on the interactive scanning process itself at the time in which it was performed. That is to say, unlike in radiology, the creation and interpretation of images with RT were becoming increasingly interrelated in space and time in that the person who was performing the scan was simultaneously interpreting the images and drawing diagnostic conclusions. Thus, the technique of real-time imaging created a much more interactive relationship between the skills of image construction and interpretation - locating the latter more directly at the point of practice. This was problematic for the traditional social organisation of radiology - where practice had been moulded by the very different technology of x-rays, and had been divided in a hierarchical manner between radiographers (image creators) and radiologist (image interpreters). In Kirkcaldy, Aitken's accommodation of this problem was to cede some degree of authority in image interpretation to the radiographer. In essence, Mrs Young was authorised to diagnose 'normality', and to carry out basic measurements and assessments, but any suspected anomaly displayed in the image had to be verified in a scan performed by one of the hospital's ultrasound-experienced obstetricians.

This division of labour had a direct impact on the way in which ultrasound equipment was assessed and the design attributes that appealed to those responsible for the choice of new

[113] See Chapter 2, where the differences between ultrasound and x-rays in terms of the way images are presented is explored in relation to the involvement of radiological staff with ultrasound at Aberdeen Maternity Hospital.

machines. As Chief Radiologist for all of Fife's hospital services, Dr Aitken occupied a powerful position within Fife Regional Hospital Board. Not only was he in a favourable position to lobby the Board for finance, he was also largely responsible for the choice of new equipment. In 1979, he persuaded the Board to buy a Diagnostic Sonar 'System 185' for Forth Park's obstetric ultrasound service. This machine was the second model produced by Diagnostic Sonar - which went onto the market in around 1979 - and was essentially a redesigned version of the 'System 85' with a few added features.[114] Aitken first noticed this machine during a demonstration at Perth Royal Infirmary. Sandy Christie, who provided this demonstration, had developed a good working relationship with the two directors of Diagnostic Sonar when they worked for Nuclear Enterprises. Demonstrations such as this were beneficial for both parties - providing a direct marketing opportunity for the manufacturers and enabling Christie to extend his growing reputation in the field as a significant actor at the 'cutting edge' of developments in the technology.

The Kirkcaldy Radiologist recalls this particular Diagnostic Sonar machine as the 'nicest linear array' which had 'the nicest picture and most easy to use unit'.[115] Given the division of labour at Forth Park, ease of use had become an important consideration and of the linear arrays he had seen, this particular model was viewed as the best for facilitating this without sacrificing the clarity of the image. There were, however, other aspects to this machine which were also considered to be valuable:

> I had also been interested in the recording side of this - writing up the records and so on - for the obstetric cases in particular. [Diagnostic Sonar] developed this little device that had, instead of looking up the tables and deciding what it was, it did it quickly - just like that. You put

[114] Details of the extra features added to the 'System 185' can be found in Diagnostic Sonar's advertising literature and Health Equipment Information, (1979), 'Evaluation of real-time ultrasonic scanners - first report', August issue, No. 81, p32. (BMUS Historical Collection, Ultrasonic Equipment Index, Folder AAAAA).
[115] Interview with Dr Peter Aitken, 22/02/99.

> your probes on, it read out the BPD and it gave the other things right away.[116]

What Aitken is referring to here is the electronic box designed by Diagnostic Sonar and added to the 'System 185'. Using the equipment's on-screen callipers (what Aitken refers to above as the 'probes') the operator could indicate the points at which she wanted to take measurements of, for example, bi-parietal diameter or crown-rump length. The electronic unit would then not only calculate and display those measurements, but would also use them to work out the gestational age of the fetus and its expected delivery date (using the date of the scan). All of this information was then displayed on-screen - along with the image itself. Furthermore, the 'System 185' could also be purchased with a photographic unit which could print out the display - creating a hard copy of both scan image and measurements, etc. which could be placed in the patient's record.

Once again, Aitken's perceptions of the greatest benefit (or value) of this system related directly to the way in which scanning was organised in the Fife maternity hospital. Before this machine was put into practice, Mrs Young, working largely independently, had to relate the measurements she took from the scan images to the charts produced by Stuart Campbell and his colleagues.[117] She then had to write the estimated dates and gestational age into the patient's record by hand. This new machine, however, would do most of this work for her - lessening the time taken up on such tasks. In addition, it could be argued that the machine's ability to print out both the image and the data which could then be kept as a record, could be used as a technical accommodation of Forth Park's medical supervision 'problem'. The clinicians (radiologist or obstetrician) could oversee her scanning to some degree by examining the printout showing where the callipers had been placed and what measurements had been taken.

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[116] *ibid.*

[117] Charts (or 'normograms') of normal fetal growth expressed as biparietal diamter were produced by Campbell and Newman in 1971. See Campbell, S. & Newman, G.B., (1971), 'Growth of fetal biparietal diameter during normal pregnancy' *Journal of obstetrics and gynaecology of the British Commonwealth,* Vol. 78, No. 6, pp. 513-9.

While the problems associated with not actually observing the scan being performed remained, these features of the Diagnostic Sonar machine nevertheless provided additional ways to communicate information about each scan within the hierarchical division of labour that had been established. In other words, the technical features of this equipment were perceived as one means whereby the organisation of obstetric scanning at Forth Park could be made to resemble x-radiography more closely.

Here again, therefore, two important points can be made. Firstly, from a practical, clinical perspective it can be seen that it was not necessarily the revolutionary moving images which attracted potential buyers of real-time equipment – but various other features, which were important to different degrees in different locations. Furthermore, it can be clearly seen that both Aitken's choice of machine and his assessment of its 'qualities' were the outcome or result of the actual practice of scanning in Forth Park. That is to say, his decisions were shaped by the way in which scanning was organised and operated in the maternity hospital: his decisions were the emergent outcome of his interactions with the technology.

To conclude this section, it can be seen that the choice and use of real-time scanning in Kirkcaldy was determined by both social and technical factors. The NE4200, which had cost around £20 000 to buy in 1975 shaped the choice of their first RT imaging modality - being updated in 1977 with a real-time 'spinner' device. The reason for this lay with the fact that the purchase of the Nuclear Enterprises machine was integrally tied to the development of the new hospital wing, and the way in which such purchases were organised meant that the machine was acquired before it was able to be used. However, between the time of its purchase and installation, the nature of ultrasound had began to change and real-time scanners were beginning to appear and so, the easiest and cheapest way for Kirkcaldy to make use of the new form of scanning was by updating their existing machine with an RT probe. Nevertheless, it was put into use for only a couple of years before being replaced by a much less costly machine.

Furthermore, an examination of the way in which RT was used in Kirkcaldy highlights two important points. Firstly, a number of contingent factors which were grounded both historically and locationally (such as the geographical separation of the two hospitals, the division between gynaecology and obstetrics, and the timing of the building programme at the maternity hospital) were tied to, and helped to shape, both the choice of equipment and its practical use. For example, the choice between the 'spinner' and the linear array did not centre completely on the 'quality' of the resultant images. Instead other technical features (such as the 'spinner's ability to be fitted to the compound scanner or the linear array's electronic measurement system) emerged as important points of difference, and these decisions were, in turn, informed by a number of site-specific factors.

There are clear similarities between the introduction of RT in Kirkcaldy and in the Western Isles. Both Aitken at Forth Park Maternity and Crichton at the Lewis Hospital chose their machines for pragmatic and practical reasons. At the Lewis, a linear array unit was picked because of its cost effectiveness, while at Forth Park, the ability of the 'spinner' to be installed on an already purchased machine motivated consumer choice. In both centres, however, other attributes and qualities emerged as a consequence of the technology's use in each location, which then influenced later interpretations of design. Furthermore, although both forms of RT may well have produced inferior images compared to static B-scan machines, they were nevertheless regarded as adequate. These hospitals were not specialist tertiary centres conducting intricate and detailed diagnoses and thus the role which ultrasound was asked to perform centred on basic measurements and checks into the on-going status of pregnancies scanned. Thus, in light of the technological options on offer at this time, choices were made on the basis of practical, routine expectations and requirements. Nevertheless, as both examples highlight, once specific machines had been chosen and introduced into practice, they themselves helped to mould and shape the contours of the technology's development in each location.

Conclusions

The arrival of real-time ultrasound in the late 1970s heralded a new era in both the market for, and practice of, obstetric ultrasound. Nuclear Enterprises, whose static B-scan machines had dominated as the principal form of the technology adopted in Scottish hospitals from the mid 1960s, came under threat from a whole host of companies entering the market. Whilst some of these were large enterprises which had found success in other countries or sectors of the medical imaging market, others were smaller enterprises such as Diagnostic Sonar who emerged specifically from within the context of this flourishing new market. What made the diagnostic ultrasound market attractive at this time was the advent of new modalities of imaging. Linear-array real-time machines were cheaper to produce - they required neither the large gantry nor the complicated electronic systems demanded by the static B-scan design. This, in conjunction with their smaller size entailed that, potentially, they could be sold in greater numbers - both to hospitals and clinics that had not previously been able to secure the funds for the more costly B-scanners, and as additional machines to those who already used the technology. For example, some hospitals located RT machines in labour wards, where fetal presentation could be checked when pregnant women were admitted. Thus, the commercial success of the new designs (and the companies which produced them) was founded on both the displacement of static scanning in hospitals which already had ultrasound and on the expansion of sales in the 'virgin territory' of those hospitals who were not already ultrasound-equipped.

The new RT manufacturers employed a variety of marketing strategies in their attempts to achieve these objectives, from mail drops of advertising literature and demonstrations of equipment, to forming close working relationships with their potential customers through sales teams, loans of equipment on 'trial basis' and technical support. The British Medical Ultrasound Group (BMUG) in particular emerged as an important conduit for such marketing. The Group's annual conference presented opportunities to sponsor wine receptions, but also (and more importantly) to demonstrate equipment. The first such manufacturers' exhibition occurred when the conference was held in Leeds in 1974,[118] but the scale of this exhibition increased in the late 1970s and, from then, became a regular feature of the re-named British Medical Ultrasound Society's annual conferences. One particularly popular strategy employed on these occasions was the 'live' demonstration during which young, mainly female, models were scanned, either by sales representatives themselves or by medical personnel with whom they were associated, using the latest equipment on offer by the company. This practice (particularly when pregnant women were involved) came under heavy criticism in the early 1980s when concern over safety became a significant issue, although it has since re-appeared.[119] Not only did such demonstrations provide direct marketing opportunities, but they also enabled sales representatives to meet potential new clients, form new contacts and discuss new developments.[120] Furthermore, the society's journal (*Bulletin of the BMUS*), published three times per year, also provided advertising opportunities. From 1983 onwards, the *Bulletin* was redesigned into a glossy and more lengthy publication and for the first time manufacturers could buy advertising space. A new era of mass marketing and commercialism had thus arrived.

This heightened commercialism gave those seeking to purchase ultrasound machines their first taste of 'consumer choice' from the various imaging modalities and machine designs on offer. However, it is apparent from the above discussion of the introduction and use of RT ultrasound equipment that a wide variety of factors influenced the choices made between different models and designs. At the Queen Mother's, for example, RT was initially adopted in the context of research - with machines being assessed for their efficacy and utility in obstetric practice. In the smaller institutions in Kirkcaldy and Stornoway, on the other hand, the relative financial costs associated with different models played a significant role in influencing choice: a mechanical

[118] BMUG, (1974), *Bulletin of the BMUG,* No. 12, November.
[119] The 1980s safety debate is examined in Chapter 4.
[120] Walking around one such exhibition with John Fleming in Glasgow, it was apparent how fruitful such manufacturers' displays were for the companies involved. On the one hand, it was evident that close inter-personal relationships had been built up between sales staff and ultrasound workers. Furthermore, in addition to the ubiquitous conference packs, advertising literature was also distributed in the form of posters, mugs, pens, and even umbrellas with company logos. The costs associated with such forms of marketing were clearly considered justifiable by the manufacturers.

spinning probe was chosen in Kirkcaldy because it could be fitted to existing equipment, while the Western Isles Health Board chose the cheapest model they could obtain – a linear array from Diagnostic Sonar.

Nevertheless, the most profound technical difference between real-time machines and static B-mode scanners was the ability of the former to display motion in an instantaneous rapidly renewing image. It would thus be tempting to suggest that this more than any other aspect of the new forms of the technology secured its adoption. However, the above discussion highlights that while this was undoubtedly regarded as an advantageous feature, it was by no means the most significant factor in accounting for the successful diffusion of these machines. Indeed, actors from all hospitals in this study recall the deficiencies perceived in the new imaging modalities in comparison to static B-scan equipment – particularly the poorer image quality and smaller scan view. Thus in order to explain why particular actors chose particular models, a number of features including portability, ease-of-use and probe design must be examined in terms of how they were valued in different locations.

Furthermore, the features most valued in each centre were not necessarily anticipated at the outset. In the Western Isles, for example, the portability of the smaller linear array machines emerged as a highly important aspect of this technology and one which helped to shape future ultrasound provision in the area. The initial Diagnostic Sonar machine was not, however, chosen because of its portability. In the Queen Mother's, any questions regarding the role of RT in a large specialist centre were answered through its use to visualise invasive procedures such as amniocenteses. Thus, the qualities valued in each technological design when it was first purchased, were not necessarily those which emerged as most significant when it was placed into practice. That is to say, the reasons underlying why a particular machine is introduced do not always correlate with why it is valued in practice.

This observation has two important consequences for the manner in which technological development is theorised. Firstly, consumers of technology need to be viewed as interested actors whose activities in practice shape their perceptions of artifact design. What they *do* with the technologies they use is as significant as *why* they purchase them. In other words, in terms of the SCOT approach, actors' interpretations of artifacts are formed through practice - how a technology is perceived can change as it is put into use.[121] Secondly, while the concept of 'relevant social groups'[122] influencing technological change through their shared interpretations of artifacts is attractive, it perhaps conceals more than it enlightens. If experience is accepted as a factor which influences machine choice and interpretation, then the very heterogeneity of that experience will lead to differences in actors' perceptions. In the Western Isles, Jack Crichton valued the portability of the linear array design; in the Queen Mother's its ease of handling during invasive tests became its most significant attribute; while in Kirkcaldy its ease of use and on screen measurements were important. Thus while actors in these locations shared a similar preference for a particular design it was for very different reasons, and these reasons themselves emerged from practice. Thus the idea of 'relevant social groups' with a shared, homogenous view of technology is not applicable in this case.

Furthermore, the development of RT scanning in each location was shaped by the interplay of an array of particular and site-specific factors. What was valued in the Western Isles, characterised by its distinctive social geography and local arrangements, was not necessarily important in a large, urban, specialist centre like the Queen Mother's or Aberdeen Maternity Hospital. It is thus clear that to understand the process of diffusion of technologies such as RT ultrasound, the actions performed by consumers and users – be they institutions or individuals – need to be analysed within their specific historical and spatial contexts. In a manner similar to the development of the mountain bike as highlighted by Paul Rosen,[123] a variety of site-specific events, circumstances and developments influenced the way in which ultrasound machines were used.

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[121] Pinch, T.J. & Bijker, W.E., (1987), 'The social construction of facts and artifacts'.
[122] *ibid.*
[123] Rosen, P., (1993), 'The social construction of mountain bikes'.

In summary, therefore, the process of technological change in obstetric ultrasound was complex, messy and multi-causal. What motivated actors to choose specific designs cannot be explained exclusively by either general, shared social intentions, nor by common interpretations of technical superiority. Furthermore, the actors who purchased and used ultrasound machines were neither 'consumer dopes' nor 'cultural heroes'. In their choice of equipment they made rational decisions which were not simply based on an abstract assessment of the choices available, but which were instead formed through their knowledge of local site-specific circumstances and arrangements. In this way a variety of economic, organisational and material factors peculiar to each location influenced the decision-making process. Moreover, once placed into practice, these same local conditions shaped the way in which the machines were used. Artifacts could be directly manipulated in order to perform in hitherto unpredicted ways, while the technical qualities and capabilities of a machines could be accommodated by manipulating its social organisation. For this reason, the diversity that is apparent in the way identical artifacts were employed and used by actors in different Scottish hospitals provides further evidence to show that 'diffusion' and 'innovation' are not mutually exclusive terms. The practices associated with such equipment emerged in very distinctive and innovative ways in each centre. Thus the spread of this technology to new centres interacted with a variety of other forms of organisation and practice specific to each location. These interactions, in turn, produced new practical, cognitive and organisational developments, as an emergent outcome of the way in which RT ultrasound was accommodated and used in each centre. A whole host of unanticipated features interacted with one another and gave the technology its distinctive form in each location. Thus, the spread of RT machines themselves did not represent the diffusion of the technology - rather the spread of such equipment, when added to a multitude of other factors specific to each site, took part in the creation of novel forms of activity and practice. Thus innovation and diffusion need to be viewed as integrally related processes - rather than the beginning and end of a single historical development.

Chapter 4

Regulating the routine? Stabilisation, standardisation and heterogeneity in the routine use of ultrasound.

Introduction

By the start of the 1980s, the technical wars between different types of ultrasound scanner had been effectively won by the linear array real-time (RT) machines. While mechanical sector scanners (such as the 'spinner') continued to be used in some institutions, and while others still made use of previously purchased static B-scan equipment, new machines were universally chosen from amongst the various models of linear array equipment. The success of the linear array design did not, however, indicate the end of the technical development of ultrasound equipment. A number of changes in transducer design emerged including curvilinear arrays (smaller probes which produced wider views into the body than the original linear arrays using slightly different 'firing' mechanisms) and trans-vaginal probes (transducers inserted into the vagina which used higher power output and a design akin to a hybrid between the 'spinner' design and the curvilinear array). Colour Doppler (which could visualise the direction of fluid motion and thus be used to assess blood flow between fetus, placenta, and mother) was also introduced into obstetric equipment. Furthermore, developments in information technology, keyboard design and microchips also all had a significant effect on technical design. Thus subtle differences in design between the various models persisted. These however amounted to design preferences and added features which did not 'compete' with the basic imaging modality of RT - the real-time ultrasound scanner had become the definitive form of the technology - although the particular model chosen was a matter of taste, preference and requirement. This is neatly illustrated by one prominent actor's comments on the difference between models from the early 1980s:

> if somebody was to give you a machine for Christmas, in your stocking, if it was free it wouldn't matter what it was. If you had a choice, you would still make your own personal choice, but that's a subjective thing - maybe you like the colour, maybe the buttons are in a better place, the arrangement on the keyboard is better, the screen is bigger, whatever. You know, if it was up to you, you'd always choose one over the other, but if

somebody gave you one for nothing you wouldn't care - you really wouldn't mind.[1]

Thus obstetric ultrasound equipment in the 1980s could be described as a relatively stable artifact, in terms of the basic form of imaging modality employed. The increased competitiveness of the ultrasound market which emerged in the 1970s continued to ensure that differences in design and consumer choice were endemic features of the supply of equipment, but this did not imply the kind of competing technological forms associated with the introduction of RT.

Furthermore, the actual practice of obstetric scanning also reached something akin to a 'standard procedure' - a routine feature of antenatal provision. Firstly, it achieved stability in terms of its ubiquity. A survey carried out in 1977 (and reported in 1979) indicated the use of diagnostic ultrasound (although not confined to obstetric ultrasound) in 26 Scottish hospitals, and a total of 34 machines in regular clinical use.[2] No estimates, however, were made of the number of scans performed. By 1983, however, all 27 of Scotland's Consultant obstetric units operated an ultrasound service, while a significant number of smaller satellite clinics and general practitioner obstetric units also operated the technology.[3] This amounted to 96 ultrasound scanners used for obstetric diagnoses, only 19 of which were static B-scan machines still in use, with a further seven B-scan machines with the 'spinner' RT probe.[4] The 27 Consultant obstetric units administered obstetric care to around 94% of the pregnant women in Scotland (the vast majority of the remaining six percent being managed by Scotland's 48 General Practitioner (GP) obstetric units. With a total of 124, 604 scans being performed in 1983, the National Medical Consultative Committee (NMCC) report of 1986 estimated that 87% of all pregnancies in Scotland were examined ultrasonically.

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[1] Interview with Dr Sandy Christie, 10/12/97

[2] Scottish Home and Health Department, (1979), 'Report on the future development of ultrasound in Scotland' (unpublished paper), p.1 & Tables 1&2.

[3] Scottish Home and Health Department/Scottish Health Service Planning Council, (1986), 'Obstetric ultrasound in Scotland: report of the ad hoc group appointed by the specialty sub-committee for obstetrics and gynaecology of the National Medical Consultative Committee' Her Majesty's Stationary Office, Edinburgh, p16.

[4] *ibid.*, p. 25, table 4.

Furthermore, a certain degree of 'stabilisation' can also be detected in the actual practice of obstetric scanning. That is to say, the way in which images were created - the activities required to produce images - and the kinds of information sought, had begun to coalesce around a number of standard practices such as measurements of bi-parietal diameter (BPD) and crown-rump length (CRL), placental localisation and examination of the fetal spinal structure. That is not, of course, to argue that heterogeneity disappeared - key differences in the way scans were conducted by actors working in different centres remained. At the local level, however, the subtle design differences between the various models were not associated with any major reorientation in the skilled practice of ultrasound scanning.

Obstetric ultrasound had thus, by the beginnings of the 1980s, become an established part of the routine of antenatal care used on a regular basis for the diagnosis of a variety of conditions and pathologies in pregnancy. At this point therefore, the career of obstetric ultrasound appears to bear all the hallmarks of the 'standard procedure' described in John B McKinlay's 'Seven stages in the career of a medical innovation':

> There follows a period during which the innovation [...] achieves the privileged status of a 'standard procedure'. For a period of time it becomes generally accepted by interested parties as the most appropriate way of proceeding with a particular problem or situation.[5]

The increased number of patients being offered ultrasound examinations; of obstetricians who supported and advocated the use of the technology; of locations providing the service; of personnel employed; and of clinical conditions which could be detected, all testify to ultrasound's position as a standard practice within obstetrics.

There are, however, problems in using the term 'standard procedure' to describe ultrasound practices in Scotland. The term can be used to imply uniformity of practice, conformity to a

[5] McKinlay, J.B., (1981), 'From "promising report" to "standard procedure": seven stages in the career of a medical innovation' *Milbank Memorial Fund Quarterly/Health and Society,* Vol. 59, No. 3, p. 387.

particular universal standard. This chapter will argue that such uniformity did not exist, despite a series of attempts throughout the 1980s to impose this. Although obstetric ultrasound became a regular feature of the antenatal care of pregnant women across Scotland the way in which it was used, and by whom, was never truly 'standard'. Key differences can be observed in the technology's 'career' from location to location and thus heterogeneity of practice persisted throughout the 1980s. Thus ultrasound may well have become 'generally accepted by interested parties as the most appropriate way of proceeding' but the manner in which it was employed in the various locations differed substantially. The ubiquity and regular use of obstetric ultrasound did not, therefore, equate to a standardised form of practice. Thus the term 'standard practice' in this context can only be applied on a site specific basis - a standard routine was established in each centre to fit local circumstances, but this was not translated into a universal form of practice shared by all. In the end, therefore, the appropriateness of the very term is questionable as it may give the impression of a uniformity that is non-existent.

It is also tempting to interpret both the ubiquity of the linear array design and its relatively widespread, routine and standard usage within obstetric practice as the 'stabilisation' of obstetric ultrasound in the social construction of technology (SCOT) sense of the term.[6] It could be suggested, for example, that controversy over machine design had become 'closed' through demonstration of its utility in practice or that opponents of the use of ultrasound in obstetrics had been silenced through social persuasion of the technology's efficacy and that all interested parties (relevant social groups) had come to share the same interpretation of the technology. This type of 'stabilisation' would, from a SCOT perspective, indicate the final stage of development.

This, however, presents certain problems in analysing the further developments that occurred in obstetric ultrasound during the 1980s. Firstly, while the technology persisted as a regular feature of obstetric medicine, it was (as noted above) never completely stabilised in terms of design. Thus the concept of an artifact's 'stabilisation' can only be accepted if it is considered

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[6] Pinch, T. & Bijker, W., (1984), 'The social construction of facts and artifacts; or how the sociology of science and the sociology of technology might benefit each other,' *Social studies of science,* Vol. 14, pp. 399-441.

in relative terms. Although the technical developments that occurred at this time did not represent a challenge to the underlying design principles of RT, they do nevertheless demonstrate that technical innovation is an on-going process. Indeed, the present debate over the potential uses of three-dimensional ultrasound provides further evidence that this technology is far from being technically 'stable'. However, the 1980s did mark a period of 'relative' stability in comparison with the development of RT ultrasound in the 1970s in that the changes in technical design which occurred were more subtle in nature.

Moreover, this chapter will problematise another aspect of the SCOT perspective. Obstetric ultrasound underwent a period of major transformation during the 1980s, during the time in which this relative stability occurred. In essence, this period saw ultrasound reconceptualised as a screening technology - i.e. one which was used on a universal basis to scan women whose pregnancies were otherwise considered 'normal' (i.e. non-pathological). This translation of ultrasound from a selective diagnostic tool to a universal screening device represented a significant reconceptualisation of the technology in terms of its purpose, role and social organisation. Importantly, however, this was neither caused by, nor resulted in, any significant reconfiguration of ultrasound as an 'artifact'. Instead, it was the social organisation of the technology that was reconfigured. That is not to say that the social relations of ultrasound technology did not interact with technical changes in the equipment, but they were neither a direct product of, nor did they directly shape, the latter. Instead, as will be argued in this chapter, the transformation of obstetric ultrasound in the 1980s represents an instance of technological change *without* major technical change, and thus even the relative stabilisation of a technological artifact cannot be presumed to represent the stabilisation of a technology. In other words the lid of the 'black box' can never fully be described as closed, even if the artifact itself appears relatively stable.

This chapter will make two inter-related points. Firstly, it will be argued that the concept of a universal, standardised and routinely applied ultrasound screening service was never fully achieved, despite a number of attempts to do so. A number of factors including the technology's site-specific organisation and the nature of the practice itself militated against this.

For this reason, routine ultrasound screening in pregnancy remained a heterogeneous form of practice. Secondly, stabilisation as it is currently applied in sociological theories of technology will be problematised. On the one hand, the relative stability of a technological artifact (in terms of its acceptance and adoption into practice) is insufficient grounds on which to make any claims in relation to the stabilisation of the technology as practised. Major transformations and developments in the way a technology is used and for what purpose can occur without necessarily heralding changes in technical composition. In addition, stabilisation in the practice of obstetric ultrasound can only be observed at the local level. For this reason, the concept is only useful in technology studies when it is used to express stability of local arrangements and practices. Even then, it cannot be assumed to be the end of a technical change, but merely a relative hiatus in an on-going developmental process.

In the following pages, the development and significance of universal screening strategies in each case study centre will be compared. As will be demonstrated below, the nature of 'routine' ultrasound differed from location to location in terms of delivery, staffing, training, as well as the intentions and ideologies that underpinned their development.

Furthermore, the appropriateness of using the technology for screening; as well as the attendant problems associated with the larger volume of work and the increasing use of lower grade staff to undertake this more repetitive form of practice, became issues of concern and debate amongst representatives of the various professional and government bodies. This debate was given added impetus in 1984, when the issue of the safety of diagnostic ultrasound became a matter of considerable public concern. In what follows, these debates will be outlined, and assessed in terms of what impact, if any, they had on the development of routine scanning in Scotland.

It will be argued that the policy recommendations made during this period took the form they did as a direct result of the heterogeneous nature of the diffusion and development of obstetric ultrasound. That is to say, the diverse circumstances which had both shaped, and themselves been moulded by, the diffusion of this technology had to be accommodated in any attempts to standardise the technology's provision. The wider Scottish and UK policies that emerged accommodated this diversity by allowing considerable scope for differences in practice. Thus 'standard practice', 'routine screening' and 'stabilisation' can only be used as terms to describe site-specific occurrences, rather than to signify any generalised, universal form of practice.

Universal screening with ultrasound in Scotland: some key characteristics

Although the number of cases examined using ultrasound gradually expanded throughout its history, as the number of conditions it could be used to help diagnose increased, it was largely perceived as a diagnostic tool for 'selective' cases in most hospitals until the 1980s. It was, in other words, offered only to women who presented with certain clinical indications - either resulting from clinical examination or history. Bleeding in early pregnancy, suspected multiple pregnancy or large- or small-for-dates fetus, history of recurrent miscarriage or fetal malformation, etc. are all examples of the kinds of cases which would be offered ultrasound examination. Many of these clinical indications were relatively common, such as bleeding in early pregnancy, and thus a high proportion of women would be scanned. Ultrasound therefore became a regular feature of obstetric medicine offered to an ever-growing number of women.

However, as confidence in the technology's capabilities grew, a number of centres began to develop policies in which all pregnant women (regardless of 'clinical risk') would be offered an obstetric ultrasound scan as a matter of routine. A number of motivations can be suggested for the expansion of the technology's use in this manner. There can be, for example, powerful economic incentives to increase the capacity utilisation of expensive pieces of medical equipment. While ultrasound machines were costly to purchase, they were relatively inexpensive to run in comparison with other imaging technologies such as x-rays, computed tomography (CT) and magnetic resonance imaging (MRI). Increased use, therefore, represented the medical equivalent of 'economy of scale' - overall costs per examination were lower as the initial capital expenditure was spread over greater numbers of scans. In this way, ultrasound could appear less expensive (on paper, at least). Another way of conceptualising this is the 'if it's there - use it' mentality, neatly noted by Sally Inch.[7] Furthermore, it is possible to suggest that modern medicine draws much of its authority from specialist technology and that the desire to display technological sophistication provides a powerful incentive for increasing the use, and consequently the visibility, of its technologies.[8] A hospital which comfortably and routinely makes use of technologies such as ultrasound clearly displays its familiarity with modern developments in medicine. A final motivation, which was perhaps particularly prevalent from the 1980s onwards, was the danger of litigation. A number of medical malpractice suits made it evident that the non-use of an available technology could present legal dangers almost as much as its misuse.[9] The extent to which any or all of these social and economic factors influenced the development of universal screening policies is impossible to gauge. However, the clinical rationale that underpinned them is more accessible. In particular, the advantages of accurate dating via ultrasonic measurements of the fetus (in terms of the later diagnosis of a number of conditions as well as the management of late pregnancy and the induction of labour) and the identification of multiple gestations (which substantially increased the risk of both maternal and fetal mortality) were considered significant enough to justify such policies.[10] Overall, therefore, and in addition to its function as a diagnostic tool for a number of clinical conditions, obstetric ultrasound was re-conceptualised as a screening technology - to be applied universally to all pregnant women. This was often referred to as 'routine ultrasound'.

The development of ultrasound into a screening technology was not a unique occurrence. Throughout the twentieth century, screening technologies within medicine have become increasingly prevalent and many forms of antenatal monitoring have developed along these

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[7] Inch, S., (1982), *Birthrights: a parent's guide to modern childbirth,* Hutchison & Co., London.
[8] Banta, H.D., (1984), 'Embracing or rejecting innovations: clinical diffusion of health care technology' in Reiser, S.J. & Anbar, M., (eds.), *The machine at the bedside: strategies for using technology in patient care,* Cambridge UP, Cambridge, pp. 65-92; Reiser, S.J., (1978), *Medicine and the reign of technology,* Cambridge UP, Cambridge, chapter 8.
[9] Many of those interviewed who operated obstetric ultrasound in the 1980s mentioned their belief that the fear of possible litigation had increased the routine use of the technology. See also Curran, W.J., (1984), 'The unwanted suitor: law and the use of health care technology' in Reiser, S.J. & Anbar, M., (eds.), *The machine at the bedside,* pp. 119-134; Reiser, S.J., (1978), *Medicine and the reign of technology,* chapter 8
[10] Scottish Home and Health Department/Scottish Health Service Planning Council, (1986), 'Obstetric ultrasound in Scotland'; Royal College of Obstetricians and Gynaecologists (RCOG), (1984), 'Report of the RCOG working party on routine ultrasound examination in pregnancy' The Chameleon Press Ltd, London.

lines. Indeed, the very concept of antenatal 'monitoring' - i.e. the surveillance of an outwardly natural physiological state in the attempt to detect hidden pathology - is by definition a method of screening.[11] However, the increasing centralisation of maternity services in the twentieth century (which was accelerated by - although not directly the product of - the formation of the National Health Service in 1948) helped to enshrine screening practices at the centre of the medical management of pregnancy.[12]

Nevertheless, there is nothing inevitable about the translation of a diagnostic device into a screening technology. For example, the nature of the technology itself is crucial in determining whether it is practical to employ it as a screening device. Obstetric ultrasound was non-invasive, relatively inexpensive to run (although costly to purchase), results could be obtained immediately, routine scans could be delegated to lower grade staff, and examinations performed relatively quickly. Of course, many of these 'advantages' were historically specific and had emerged from the development of the technology over time but, nevertheless, key aspects of obstetric ultrasound made it well suited to performing a screening role.

Furthermore, the translation from diagnostic tool to screening device requires organisation, planning and resources. It is not, therefore, something which simply appears overnight but instead is carefully planned and, once implemented, gradually shaped to accommodate the realities of such a policy in practice. In this manner, ultrasound screening policies in Scottish hospitals can be observed to change over time and, more significantly, to reflect the site-

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[11] There is a vast literature (mainly in the Fouculdian tradition) which examines screening technologies in medicine in terms of control over, and surveillance of, otherwise normal populations. See, for example, Armstrong, D., (1983), *Political anatomy of the body: medical knowledge in Britain in the 20th century,* Cambridge University Press, Cambridge; *idem,* (1993), 'Public health spaces and the fabrication of identity' *Sociology,* Vol. 27, No. 3, pp. 393-410; Inch S (1989) *Birthrights: a parent's guide to modern childbirth(second edition),*The Merlin Press Ltd, London; Nettleton, (1992), *Power, pain and dentistry,* Open University Press, Buckingham, Philidelphia; Nettleton, S. & Bunten, R., (1995), *The sociology of health promotion: critical analyses of consumption, lifestyle and risk,* Routledge, London; Oakley, A., (1984), *The captured womb: a history of the medical care of pregnant women,* Basil Blackwell, Oxford. See also Jewson, N., (1976), 'The disappearance of the sick man from medical cosmology, 1770-1870' *Sociology,* Vol. 10, pp. 225-244. Although obstetric ultrasound has been used to explore these issues, a full engagement with this type of theoretical discourse lies beyond the scope of this chapter.

[12] Oakley, A., (1984), *The captured womb.*

specific characteristics within which they operate.

Although it is a phenomenon most associated with the 1980s, it is significant that a number of centres began to adopt obstetric ultrasound screening policies from the mid 1970s. In 1975, Perth Royal Infirmary (PRI) was the first Scottish centre to introduce a screening policy for all pregnant women, regardless of whether they were categorised as 'high' or 'low' risk by clinical examination or obstetric history. Ninewells Hospital in Dundee, which shared the same obstetric ultrasound team as the smaller Perth hospital, followed suit in 1977. In 1978, the Queen Mother's Hospital also joined in, formally instituting a screening policy. What is significant about these early adoptions of screening policies is that they occurred before the introduction of real-time equipment - these routines were established using static B-scan machines.[13] Thus it is clear that the desire or interest to apply ultrasound universally existed before RT equipment was introduced into clinical use. This highlights therefore that although routinisation was very strongly associated with real-time equipment, it was not dependent upon it.

The strong connection between RT and the routine use of ultrasound is well documented, both by the professions directly involved as well as a number of later commentators. Within the version commonly espoused by the obstetric ultrasound community, (which is recounted in the 'history' sections of government advisory documents and reports from professional bodies, as well as numerous retrospective articles) the smaller, lighter and easier-to-use real-time machines effectively *caused* the development of ultrasound screening. The following, for example, is from a Royal College of Obstetricians and Gynaecologists (RCOG) working party report on routine ultrasound from 1984:

> The introduction of the linear array real-time scanner in the mid 1970s *was the trigger* for an explosion in the amount of ultrasound imaging performed during the antenatal period. ... Obstetricians began to introduce routine scanning of all pregnant women... [emphasis added][14]

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[13] Although RT machines were introduced into the Queen Mother's around this time, it is clear that they were not initially used in regular clinical practice at the hospital (see Chapter 3).

[14] RCOG, (1984), 'Report of the RCOG working party' pp. 2-3.

However, these examples of institutions which began the universal screening of pregnancy with static B-scan equipment suggest that the relationship between RT and screening should be viewed as an inter-related, rather than causal, one. The introduction of RT did have a significant impact on the development of screening policies - adding impetus to those already in place, while undoubtedly facilitating the evolution of screening in smaller, or more remote centres. Nevertheless, screening policies were in place before the arrival of RT, while the particular requirements of universal screening helped to shape further technical changes in the equipment on offer and to consolidate the success of the linear-array RT design.

By 1983, according to the RCOG working party report, 66% of Scottish hospitals offered every pregnant woman at least one routine scan.[15] This included all of the case-study centres examined in this thesis except one - Aberdeen Maternity Hospital did not institute such a service until 1986 and, as such, was one of the last Scottish hospitals to do so. This raises a second significant point in relation to the development pattern of routine obstetric scanning. Writers such as McKinlay and Banta have noted that new innovations in medicine tend to diffuse first amongst the large tertiary establishments - especially teaching hospitals with links to university funding and research - before they are adopted by smaller, district general hospitals.[16] However, it was Perth Royal Infirmary, a small, local provider, which was first to develop an ultrasound screening programme, while one of Scotland's largest tertiary referral centres (Aberdeen Maternity) was one of the last. This suggests that such generalisations should be approached with caution as they may obscure more than they reveal.

In the case of Perth, for example, a closer examination of the context within which ultrasound screening developed reveals many of the factors which contributed to its early move in this direction. First of all, PRI was closely connected with Ninewells Hospital in the nearby city of Dundee. Thus, while not itself a tertiary referral centre, PRI did have access to research staff

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[15] *ibid.*, p.4.

[16] Banta, H.D., (1980), 'The diffusion of the computed tomography (CT) scanner in the United States' *International journal of health services,* Vol. 10, No. 2., pp. 251-69; McKinlay, J.B., (1981), 'From "promising report" to "standard procedure"'.

and also played a role in medical training. More significantly, PRI and Ninewells shared the same ultrasound personnel, led by Sandy Christie, who worked between the two institutions. According to Christie, the lower delivery rate in Perth (around 1200 per year in the 1970s, in comparison to Ninewells' roughly 3800) made the smaller maternity hospital the ideal location for him to try out new practices and procedures. In Christie's words, he used Perth as a 'pilot unit' and those practices that worked would then be transferred to the larger hospital in Dundee.[17] Furthermore, PRI had better access to funds for the purchase of medical equipment through the patronage of a local Trust Fund (The Gannachy Trust) provided by the whisky company Bell's, which was based in the town. According to Sandy Christie, this often enabled Perth to acquire new forms of equipment (such as colour Doppler, for example) before some of the large teaching hospitals. These local circumstances make Perth's early adoption of ultrasound screening appear much less anomalous.

Similarly, the timing of Aberdeen's introduction of a routine screening policy is explicable when examined in context. First of all, Dr Valerie Farr, who had headed the ultrasound team since the departure of Christie in 1970, did not support the routine use of ultrasound:

> To begin with I fought very strongly against routine scanning. I still don't agree with it because it increases your workload unnecessarily - the more you do, the more mistakes you're going to make. [...] I remember, when I was a student, a physician saying he thought it was quite interesting that the older and deafer physicians got, the more heart sound they could hear and I suspect the same applies to ultrasound. The more you do, the more you *think* you see.[18]

For Valerie Farr, therefore, the universal application of obstetric ultrasound was viewed as a development that actually diminished the clinician's ability to diagnose pathological conditions, rather than assist in identifying them. The view being voiced here is one of two closely-linked discourses which could be used to oppose universal screening - i.e. that a higher volume of

[17] Interview with Dr AD Christie, 10/12/97.
[18] Interview with Dr Valerie Farr, 10/05/98.

cases would lead to greater numbers of 'false-positive' diagnoses of pathology, which would then lead to yet-more monitoring. In other words, the time and energy expended on routine ultrasound and follow-up could be better spent concentrating on cases in which either symptoms or risk factors had been identified. The second discourse which, although similar, actually makes an opposing argument, was that routine ultrasound would fail to spot pathology as a result of the higher workload. In this case, the higher volume of 'normal' cases would lead to a greater number of 'false-negative' diagnoses. Despite the apparent contradiction between these two discourses, they were used simultaneously by Farr in her opposition to routine ultrasound:

> I'm all for using technology to help you but I see no point as a substitute. Why scan 100% of the population when 95% of babies are perfectly healthy and only 5% are abnormal? And the chances are you can't pick up all those abnormalities - you've got to have a pretty high accuracy rate. If you didn't scan any patient and you said, 'this baby's all right,' you'd be 95% right. If you can't work out what is a low risk pregnancy then you shouldn't be an obstetrician![19]

Although Farr's views on routine ultrasound did not reflect the majority view on ultrasound at the time, they were not unique. A number of obstetricians questioned the appropriateness of routine screening, while a small number continued to question the technology's contribution to obstetrics at all.[20] Nevertheless, the significance of Farr's attitude was that it had a direct impact on her own interactions with the technology and on the development of obstetric scanning in Aberdeen. Her opinions carried significant weight because of the fact that none of the hospital's obstetricians actually performed their own scans. Unlike, for example, the Queen Mother's where all junior clinicians were encouraged to scan patients, ensuring a constant turnover of clinical staff with scanning experience, none of the obstetricians in Aberdeen had any direct experience of scanning. Thus Aberdeen had no obstetricians who were trained to use the

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[19] Interview with Dr Valerie Farr, 10/05/98.

[20] One such clinician in Kirkcaldy refused to participate in the routine screening programme introduced there in 1982 and thus women's exposure to routine obstetric ultrasound was conditioned by which clinician was responsible for their overall care.

technology, the scanning team being comprised only of Farr (who, as noted in Chapter 3, was not a trained obstetrician), a technician and a radiographer. For this reason, it can be suggested that her views on what could (and could not) be achieved through routine ultrasound were given considerable credence.

A change in clinical staff, beginning in 1985, however, signalled a watershed period for obstetric ultrasound in Aberdeen. Within a year three new clinicians had arrived at the hospital - a new Professor of Obstetrics and Gynaecology, Allen Templeton and two obstetricians (Dr Norman Smith and Dr Patricia Smith). Both of the Doctors Smith had came directly from the Queen Mother's Hospital, where they had been trained to use obstetric ultrasound by Margaret McNay. They had also therefore worked in an institution that valued the routine use of obstetric ultrasound. Thus the arrival of younger clinicians with first-hand experience of ultrasound, marked a decisive shift in the way the technology was perceived.

There was, however, also a more economic reason for the timing of routine ultrasound's introduction in Aberdeen. Although a dedicated scan room had been constructed when obstetric ultrasound was first introduced to Aberdeen in 1967, this had been designed for the requirements of a single static B-scanner.[21] Thus the small amount of hospital space that was made available for ultrasound scanning acted as a constraint on the expansion of the service and increased volume of work associated with screening. In 1985, however, some adverse local publicity about under-resourcing of the maternity hospital (particularly in terms of bed space and facilities) prompted the Health Board to release extra funds for the hospital's budget.[22] Nevertheless, the fact that the construction of a new Ultrasound Department (officially opened on April 1st 1986) was the first fruits of this investment, is probably also a result of the interests of the new clinical management.

Thus when examined in context, it is clear that a variety of factors affected the timing and manner of the introduction of routine ultrasound screening in individual hospitals, and that it

[21] See chapter 2.
[22] Telephone interview with Professor Allan Templeton, 05/09/99.

was not simply a result of the type or size of each. Thus generalisations such as those of McKinlay or Banta actually serve to obscure the heterogeneity which is evident in the diffusion of practices such as this.

Another noteworthy feature of the general pattern of diffusion of ultrasound screening practices lay in the variety of procedures adopted. Most institutions such as the Queen Mother's, Forth Park in Kirkcaldy, Ninewells, the Lewis Hospital and Aberdeen Maternity, began cautiously by offering a single routine scan. However, while some went on to introduce an additional routine scan, others maintained a single scan policy. Perth, once again, was the most anomalous, offering no less than three routine scans from the very start of their service. Furthermore, differences can also be clearly observed in terms of when a scan would be offered. In 1983 for example, of those hospitals offering a single scan, just over half opted for a late first trimester scan (between 10 and 12 weeks gestation), usually when the patient was booked. The remainder offered their single scan at around 16 weeks gestation.[23] Similarly, of those who offered two routine examinations, the majority opted for a booking scan plus a second scan, although the timing of this could be anywhere between 16 and 21 weeks gestation.[24] The main exception to this strategy was the Lewis Hospital, which offered its routine scans at 16 and 32 weeks. Once more however, this difference can only be explained by examining the development of each screening policy in context.

Offering a routine scan late in the first trimester had both practical and clinical value. In practical terms, pregnant women were normally booked in under a Consultant Obstetrician at this time. This constituted a pregnant woman's first hospital antenatal appointment, when she would be examined by a doctor and have her obstetric history recorded. It was thus administratively practical to include a routine ultrasound scan at this time, obviating the need for women to return to the hospital at a later date. A number of pieces of clinical information could be garnered from a scan at this point in pregnancy. The on-going status of the pregnancy

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[23] Scottish Home and Health Department/Scottish Health Service Planning Council, (1988), 'Obstetric ultrasound in Scotland' p. 18.
[24] *ibid.*

could be confirmed, multiple gestations diagnosed, placental location noted and fetal measurements taken (principally crown-rump length (CRL) and bi-parietal diameter (BPD)). This early scan could not, however, be used to detect any but the most severe forms of fetal malformations - the fetus was simply too small and many of the organs would not be sufficiently developed to be examined. Furthermore, a low-lying placenta at this stage in pregnancy was a much less reliable indicator of the potential development of placenta praevia than those observed later in the second trimester.

There was a much greater chance of observing such defects in those institutions where a single scan was conducted at (or just before) 16 weeks. There was, however, a trade-off to be made here. The pregnancy's duration would be provisionally calculated via the dating of last menstrual period (LMP), which would be used to determine when the scan was to be performed. If this estimate was wrong (which could happen if, for example, the woman had recently been using oral contraceptives, or had irregular periods) then the optimum period for drawing blood for maternal serum alpha fetoprotein (MSAFP) testing (16-18 weeks) might have passed. Furthermore, from roughly 16 weeks onwards fetal measurements became increasingly less predictive as it was generally accepted that fetal growth rates began to vary from the latter half of the second trimester.[25]

There were thus advantages and disadvantages associated with each of these scanning times. Which of these two options was chosen itself depended on a number of factors, including local circumstances. In the Western Isles for example (as noted in Chapter 3), the later 16 week scan was preferred when a single scan routine was in operation, and this was in direct response to the Consultant Obstetrician's assessment of the deficiencies of his equipment. However, given the difficulty of local travel arrangements, the clinician needed to keep the frequency of appointments to a minimum and so he reorganised his booking clinics to coincide with the 16

[25] The accuracy of fetal biparietal diameter measurements for the estimation of gestational age is generally considered to decrease from +/- 1.1 weeks (when the measurement is taken at 14-20 weeks gestation) to +/- 1.6 weeks (from 20-26 weeks gestation), and to +/- 3.4 weeks (after 30 weeks gestation). See www.medicine.creighton.edu/radiology/ultraoffetalbiomet (accessed 11/9/02).

week scan. In the Queen Mother's, on the other hand, it is possible to suggest two reasons for their opting for an early booking scan as routine. Firstly, they were at this time using static B-scan machines with their superior image quality. Thus the detail which could be observed at 12 weeks gestation (by highly skilled staff in an ultrasound centre of excellence) would not perhaps be greatly improved upon if scanning were delayed for another month. Furthermore, it is possible to argue that the Queen Mother's had an institutional commitment to ultrasonically determined gestational dating. The huge amount of work done in the hospital by the staff from the late 1960s onwards on fetal cephalometry in particular, suggests that they placed a high value on acquiring early and accurate ultrasound dating of pregnancy.[26] Indeed, the importance of this as the main underlying reason for performing routine ultrasound is reflected in the views of the Queen Mother's staff. According to Dr Margaret McNay, for example:

> I think one of the main problems still is that people do not know how far on [in the pregnancy] they are. Judging simply by the last menstrual period is not an accurate assumption, and therefore I think for everyone to be scanned for dating is a very sensible idea.[27]

Finally, the centre that handled all MSAFP tests for the West of Scotland (The Duncan Guthrie Institute of Medical Genetics) shared the same Yorkhill site as the Queen Mother's. The close relationship which existed between these two centres in terms of genetic screening, amniocentesis, etc. means that it was probably prudent that the Queen Mother's, of all places, got their samples of maternal blood drawn at the correct time.

However, in relation to the timing of MSAFP tests it is evident that there was no clear cut consensus on which scan time was most appropriate. Actors both from centres that operated a 10-12 week policy, and those which scanned at around 16 weeks, cite timing of MSAFP as an

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[26] These include Hall, A.J., Fleming, J.E.E. & Abdulla, U., (1970), 'Ultrasonic fetal cephalometry: some improvements and future developments' *Ultrasonics,* Vol. 8., pp. 34-5; Robinson, H.P. & Fleming, J.E.E., (1975), 'A critical evaluation of sonar "crown-rump" length measurements' *British journal of obstetrics and gynaecology,* Vol. 82, No. 9, pp. 702-10; Hall, A.J. & Fleming, J.E.E., (1980), 'A coded cephalometer for multiple measurements of biparietal diameter' *Ultrasound in medicine and biology,* Vol. 6, pp. 285-9.
[27] Interview with Dr Margaret McNay, 05/11/97.

important influence on their policy. At Forth Park Maternity Hospital, for example, the later single scan at 16 weeks was initially preferred. According to Dr Michael Hill, one of the consultant obstetricians at Forth Park since 1972 and now Chief Obstetrician at the hospital, this was tied to their early involvement with the East of Scotland MSAFP Screening Programme run from the Simpson's Maternity Hospital in Edinburgh.[28]

For many centres (including the Queen Mother's and Forth Park) the trade off between achieving early and accurate ultrasonic estimation of gestational age and being able to clearly visualise a number of fetal pathologies was overcome via the introduction of an additional scan. During the 1980s, this second scan (anywhere from 16-21 weeks gestation) was increasingly referred to as an anomaly or detailed scan and was the examination during which the fetus in particular was given a 'full check-up'. The position of the placenta would also be assessed here as low-lying placenta at this stage in pregnancy provided a better prediction of the potential development of placenta praevia than it did during the first trimester. Nevertheless, the fetus was by far the main object of the medical gaze during this scan, and its major organs, structures and overall 'wellbeing' would be assessed, measured and scrutinised. It is important to note that this examination was extremely technology-dependant. The detail sought in such scans was reliant upon equipment that provided good image resolution, and also upon the skills of the operator. Thus the number of checks made and details examined increased throughout the 1980s as both the resolution of images improved and the expertise of staff increased. Thus by the mid 1980s a number of routine strategies were employed - a single scan at 10-12 weeks, a single scan at around 16 weeks, or a booking and an anomaly scan at 16-21 weeks, or a 16 week scan and a 32 week scan. And then there was Perth - the first centre to develop an ultrasound screening policy and the only Scottish hospital to ever offer three scans to every pregnant woman - one at booking, one at 19 weeks and one at 36 weeks. This requires explanation.

First of all, the small number of maternity patients involved (in relation to Dundee) probably meant that the scan team which worked between the two hospitals (Christie and two assistants)

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[28] Interview with Dr Michael Hill, July 1996.

had more scope in which to develop a comprehensive service at Perth. Furthermore, as with the Queen Mother's, and unlike Ninewells, PRI dealt only with obstetric cases - the only gynaecological examinations carried out were those associated with early pregnancy.[29] Thus not only were patient numbers relatively small, the range of cases to be examined was also more limited. Therefore it can perhaps be suggested that a smaller patient population of virtually exclusive maternity cases, provided the perfect opportunity for Christie and his team to explore the full potential of universal screening. As already noted, Christie tended to use Perth as a pilot study for the larger hospital but the same difference in patient numbers which led him to do so perhaps also meant that some practices could not be transferred so easily to Ninewells. Indeed, when Ninewells began its routine scanning, some two years after Perth, a single examination was offered - at 19 weeks. The larger volume, and greater range, of cases in Dundee, led Christie to opt for what he perceived to be the most clinically useful of the three routine scans performed in Perth.

However, a factor of perhaps greater significance was Christie himself. As the only medical physicist in Scotland who headed an ultrasound scanning team, Christie's position *vis à vis* the technology was markedly different from other workers in the field. By virtue of the fact that he was not a clinician, none of his time was claimed by other clinical work - he was exclusively an ultrasound specialist - or, as he prefers to name it, an 'ultrasonologist'.[30] His sole role when visiting the Perth hospital was to scan obstetric patients and thus Christie essentially had a freedom of action not afforded to many other ultrasound workers at that time. In this way it is possible to suggest that actors in other institutions may also have preferred to perform greater numbers of routine scans had circumstances enabled them to do so. Indeed, Jack Crichton in the Western Isles, in a letter to one of the GPs who performed routine ultrasound in the peripheral clinic on Benbecula, expressed this very sentiment:

> With regard to when patients should be screened, I would like you to carry out basic scanning at between 16 and 18 weeks and at about 32 weeks. This is the screening that I am doing in Stornoway, and it is essentially a

[29] Interview with Dr AD Christie, 10/12/97.
[30] *Ibid.*

> compromise dictated by the logistics of the situation. Had I time, I would also like to scan the patients between 17 and 18 or even up to 19 weeks when there is a lot of more interesting detail to be seen and had I even more time, I would also like to scan patients at about 30 and 34 or 35 weeks. So for the moment, providing you can do the basics in the second trimester and third trimester, they can have as many additional scans as you have time for. It is interesting to look at the foetus about 18 or 19 weeks.[31]

More than this, however, as a medical physicist (and, indeed, one who had been an electronics engineer until a decade previously) Christie was much more technology-minded than many of his clinical peers. The specialist area of medical physics prided itself on its innovative practices: developing new procedures and manipulating equipment to try new things.[32] This sentiment is reflected in Christie's own view of his role, which can be inferred from the following (somewhat disparaging) comments on radiographers and midwives:

> we [the scan team at Ninewells] have always believed that radiographers and midwives can be trained by their doctors (or whoever's training them) up to a certain level to do what they are told to do, but they are not, and never will be, innovators. They will never be developers because it's not in their nature or in their remit to be developers.[33]

However, Christie's love of technology went beyond this. As a non-clinician with an authoritative position in charge of an ultrasound team, he was much more inclined to favour ultrasound diagnosis over all other forms of clinical knowledge. This is clearly evident in his views on the value of routine scanning:

> And then there was the argument that I always, that I didn't believe in, 'why scan everybody when most of them are low risk pregnancies?'. And my opinion of that is, 'how do you know it's a low-risk pregnancy?'. Nobody knows that - it's just ridiculous. ... I'm not saying ultrasound solves all the problems, but what I am saying is that ultrasound reveals problems that you did not know were there. It's a very simple maxim - if

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[31] Letter from Dr Jack Crichton to Dr Louise Hodgeson, 13 March 1987 (JC Correspondence, Western Isles Box, BMUS Hist Coll.)

[32] This is also evident in the comments made by Professor John Mallard in Chapter 2.

[33] Interview with Dr AD Christie, 10/12/97.

> you don't look you'll never see, so why not look? I mean, any fool can guess about a pregnancy - the patient needn't even come into the hospital, you can talk to her on the phone, 'how are you?' 'Fine.' 'Fine - it's a low risk pregnancy' - it's ridiculous![34]

Thus while clinicians who were involved with ultrasound screening were more likely to emphasise its contribution to the medical management of pregnancy (in conjunction with an array of clinical, diagnostic practices) on a more general level, Christie's attitude could be described as more technology-dependent. That is not to suggest that he believed ultrasound replaced or superseded all other forms of clinical diagnostics, but simply to make the point that his extensive knowledge of ultrasound, and lack of expertise in other forms of clinical practice, predisposed him to ultrasonic evaluation of all pregnancies. [35]

The importance of Christie's professional background in engineering and medical physics in this context ties in with another feature of the heterogeneity of screening practices developed in Scottish hospitals - operating personnel. The increased workload associated with screening every pregnancy (as opposed to selective cases) brought with it a demand for greater numbers of operating staff. However, clear differences emerged between locations in terms of the kind of personnel used. Indeed, Scotland appears to have exhibited the greatest degree of diversity in this context. The RCOG working party report on routine obstetric ultrasound published in 1984, made use of two surveys of scanning personnel carried out in Scotland and the South East Thames region of England.[36] The findings (although described in the report as being 'broadly similar'[37]) show marked differences in the distribution of scanning commitments amongst the various groups (see Table 4.1).

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[34] *Ibid.*
[35] Indeed, in another interview he criticised doctors who abandoned their clinical judgment to ultrasonic measurement of BPD in deciding when to induce pregnancy. (Dr AD Christie, interviewed by Ian Spencer and John Fleming, courtesy of Nicolson, Spencer & Fleming, transcript p5.)
[36] RCOG, (1984), 'Report of the RCOG working party' pp. 8-9 & Table 2.1, Figure 1 (p. 26) & Figure 3 (p.28).
[37] *ibid.* p.8.

Figure 4.1: Number of antenatal scanning sessions performed by different groups of workers in Scotland and the South East Thames region.

	No Deliveries/ year	Obstetric scanning patients/ week	Radiographer	Radiologist	Obstetrician	Midwife	Others
Scotland	66.000	368	165(45%)	32(9%)	93(25%)	16(4%)	61(17%)
SE Thames	45,000	197	120(60%)	14(7%)	35(18%)	18(9%)	10(5%)

(from RCOG, (1984), 'Routine ultrasound examination in pregnancy,' p. 26.)

Most striking are the significantly higher number of scanning sessions performed in England by radiographers (60%, compared to 45% in Scotland), and the lower number of obstetricians performing scans (18%, compared to Scotland's 25%). Also noteworthy is the much higher incidence of scanning sessions being performed by 'others' in Scotland (largely general practitioners, clinical assistants, technicians and medical physicists). Thus, as the RCOG report fails to note (but which is reported in the later NMCC report published in Scotland[38]) radiological staff (radiographers and radiologists) were much less dominant in antenatal screening in Scotland than in England. Once more, the wide variations between individual hospitals in terms of personnel can only be explained through reference to local context.

In both Perth and Dundee, medically trained staff were employed as clinical assistants in Christie's team. These workers, however, were not qualified obstetricians but medical graduates employed exclusively as ultrasound operators, and both Perth and Dundee continued to rely on such personnel.[39] However, unlike many of the junior medics who used the technology in hospitals such as the Queen Mother's, Perth and Dundee's clinical assistants did not undertake ultrasound as part of any training for higher posts; instead they were employed solely as ultrasound operatives. The fact that these clinical assistants were women, employed on a part-time basis, suggests that a specific pool of available labour, in the form of medical graduates with family commitments, was being tapped in Perth and Dundee. This however cannot fully explain why these two hospitals developed such a unique division of labour.

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[38] Scottish Home and Health Department/Scottish Health Service Planning Council, (1988), 'Obstetric ultrasound in Scotland' p. 22.

[39] In the early 1990s the close affinity between the two institutions was severed and they became governed by two separate Health Trusts. Dundee continued to enjoy the services of Christie's team, while Perth's obstetric ultrasound service was taken over by The Department of Radiology (which was renamed as the Department of Medical Imaging). Interview with Dr AD Christie, 10/12/97.

According to Christie, the availability of such workers was coupled with an actual preference of the consultants at Perth and Dundee (as well as himself) for medically-trained personnel over radiographers, midwives or technicians. For Christie at least, it was the perception that lower grade staff were unable to develop innovative practices which led him to favour medically qualified operators.

However, in light of Christie's own background, this preference seems somewhat odd. He himself had no medical training and his knowledge of obstetrics was confined to his knowledge of obstetric ultrasound.[40] Instead, it could be suggested that Perth and Dundee's use of this kind of personnel was directly related to the prominent role that Christie occupied. None of the consultants in either hospital scanned their own patients and thus, like Valerie Farr in Aberdeen, Christie was in overall control of a clinical technology with which the hospitals obstetricians were not as experienced. However, as a non-clinician Christie was not essentially qualified to make diagnoses. Thus, it could be suggested that the employment of clinical staff (i.e. personnel with medical training) enabled that particular clinical obstacle to be overcome. Indeed, Valerie Farr claims that this was one of the reasons why she was appointed to the Aberdeen scan team (following the departure of Dr Sandy MacIntosh) during Christie's employment there. According to Farr, Christie had to be assisted by a clinician, but there were no willing volunteers from amongst the obstetrics staff.[41]

At the Queen Mother's, the staff who initially carried out routine scanning were also medically qualified, but the vast majority were consultant obstetricians scanning their own patients, or junior doctors undertaking research for MDs or, later, registrars seeking membership of the Royal College of Obstetricians and Gynaecologists. Gradually, however, midwives were employed in this capacity and this group had taken over much of the routine workload by the middle of the 1980s.

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[40] See Chapter 2 for a fuller account of Christie's early career in ultrasound. Although Christie was given some degree of clinical knowledge by the Obstetrics Professors in both Aberdeen and Dundee, this was nevertheless geared at instilling in him an awareness of the clinical and physical aspects of the structures he was viewing with ultrasound. Furthermore, John Mallard hints that this 'obstetric training' may have been instigated more by Christie himself, than the obstetricians involved.
[41] Interview with Dr Valerie Farr, 10/05/98.

The fact that additional staff was drawn from midwifery in this case, was related to the institutional independence of the QMH ultrasound service from radiology. Because the obstetric scanning service was geographically separate from the Western Infirmary, and was operated entirely by obstetrics, there was never any radiological involvement with obstetric ultrasound at the Queen Mother's. Thus despite the fact that gynaecology scanning was mainly under the control of radiology in the Western Infirmary, and that obstetric ultrasound in the city's other main maternity hospital (the Royal Maternity in Rottenrow) had been run by the radiology department since Donald's obstetric beds had relocated to the Queen Mother's in 1964, the QMH service was a resolutely obstetrician-led practice. This entailed that the Queen Mother's did not really have the access to radiological staff for scanning - whereas there was scope to introduce midwives to ultrasound.

This was also the case in Aberdeen, where midwives were introduced into the scan team to carry out the vast majority of routine examinations. Once again, institutional independence and the location of the Ultrasound Department within the maternity hospital help to explain this development. It is also evident that many clinicians and midwives in centres where midwives operated the technology felt that there was something particularly advantageous about drawing on this group. In particular, midwives were felt to provide a more holistic approach to scanning. According to Margaret McNay, for example, midwives are better equipped to discuss wider issues with pregnant women, as well as those which arise from the scan itself:

> there is no doubt that your midwife, by nature of her training, she knows far more about the pregnancy than your average radiographer will. [W]hen you are scanning, you're often having a chat with the patient and you are not just pointing out the fetus, but its an opportunity for [the patient] to be in a relatively pleasant relaxed atmosphere and maybe [she] will be more ready to ask questions about other things, unrelated actually to the scan. If somebody brings up questions about other aspects of antenatal care then she [the midwife] ought to be able to answer these whereas your radiographer may not.[42]

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[42] Interview with Dr M McNay, 05/11/97.

Furthermore, the presence of a midwife as sonographer was also considered advantageous when abnormal findings from ultrasound screening were discussed with patients. Professor Allen Templeton, for example, cited this as a major reason for introducing midwives to ultrasound in Aberdeen:

> [Midwives] could be trained just like anyone else, but the more important issue was that they could interact with the patient much better. Particularly in later scans where a problem ensued, quite often if a radiologist or radiographer was doing the scan, they would feel uncomfortable having any conversation about the implications of the finding, particularly if it showed an abnormality of any sort. So it was really, I felt the midwives would be better all-round at counselling and so forth.[43]

Similar points were also made by the midwives themselves who participated in ultrasound screening, all of whom mentioned their 'holistic' approach.[44] Edward Yoxen, however, (as mentioned in the Introduction of this thesis) has noted elsewhere that midwives in some hospitals in England were hostile to the idea of participating in ultrasound scanning, claiming that it would diminish their skills as midwives.[45] The sentiments expressed by midwives who performed ultrasound, cannot therefore be taken as representative of a general attitude amongst this professional group. Instead, their attitudes were themselves grounded in their involvement with the technology. Their actual experience with the technology led them to recognise certain aspects of their professional training as useful and valuable in their role as scan operators. For this reason, both the attitudes of midwives who performed ultrasound, and the reasons they give for their greater suitability, should perhaps be viewed as an outcome of their involvement with the practice, rather than a cause.

Furthermore, the comments noted above should not be regarded as an indication that radiographers were considered unsuitable for the job of scanning. While some actors did

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[43] Telephone interview with Professor Allen Templeton, 5/3/99.
[44] Sister Grace Porter, for example, noted that while abnormalities are explained to patients by clinicians, the midwife scan-operator is 'often left then to explain again'. (Interview with Sister Grace Porter, 01/04/98).
[45] Yoxen, E., (1987), 'Seeing with sound: a study of the development of medical images' in Bijker, W.E., Hughes, T.P. & Pinch, T.J., (eds.), *The social construction of technological systems,* MIT Press, Cambridge, Mass., pp. 281-2.

consider this to be the case (including, for example, Sandy Christie, Jack Crichton and Allen Templeton) others argued that what radiographers lacked in terms of their knowledge of pregnancy, was offset by their fuller technical understanding of the technology.[46] Those radiographers interviewed in Kirkcaldy, for example, highlighted that their greater understanding of how ultrasound images were produced, and of the technical advantages and disadvantages of a particular machine, in comparison to midwives, led to a heightened ability to get the best images from the equipment in use.[47]

Finally, the employment of GPs as ultrasound operators in the Western Isles provides another example of the varied mix of personnel employed in ultrasound screening. Here again, this is only explicable in terms of local circumstances. First of all, and most importantly, the geographical difficulties associated with the Western Isles (as outlined in Chapter 3) presented problems for any attempt to screen all women in the Health Board region within the hospital itself. Furthermore, as a lone consultant Crichton was only able to visit the peripheral clinic on Benbecula once every six weeks - not frequently enough therefore to ensure pregnancies were screened at the desired time of 16 weeks gestation. Thus the use of local GPs was a practical solution in the circumstances. In addition, the extension of the service to GP practices in other areas was an historically and contextually emergent development. Those GPs who came on board (Dr Bickle in Barra in 1987 and Dr Ratchford in Ness in 1988) were based in the most remote areas of the Isles[48] and had an interest in obstetric medicine. Thus, despite the fact that community-based obstetric scanning operated by unsupervised general practitioners was highly unusual, this service, when placed within the particular local circumstances from which it evolved, made sense on a practical basis.

In summary, there was no universal 'standard procedure' or 'routine' for antenatal screening with ultrasound. Hospitals that operated such policies differed from one another in a number of key areas - number of scans performed, timing of antenatal screening and personnel operating

[46] Margaret McNay expressed this point, as did the midwives and radiographers interviewed.
[47] Interview with Mrs Eleanor Young, July 1996; interview with Mrs Enid Barker, July 1996.
[48] Castlebay on Barra is the most southerly community habitation in the Isles, while Ness at the top of Lewis, is the most northerly.

the technology. However, what is evident is that, while each centre developed very different forms of routine procedure, all can be seen as emerging from the particular circumstances and factors associated with each location. Thus, although it is difficult to make out a specific pattern, the procedures adopted in each centre made sense on an individual level, located fully within their historical and locational context.

However, by the mid 1980s, when it was estimated that some 70% of pregnant women were exposed to routine ultrasound[49], this lack of uniformity began to become an issue of concern to both the state and professional bodies such as RCOG. The worry appears to have been that diversity was symptomatic of the unregulated growth of routine screening practices, which might result in a lack of universal standards and thus doubts regarding quality of care on a more general level. In particular, the ever-increasing use of lower grade staff such as midwives and radiographers, raised fears that supervision and training of such workers might not be sufficient. Attempts, therefore, to create a more uniform 'standard procedure' in the routine application of ultrasound were made on two fronts - uniformity of delivery and uniformity of training. When discussions and debates over how best to achieve this were at their height, however, the safety of obstetric ultrasound erupted as a matter of considerable public debate. As safety is one of the fundamental issues which underpins any screening technique, this debate marked a crisis in the development and use of routine ultrasound. It is therefore worth considering the responses to this crisis in some detail.

The safety debate

Safety scares attached to medical interventions are always controversial, but this is particularly true of those associated with pregnancy where the moral and emotional stakes are, arguably, higher. In 1962, for example, the discovery that the drug Thalidomide (administered to pregnant women to counteract morning sickness) caused severe birth defects, resulted in a huge public outcry and the rapid international withdrawal of the drug. Nevertheless, how a potentially hazardous technology will fare in such circumstances is historically contingent and dependant

[49] Scottish Home and Health Department/Scottish Health Service Planning Council, (1988), 'Obstetric ultrasound in Scotland' p. 16.

upon the availability of alternative techniques. For example, x-ray imaging of the pregnant uterus continued to be performed for a number of conditions following the publication of Alice Stewart et al's research linking it to childhood cancer.[50] Prior to the introduction of ultrasound, for example, x-rays were used to confirm suspected diagnoses of twin pregnancies.[51] X-ray pelvimetry was also practised well into the 1980s, if it was suspected that vaginal delivery might be problematic.[52] In both of these examples, the possible hazards associated with the delivery of such cases were considered to outweigh any hazard associated with the technology.

However, when a technology is employed for screening purposes the threshold of acceptable risk is substantially lower. The fact that whole populations are exposed, and that a considerable proportion of these are expected to be 'healthy', entails that the safety of the tool used is paramount. Thus, as both an obstetric technology and one used to screen all pregnant women, it was inevitable that any concerns raised over the safety of ultrasound as a procedure would pose a significant threat to its continued use.

On May 10th 1984, an ITN 'News at One' programme reported on a meeting of the National Childbirth Trust where concern over the use of ultrasound on pregnant women was raised. This meeting was, in turn, prompted by a number of research papers suggesting that diagnostic ultrasound might have harmful biological effects on the fetus. In particular, a group of researchers at Albert Einstein College of Medicine in New York conducted a number of *in vitro* experiments using both mouse and human cells, and reported chromosomal and morphological

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[50] Stewart, A., Webb, J., Giles, D., Hewett, D., (1956), 'Malignant disease in childhood and diagnostic irradiation *in utero*' *Lancet,* Vol. 2., p.447.

[51] Two of the hospitals in this study continued to perform x-ray imaging for the confirmation of multiple pregnancy after ultrasound was introduced, if the results from the scan were ambiguous. It should also be noted that x-rays are still used to image the fetus, although this has become a very rare practice, and is only performed during late pregnancy.

[52] Ultrasound technology was ill-suited for measuring the pelvis (because of its bony structure) until the introduction of trans-vaginal probes. For a more detailed history of the development of pelvimetry see Hiddinga, A., (1992), 'X-ray technology in obstetrics: measuring pelves at the Yale School of Medicine' in Pickstone, J.V., (ed.), *Medical innovations in historical perspective,* St. Martins Press, New York; Hiddinga, A. & Blume, S.S., (1992), 'Technology, science and obstetric practice: the origins and transformation of cephalopelvimetry' *Science, technology and human values,* Vol. 17, pp.154-179.

changes in cells exposed to ultrasound from diagnostic equipment.[53] In response to these reports, the National Institutes of Health in the USA, the World Health Organisation (WHO) and the Danish Minister of the Interior had all issued guidelines and statements declaring that the routine use of ultrasound on all pregnant women should not be practised. However, it was the broadcast of the ITN news item that really signalled the start of the debate in the UK.

The response of the ultrasound community in Britain, at least as it was represented in the British Medical Ultrasound Society (BMUS), appears initially to have been somewhat dismissive of the issue. In the August edition of the Bulletin, for example, the President of BMUS, Tony Whittingham, criticised what he perceived to be the alarmist nature of the news report:

> Although the programme contained little to which an informed and very attentive viewer could take exception, the mere mention of emotive words such as cancer and deformities might well have been expected to cause consternation in Mrs Public, half watching the telly over her ironing board.[54]

It must be borne in mind that for many of those most active in the field (including the incumbent BMUS President) these research findings were not a major revelation. The research had been published in the medical literature a few years earlier and most actors involved in the further development of ultrasound technology were familiar with it. They were also familiar with the many other experimental studies which reported no significant biological effects from the use of pulsed ultrasound, as well as the methodological problems associated with relating the results of *in vivo* animal studies and *in vitro* experiments to the use of diagnostic ultrasound

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[53] Liebeskind, D.E., Bases, R., Elequin, F., Neubort, S., Leifer, R., Goldberg, R., Koenigsberg, M., (1979a), 'Diagnostic ultrasound: effects on the DNA and growth patterns of animal cells' *Radiology,* Vol. 131, pp. 177-84; Liebeskind, D.E., Baes, R., Mendez, F., Elequin, F., Koenigberg, M., (1979b), 'Sister chromatid exchanges in human lymphocytes after exposure to diagnostic ultrasound' *Science,* Vol. 205, pp. 1273-5; Liebeskind, D., Padawar, J., Wolley, R., Bases, R., (1982), 'Diagnostic ultrasound time lapse and transmission electron microscopic studies of cells insonated in vitro' *British journal of cancer,* Vol. 45 (suppl.), pp. 176-86.

[54] BMUS, (1984), *Bulletin of the BMUS*, No. 35, August, p.2.

in medicine.[55] Perhaps more significantly, however, they were also able to draw on over 25 years of first-hand clinical experience with the technology, which had thus far revealed no observable hazard to patients, their offspring, or operating personnel.

The debate, however, continued and was placed on a more formal public footing. In a written response to a parliamentary question on the subject, the Junior Health Minister, John Patten, made the following statement:

> As the use of ultrasound is a matter for clinical judgement, such tests should not therefore be performed as a matter of routine.[56]

Furthermore, the Minister advocated a wider review of the practice of routine scanning and drew attention to the report on this matter currently being prepared by the RCOG Working Party.[57] The controversy continued to gain momentum. The Association for Improvements in Maternity Services (AIMS) lobbied the Ministry for stronger action to restrict the practice of obstetric ultrasound, while some pregnant women began asking questions about the necessity of a scan, and ultrasound operators penned worried letters to BMUS regarding whether they should continue to provide routine examinations. There were even claims that hospital appeals for scanning equipment were affected, or cancelled altogether, as a result of the safety fears. The matter came to a head (at least in terms of public debate) towards the end of 1984. On October 22nd, the Daily Mail published a letter written by Patten to AIMS in which he stated that 'we would not expect any Health Authority to be advocating screening for all mothers as a routine procedure'.[58] Furthermore, the Ministry persuaded the Medical Research Council to organise a meeting of UK ultrasound experts to discuss the risks and benefits of the

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[55] The conflicting scientific evidence was assessed (ultimately in ultrasound's favour) in a number of official publications issued by a variety of bodies including the Medical Research Council and RCOG in the UK, and the Federal Drug Administration and National Institutes of Health in the USA (RCOG, (1984), 'Report of the RCOG working party' Appendix 2, pp. 50-73.)

[56] John Patten, quoted in BMUS, (1984), *Bulletin of the BMUS*, No. 36, November, p.3.

[57] RCOG, (1984), 'Report of the RCOG working party'. In light of the safety debate an appendix of some 15 pages was devoted to an examination of the evidence.

[58] Daily Mail, October 22nd 1984, quoted in BMUS, (1984), *Bulletin of the BMUS*, No. 36, November, p.3.

technology.[59] In two television interviews that evening, the Junior Health Minister attempted to elaborate the government's position:

> Some other West European countries, like the Danes, have decided that ultrasound should not be a technique which is used routinely, and the World Health Organisation has said quite firmly that it does not think, at the moment, that ultrasound and the evaluation of ultrasound is in such a position that every mother should have it automatically, and I think that is very much our position.[60]
>
> We are not stopping anyone in the country - I must stress that, anyone in the country - having a scan if her doctor says it's a good idea for her to have a scan. All we are saying is that we do not want the NHS, the District Health Authorities up and down the country, to go any further down the road of developing this as a totally routine technique until we have had this further examination [i.e. the MRC Review].[61]

It is evident, however, from the statements made by the government, that its position in this matter was highly ambiguous. While the letter to AIMS suggests it did not want *any* health authority to carry out ultrasound screening, the junior minister's television comments merely indicate that health authorities should not go 'any further down the road of developing this as a totally routine technique'. The implication of the latter comment is that those centres already operating such policies could continue to do so. Thus while claiming to hold a position which was in accordance with that of the World Health Organisation, the additional comments made by the Junior Health Minister belied this sentiment. In short, through the use of ambiguous and sometimes contradictory statements, the Ministry of Health appeared to criticise the routine use of obstetric ultrasound while its safety was being questioned, but fell short of calling for a temporary halt to the practice. Caught between the demands of medical professionals (who had increasingly come to rely on the routine use of this technology as a central component of

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[59] The outcome of this meeing was published in 1986 (Medical Research Council, (1986), 'Report on an ad hoc meeting on the risks and benefits of obstetric ultrasound' Medical Research Council, London).
[60] Interview with John Patten on BBC '6 O'clock News', quoted in BMUS, (1984), *Bulletin of the BMUS,* No. 36, November, p.3.
[61] Interview with John Patten on ITV 'News at Ten', quoted in BMUS, (1984), *Bulletin of the BMUS,* No. 36, November, p.3.

antenatal screening), and its desire to be seen to act responsibly by the public in light of the safety controversy, the Ministry chose the time-honoured political option of 'fudging' the issue.

The ambiguity of the government's stance was not lost on the ultrasound community. In an editorial of the BMUS Bulletin, for example, which spelled out the Society's advice to its members, the President chose to emphasise parts of the Minister's comments and not others. In addition to advising its members to ensure that all ultrasound examinations were performed on the basis of 'informed consent' by the patient, BMUS also made full use of the unclear nature of the Ministry's advice by appealing to 'clinical judgement':

> It [the Department of Health] has clearly stated that *it would not wish to question a doctor's clinical judgement* in favour of a scan, for any reason. It should therefore be possible for a doctor to comply with the spirit of the Minister's remarks and still have routine scans done on his patients, provided he explains to them that, *in his judgement*, a routine scan is a worthwhile check, even for an apparently problem free pregnancy, and offers them the chance to say no. [Emphasis added][62]

Thus, clinicians were advised that if they felt a routine ultrasound examination was a medically justifiable procedure, and the patient consented, then they could continue to perform routine scans without fear of contravening government advice. This amounted to an oft-used appeal to the autonomy of the clinician in all matters relating to patient care. As with the framing of the government's response to the question of risk, this appeal can be traced to the historical relationship between the state and the medical profession in Britain. Medical autonomy over all matters of patient care had been enshrined within both the panel system of the 1911 National Insurance Act, and the setting up of the National Health Service in 1948. To gain the profession's co-operation with these schemes both Lloyd George and Aneurin Bevan had to overcome the medical community's hostility towards state regulation; a hostility acquired through their experiences of the 19th century Friendly Societies and Poor Law Authorities.[63]

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[62] *ibid.*
[63] Stevens, R., (1966), *Medical practice in modern England: the impact of specialization and state medicine,* Yale University Press, New Haven, Conn.

This was achieved by affording the profession full authority over the treatment of patients: the state could not directly interfere with the doctor/patient relationship by demanding that certain drugs, practices or technologies should or should not be used. Of course, the relationship between the state and the medical profession was always historically contingent. Changes in the organisation of the NHS (such as the introduction of Trusts and GP fundholding) were tied to shifting power relations. Furthermore, the increasing prevalence of medical malpractice suits in the late twentieth century also blurred the boundary between the state and the profession. Nevertheless, the state's historically negotiated inability to *dictate* medical practice enabled the profession to continue with routine scanning programmes - despite the existence of controversy over the safety and appropriateness of the procedure.

With this in mind, it is perhaps unsurprising to observe that routine screening programmes carried out in the Scottish hospitals in this study appear to have been unaffected by the safety debate in the 1980s. Indeed, despite the explicit appeal of the Department of Health that routine scanning should not be extended until the various bodies had reported their findings, both Aberdeen Maternity Hospital and the Lewis Hospital in Stornoway extended their routine services during this period. How can this situation be explained?

The screening of all pregnancies with diagnostic ultrasound had come to form one of the basic components of antenatal care and management with numerous decisions such as when to induce labour, whether to perform caesarean sections, whether to admit women for bedrest, whether to offer a termination of pregnancy, etc. being based upon its findings. Thus practice itself had become moulded around the technology and its routine use. In this way, it can be seen that routine ultrasound had altered the nature of obstetric practice and, therefore, was not easy to abandon. Furthermore, the particularities of each routine service had evolved from particular local and historical contingencies. Each system had been shaped by a variety of factors and thus it was grounded in its location as much as it was created from the historical processes from which it emerged. Thus in the centres in which it was currently employed, it could not simply be plucked from practice without having a fundamental affect on the administration and organisation of antenatal provision.

Thus, in terms of its increasing ubiquity (both within individual centres and as a practice carried out in a rising number of institutions) routine obstetric ultrasound was surprisingly unaffected by the safety controversy. Even at the height of the dispute over safety, the policy of screening all pregnant women continued, and indeed began to expand as more hospitals began their own routine procedures. Nevertheless, there was one significant way in which this public attention affected the technology. Confronted with unprecedented levels of media scrutiny and public concern, advocates of the technology found themselves having to defend the routine use of ultrasound in all pregnancies by explaining its benefits. This in turn emphasised the growing perception that the organisation and delivery of ultrasound services needed to be standardised. To be seen to be an effective screening tool, comparability in the technology's organisation and regulation was required.

Standardisation or harmonisation? Regulating routine ultrasound

The first issue to be addressed by the ultrasound community related to the appropriate training and supervision of scanning personnel. When assessing the delivery of routine ultrasound in the UK, the RCOG working party on routine ultrasound was highly critical of the large volume of work being undertaken by unsupervised radiographers. In their survey of the 191 hospital districts in England (carried out in May 1984) they found that radiographers comprised 63% of all scanning personnel, and that the vast majority of these (141 from a total of 183) performed ultrasound without direct supervision.[64] Furthermore, the South East Thames study indicated that, despite the fact that only 7% of scan sessions were carried out by radiologists, nearly half of all scanning sessions were performed in x-ray departments. This added to their concern that there was not sufficient clinical support on hand for radiographers. When RCOG published its report on routine ultrasound in 1986, one of the many recommendations made was that non-medically qualified staff should be given greater support by clinicians (radiologists or obstetricians). However, this amounted to a request that a Consultant undertake 'a regular weekly scanning session'.[65]

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[64] RCOG, (1984), 'Report of the RCOG working party' p.27, Table 2.2.
[65] *ibid.*, p. 21, Recommendation 3.

The situation in Scotland, however, was somewhat different. As noted in Table 4.1 above, a smaller percentage of radiographers were involved with obstetric ultrasound in comparison with England. Furthermore, the vast majority of obstetric scans in Scotland (76%) were carried out in obstetrics departments, while only 15% were conducted in x-ray departments.[66] Thus, as the case of Forth Park highlights, where radiographers were involved, this was often in association with obstetrics. In Scotland, therefore, arrangements were more disparate, with many hospitals conducting obstetric ultrasound within obstetric departments, but drawing on both radiographical and obstetric staff, as well as a significant proportion of 'other' staff (17%).

Thus in England, the greater centralisation of ultrasound services in x-ray departments and using radiographical staff meant that the appropriate regulation, supervision and training of such staff was a more significant issue there than it was in Scotland. Thus, in its report the RCOG Working Party advocated the introduction of a specialist qualification in obstetric ultrasound, which should be held by all personnel conducting unsupervised scanning sessions. This, in essence, amounted to a concession to the reality of the increasing involvement of non-medical staff with the technology. The increased volume and repetitive nature of the work associated with routine ultrasound screening, inevitably brought with it the continuing delegation of such tasks to lower grade personnel.

Nevertheless, it is clear that the RCOG working party felt that ultrasound technology differed from other imaging modalities such as radiography in a way that was not particularly suited to such delegation:

> The accuracy of ultrasound scanning is very dependent on the skill of the doctor or technician performing the scan. This is more true for ultrasound diagnosis than for other types of investigation such as biochemistry, radiology or nuclear medicine where fairly standardised procedures are adopted. Ultrasound *demands* the ability to interpret images and adapt the scan technique, gain control and dynamic focus settings of the equipment,

[66] Scottish Home and Health Department/Scottish Health Service Planning Council, (1988), 'Obstetric ultrasound in Scotland' p.21, Fig. 1.

> according to the position of the fetus, the size of the mother, the amount of amniotic fluid and many other variables.[Emphasis added][67]

Thus the nature of the technology demanded certain skills, competencies and responsibilities which were not usually delegated to non-medical personnel. The interactive nature of ultrasound scanning, the immediacy of interpretation and diagnosis, the number of variables which could affect the image and the skills required to construct them, all coalesced to make obstetric ultrasound more akin to a form of 'art' requiring craft skill than an easily quantified and regulated 'science'. Admittedly, the transformations in technical design had made ultrasound a much simpler technology to operate. However, human skills and competencies had not been completely replaced by technical means. If RCOG were to advocate the practice of ultrasound screening, they would also have to accept the new division of labour. Thus for the RCOG working party, control over the training of personnel, and therefore the authority to designate who did and did not possess these skills, was a solution to the disharmony of matching obstetric ultrasound to the new division of labour associated with routine ultrasound:

> We believe that this [Diploma in Obstetric Ultrasound] is important in view of the high level of interpretative and communicative skills demanded of those practising obstetric ultrasound, the high degree of personal responsibility involved and the critical nature of the decisions which are often based on the ultrasound findings.[68]

The proposed Diploma in Obstetric Ultrasound was to be the joint responsibility of RCOG and the Royal College of Radiologists. It was to be held by all staff (medical and non-medical) who undertook unsupervised scanning; it would be a specialised form of training dealing only with obstetric scanning; and it would be assessed on the basis of a practical examination. While this may appear to be a fairly sensible and straightforward recommendation, it was in fact highly contentious - the issue of appropriate training had been debated since the late 1970s.

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[67] RCOG, (1984), 'Report of the RCOG working party' p.18.
[68] *ibid.*, p.19.

Throughout the history of obstetric ultrasound's use in clinical practice, the training of new operators had been a largely ad hoc affair. More significantly, it had also been a form of training based largely on practical experience. Although a variety of training courses were offered by various centres (including those in Glasgow and in Dundee) which included lectures on the physics of ultrasound and so on, these were neither universally attended, nor a necessary condition of employment. Instead, new personnel were taught in-house, by staff who were already familiar with the technology. This was also related directly to the types of skill required in ultrasound imaging. A phrase commonly used by ultrasound operators is 'getting your eye in' - learning to be able to read ultrasound images and translate the two dimensional images into three dimensional structures. Furthermore, a certain degree of spatial awareness and manual dexterity was demanded in order to position the probe in the place best suited to achieve the desired image. These therefore were skills that could not be taught by formal lectures, but 'picked up' through practical experience. Even then, as Professor Charles Whitfield notes, not all trainees were able to develop these abilities:

> The funny thing about ultrasound - some bright people who are good clinicians, well trained, just cannot use it. It's like people who want to fly, they find out that some just can't manage and it's to do with three-dimensional co-ordination. I can remember one girl in Manchester who was a bright Australian, and she was absolutely hopeless at it. She said, 'I know I'm competent,' (we both did), 'but I just cannot do this.' And she said, 'some people come in here and can do it in a day or so, and I've been trying for months.' And she just hadn't got the perception.[69]

Thus ultrasound was viewed as a skilled activity which could only be taught through practice. Nevertheless, the differences in the way ultrasound was operated from location to location meant that purely in-house forms of practical training posed significant problems for the construction of universal standards of training. Such methods were also problematic in terms of 'transferable skills' for those who wished to relocate to other centres. For these reasons, and given the increasing use of lower grade staff, the 'problem' of training was a matter of considerable debate.

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[69] Interview with Professor Charles Whitfield, 24/08/99.

The issue was first raised in the BMUS Bulletin towards the end of 1979 and continued to be a regular feature of debate in the journal throughout the 1980s. Initially, however, the debate was generic to medical ultrasound as a whole - and thus not explicitly confined to obstetric applications. However, in 1984 when the issue of the safety of ultrasound in pregnancy was raised, and in particular the appropriateness of routine obstetric scans (given the questions which were being raised over the procedure's possible health risks), the debate over training requirements became more directly focused on ultrasound in obstetrics. Thus, although the debate was in essence generic to the practice of diagnostic ultrasound as a whole, the safety aspects of its application in obstetrics led to a greater focus on training and regulation within that specialist area of medicine.

The first professional body to institute a formal qualification for diagnostic ultrasound was the College of Radiographers. As early as 1977, the College introduced a postgraduate Diploma in Medical Ultrasound (the DMU) which was based on a training period of 12-18 months, final examinations and viva voce, as well as 30 continuous assessment reports. Furthermore, the qualification covered scanning techniques and normal/abnormal appearances in all the major medical specialties, as well as areas such as equipment checks, safety levels, and so on.[70] Nevertheless, at its initial inception, the qualification was not a necessary prerequisite for radiographers wishing to undertake medical ultrasound and many radiographers continued to practice without the DMU. Indeed, Scotland did not have a single centre that administered the DMU until the late 1980s and thus very few Scottish-based radiographers attained this qualification. Those who did tended to be those seeking posts outwith Scotland where, although the DMU was not a pre-requisite for practice, those without this qualification were at a considerable disadvantage.[71]

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[70] An outline of the course requirements for the DMU can be found in BMUS, (1986), *Bulletin of the BMUS*, No. 41, May, pp. 6-7.
[71] Scottish Home and Health Department/Scottish Health Service Planning Council, (1988), 'Obstetric ultrasound in Scotland, p.48.

Part of the reason why the DMU was so poorly valued in Scotland relates to the fact that ultrasound services were not concentrated in x-ray departments in the same way they were in England, as noted above. The greater centralisation of ultrasound services in England meant that the DMU qualification for radiographers was more appropriate for their purposes. Unlike their colleagues in Scotland, radiographers who conducted obstetric ultrasound scans in England would also provide ultrasound examinations for a number of other specialties. Thus a form of training that offered a general knowledge and competence in medical ultrasound, rather than a specialist training in its obstetric applications, was a more suitable qualification.

Despite the introduction of the DMU, therefore, the training of the vast majority of ultrasound operators in Scotland (clinicians, technical staff and personnel from other backgrounds) remained in-house and ad hoc. However, by the end of the 1970s, the changing nature of ultrasound diagnosis, and the increasingly specialist nature of examinations, raised concerns that such training procedures were inadequate. In November 1979, an editorial in the BMUS Bulletin outlined some suggestions relating to the future training of ultrasound operators.[72] In particular they advocated two main developments: the creation of recognised training centres which would cater for the training of personnel in all specialties and at all levels; and the creation of a British Institute for Ultrasound in Medicine which would be responsible for the accreditation of courses and the registration of members on the basis of formal training and continual assessment. Thus, initially at least, BMUS favoured a collective form of training, presided over by a body independent of all the main professional groups. With these recommendations in mind, the BMUS committee set up a meeting with the various professional colleges and societies associated with the delivery of diagnostic ultrasound to discuss the issue. The outcome of this meeting was reported in the Bulletin in October of 1980, with the following conclusions:

> In general the representatives of the various colleges and societies were against the idea of setting up a joint institute to look after education in ultrasonics and certification of personnel. It was concluded that each group

[72] BMUS, (1979), *Bulletin of the BMUS*, No. 25, November, p.1.

> e.g. radiologists, physicists, obstetricians, radiographers, etc., would have to look after their own training.[73]

For the historian of medicine, it is tempting to explain this resistance to the idea of unified and centralised training centres by reference to professional interests and inter-specialty power dynamics. Thus it could be argued that vested interests in maintaining control over the technology within one's own field led to an unwillingness to allow members of a particular professional body to be trained by other personnel. Nevertheless, it is clear that the outcome of this debate was again fashioned more by the nature of ultrasound imaging than by professional interests. Standardised training of this magnitude was simply impractical for a technology characterised by heterogeneous forms of practice. Within obstetrics, for example, the sheer number of diagnoses of increasing complexity that could be made, not to mention other skilled practices such as invasive procedures guided by ultrasound, entailed that the expertise required of senior clinicians within the field was highly specialised. A common qualification held by all operators in all specialties was clearly felt to be inappropriate.

Thus the call made by the RCOG working group in 1986 for a standardised obstetric ultrasound diploma must be viewed from within the context of this debate. The recommendation they made was much more limited in nature, but was nevertheless a call for a standardised level of basic training for all staff performing unsupervised sessions. In their opinion, the DMU was too generalised to demonstrate adequate competency in obstetric ultrasound and thus even those radiographers who possessed this qualification were not necessarily competent to conduct unsupervised sessions.

Once again, however, the call for a standardised basic training in obstetric ultrasound did not become a reality and the various professional bodies continued to regulate the ultrasound training of their own members. Knowledge and practical experience of ultrasound (including 200 hours of supervised scanning of which at least 75 hours had to be in obstetrics) was included amongst the requirements for the Fellowship of the Royal College of Radiologists,

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[73] BMUS, (1980), *Bulletin of the BMUS*, No. 28, October, p.1.

while the Royal College of Obstetrics and Gynaecology required knowledge of obstetric ultrasound (assessed via examination) from all those seeking Membership.[74] Furthermore, in 1986 a Joint Ultrasound Group (chaired by Professor Charles Whitfield) was established between the two Royal Colleges, whose specific remit was to harmonise the training of obstetric ultrasound for radiologists and obstetricians, a substantial part of which was to be based on practical experience.[75] The proposed course was aimed at clinicians planning to take a leading role in the delivery of obstetric ultrasound services, and therefore was not proposed as a form of 'basic' training - this continued to be dealt with separately.

Implicit in the resistance to a universal form of training for all ultrasound operators, was the idea of a hierarchy of examination 'types' and thus a hierarchy of skills and competencies required. In other words, not all ultrasound procedures were considered suitable to be carried out by lower-grade staff such as midwives and radiographers. Thus a notion of different levels of expertise and therefore non-uniform skill requirements, was threaded through the debates over training. However, while this perspective was commonly held amongst those who worked with the technology, defining where the boundaries were drawn between different types of practice was problematic. First of all, the way in which certain procedures were viewed was historically contingent. In both the Queen Mother's and Aberdeen Maternity Hospital, for example, ultrasound-guided amniocenteses were initially only done by clinical staff. Towards the end of the 1980s, however, midwives were also performing these tests.[76] The reasons for the 'downgrading' of this practice were numerous. The increasing quality of ultrasound images and improved ergonomics of probes provide a technical reason. As Charles Whitfield commented:

> Technological developments, which continue to be frequent, not only enhance the performance and range of application of equipment but often

[74] Scottish Home and Health Department/Scottish Health Service Planning Council, (1988), 'Obstetric ultrasound in Scotland, p.47.
[75] Royal Colleges of Obstetricians and Gynaecologists and of Radiologists, (1987), 'Report of the joint ultrasound group' London, RCOG; Whitfield, C.R., (1992), 'Training in ultrasound in obstetrics and gynaecology' in Chervanek, F., Isaacson, G. & Campbell, S., *Ultrasound in obstetrics and gynaecology,* Little, Brown & Co., Boston, Mass., (offprint).
[76] Interview with Dr Margaret McNay, (05/11/97); interview with Dr Patricia Smith, (01/04/98); interview with Dr Norman Smith, (01/04/98); interview with Sister Grace Porter, (01/04/98).

> simplify their operation and make training easier so that some of the guidelines and expected skills will change.[77]

In addition, the proliferation of more complex procedures (such as intrauterine fetal surgery and chorionic villus sampling) and the increasing numbers of amniocenteses requested - particularly in light of AFP screening programmes - exerted an organisational pressure for the delegation of this task in order to free clinicians for more difficult procedures.

A further complicating factor was locational diversity. First of all, practices considered to be complicated procedures to be performed only by clinicians in one centre, might not be regarded as such in another. The difference between district general hospitals and large tertiary centres, in terms of size, staffing levels and patient characteristics, came into play here. So too did the quality of equipment being used. Furthermore, the site-specific mix of personnel in each centre also made the implementation of a universal hierarchy difficult to achieve. In Perth and Dundee, for example, a strict 'clinicians only' rule for certain procedures would effectively entail the replacement of Sandy Christie as head of the scanning team.

In Scotland, this diversity of practice was clearly evident to the NMCC's Ad Hoc Ultrasound Group when they examined the delivery of obstetric ultrasound. More importantly, it shaped the recommendations they made for harmonisation of services across the country. In their report, they acknowledged the emergence of a three-tier pattern of expertise and function. However, in attempting to specify the contours of this pattern in the form of a recommended hierarchy they were careful to note that it should encompass 'flexibility in accordance with local practices'.[78]

The structure proposed by the Ad Hoc Group was thus a reflection of current 'best practice' (see Appendix 1). This was to provide the template for the delivery of obstetric ultrasound in the context of universal screening and the use of non-clinical staff. The first level of scanning related to the types of practices associated at the time with screening. All observations (except

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[77] Whitfield, C.R., (1992), 'Training for ultrasound' p.3.
[78] Scottish Home and Health Department/Scottish Health Service Planning Council, (1988), 'Obstetric ultrasound in Scotland, p.39.

determining gestational age and fetal presentation) were asterisked to indicate that abnormal findings were to be referred for further scanning.

However, the way in which such a follow-up referral system was organised differed from location to location. In centres where a clinician was always on hand to re-scan patients, abnormal findings were always diagnosed on the same day. This was easier to achieve in those centres (such as the Queen Mother's, Aberdeen and Kirkcaldy) where ultrasound was located within obstetrics departments and where obstetricians were trained to use the technology. In centres where clinical support was provided by radiologists, suspected anomalies would be given another appointment to see an obstetric consultant who would report the ultrasonic findings. In the Western Isles, where much of the screening took place off-site in peripheral clinics and GP surgeries, anomalous findings were referred either to the Lewis Hospital or to the Queen Mother's in Glasgow, depending on the nature of the problem.

However, in light of the literature on the potential for 'bonding' to take place between pregnant woman and unborn child, ultrasound operators were actively encouraged to explain the images to pregnant women, to point out features in the scan.[79] This, coupled with the immediacy of real-time imaging and its interactive nature, entailed that the silence of the operator and the very fact that an additional scan was to be performed by another person, alerted pregnant women (and their families, if present) to the presence of a problem. A number of strategies were employed in an attempt not to worry patients and to ease the pressure on non-medical staff confronted by worried questions. In Kirkcaldy, for example, the scan would first be conducted with the screen turned aside from the pregnant woman. If normal the scan would be repeated to show pregnant women the 'baby'. If a problem were detected, excuses such as poor resolution ('I can't get a good picture') would sometimes be used. In the Queen Mother's, patients would be told at the outset that the operator would 'take a while' to make measurements etc. before explaining the image - thus providing a reason for operator silence at the outset. Nevertheless,

[79] Both the RCOG working party report and the NMCC Ad Hoc Group report noted that pregnant women should be encouraged to observe the scan images. The issue of bonding is discussed in greater depth in the coda to this thesis.

the inability of operators performing Level 1 scans to communicate problems to pregnant women was an uncomfortable situation.

At the second level (which included amniocentesis and detailed anomaly scans) a greater level of expertise was required for the more detailed analysis of the ultrasound image and formal diagnosis of specific conditions. Aside from obstetricians and radiologists, the only other staff appropriate to carry out such examinations were those radiographers and midwives who had a major role in the training of staff. From their discussion of this system, it is clear that the Group felt the most appropriate personnel for this level were obstetricians. They emphasised the continuity of care that could be provided by this group when decisions regarding future medical management were made. Furthermore, the few lower-grade staff who operated scans at this level were again confined by their inability to formally diagnose - this had to be done either by the obstetric team in charge of the patient's overall care, or by the clinician in overall charge of the service (if he/she was an obstetrician). The Group advocated that scans at Level 1 and 2 should be available in all hospitals, while peripheral clinics and larger GP obstetric units should be equipped to perform only Level 1 scans. The more specialised and interventionist forms of ultrasound were confined to Level 3 and were considered appropriate only for regional referral centres in the four main cities (Glasgow, Edinburgh, Aberdeen and Dundee).

Unlike the attempts made by RCOG to standardise training requirements, the Ad Hoc Group's guidelines for standardising the organisation of ultrasound services were relatively successful. As late as 1998, for example, the 'Three Levels of Obstetric Ultrasound' table was reproduced in an overview document on obstetric ultrasound provision in the Grampian region.[80] Furthermore, the language of 'Levels' entered into common parlance, and (when interviewed for this project, for example) actors would commonly refer to Levels 1, 2 and 3 when discussing what their job entailed. Thus the Ad Hoc Group's recommendations were successful in providing a set of parameters for the organisation of practice and a common language

[80] Anon, (1998), 'Obstetric ultrasound service in Grampian: working document to establish the past, present and future provision of obstetric ultrasound for Grampian' Aberdeen (no publisher given).

through which activities in different locations, performed by different actors, could be compared and discussed.

Nevertheless, it is evident that this form of standardisation was successful precisely because it was vague enough to allow heterogeneity in practice to continue. Unlike the clearly defined division of labour within x-ray imaging, for example, the division of labour described here reflected diversity. For example, the fact that *some* radiographers and midwives were included as appropriate staff at Level 2 can only be viewed as an acceptance of current practice in some areas such as Glasgow. Furthermore, the training required for each level was defined in practical experience terms rather than in terms of formal qualifications, such as the DMU as a pre-requisite for radiographers. They also advised health service planners to provide resources for screening strategies of 2.5 scans per pregnancy: i.e. between two and three scans per patient. In this way, they did not directly advocate any of the systems in current practice - instead providing ample scope for continuing flexibility.

Thus, rather than set down specific and tightly defined *prescriptions* for the staffing and delivery of obstetric ultrasound, the Ad Hoc Group attempted to provide an over-arching *description* of current practice. This was not, therefore, an attempt to impose standardisation in the usual sense of the term, but an act of harmonisation which attempted to encompass the heterogeneity and diversity of ultrasound practices in Scotland. In this way, a variety of local circumstances shaped site-specific local arrangements, which in turn shaped national policy. Heterogeneity thus emerged as an endemic feature of the routine use of ultrasound in obstetrics.

Conclusions

During the 1980s obstetric ultrasound emerged as a regular feature of antenatal provision in Scotland. Not only did it become an indispensable tool, used in the diagnosis of an increasing number of conditions and pathologies in pregnancy; it was also reconceptualised as a screening technology to search for hidden pathology when no clinical signs were identified. In addition, the routine performance of ultrasonically determined fetal measurements became the cornerstone of the medical management of pregnancy. These measurements were used to determine gestational age which in turn became the basis upon which a number of organisational and clinical decisions were made (from when a pregnant woman next needed to attend the antenatal clinic to decisions regarding induction of labour). Thus obstetric ultrasound in the 1980s performed a prominent role in the medical management of pregnancy and the overall delivery of obstetric medicine.

Furthermore, a significantly high proportion of staff, drawn from a number of professional backgrounds, were involved in the delivery of the technology, particularly in terms of its use as a universal screening device. However, the performance of routine ultrasound involved two separate kinds of competency. The first was the ability to take accurate measurements from the fetus (head circumference, BPD, crown-rump-length etc) and to perform a series of checks (location of placenta, number of gestations, fetal heart movements, and so on). In addition, however, ultrasound was also used for the direct visualisation of pathology - intrauterine death, placental abruption, fetal abnormality. While the former types of competency could more easily be delegated to non-medical staff, this was not the case with the latter. Thus although the development of routine ultrasound was achieved via the increased use of non-clinically trained staff to perform the majority of examinations, this was not an easy division of labour to manage. A number of strategies evolved to deal with diagnoses of pathology encountered by non-clinical staff performing routine scans.

Nevertheless, while it might be tempting to conclude that ultrasound had thus become a stabilised technology and a standard procedure, the enduring heterogeneity that existed in the technology argues against this. On a site-by-site basis, key differences remained in the delivery of ultrasound, including the training of operating personnel, their professional backgrounds, the timing of routine examinations and the overall shape of ultrasound services.

For this reason, the concepts of 'standard procedure' and 'stability' in terms of the technology's provision across Scotland can only be applied at a very superficial level. It was ubiquitous; it was regularly used; and there were some basic similarities in its delivery. Nevertheless, enough diversity remained to justify the conclusion that it was never a completely standardised or stabilised technology. Thus, rather than apply these terms in a generalised manner, they are perhaps more appropriately used to describe site-specific developments. That is to say, the 1980s witnessed the increasing stability of local practices as the role and organisation of ultrasound became more clearly defined in each location.

Nevertheless, that is not to suggest that even at the local level, major transformations did not occur. The reconfiguration of ultrasound's delivery to encompass its new role as a screening technology was a significant development during this period and was accommodated in different ways in each location. When placed into practice, each location pursued a routine policy suited to its particular circumstances and thus imposed its own form of stability on the new arrangements.

Furthermore, it can be argued that the reconceptualisation of obstetric ultrasound as a screening technology represents an instance where the use of a relatively 'stabilised' artifact did not represent the end of the development of the technology. The underlying technical configuration of real-time ultrasound was not challenged during this period, and yet the technology underwent a period of significant reorganisation. The debates surrounding the development of ultrasound screening were as prominent as those which surrounded the introduction of RT in the 1970s but were of a different nature in that they related more specifically to the social organisation of the technology than to its technical composition. Thus the relative stability of an artifactual design should never be considered as the end stage of a technology's development. Furthermore, the persistence of heterogeneity in the face of a number of attempts to create greater standardisation of obstetric ultrasound, suggests that technological debates and controversies are not always 'closed' through the formation of consensus. Instead, the debates over the delivery of routine ultrasound and the training of staff suggest that diversity can be embraced in technological decision-making.

In conclusion, therefore, the term 'routine ultrasound' is something of a misnomer. Routine practices were developed at the local level, but never universally standardised. This in turn was a direct consequence of the way in which local factors shaped the nature of ultrasound technology and thus of the diversity of local arrangements. In comparative terms, obstetric ultrasound remained a heterogeneous practice, within which a variety of routine procedures (which had emerged from, and been integrated with, local conditions) co-existed.

Coda

Scan stories: pregnant women's experiences with obstetric ultrasound

What swims up on screen resembles
The satellite weather-map before
The news.   ... Zoom
To another part of the sky, to a moon
Half-buried in cloud. An orbit
Already guessed at. It shows us
Its dark side, the face that no one sees.
I look at it hard while Dr. F. makes stills,
Clicking around it with the mouse.
And now, time for the news.
As usual, it's bad.[1]

Introduction

The aim of this coda is to present a collection of individual accounts of women's experiences of obstetric ultrasound during pregnancy. While these accounts do not contribute to the elaboration of the themes outlined in this thesis, they nevertheless provide an alternative view of the technology and its application within obstetrics. Furthermore, a wealth of material is already available, which addresses the impact this technology has had on the experience of pregnancy.[2] Most of these studies and commentaries have emerged from feminist discourses and are centred around themes such as the medicalisation of the pregnant body, alienation in the experience of technologically-managed pregnancy and the changing power dynamics between pregnant woman, medical profession and fetus. It is not the intention here, however, to engage

[1] Crowe A., (1994), 'Forecast', in Kennedy A.L., McGonigal J. & Bateman M. (eds.), *A Sort of Hot Scotland (New Writing Scotland),* Association of Scottish Literary Studies, Aberdeen.

[2] Düden B. (1993), *Disembodying women: perspectives on pregnancy and the unborn,* Harvard University Press, Cambridge Mass. & London; Greig R., (1995), *Pregnancy in a high-tech age - paradoxes of choice,* New York University Press, New York; Oakley, A. (1984), *The captured womb: a history of the medical care of pregnant women,* Basil Blackwell, London; Petchesky, R. (1987), 'Fetal images: the power of visual culture and the politics of reproduction', *Feminist Studies,* Vol 2, No. 2, pp. 263-93; Rapp R. (2000), *Testing women, testing the fetus: the social impact of amniocentesis in America,* Routledge, New York; *idem.,* (1997), 'Real-time fetus: the role of the sonogram in the age of monitored reproduction' in Downey, G.L. & Dumit, J., (eds.), *Cyborgs and citadels,* School of American Research Press, Santa Fe, New Mexico; Saetnan, A.R., (forthcoming), 'Thirteen women's narratives of pregnancy, ultrasound and self' in Saetnan, A.R., Oudshoorn, N. & Kiejczyk, M., (eds.), *Localizing and globalizing reproductive technologies,* Ohio State University Press, Ohio.

with the various theoretical debates and perspectives associated with this literature: these lie beyond the remit of this thesis and will be addressed elsewhere.[3]

Instead, women's recollections of their ultrasound experiences will be presented as an adjunct to the main thesis. However, in order to provide a framework within which women's experiences and stories can be compared, the theme of inclusion/exclusion in the experience of obstetric ultrasound will be explored. How involved did women feel in the scanning process, and what factors affected their experiences? What will be emphasised, is that women's accounts of the scanning process have to be viewed with reference to their wider experiences of pregnancy, their interpretations of the purpose of their own ultrasonic examinations and their perceptions of the images produced. There are, in other words, no straightforward, mono-causal explanations that can account for the variety of individual women's accounts.

In all thirteen women were interviewed about their ultrasound experiences. The interviews themselves were informal and open-ended, lasting anywhere between half an hour to two hours. In order to maintain confidentiality, the women have been given pseudonyms while the names of obstetricians, ultrasound operators and hospitals have been excised from the accounts.[4] It should also be noted that these accounts should not be directly related to the hospitals used as case studies in this thesis: they have been drawn from women attending a variety of centres across Scotland.

A few topic areas were used as a prompt and guide but, as much as possible, the women were encouraged to tell their stories themselves. As an 'outsider' and non-medical researcher, it was inappropriate to use medical records to trace possible interviewees. Thus the women in the study were contacted through a variety of formal and informal means: through advertisements

[3] Nicholson, D., (forthcoming), 'Interacting with images: experiences of obstetric ultrasound during pregnancy' (unpublished work-in-progress).

[4] The only exception to this is Betty's story. Given that this account dates from very early in the history of the technology (1960) and that this, in itself, was an important feature of Betty's experience, it was considered appropriate to identify the hospital and personnel. This does not effect Betty's anonymity and allows a more detailed account of ultrasound in this experimental stage from the patient perspective.

in local newspapers, suggestions from colleagues and friends, etc. There is therefore no means of assessing the representativeness of this 'sample' - of generalising from their stories to make claims regarding 'all' women who received ultrasound.

However, for the purposes of this examination, 'representativeness' is not an important issue.[5] These women speak for themselves about their interactions with technology - about the way in which they perceived ultrasound, its effect on their pregnancy and how they felt about it. In other words, in the same way in which ultrasound as a technology developed in a subtly different way in each centre in this study as a result of particular, local circumstances, each woman's experience of ultrasound was born from the interactions between her, the equipment, the location, the operator and other events or circumstances in her life. Therefore, they do not, and cannot, speak for all women - however one might choose to subdivide, categorise or quantify that population. Nevertheless, the fact that some similarities in experience can be detected, both amongst the group of women in this study and through comparison with women interviewed elsewhere[6], points to possible areas where generalisations can be suggested.

What will be presented in this coda, therefore, is the variety of factors that were pulled into individual women's interactions with ultrasound. These factors did not mediate between woman and technology - they were encompassed in that relationship, part and parcel of their experience. Thus for each woman ultrasound 'meant' something different. However, given their assigned role as patient (and female patient, in particular) this form of 'interpretative flexibility'[7] did not lead to technical manipulation or development. In the UK, as in other countries[8], the voices of pregnant women have not been prominent in debates over the use of

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[5] More comprehensive studies, drawing on larger and more standardised selections of interviewees have been carried out elsewhere. For a comprehensive bibliography of such studies see Garcia, J., Bricker, L., Henderson, J., Martin, M., Mugford, M., Nielson, J., Roberts, T., (2002), 'Women's views of pregnancy ultrasound: a systematic review' *Birth,* Vol. 29, No. 4, pp. 225-250.
[6] Garcia, J. *et al,* (2002), 'Women's views of pregnancy ultrasound'; Greig R., (1995), *Pregnancy in a high-tech age;* Rapp R. (2000), *Testing women, testing the fetus; idem.,* (1997), 'Real-time fetus'; Saetnan, A.R. (forthcoming), 'Thirteen women's narratives of pregnancy, ultrasound and self'.
[7] Pinch, T.J. & Bijker, W.E. (1984), 'The social construction of facts and artifacts; or how the sociology of science and the sociology of technology might benefit each other' *Social Studies of Science,* Vol. 14, pp. 399-441.
[8] See, for example, Saetnan, A.R. (forthcoming), 'Thirteen women's narratives of pregnancy, ultrasound and self'.

medical interventions such as ultrasound. The only UK lobby group which professes to 'speak for' them is AIMS (the Association for Improvements in Maternity Services).[9] This group, however, does not carry much weight and although it professes to provide a focal point for women's dissatisfaction with their care during pregnancy, it has not gained a wide membership or affiliation even from women with such experiences.

Nevertheless, although the interpretations of ultrasound formed by the women interviewed were not powerful enough to shape the technology, in some respects elements of their accounts can be interpreted as 'accommodation strategies'. Depending on their individual circumstances, women came to terms with this technology in different ways by translating ultrasound into their general experiences of pregnancy, childbirth, risk, pathology and antenatal supervision. Their perceptions of the technology, therefore, were the result of a myriad of factors and circumstances.

The women and their pregnancies

The thirteen women interviewed received ultrasound examinations throughout a period spanning over thirty years, the earliest dating from 1960 and the most recent from 1992. Their experiences thus cover most of the technology's development from innovative procedure to routine screening device. In total, they were scanned during twenty-five pregnancies.[10]

Seven women were scanned during one pregnancy, four during two pregnancies, one over four and one over six. Interestingly, nine of the thirteen women received scans during at least one pregnancy for non-routine purposes. In other words, these women were examined ultrasonically for specific clinical diagnostic purposes ranging from problems associated with their obstetric history to potential problems identified from their current pregnancy. Betty, for example, was scanned in 1960 after three previous miscarriages. Janet had previously given birth to a child

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[9] More information on AIMS can be found at www.aims.org.uk. They also produce a monthly journal, one volume of which is dedicated to their views on ultrasound (AIMS, (1992), 'Ultrasound? Unsound' *AIMS journal,* Vol. 5, No. 2).

[10] Women who were given ultrasound scans during more than one pregnancy often had different experiences from one pregnancy to the next. Therefore, to avoid confusion, when reporting their narratives, the year of the scan to which they are referring is noted (unless they are providing a more general account), along with their 'name'.

with neural tube defects in the early 1970s, who died of meningitis at 4 months of age. In 1968 Catherine was examined - presumably because at 41 she was considered 'high risk'. Other women were scanned because they were suspected of carrying twins, had high or low blood pressure, suspected placenta praevia, or large or small for dates gestations. Two women were also offered 'reassurance' scans when they themselves felt there was something wrong with the pregnancy, and a further two women received ultrasound as part of amniocentesis testing. Thus, although these women represent only a very small proportion of the number of women exposed to ultrasound during this period, their experiences cover a wide range of the uses of the technology throughout its history.

Betty's is the earliest account - dating from 1960, during the technology's innovation period in Glasgow. Having had three previous miscarriages, Betty was referred to Professor Donald by her general practitioner. As soon as she found out she was pregnant again (at about eight weeks) she was admitted to the obstetric ward in the Western Infirmary where she remained as an in-patient until she was about seven months pregnant. Thus, in some senses Betty's ultrasound scan had little to do with the management of her pregnancy - in the 1960s bed rest was by far the most common 'treatment' for repeated miscarriage.[11] However, the almost five months which she spent in hospital was associated with loneliness. Hospital policy did not allow children to visit the ward, and so Betty was separated from her one-year-old son throughout this time.

Betty was one of a group of four women sharing a ward for long term patients - all of who were asked to participate in the testing of the new ultrasound machine. In terms of her introduction to the technology, therefore, Betty's experience was rather unusual. She was not being introduced to a machine which, although new to her, was a standard part of the obstetrician's day, but was being asked to participate in the trial of an innovation. Given this rather unique situation, it is perhaps unsurprising to learn that Betty was asked for permission for ultrasound to be used; was

[11] Indeed, according to Oakley, McPherson and Roberts, bed rest remained the most popular method of managing women with an 'incompetent cervix' (which was Betty's eventual diagnosis) until at least the 1980s. Oakley, A., McPherson, A. & Roberts H., (1990), *Miscarriage,* Penguin Books, London, pp. 133-136.

taken down to see the machine the day before her scan; and was shown the resultant Polaroid pictures by an enthusiastic Ian Donald the day after.

Furthermore, Donald explained both the purpose of the scan and the procedure itself to Betty. This, as will be demonstrated when the experiences of other women are considered, is probably the most unusual aspect of Betty's scan:

> I must have been in about four months when he asked me. He explained the technique, that it wouldn't harm my baby, because, I mean, in those days you didn't know whether it harmed your baby or not. He said it'd be a great achievement if he could make anything out of it once the scan was done. He took me into this room and showed me the machine.[12]

Thus Betty's scan, occurring as it did when the technology was still very much its infancy, was characterised by a great deal of consideration for her position as a 'guinea pig'. Donald appears to have made an effort to ensure that she did not feel frightened of, or worried about, the procedure.

From this it could be argued that this early patient encounter with ultrasound was characterised by a relatively large degree of information and explanation of the process. However, the importance of this should not be overstated. The information was still communicated from within the context of a consultant obstetrician telling his patient that consenting to this examination was in her interest and was his medical advice. Mediated by that context, therefore, it is fair to say that she was only given as much information as was deemed appropriate by Donald. For example, Betty's recollections of how Donald explained the procedure are that:

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[12] Interview with Betty, December 1997.

> He said it took, it would take pictures of the baby in the womb and everything to tell him if everything was okay, or not okay...'It'll crawl over your tummy', he said.[13]

For other women, however, very little information was offered either in relation to why they were being given scans or what the examination involved. Catherine, for example, was scanned in 1968. Pregnant for the first time at the age of 41 she presumes she was considered a high-risk case as a result of her age. However, she was scanned for the first time after being admitted for a week with high blood pressure, and was examined with ultrasound twice more shortly before labour:

> I thought everyone had them but one of the nurses said to me, 'we have to wait until Dr X comes, he's the only one who can operate it'. So then I realised it was something very new. They didn't explain what it was for. There was no communication with us at all to say why I was being chosen. I never thought to ask the purpose of it - I thought everyone got this treatment.[14]

Many of the other women also report similar experiences - of not being entirely sure why they were being scanned or what was being looked for. Many, like Catherine, made their own conjectures: 'I think probably my age was the reason' (Catherine, 1968); 'I was late and I think they thought the placenta was coming before the baby' (Molly, 1979); 'I take it it was to do with the urine sample they were collecting' (Frieda, 1982); 'I assumed it was just part of the routine' (Sharon, 1989). It is interesting to note that these similar experiences occurred despite the women being of different ages when they were scanned (22-41) and at different periods in the history of this technology (1968 - 1989). Thus it would appear that a persistent feature of at least some women's experiences is a lack of information or explanation of the purpose of the scan. This therefore would appear to support to some extent the claims of feminist critics such

[13] Interview with Betty, December 1997.
[14] Interview with Catherine, July 1998.

as Oakley and Düden that technologies such as ultrasound can contribute to a feeling of alienation and powerlessness.[15]

However, this should not be viewed either as an inherent feature of ultrasound or as a feature peculiar to the technology. Lack of communication between doctors and patients more widely has been a persistent feature of the critique of medical practice.[16] In their testimonies, the women mentioned a number of procedures carried out during pregnancy and labour which they did not know the purpose of (Frieda, for example, did not know what the numerous urine samples were for). Furthermore, one of the women expressed a large degree of dissatisfaction with the amount of information she received throughout her pregnancy, *except* during one of her ultrasound scans. In Roberta's view, her status as a single parent and her social class position led her to be treated unfairly:

> there was a woman in the next bed who was a social worker, or her husband was, and she held quite a good position in her job and the way they approached and spoke to them, it was like they had more time. If she, or her husband, wanted to know something they sat down and explained things. My mum was forever running out the ward chasing somebody to find out information.[17]

In addition, only two of the women had some idea of how ultrasound actually worked. One was a practising midwife when she became pregnant and had acquired her knowledge of the technology through her training. The second had a complicated history of neural tube defects and became something of an amateur expert on the technology over her six pregnancies. Nevertheless, none of the thirteen women (except for Betty) had the technology explained to them before the scan - none were given any details as to how the images were created using

[15] Oakley, A., (1984), *The captured womb;* Düden, (1993), *Disembodying women.*
[16] For studies of doctor/patient communication out with obstetrics see, for example, Stoeckle, J.D., (ed.), (1987), *Encounters between patients and doctors: an anthology,* MIT Press, Cambridge, Mass. For a study of clinical encounters during pregnancy see Oakley, A. & Graham, H., (1981), 'Competing ideologies of reproduction' in Roberts, H., (ed.), *Women, health and reproduction,* Routledge and Kegan Paul Ltd., London.
[17] Interview with Roberta, March 1998.

sound waves. In the absence of such information, the women were left to make sense of the technology themselves:

> To me it looked like a microphone, which it is because it's picking up the heartbeat, isn't it?[18] (Lucy, 1979)
>
> I wasn't worried about side effects or anything because I realised there was nothing going inside me, nothing was coming into contact with the baby or anything.[19] (Molly, 1979)
>
> He hadn't told me anything. He never said it was painless, just that it would determine whether there was one or two [fetuses].[20] (Kelly, 1976)

However, it is interesting to consider that even for women who had never heard of ultrasound before, very few of them actually worried about what was going to happen or what a scan might involve. Nevertheless, this must be viewed in the context of their more general experiences of pregnancy. For many, the fear that something might be wrong entailed that they were concerned about the results of the scan - rather than the procedure itself:

> In a way I suppose we could be taken advantage of. I got to the stage where they could do what they liked as long as everything was all right.[21] (Catherine, 1968)

Another common theme was faith in the medical profession and the general authority with which they were viewed. For all these reasons, the women implicitly consented to a whole battery of tests and procedures without question and these themes run throughout many of their narratives:

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[18] Interview with Lucy, July 1996.
[19] Interview with Molly, July 1996.
[20] Interview with Kelly, March 1998.
[21] Interview with Catherine, July 1998.

> You know in they days your doctor was always right - if he advised it was good for you, you would do it. Your faith in your doctor was complete. You just, you put your faith in this man. He was a great man. I always trusted him...I mean, you know, if he'd have said 'I'm going to cut you open' that'd have been all right. I would have done handstands for him.[22] (Betty, 1960)

> They didn't tell me anything, I just presumed they were having a look to know what was happening, but they never told me anything. And I'm not the kind of person who would have asked, I mean, I would now but not when you're younger, you don't know what's happening. I had total trust in them, though. I think it's because you're so ignorant. You just do what you're told. I mean, you trust them because they're the experts.[23] (Molly, 1979)

The scan

Women's accounts of the actual scan itself were varied, although there were a few shared experiences that cropped up in their narratives. The scanner itself was rarely something clearly remembered by the women. To them, it was simply another piece of medical equipment being used to check everything was okay. Some women, who were scanned in the 1960s and early 1970s, recall the large gantry over the bed ('...it was a big machine where something attached to a frame came over you'). Women scanned with later, real-time equipment often likened it to a computer ('there was just one lady sitting at like a massive computer with the screen'). Given the relatively little information they were given about what the process involved, it may seem rather surprising that they were not more curious about what the machine was. However, in terms of their recollection of the procedure it is possible to perceive a divide between visual and 'felt' knowledge. All of the women have clear recollections of the physical sensations associated with the scan, the contact gel applied to their abdomens and particularly the discomfort of maintaining a full bladder:

> You would go in the morning with a full bladder and would change into a gown. I think latterly they just asked you to pull your underwear down

[22] Interview with Betty, December 1997.
[23] Interview with Molly, July 1996.

> or asked you to take your pants off because the gel is quite messy.[24] (Janet)
>
> I had to drink lots of water and even when you got there you had to drink more and couldn't go to the toilet. It was uncomfortable and there was people going in for their scan and getting sent back out again because their bladder wasn't full enough.[25] (Kelly, 1986)
>
> There was like a little reception, and I got my card and was sent round to where the little waiting area was and sat there, because of course, you've to have a full bladder which is most uncomfortable. I think I sat there for about 15 minutes and had to drink more water before I went in. I couldn't wait and had to go to the loo, and so I had to drink more water.[26] (Lucy, 1979)
>
> That was a nightmare, and not just that you have to drink it - you have to hold on to it for a long, long time, before they say you can go to the loo. All you can think about is going to the loo and I'm sure I had to give them a mid-stream sample and all you want to do is get rid of it all![27] (Sharon, 1989)

It could be argued that as pregnancy is something which women experience rather than observe, they become more attuned to physical sensations than visual ones in their encounters with medical care. However, given the number of diagnostic tests to which they are exposed, from internal examinations to needles for extracting blood, it is perhaps unsurprising that physical sensation is more memorable than things which they see. Pain and discomfort are arguably more immediate in their effects on the body.

Perhaps the most unusual scan story is Betty's. Although Ian Donald had gone to great lengths to introduce her to his (at that stage) still experimental machine, there was one significant detail which he missed out:

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[24] Interview with Janet, July 1998.
[25] Interview with Kelly, March 1998.
[26] Interview with Lucy, July 1996.
[27] Interview with Sharon, March 1998.

> When I did go in eventually, there was only one big light and it was like a theatre table that I lay on and the nurse smeared stuff *all* over my stomach - not these wee bits and pieces they do now. And then it just, 'click', like it was crawling all over clicking and then the lights went up and we were surrounded by all these students. They'd been very quiet - I was mortified! And if he had told me, it wouldn't have bothered me, but I just didn't know they'd be there.[28] (Betty, 1960)

While dimming the lights may have been a gesture towards keeping Betty's nervousness to a minimum, it would probably have been technically necessary so that the others in the room could see the picture developing on the screen. However, given the effort Donald appears to have made to provide her with as much information as possible, it is perhaps slightly unusual that he did not ask her permission to use her scan for demonstration purposes.

For all of the other women, however, the scan was a more private affair. The majority had only one or two medical staff in the room (if two were present, one was always a clinician). Only three women were invited to bring along another family member during the scan - Jane brought her husband, Kelly brought her daughter and Roberta, a single parent, was accompanied by her mother.

The theme of inclusion/exclusion can again be identified in the women's recollections of the scan process. The more involved they felt with the procedure, the more detailed their memories. Irene, for example, was not spoken to during the scan and was not directly informed of what the examination was for:

> I remember lying down, but I don't remember paying any attention to it because that wasn't on my mind, you know, it was just the outcome. I think I must have been apprehensive about the whole thing, but I

[28] Interview with Betty, December 1997.

possibly didn't know that that machine was connected with me.[29]
(Irene, 1972)

For others, such as Lucy and Catherine, their lack of involvement in the scanning process is clearly linked to the actions of the scan operator(s):

> I can't remember them saying anything very much at all, to be honest. I felt kind of isolated now that I think about it, sort of anonymous as well. I mean I wasn't scared, but you're a wee bit apprehensive when you're getting something that you've never had before. I was never really given the opportunity to ask questions, I mean, no one really invited me to do that. They spoke to each other and they never included me in anything they said to each other. They were speaking about what they were writing down, but they were never forthcoming.[30] (Lucy, 1979)

> He never spoke. He just came into the room and the stuff was rubbed on your belly and that was it. He didn't speak until the very last time when I asked how things were, because I was a bit suspicious because they had taken me [for a scan] for a third time, and I didn't know if it was routine or not. He said, 'you have a fine, healthy baby', and I thanked him very much.[31] (Catherine, 1968)

Clearly, non-communication with pregnant women during ultrasound scans can contribute very directly to feelings of alienation and detachment. There is evidence to suggest that as the technology has changed, so too has the degree of involvement felt by pregnant women undergoing the procedure. Most of the women interviewed whose scans were done in the later 1980s felt much happier about the amount of information they were given during the scan:

> Never having had one before you hadn't a clue what was going on and they really did explain what they were doing and pointed things out.[32] (Sharon, 1989)

[29] Interview with Irene, March 1998.
[30] Interview with Lucy, July 1996.
[31] Interview with Catherine, July 1998.
[32] Interview with Sharon, March 1998.

> She spoke all the time. She said everything seems fine, length and this sort of thing, and dates.[33] (Kelly, 1986)

Furthermore, many hospitals, such as Aberdeen Maternity began providing information leaflets and posters in their waiting areas, detailing what the scan procedure involved and what could be detected (see Appendix 2). There has also been a proliferation in the 1980s and '90s of 'maternity magazines', almost all of which include articles on ultrasound scanning. Nevertheless, much of this can be more directly associated with the increasing prominence of the fetus as a cultural product, in addition to a changing attitude towards patient involvement in obstetric tests. As Baker, Yoels and Clair note in their study of doctor-patient encounters, the enduring centrality of the bio-medical model (or the clinical gaze) in medicine undercuts the rhetorical claim that the late 20th century saw an increasingly patient-centred form of medical practice.[34] Medical students are taught to cut through patient narratives and to elicit only the biomedical facts and thus patient communication is regarding as something of a 'one-way street'. Thus it is perhaps unsurprising that what communication does exist is very much limited by medical parameters.

It is also important to note that pregnancy can be a worrying time for women for a variety of reasons. Coming to terms with bodily and hormonal changes, the ways in which they accommodate their new status with their existing social roles, etc. can all contribute to heightened anxiety during this time. In particular, however, it is not uncommon for first time mother to be very apprehensive about the birth itself and, in this context, comments made by care givers (while appearing innocuous to them) can increase this anxiety:

> I feel nurses shouldn't say anything unless they're definite about what they're talking about, but the [operator] says, 'Oh my God, that's a big one, a ten pounder!'. I remember her words because I thought, 'Oh God!', I mean you don't know what's ahead of you when it's your first

[33] Interview with Kelly, March 1998.
[34] Baker, P.S., Yoels, W.C.& Clair, J.M., (1996), 'Emotional expression during medical encounters: social dis-ease and the medical gaze' in James V. & Gabe J., (eds), *Health and the sociology of emotions,* Sociology of Health and Illness Monograph Series, Blackwell Publishers/Editorial Board, Oxford, pp. 173-200.

> and I was really worried because I was huge. I mean, I was worried sick.[35] (Molly, 1979)

However, there are other factors more directly associated with the technology of ultrasound which can account for the degree of silence some women experience. For many of the women in this study, it was a non-clinical member of staff (radiographer or midwife) who operated the equipment. As has been noted in the previous chapter, the greater use of such staff brought with it organisational problems associated with their inability to make diagnoses. Sharon, for example, experienced the classic scenario where the radiographer informed her that she couldn't get a clear picture and that she had to fetch another member of staff:

> That scan was horrific because they all shut up, they didn't say anything and there was silence.[36] (Sharon, 1992)

Thus it could be argued that saying very little to the patient until the scan is over can be used as a strategy to avoid awkward situations which arise when something is detected on the scan which the operator is unauthorised to communicate. Thus the particularities of this technology and its organisation must be taken into account.

Interacting with images

Although actors such as Ian Donald had long recognised that ultrasound could be used to promote a sense of bonding between mother and unborn child (see Chapter 3), it became a common theme in the medical literature from the early 1980s onwards.[37] The most important aspect of this was the image itself: viewing the scan pictures would enable women to become acquainted with the fetus more directly than with other antenatal procedures. A couple of the

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[35] Interview with Molly, July 1996.
[36] Interview with Sharon, March 1998.
[37] For example, Fletcher, J.C. & Evans, M.L., (1983), 'Maternal bonding in early fetal ultrasound examinations' *New England journal of medicine,* Vol. 308, No. 7, pp. 392-3; Reading, A.E., Cox, D.N., Sledmere, C.M. & Campbell, S., (1984), 'Psychological changes over the course of pregnancy: a study of attitudes towards the fetus/neonate' *Health psychology,* Vol. 3, No. 3, pp. 211-21.

women interviewed in this study had just such an experience:

> I was able to see everything on this scan - right down to the fact that there was no doubt it was a boy. It was nice and made it a bit more personal. There was this baby that was my little boy and it all seemed so real.[38] (Roberta, 1983)
>
> It was really special in that you can see the baby moving and everything looks all right at a glance. You can see two legs, two arms and everything seems okay from that point of view. It's exciting - seeing your baby for the first time. If you find out you're pregnant and (aside from people who maybe have morning sickness which confirms pregnancy for a lot of people) - for people who don't have that and don't feel any different and you think, 'well, is there something there? I don't feel any different'. It does in a way confirm it because you can see something is there.[39] (Jane, 1989)

Even for these two women, however, the story is not quite that straightforward. Jane as a practising midwife was also aware of the possible problems that could be identified by ultrasound and part of the way in which she viewed the scan image was acquired through her training:

> My husband would look at it and think, 'Oh, there's a baby', but myself, I would think, 'That bit's there and that bit's in the right place'. I think anybody would if they've got the right training behind them.[40] (Jane, 1989)

Thus, Jane's perception and interpretation of the scan image was an amalgamation of two different ways of viewing. On the one hand, she perceived the images as an expectant mother and on the other as a medical professional. This highlights the importance of the gaze and the fact that ultrasound images do not necessarily 'speak for themselves'.

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[38] Interview with Roberta, March 1998.
[39] Interview with Jane, March 1998.
[40] *ibid*

Roberta also adds an interesting point to her account when she reports that:

> I think my bond actually happened with my scan. I know it sounds silly, but it did.[41] (Roberta, 1983)

This echoes a story which is recounted by one of the women interviewed by Robyn Gregg:

> I can remember saying to [my husband] on the ride [home], that I was having a strange sensation of having left the baby back in the office, you know, that the baby was there in the screen... What we saw couldn't possibly be right there with us, in the front seat, in my womb. It just, I mean, I still didn't feel I could make the connection... so I felt I left it there for safe keeping.[42]

This type of response to ultrasound imaging could be thought of as a form of 'fetish'. That is to say, it is the ultrasound image itself, rather than the fetus *in utero* which is imbued with meaning. The technology of ultrasound has imposed its existence in the image, as the means whereby the invisible fetus is rendered visible, the ultrasound image itself is the object of the gaze. Thus it is the representation of the fetus, rather than the fetus itself which is associated with emotional meaning. In a sense, this is the opposite of the irony which Roland Barthes explores in *Camera Lucida.*[43] Here Barthes discusses the way in which the photograph itself is rendered invisible because of the central importance of the referent. In this case, however, the only visual knowledge which the pregnant woman (or spectator) has of the referent is via the technology of ultrasound and the image or representation itself therefore has greater importance.

The majority of women, however, were not able to make even this level of connection with the images - no matter how hard they tried. The day after being scanned with the innovative new

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[41] Interview with Roberta, March 1998.
[42] quoted in Gregg, R., (1995), *Pregnancy in a high-tech age.*
[43] Barthes, R., (2000), *Camera Lucida,* Vintage, London.

device in 1960, Betty was shown the resultant small Polaroid picture by an enthusiastic Ian Donald. He was apparently very pleased with the image, but Betty was completely unable to interpret it - even when an effort was made to point important features out to her:

> It was the next day he came round with this wee print and he was all excited and to me it just looked - it was like a black mountain with snow going the wrong way on it. He kept saying, 'that's the head', but there was nothing to my eye and you would never have known - you'd have just thought it was a dud picture. But he was highly excited about it.[44]

Donald's gaze, used as it was to interpreting both ultrasonic images of different tissues and, crucially, other medical representations of women's bodies in different states of disease and pregnancy, possessed a very specialised set of skills with which to guide himself through the image. Betty, however, did not possess these skills and could not connect with what was being shown to her: she had no point of reference.

On the other hand, she was not simply a casual observer. The picture she was shown was of her unborn baby and might also hold the key to enable her to carry it to term. Therefore, it could be suggested that Betty's perspective was largely emotional and psychological but this perspective was not adequate to give Betty the framework with which to view and interpret the image. That is not to say, however, that she did not try:

> I thought, 'that's my baby', but I couldn't see it, if you know what I mean. I was trying to study it, I even held it upside down.[45]

Other women shared Betty's inability to interpret the images in any coherent way - one describing it as a 'black blob', while others noted seeing things move but being unable to make

[44] Interview with Betty, December 1997.
[45] *ibid.*

out what they were:

> I can't say I understood anything I saw because it was just all things moving. It didn't look like a baby at all to me - I just couldn't see it at all. [The operator] was saying, 'look at the head', and I could see this sort of line, but it didn't look like a head to me. I was hopeless...[46]
> (Lucy, 1979)

These accounts are significant in terms of the notion of 'bonding'. In order to be able to attach any tangible meaning to an image, it is first necessary to have some kind of perspective on the image: to interpret it, one has first to be able to *see* it. Furthermore, it is too trite to explain this inability to interpret the image as the result of inferior equipment or early machine design. Firstly, these accounts span almost 20 years of the technology's development from 1960 to 1979. Some were produced from static scanners and some from real-time equipment. Furthermore, the images were certainly clear enough for the operators to not only discern the areas of interest, but also to make clinical diagnoses from them. Instead, what appears to be lacking here is a coherent perspective: a semiotics of ultrasound with which to interpret the signs displayed in the image.

Women's experiences of ultrasound images, like the ones above, demonstrate the pivotal role which interpretation from a very particular perspective plays in the use of ultrasound for diagnostic purposes. The ultrasonic images did not speak for themselves in any coherent language which was freely recognisable by any observer - they needed to be looked at from a particular standpoint.

However, that is not to say that the ability to perceive the images was a purely social phenomenon, dependant entirely on the formation of a 'gaze' with which to view them. A number of material factors also come into play. For example, whether or not the fetus could be viewed in its entirety in a single frame could effect the ability to discern anatomical details by

[46] Interview with Lucy, July 1996.

their position in relation to one another (head, torso, legs, arms etc). Again, however, there are technological dimensions to this. While static scanners could visualise the whole abdominal area in one image, real-time equipment had a much smaller 'window' (see chapter 3). Thus, for women scanned using RT equipment, late third trimester scans would not be able to display the fetus in one frame: in this case, therefore, even the size of the fetus (i.e. the date of the scan) can have an effect. Furthermore, the position of the fetus in relation to the probe also effects the technology's ability to 'render' a recognisable image. Here too, machine design plays a role as, with RT, the vantage point from which the fetus is viewed can be changed by changing the position of the probe.

Nevertheless, the very fact that ultrasound 'sees with sound' rather than light entails from the outset that what is produced is significantly different from what could be viewed by the naked eye. The fact that it simultaneously displays both the internal and external features of the fetus through the construction of a cross-sectional image means that it renders something which cannot be known visually in precisely the same form by any other means nor by the naked eye, either inside or outside the womb. Thus, rather than expressing surprise at many women's inability to 'see' their baby, it should perhaps be more surprising that so many can.

For other women, however, their obstetric lives can become so interwoven with the technology of ultrasound that they do become adept at viewing scan images from a clinical perspective. For Janet, the death of her first child (who was born with hydrocephalus (water on the brain) and spina bifida) meant that obstetric ultrasound became a regular and important feature of her subsequent pregnancies. Her second pregnancy was terminated at seventeen weeks, after being diagnosed with anencaphally. Although the final arbiter as to whether or not a neural tube defect was present was an amniocentesis test, it was during the scan beforehand that the anomaly was detected.[47] Her next pregnancy was terminated after anencephally and spina bifida were diagnosed. Again these pathologies were detected by ultrasound, and confirmed by

[47] At this time, 1976, amniocenteses were not carried out under direct ultrasound guidance. Ultrasound was used to detect the position of the placenta and fetus and marks were made on the abdomen to indicate the best point for the insertion of the needle (see Chapter 3).

amniocentesis - this time at fourteen weeks. After a fourth pregnancy which ended in miscarriage, Janet went on to have two children when she took part in a clinical trial of folic acid as a prevention for this condition. Her previous experiences, however, made her quite skilled at viewing the scan images - particularly the fetus's spinal column:

> [The obstetrician] could show me that the spine hadn't developed. Towards the end, I could pick things up for myself. I got quite good at spotting the vertebrae on the spine.[48]

Thus, Janet's gaze was much closer to the 'clinical gaze' of the medical profession than the other women interviewed. The detection of anomaly prior to birth was the most important aspect of ultrasound scanning for her:

> For myself, [ultrasound] was crucial in my decision making. I would not have considered another pregnancy without it. I couldn't have gone nine months without knowing. Even if the vitamin research had come in, without ultrasound I don't know if I would have taken part. Nine months is a big slice out of your life. To go through the trauma of nine months not knowing at the end of it if you're going to have a healthy baby...[49]

Again therefore, it was Janet's own personal circumstances - her obstetric history and her desire to have a healthy baby - that caused her to interact with the technology and the images in the way she did. Hers was an emotional gaze but of a different sort. She did not want any more children to suffer the same fate that her first daughter did and thus the clinical diagnosis was paramount. Nevertheless, as Janet's story clearly demonstrates, these circumstances were not the wider context into which ultrasound scanning was placed. It was the interaction between the two - her ultimate intentions, what she wanted to know about the pregnancy and what the technology could tell her - which mutually constructed both her experiences of pregnancy, the

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[48] Interview with Janet, July 1998.
[49] *ibid.*

decisions she made and her perceptions of ultrasound imaging.

However, some of the women interviewed never saw the ultrasound image at all - either because they were not encouraged to look or because they did not want to. Irene and Frieda, for example, who were given ultrasound examinations in 1971 and 1982 respectively, were not asked if they would like to see the screen either during the procedure or after the examination was finished. Neither woman, however, had a particular desire to see it. Before Irene received her scan she had glimpsed her file that stated that the scan was to exclude any 'fetal abnormalities' and so she was more concerned about the outcome than the procedure itself. Frieda was an in-patient at the time after several urine tests had highlighted some potential problem (she doesn't know what this was and went on to have a normal delivery). Although she thinks now that the scan was something offered to everyone, at the time she didn't know the purpose of it and, again, was worried that something was wrong. Catherine's story is similar:

> You were aware there was a picture of the baby, but they didn't say, 'look round and see it'. Actually, one of the nurses asked if I wanted to look but I said, 'Not really'. I just asked if the baby was all right. I wasn't all that interested - your mind is focussed on only one thing.[50]
> (Catherine, 1968)

Thus it is not simply the changing nature of ultrasound technology and its delivery or presentation which effects women's ability to interact with ultrasound images - the general context of the scan and why it is being performed can also effect this. The fear that something might be wrong with the pregnancy can lead to something of a detachment from the whole process. A scan which is routine in nature and where there is a general expectancy on the part of the pregnant woman that everything is probably okay can produce a different outlook towards the process and the images produced than a scan in which concern has been voiced.

This, however, is not the case for all women. Helen, for example, was offered a 'reassurance

[50] Interview with Catherine, July 1998.

scan' after she felt that something was wrong with her pregnancy:

> Just about the 28 week stage, when I was due to go up anyway to see the consultant, I realised that something was wrong because I was aware almost of a falling sensation, as if the baby had dropped in the way they do drop prior to birth. [...] I had had this sensation and also, although I didn't feel there was anything terribly wrong with me, my whole tummy area didn't feel right and I was aware that looking at the shape of the bump, it was no longer round, it was more flattened.[51] (Helen, 1988)

Unlike the three women mentioned previously, however, viewing the scan images themselves was an important factor in reassuring her (at least initially) that the pregnancy was not in danger. After the fetus's heart rate and her own blood pressure were monitored, Helen was still not completely convinced and so she was booked in for a scan appointment 10 days later:

> She did the scan and specifically pointed the placenta out to me and the fetus and everything was in place. I felt fine after that and celebrated with a nice lunch and felt I was just being silly.[52]

As it turned out, however, Helen was not 'being silly'. Four days later she began to haemorrhage and was rushed to hospital with placenta praevia: the scan operator had made a grave misdiagnosis from the ultrasound:

> It was only when I got to theatre and the [doctor] questioned me about my medical history to that point, and especially about my care to that stage, that I realised there had been something wrong with the scan because he was aghast that I had had a scan only a few days previously and that the placenta had been shown to me to be in place, and everything okay. That I should have been reassured at that stage, given my internal state and given the fact the baby would definitely not have been sustained at that point, in his opinion, he was really furious. I'll never forget that obstetrician's face - he was so incredulous. He was amazed that three days previously she [the operator] had been able to

[51] Interview with Helen, October 1999.
[52] *ibid.*

> look at a screen and not detect a case of placenta praevia, especially as I was there for careful monitoring, not just as a standard outpatient. The obstetrician said it was impossible for the baby to have been attached, given the state of distress and the extent of the haemorrhaging.[53]

Helen's tale ended tragically. She was given an emergency caesarean and her baby son was delivered 10 weeks premature. After surviving in hospital for over 15 weeks, he died suddenly. The death was recorded as Sudden Infant Death Syndrome (SIDS or cot death).

In terms of ultrasound, what is most significant about Helen's case is that the technology was used to override her own subjective knowledge that something was wrong, with tragic results. Her own feelings about her pregnancy were silenced by the apparently more objective and reliable evidence of the scan. This case, therefore, lends support to Ann Oakley's claim that obstetric technologies such as ultrasound are used as a replacement for women's subjective knowledge, rather than an addition.[54] It also highlights the important way in which visual information is valued more highly than 'experienced' knowledge.[55]

Furthermore, the importance of the 'gaze' is also dramatically highlighted here. Despite her symptoms and the signs she was detecting from her own body, Helen's fears were lessened by the ultrasound scan. She herself did not have the clinical knowledge or experience of ultrasound to 'identify' the placenta on the screen. Nevertheless, she believed she had seen the attached placenta, when the scan operator pointed to an area of the screen and told her that was where it was. Thus although Helen did not 'see' the baby or the placenta, she believed that she had because that was the interpretation she was given. It was not the visual image which lessened her fear but the verbal interpretation of it: a sign of a sign.

A few of the women interviewed were given pictures to take home with them. This practice was introduced at different times and in different ways from location to location, but only

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[53] *ibid.*
[54] Oakley, A., (1984), *The captured womb.*
[55] Düden B., (1993), *Disembodying women.*

became a technical capability with the introduction of real-time scanners.[56] Many of the women who were not offered this keepsake, expressed regret that their friends and relatives had such mementoes when they did not. For those who did, the scan image often became the first picture in the baby album, although for others, tragically, it was to be the only representation of their lost babies. This can cause mixed emotions with regard to the scan. Sharon, for example, miscarried her twin pregnancy at twenty-seven weeks, a few days after having a chorionic villus sampling (CVS) test. She was referred for this test after an ultrasound scan during which concerns were raised that one of the fetuses might have spina bifida. Although CVS is known to carry a statistically higher risk of miscarriage it is, of course, impossible to directly relate the test to Sharon's miscarriage. She was, however, never given the results of this test and thus does not know for certain whether either, or both, of her twins were actually affected by the condition. Initially the ultrasound scan was considered normal, but later the clinician began to suspect that an anomaly might be present:

> The first scan I had done, the way one of their legs was [positioned] they said, 'this one is going to be a footballer'. And this was all great, with this picture that I got, and then it turned out they began to wonder if there was maybe something wrong. I thought, 'it's ironic that this is the big laugh in the hospital, with this scan, about the football player'... The legs never moved and they were always in this one position, and that was when they started to pick up on it.[57]

Thus for Sharon, the scan picture is bitter-sweet: while it is one of the few pictures she has of the babies she lost (she also has photographs taken after they were born), it also reminds her of the circumstances surrounding their loss:

> I think you need [a picture] and the scan photo I have turned out to be totally ironic, but I'm still glad I've got it. I have [a photo] in a frame in my room, but I would put it in the living room and, I know it wouldn't

[56] With static scanners, the still polaroid image was the only record which could be kept of the scan and was thus valuable for its clinical utility and retained by the hospital.
[57] Interview with Sharon, March 1998.

> bother them, but I feel for other people [family and visitors to her home] it's not the done thing.[58]

In this case, the scan picture is one of the few tangible mementoes which Sharon has of her twins. For this reason, perhaps, it has more symbolic and emotional meaning than the scan stills kept by other women. Furthermore, the scan refers to the only time in which Sharon 'knew' her babies, its significance has not been diminished by other photographs and pictures representing different stages in the development of her babies into childhood and beyond. In a sense therefore, the images (both photographs and scan) have been reified: having lost the babies there is no living child or adult referent for them.

Conclusions

The ultrasound experiences presented here suggest that while there is scope to suggest that women can be marginalised during scans, this is neither an inherent feature of the technology, nor peculiar to it. Nevertheless, for some of these women, lack of communication and information before, during and after the procedure, contributed to a feeling of exclusion and, in some cases, disinterest. For others, however, it was the anxiety about what the scan might reveal which led to such feelings: in other words, the very fact that the technology represented potential pathology led to feelings of disengagement. Yet other women, however, felt both informed about, and included in, the procedure.

Thus it is clear that the differences in women's experiences of ultrasound need to be examined as more than simply an historical phenomenon. While it is undoubtedly true that the delivery of antenatal care more generally has undergone major changes from the 1960s to the 1990s, this alone cannot account for the variety in these women's accounts. Technological changes (both of equipment and organisation) as well as the particular circumstances which women bring with them to the scan room, also produce their experiences of being scanned. Nevertheless, the

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[58] *ibid.*

technology itself is not infinitely malleable. While it can be used in different ways and can be shaped by the various elements which constitute it, the type of information which it does and can produce itself effects women's experiences of it. In the above discussion of communication during the scan, for example, even this is in some ways set by the parameters of the technology. Thus the way in which the scan is presented to women while they are in the scan room is not simply the context into which the procedure is slotted: it is an integral feature of the technology. To explain the variety of women's experiences it is necessary to supersede the old distinctions commonly made about the context and content of technology. A whole spectrum of elements coincides during an ultrasound scan to produce the event as experienced by women.

Furthermore, in terms of women's interpretations of the actual scan images produced by ultrasound, it is evident that a myriad of factors combines to construct the way the scan is viewed. What these pregnant women saw in the scan was the emergent outcome of their obstetric history, their current feelings about their pregnancy, their interactions with operating staff, the equipment itself, the rendering of the images, etc. Thus it would appear to be unfruitful to reduce these experiences to a single totalising narrative or explanation. Instead, women's interactions with ultrasound can be viewed more realistically as an emergent phenomenon in which the historical transformation in the technology is only one aspect.

Conclusions: secrets of success

Introduction

Contained within the preceding pages is an account of the introduction, development and use of obstetric ultrasound in Scotland. Covering a period of more than thirty years, this thesis traces a history of the technology from its origins in Glasgow in the late 1950s, to its ubiquitous use across the country by the end of the 1980s. Nevertheless, this account was not intended to portray a complete overview of technological change, or to map out obstetric ultrasound's development across time in all locations. Rather, the intention was to highlight the complexity and variation contained within the diffusion of this technology through detailed and contextualised examples of technological transfer and application in practice. Drawing on a variety of different types of source (official publications, memoirs and oral testimony, as well as the artifacts themselves in the form of ultrasound machines and images), this thesis presents an account of the varied and dynamic nature of technological change in the diffusion of obstetric ultrasound.

The study began with an examination of the work of Professor Ian Donald and his co-workers in Glasgow on the early development of The Diasonograph - the first commercially available form of diagnostic ultrasound in Scotland. Examining this period in the history of the technology provided a starting point from which to examine continuity and change over time by considering the way in which a technology used in one context (industrial flaw detectors) were adapted for use in a completely different setting. In addition, consideration of this period was crucial to the development of one of the central themes of this thesis - the dynamics of innovation and diffusion. The type of work undertaken by Donald and his colleagues has traditionally been bracketed off and labelled as the 'innovation stage'. Thus in order to challenge the use of innovation and diffusion as periodising concepts in 'stage' models of technological change, it was necessary to consider the period traditionally considered as the sole preserve of the former.

The fact that this technology emerged within the clinic – with early prototypes being used to examine gynaecological patients within the hospital – perhaps made the overlap between innovation and diffusion even more pronounced. For example, as Thomas Brown worked on new prototypes (the bed table scanner, the automatic scanner and the Sundén machine) earlier versions were used by Donald and the other clinicians in the team not only to increase their knowledge of the technology's potential uses, but also as an aide to clinical diagnosis. For example, ultrasonic investigations such as the differential diagnoses of tumours, cysts and early pregnancies were carried out with increasing regularity in the hospital. The fact that these scans were performed on the grounds of clinical diagnosis, rather than technological experimentation, is not the form of development commonly associated with 'innovation' but is more clearly akin to 'diffusion'. In other words, such activities demonstrate the technology's spread into clinical practice prior to its commercial introduction as a commodity.

Furthermore, it is evident that in some respects the diffusion of the technology preceded the movement of actual artifacts - often regarded as one of the defining features of 'diffusion'.[1] In particular, the movement of patients as referrals from other hospitals demonstrates that it is not necessary for artifacts to disperse in order for diffusion to occur. On the other hand, the early publications produced by the team were also significant tools associated with the technology's diffusion. Publications such as the *Lancet*, but more significantly the *Journal of Obstetrics and Gynaecology of the British Commonwealth* – a favoured publication within the specialist field who would form the key customer groups for the new technology – provided a means of spreading knowledge of diagnostic ultrasound and its emerging capabilities.

Thus in the 'period' which is often bracketed off and labelled 'innovation' it is evident that both types of activities were occurring simultaneously. As new prototypes, techniques and practices were being developed, earlier versions were being employed for clinical diagnoses, patients were being referred to Donald, specifically for ultrasound investigation and knowledge of the technology was being diffused by a mixture of formal and informal means.

Nevertheless, obstetric ultrasound was, and is, a very technically sophisticated form of technological practice. As a result of this complexity, it is not the type of artifact which can be easily reproduced from scratch by workers in new locations and, for this reason, the availability of ultrasound equipment was crucial in its spread to other places. In Chapter 2, therefore, the early career of the Diasonograph was examined, with particular attention

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[1] Banta, H.D., (1980), 'The diffusion of the computed tomography (CT) scanner in the United States' *International journal of health services, Vol. 10, No. 2, pp. 251-69;* McKinlay, J.B., (1981), 'From "promising report" to "standard procedure": seven stages in the career of a medical innovation' *Millbank memorial fund quarterly,* Vol. 59, No. 3, pp. 374-411.

being paid to how it was introduced into new locations, how it was used and how it was developed. Once again, however, in this characteristically diffusion-oriented 'period' it is evident that innovation continued to be a feature of actors' interactions with the technology. On the one hand, the introduction of a factory-supplied model into a new institution did not signify that the technical dimensions of the equipment had been 'black boxed' and that new actors simply learned how to use it in its existing form. Instead, actors in new locations (such as Alexander Christie and Alexander McIntosh in Aberdeen, and Peter Aitken in Kirkcaldy) did not simply implement the technology, but continued to 'tinker' – to modify and adapt equipment with the intention of making it 'work' in each new location. Similarly, actors in Glasgow, such as Ian Donald, John MacVicar, Ussama Abdulla and Stuart Campbell continued to work in close collaboration with engineers John Fleming and Brian Fraser to adapt the Diasonograph for new types of investigation – such as measuring fetal bi-parietal diameter and placentography. This is not simply to argue that ultrasound was used as both a clinical and a research tool, but more significantly, that 'research' was not confined to exploring innovative uses for the equipment, but was also closely associated with directly altering its technical capabilities.

Taken together, therefore, Chapters 1 and 2 demonstrate that the innovation and diffusion of the Diasonograph were not separate stages of development or mutually exclusive processes, but two inter-related types of activity.

In Chapter 3 the introduction of new modes of ultrasound imaging, in the form of machines that produced moving real-time pictures, was examined. Once again, the complex origins of these forms of ultrasound demonstrate the interconnectedness of innovation and diffusion. The linear array design of real-time equipment was originally developed for use in other medical specialties (particularly cardiography and ophthalmology). Its diffusion within obstetrics, however, was facilitated by the activities of a variety of small, newly emerging companies who developed their own machine designs targeted specifically at obstetrics and gynaecology. On the other hand, the EMI 'spinner' emerged as an adjunct to static B-scan machines like the Diasonograph and was largely the outcome of work on improved transducer element design and construction. Nevertheless, it was when the various designs and models were placed into practice that the future and shape of real-time ultrasound really began to emerge. In an increasingly competitive marketplace, communications between medical users and suppliers resulted in an two-way flow of information, with suppliers performing equipment demonstrations and loaning machines out for assessment, while medical users fed information back regarding problems encountered during use. While such information flows were sometimes relatively formal (during, for example, government-funded machine assessment trials), a large part of this was conducted informally (through conversations at manufacturers' exhibitions, or through the liaison work of service engineers called out to adapt equipment for new uses, or new contexts).

At the same time, the diffusion of real-time equipment demonstrates the significance of local factors and arrangements in shaping the intentions and goals of ultrasound users. Nowhere is this more apparent than in the Western Isles, where portability emerged as the most highly valued and significant quality of an ultrasound machine, in the context of a remote and sparsely populated island region. However, even within more straightforward urban areas, local arrangements had a direct bearing on what was considered desirable in a particular machine. At Forth Park in Kirkcaldy, for example, (where the vast majority of obstetric ultrasound was conducted by unsupervised radiographers) machines that were simple to use, could perform the calculations necessary to estimate delivery date from various fetal measurements, and could provide some kind of record of the scan, were more suitable than those that (although providing better image quality) were complicated to operate. It was thus during actual practice within specific clinical settings that the future shape of obstetric ultrasound machines was forged.

Finally, in Chapter 4 the emergence and attempted regulation of routine ultrasound services was explored. The proliferating use of obstetric ultrasound can be traced as an emergent phenomenon throughout the technology's history. As the number of conditions and pathologies which could be detected increased, and as both the number of institutions operating the technology, and the number of individuals trained to use it, grew, obstetric ultrasound became an increasingly familiar diagnostic tool within obstetric medicine. Nevertheless, this gradual development was greatly exacerbated from the late 1970s onwards – partly in response to the availability of smaller and less costly equipment associated with the introduction of real-time. No less significant, however, was the development of routine screening policies which dramatically increased the demand for ultrasound equipment and the number of women exposed to the technology. In tracing the emergence of such policies and the attempts made by professional bodies (such as the Royal College of Obstetricians and Gynaecologists) and the state (at both a UK and Scottish level) to standardise and regulate them, the sheer variety and heterogeneity of practice was explored. In Chapter 4 it was argued that the same local, contextual factors which had shaped machine choice, had also simultaneously left their mark on the way in which ultrasound services were organised, staffed and conducted. In other words, arrangements had developed at the local level to suit local circumstances and thus, despite the increasingly standardised nature of the equipment used, and several attempts to standardise its use, ultrasound technology remained a heterogeneous and varied form of medical practice.

Overall, therefore, this thesis has attempted to demonstrate the complex and varied nature of the diffusion of obstetric ultrasound in both its social and technical dimensions. But what conclusions and possible generalisations might be drawn from this study of technological change in practice? In particular, what light does this study shed on the three main research themes outlined in the introduction to this work – the relationship between innovation and diffusion, and between the social and technical dimensions of technology, and the influence of local context on the diffusion of technology?

Research themes revisited

With respect to the first of these themes (the relationship between innovation and diffusion) it is clearly unhelpful to characterise these concepts as separate processes or distinct stages along a developmental trajectory. Nevertheless, while this has been noted by a number of recent sociological perspectives, the preferred solution has been to abandon the terms altogether, in favour of more general concepts such as 'development' or 'dispersal'.[2] Nevertheless, the complex and varied history of obstetric ultrasound's introduction and use in Scottish hospitals suggests that perhaps such terms conceal more than they reveal. That is to say, there is something characteristically different about the kinds of activities associated with creating new forms of practice (through interactions with technical equipment, social organisation or both) and employing those practices on a more general basis. For example,

[2] Bijker, W.E., (1995), *Of bicycles, bakelites, and bulbs: towards a theory of sociotechnical change,* MIT Press, London; Bijker, W.E., (1992), 'The social construction of fluorescent lighting, or how an artifact was invented in its diffusion stage' in Bijker, W.E. & Law, J., (eds.), *Shaping technology/building society: studies in sociotechnical change,* MIT Press, Cambridge Mass., pp?; Jordan, K. & Lynch, M., (1992), 'The sociology of a genetic engineering technique: ritual and rationality in the performance of the "plasmid prep"' in Clarke, A.E. & Fujimura, J.H., (eds.), *The right tools for the job: at work in twentieth century life sciences,* Princeton UP, Princeton N.J. pp. 77-114.

the innovative practices which developed in the Western isles (in terms of the deconstruction and regular transportation of ultrasound equipment) did not spread to other centres, but were nevertheless employed on a routine basis in the Isles themselves. They also, importantly, involved a factory-produced machine, rather than some custom-built equipment. In order to highlight that, while these developments were unique, they were none the less highly suited to this context, a line has to be drawn between activities and events which are 'innovative' and those involved in the spread of such practices. Furthermore, not all actors involved in the development of ultrasound could be described along the lines of John Law's 'heterogeneous engineers', or Thomas Hughes' 'systems builders'.[3] To identify such actors and outline their contributions, it is again necessary to distinguish between innovation- and diffusion-centred actions. Nevertheless, the evidence presented in this thesis demonstrates the inter-relatedness of these two types of activities, and indeed their mutual dependence. During diffusion, interactions between people and machines occur both more often and in new contexts. Thus the opportunity for innovation to emerge increases as different eyes, hands, imaginations, intentions and contexts are brought into relationships with artifacts. Overall, therefore, this thesis has portrayed technological diffusion as a series of events and actions rich with novelty, variety and innovation which might be difficult to conceptualise without retaining the language that enables us to highlight comparative differences in practice.

The second major theme addressed in this thesis is the relationship between the social and technical dimensions of technological change. Until recently, the principal way of theorising this relationship was to choose one side of a central dualism - technological determinism versus social determinism.[4] With technological determinism, social change is explained by technical factors, whilst the opposite account is forwarded by social determinism - technical change is the outcome of social factors. The preceding account of obstetric ultrasound, however, has tended to side with recent studies of science and

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[3] Hughes, T.P., (1987), 'The evolution of large technological systems' in Bijker, W.E., Hughes, T.P. & Pinch, T., (eds.), *The social construction of technological systems,* MIT Press, Cambridge Mass., pp. 51-82; Law, J., (1987), 'Technology and heterogeneous engineering: the case of Portuguese expansion,' in Bijker, W.E., Hughes, T.P. & Pinch, T.J., (eds.), *The social construction of technological systems,* pp.111-34.
[4] McKinlay, J.B., (1981), 'From "promising report" to "standard procedure"'; Reiser, S.J., (1978), *Medicine and the reign of technology,* Cambridge UP, Cambridge; Pinch T. & Bijker, W., (1986), 'Science, technology and the new sociology of technology: reply to Russell,' *Social studies of science,* Vol. 16, pp. 347-60; Pinch, T. & Bijker, W., (1984), 'The social construction of facts and artifacts; or how the sociology of science and the sociology of technology might benefit each other' *Social studies of science,* Vol. 14, pp. 399-441.

technology which have addressed this duality and found it wanting. The actor-network school of Latour, Law and Callon, for example, emphasises that neither the 'social' nor the 'technological' are pure and distinct objects of analysis.[5] Thus to use one to explain the development of the other is both unhelpful and misleading. Instead, actor-network theory highlights the co-dependence and mutual construction of both through the interactive relationships between people and material objects. As John Law notes, technology is a 'messy' object of analysis - there are too many hybrids here.[6] In relation to obstetric ultrasound, the technology itself was shaped by both social and material factors in each location. The nature of the division of labour and the dynamics of inter-professional relationships played a significant role in the shaping of a 'working' technology, but so too did more material factors such as local geography, the capabilities of different types of equipment and the availability of 'clinical material' in the form of the bodies of pregnant women. At the same time, pre-existing social arrangements and relationships were altered by the introduction of obstetric ultrasound. Not only were a variety of medical specialties brought into more intimate contact with one another by the technology (particularly obstetrics, radiology, radiography and medical physics) but also new professional structures began to emerge, along with new occupational roles such as 'ultrasonographer'. Nevertheless, the precise nature of these new arrangements differed from location to location and for this reason the introduction of ultrasound machines themselves does not provide an adequate explanation. Once again, therefore, it is the intersection and interaction between the 'social' (inter-personal and professional relationships, interested action by individuals, etc.) and 'technical' dimensions of ultrasound which brought about site-specific changes.

Overall, therefore, it is impossible to explain the development of obstetric ultrasound in each location by appealing to a fixed and unchanging 'social context' or to a pre-existing technological imperative. Just as the technical dimensions of ultrasound changed and emerged over time, so too did the social context into which machines were placed. The most useful way to theorise this is to appeal to Andrew Pickering's conception of 'emergent

[5] Latour, B., (1992), 'Where are the missing masses? The sociology of a few mundane artifacts' in Bijker, W.E. & Law, J., (eds.), *Shaping technology/building society*, pp. 225-58; Law, J., (ed.), (1991), *A sociology of monsters: essays on power, technology and domination*, Routledge, London; Law, J. & Hassard, J., (eds.), (1999), *Actor network theory and after*, Blackwell, Oxford.

[6] Law, J., (1991), 'Introduction: monsters, machines and sociotechnical relations' in Law, J., (ed.), *A sociology of monsters*, pp.1-25.

becoming'.[7] Through the interactions between people and machines (and between institutional arrangements, biological phenomena, social geography and so on) obstetric ultrasound emerged as a working practice. To extend Pickering's 'dance of agency' metaphor, not only are both dancers in motion, but they perform on an ever-shifting stage.

Much of the resistance towards such explanations of technological change come from a desire to map the origins of a technology down to a single causative factor. Accounts which emphasise interaction, performance and heterogeneity provide neither a chicken nor an egg in the social versus technical sense. However, if this history of ultrasound does nothing else, it demonstrates the multi-causal and contextual nature of technological change. One illustrative example should suffice - the development of the 'full-bladder technique' which had such a significant impact on the obstetric applications of the technology. To explain this, one might point to ultrasounds characteristic behaviour when it encounters a fluid interface as the single, most significant causal factor. Or, one might choose to highlight Ian Donald's scientific ingenuity and medical acumen in understanding what was being displayed in the image and what had caused it to appear visible. This in turn, might produce an explanation based on Donald's background, his social position, the influences on his life, his experiences during the war, his training as a clinician, and so on. Or, one might choose to lay the credit for this development on the poor woman too polite or embarrassed to ask to be excused to the toilet before being examined. In turn the nature of doctor/patient relations in the context of an esteemed medical institution in the 1960s might also be implicated. Alternatively, the avenues of communication open to clinicians to share their findings and 'discoveries' - the journal articles, collegiate conferences, informal demonstrations and exchange of ideas etc. - might be employed to explain this development. In reality, however, the evolution of this particular technique was a result of the inter-relationship of all of these things - it was the emergent outcome of multiple factors and the manner in which they came into contact with one another. To isolate any single one of these and hold it up as principally responsible for this practice is to imply that the full-bladder technique was, at some level, predictable. This example, along with the rest of the evidence presented in this thesis, argues otherwise.

[7] Pickering, A., (1995), *The mangle of practice: time, agency and science,* University of Chicago Press, Chicago and London, pp. 21-27.

The final theme addressed in the preceding pages is the significant influence which location has on the development of technology. From the configuration of ultrasound machines to the arrangements made for the technology's delivery, much of the diversity displayed in this thesis has been on the basis of comparative location. Thus obstetric ultrasound did not only change over time (i.e. historically) but it also was significantly transformed across space. From the 'flying ultrasound service' of the Western Isles and the hybrid machine built in Kirkcaldy, to the different mix of professional groups involved with the technology's delivery and the nature of the examinations performed, the development of obstetric ultrasound has taken a different form from location to location. What is significant, however, is that each development - each change made to the technical make-up of machines or the practice of ultrasound scanning - is comprehensible when viewed within each local context. Here again, Pickering's use of 'accommodation' and 'resistance' provide a useful way of conceptualising comparative change from location to location.[8] While, for example, the evolution of a 'flying ultrasound service' in Glasgow would appear somewhat absurd, it is comprehensible in the context of the remote and scattered communities of the Western Isles region. With geographic and demographic diversity, comes technological diversity. Furthermore, each specific location considered in this thesis has its own contextual history - the location and proximity of key institutions (general hospitals, maternity hospitals, universities), transport and infrastructural links, institutional arrangements and inter-professional dynamics, patient populations, referral arrangements, buildings etc. Each of these emerged over time and in the process created a unique local character. Thus the introduction of ultrasound was rarely straightforward - the flavour and character of each location presented certain 'advantages' and 'resistances' to the implementation of new practices and it is the way in which these were accommodated which helped produce comparative diversity. That is not, however, to argue that local context is stable or that a thorough understanding of local context can provide a basis for predicting future developments. There is always more than one solution to any perceived 'problem', more than one accommodation strategy to pursue, and in many cases this may itself involve the manipulation of local arrangements. Nevertheless, the point remains that to truly understand the dynamics of technological change, to follow technology 'in action'; we need to examine it in practice - to observe its emergence over time and in specific local settings.

[8] Pickering, A., (1995), *The mangle of practice.*

Final conclusions: the 'secrets' of success

Obstetric ultrasound succeeded as a form of technological practice precisely because it was adaptable. The ultrasound scanners of the late 1980s were technically, aesthetically and in practice very different from those of the late 1950s and early 1960s. However, it is clearly inappropriate to draw a clear and straight developmental path in machine design, or to claim that the Diasonograph, for example, was the genetic forebear of modern ultrasound machines by drawing some convoluted family tree. There are too many grey areas here, too many hybrids of questionable parentage.

Furthermore, a technical artifact is only one facet of a technology - it is only during use, in practice, that it can be defined as such. A successful experiment does not automatically lead to a successful medical practice. In other words, a working useful technology is neither born nor invented in a single historical moment of 'Eureka' but is slowly shaped by its interactive performance in the hands of a number of actors spread out across space and time. For this reason, the diffusion of a technology like obstetric ultrasound is a complex phenomenon. To reduce its history to a set of predetermined parameters and causative explanations, decided *a priori* to be the most significant, is to lose sight of this complexity and heterogeneity.

Further, in tracing the career of a successful technology like obstetric ultrasound, it is apparent that the very term 'successful' is as adaptable as the object to which it refers. The preceding chapters provide evidence of artifacts and practices whose shelf lives were short (such as the EMI 'spinner' and the 'twiddle technique') but does that entail that ultimately they should be regarded from the vantage point of hindsight as unsuccessful? For example, while the 'spinner' itself may not have survived in its entire form, modern ultrasound transducers incorporate some of the technical attributes associated with its development. The rotary motion, so central to the 'spinner' design, for example, re-emerged in the late 1980s in association with trans-vaginal probes, used on an increasingly regular basis during early pregnancy examinations. Similarly, later manufacturers also adopted the developments made in transducer materials associated with the production of the 'spinner'. Thus if technological change is accepted as an on-going open-ended process, which is never completely closed or stabilised, then any impressions formed through hindsight will also be historically specific. In the absence of any stable end-point of development, any re-assessments made through hindsight will themselves be open to later reassessment.

Thus the significance of any development remains essentially unpredictable. For example, the transformation of an industrial flaw detector into a two-dimensional imager of the human body had more widespread significance than the carry-case developed to transport Jack Crichton's portable scanner. The fact remains however, that as events unfolded, and prior to them doing so, this was impossible to predict. Further, while the work done by the Glasgow group to bring their medical imaging machine to fruition was crucial, so too was Crichton's carry-case in the context of the ultrasound system he operated in the Western Isles. In its proper context, this was as significant a development in the construction of a working practice as the evolution of two-dimensional imaging.

Similarly, the introduction of real-time scanners demonstrated that the design features which most appealed to ultrasound users was also inherently unpredictable. It was not necessarily the new imaging and display format which was attractive and, indeed, in many cases these scanners were adopted *despite* the view that the images were of poorer quality than previous forms of the technology. Instead, a whole range of other features from relative cost; on-screen display facilities; portability; ease of use; and hand-held probe design emerged as the most significant features of these new machines. Once again, because these preferences and interpretations emerged from practices imbedded in local contexts, their unpredictability was the result of their variability. For every difference in practice, from one location to another, there was the potential for the technology to be used, viewed and perceived differently.

If the conclusion to this thesis is that there are no solitary pre-existing, identifiable, causative forces which determine the successful diffusion of an innovation, then what generalisations can be made about technological change? If the historian or sociologist of technology cannot rely on predictability, and chooses to abandon grand narratives and accept diversity, where does this leave the theoretical study of technology and change?

Ideas, 'ways of knowing', machines and 'ways of doing' do not travel across time and space unscathed and unchanged. In the case of ultrasound at least, the diffusion of technology to new centres changed its very nature producing a complex and diverse picture of ultrasound in practice. Nor has the process stopped - three-dimensional imaging and colour Doppler present new technical challenges and opportunities for ultrasound users. In addition, new techniques (such as ultrasound-guided fetal blood transfusions and fetal surgery) and new practices (for example, the decline in some centres of universal screening strategies) are continuously emerging and bringing even greater diversity. Almost forty years from the commercial introduction of obstetric ultrasound, this is far from a stable technology in terms of either artifact design or use. Thus, the final conclusion to this thesis is that it is only by embracing such heterogeneity and diversity and by examining technologies *in situ*, as an emergent phenomenon, that we can begin to understand the dynamics of technological change and the multitude of factors which shape technology. It is only in the historically, contextually and locationally specific career of a technology that we can discuss the secrets of its success.

Appendix 1

11. TABLE 1 THREE LEVELS OF OBSTETRIC ULTRASOUND

FROM "OBSTETRIC ULTRASOUND IN SCOTLAND : REPORT OF AD HOC GROUP APPOINTED BY NMCC SPECIALTY SUB-COMMITTEE FOR OBSTETRICS AND GYNAECOLOGY, OCTOBER 1986"

Listed below are the observations and tasks within the competence of ultrasonographers trained to the 3 levels of scanning and having a regular commitment to obstetric ultrasound

First level	
To confirm intrauterine pregnancy* To confirm its viability* To determine: fetal number* gestational age fetal presentation To suspect abnormalities* e.g. fetal anomaly molar pregnancy pelvic tumour polyhydramnios To note placental site (after 16 weeks)* To refer for (or arrange) appropriate and/or further scanning when any of the features marked * are abnormal	Every obstetrician Radiographers Midwives Training: e.g. weekly sessions for 2 months; at least 30 hours supervised scanning
Second level (1st level plus the following)	
To detect and specify early pregnancy complications To detect and specify fetal anomalies (detailed anomaly scan) To locate accurately the placental site To comment on placental "texture" To note retroplacental or subchorionic haematoma To comment on fetal movements To guide amniocentesis To detect retained products of conception To provide in-service supervision and training To provide updating and refresher courses	Obstetricians Radiologists Other medically qualified Radiographers and Midwives (accepting a leading role in training) Training: 3 month full-time or equivalent
Third level (2nd level plus the following)	
To receive regional referrals e.g. for difficult diagnosis for specialised prenatal diagnosis To perform fetal interventions e.g. intrauterine transfusion blood sampling chorion villus sampling perhaps fetal surgery To provide regional training courses, including advanced course To have a commitment to research and development (in conjunction with clinical physics)	Obstetricians, e.g. subspecialists in fetal medicine Training: to proficiency required

ABERDEEN MATERNITY HOSPITAL

Is scanning safe ?

There is no evidence to suggest that ultrasound is harmful for you or your baby.

How can I get more information?

Questions about this scan can be answered when you attend for your appointment, or by contacting the Midwife on Telephone 01224 - 840666 Monday to Friday 8.30am - 5.00pm.
If you do not want this scan please telephone the Scanning Department Reception desk. Telephone 681818 ext.52116 and cancel your scan appointment.

Can I have a photograph of my baby?

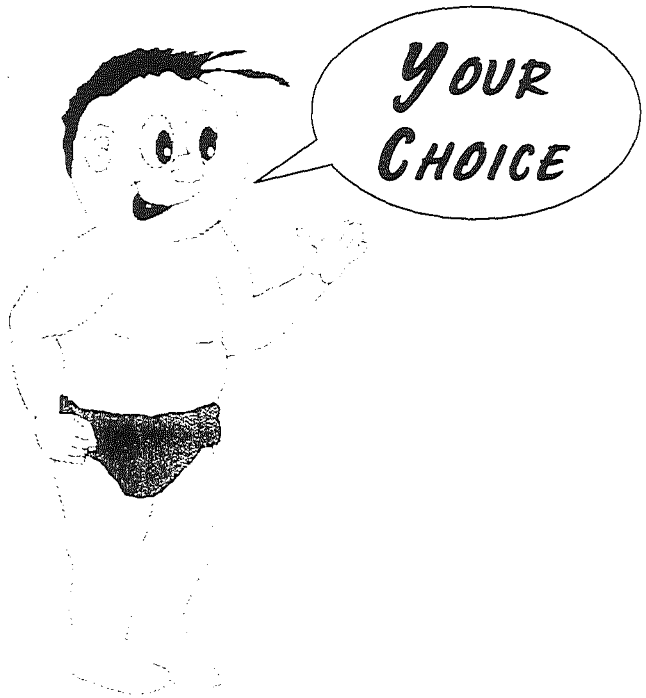
If you wish to have a photograph of your baby we will be pleased to give you one. There is a donation box if you would like to give a donation to hospital funds.

Appendix 2

ABERDEEN MATERNITY HOSPITAL

Information for Parents

The 20 week (detailed) scan



The 20 week (detailed) scan -Your Choice

This leaflet answers some questions to help you decide if you want a detailed scan.

What is the main purpose of the 20 week scan?

The main purpose of the 20 week scan is to check if your baby's growth and development are normal. A scan at this stage will detect 70 per cent of babies who have serious physical abnormalities, for example of the brain, spine, and digestive system*. Although most babies are born perfectly healthy and well, by choosing to have the detailed scan, there is a small chance of worrying information being given to you about your baby. If you do not wish to be in this situation, then you should choose not to have this scan.

How long does it take?

A detailed scan takes approximately 20 minutes. The pictures may not be very clear if you are overweight or if the baby is lying in an awkward position. Some mothers are asked to wait or come back on another day by which time the baby's position should have changed.

Does a normal scan result mean the baby is healthy ?

No, a normal scan result does not guarantee a healthy baby because scan pictures can not detect every abnormality.

*.Smith N.C., Hau C. 1996 The detection of fetal abnormality 1989-1994.

Why does scanning not detect all abnormalities?

- Some problems will not show up with ultrasound. An example of this is Down's syndrome.
- Some abnormalities may be missed because they are difficult to detect. Examples of these are defects of the heart or cleft lip.
- Scanning will not detect some abnormalities until much later in pregnancy. This includes some brain abnormalities.

What happens if an abnormality is found ?

Each year the pictures which we get using ultrasound become clearer. We see the baby in more detail than we did 5 years ago. This means we can see small variations in a baby's development which are usually not serious, and do not affect your baby's health. In this situation, you may be asked to return for further scans.

If a serious problem is seen a senior doctor will talk to you about the abnormality and discuss your care with you. Depending on the type of abnormality seen you may need to choose if you want to have more scans or a test such as amniocentesis. Sometimes a meeting with the paediatrician [the doctor who looks after babies and children] is arranged. to discuss the care of your baby after he or she is born.

On the very rare occasion that a life threatening problem is found, you are given time and support from the scanning staff to talk about the options open to you.

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