ABSTRACT

Perinatal mortality has not fallen so dramatically as other indices of medical care in our community.

The majority of babies dying during or shortly after labour may have succumbed to factors operating in the later months of pregnancy. If these factors can be assessed ante-natally such mortality may be reduced.

Pregnancy is so well designed to protect the foetus that all the tools of modern technology must be applied to extract useful information on foetal wellbeing. The foetal heart is one accessible source of such information and is an attractive focus for ante-natal investigation.

Most of the methods used to investigate adult cardiac performance have been applied to the foetus as a means of assessing its overall physiological condition. The following methods have been described - electrocardiography, phonocardiography, ultrasonography, ballistocardiography, impedance plethysmography and displacement cardiography. Consideration of these methods has shown that the foetal electrocardiograph (FECG) provides the most accurate basis for measurement of foetal cardiac cycle interval.

Recent advances in electronic technology have made it possible to produce new FECG amplifiers at an attractive low cost.

To obtain the FECG from the mother's abdomen it is necessary to cancel the superimposed maternal ECG. A simple two channel and a more complex eight channel apparatus have been designed and constructed for this purpose.

A method utilising this corrected signal to construct histograms of foetal cardiac cycle intervals on a small portable computer (Nuclear Chicago 7100 C) has already been described in a

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previous Thesis on the FECG (Curran, M.Sc., Thesis, 1969). A pilot study had shown that statistical measures of these histograms (e.g. mean, standard deviation, coefficient of variation) were very significant indices in foetal prognosis.

An entirely new clinical trial is presented here. 162 FECG examinations were made on hospital in-patients as a routine clinical technique and these statistical indices compared with the condition of the babies at birth as judged by the Apgar score.

Statistical testing of the indices failed to reach the very high levels of significance previously demonstrated. Nevertheless the indices showed very strong trends in the expected direction on a population basis and followed the clinical course of the 25 cases where serial examinations were conducted with remarkable fidelity.

A new index (standard deviation x 100/log mean) was constructed and tested. While this met theoretical requirements very closely it failed to show any practical advantage.

The results of this clinical trial show that the FECG can be a practical clinical tool. It is the most accurate method for obtaining information on the foetal cardiac cycle which, particularly in serial examinations, can be of value in assessing foetal viability.

ANTE-NATAL MONITORING OF THE FOETAL HEART

A NEW APPROACH BASED ON BEDSIDE COMPUTER ANALYSIS OF THE FOETAL ELECTROCARDIOGRAM.

Thesis presented for the degree of
Doctor of Medicine from the
University of Glasgow
by
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December, 1972.

AUTHOR'S PREFACE AND ACKNOWLEDGMENTS

This thesis is my second contribution to ante-natal foetal monitoring. The first (Curran, M.Sc. Thesis, 1969 - referred to as Vol. 1) was a basic consideration of foetal electrocardiography (FECG) and a pilot trial of its clinical usefulness. The present volume describes the further development of FECG, and other, monitoring systems and a new, more widely based, clinical trial. I bear responsibility for both the electronics and the clinical application.

The work described here was undertaken during my tenure of a lectureship in Bio-engineering at the University of Strathclyde. It forms but a small part of the Bio-engineering Unit's Obstetric Bio-mechanics programme and was financed by the University.

As the work was conducted in a multidisciplinary unit I have included some material (particularly Chapter 4 and the glossary of medical terms) for the benefit of my engineering colleagues which the medical reader may find unnecessary. In this I ask his indulgence.

I wish here to express my deep indebtedness to Prof. R.M. Kenedi, Professor of Bio-engineering and Dr. J. MacGregor, Reader in Tissue Bio-mechanics and leader of the Clinical Measurement Group within the Unit, under whose direction this study was undertaken.

I must acknowledge all the members of the Bio-engineering Unit for their instruction, criticism, assistance and support. In particular Miss Monica Jordan and her Data Processing Group who once again undertook the considerable programming effort involved in the analysis of the results.

The Clinical work in this trial was conducted at the Glasgow Royal Maternity Hospital under the auspices of Sir Hector Maclennan

and Dr. A.W. Laughland. Every member of the medical and nursing staff made me most welcome and to them all I wish to express my sincere thanks.

Mrs. Brenda Miller was my assistant throughout and Miss Jean Young and Mrs. Anne Johnston typed the manuscript.

It would be impossible here to list all those who have directly or indirectly assisted in this work but to them all I wish to acknowledge my lasting gratitude.

December, 1972.

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1. INTRODUCTION

1. INTRODUCTION

" Is it well with the child" (Book of Ruth)

1.1. Preamble - This century has seen many radical changes in medical outlook. The advent of antibiotics, blood transfusion and anæsthetics has made massive inroads into human suffering. Childbirth, despite the aura of mystery popularly surrounding it has become much less of a hazard, at least in the "advanced" nations.

Unfortunately the risk to the baby has not fallen so dramatically as the risk to the mother. Maternal death is now almost a rarity in Britain (0.2 per 1000 births) yet almost three percent of babies succumb.

In days gone by , especially in Glasgow, many families expected to lose at least one of their babies but such complacency is no longer part of the social environment and there is every reason to press for still further reduction in this loss of unfulfilled lives.

1.2. Perinatal Mortality - Perinatal mortality is defined as the number of deaths occurring after the 28th week of pregnancy and before the end of the first week after delivery per 1000 live and still-births.

An index such as this spotlights obstetric care. It includes the intra-uterine deaths, which may be avoided by improved ante-natal care and assessment, the intra-partum deaths, which may be avoided by improved delivery technique and foetal monitoring, and the early neo-natal deaths most of which are really a result of factors operating before or during delivery. The National Birthday Trust's 1958 Perinatal Mortality survey was the first concerted attempt in Britain to correlate the national picture in this respect. Its findings showed very wide variations in

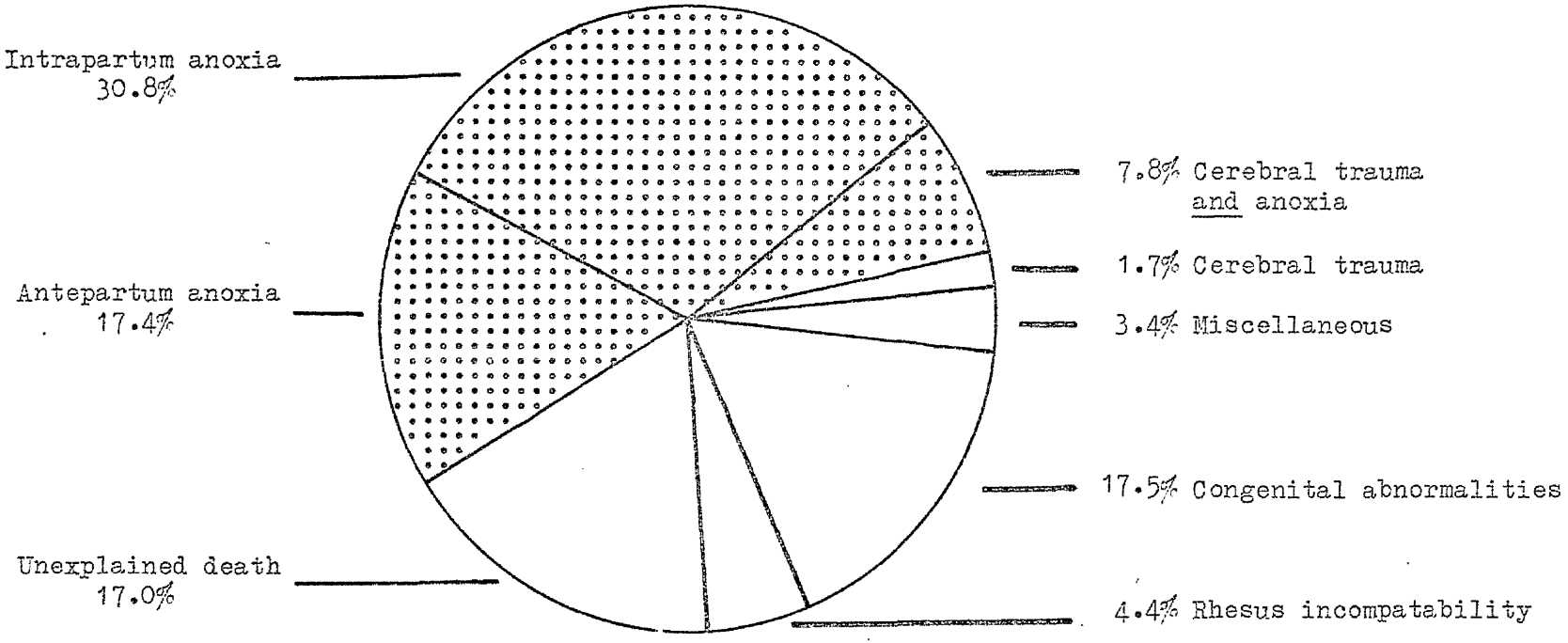


Fig.I.I 'Apple pie' diagram of causes of perinatal mortality

perinatal mortality by no means accountable to poor standards of obstretical care. In fact so many variables operate from area to area that perinatal mortality must only be regarded as a very crude indicator of progress or lack of it.

The Survey did, however, clearly define the overall causes of mortality. It identified hypoxia either ante-partum or intra-partum as the major cause of death (45%. Fig. 1.1.). There can be no doubt that if investigative techniques can be developed to accurately identify the foetus at risk from hypoxia the operative skills are already available to salvage them.

1.3. Perinatal Morbidity - Perinatal mortality is an easy index to quantify as there is no difficulty in counting live or dead infants. Perinatal morbidity on the other hand is a very different problem. The quality of infant salvaged has to date proven impossible to assess. There is a large body of intuitive opinion that hypoxia at birth may cause mental damage in the years to come and that perhaps some infants forced to survive might have been better left to die. There is very little evidence to support this view (see Chapter 3.2.) and certainly no guarantee that any infant - no matter how severely compromised - will conveniently expire.

1.4. Foetal distress - Traditional obstetrics has considered labour under the headings of the powers, the passages and the passenger. The first two have long been the object of investigation but the remoteness of the passenger has, and still does, present enormous difficulties in assessment. The major signs of foetal distress, changes in heart rate and meconium staining, have been generally only sought during labour. The time would now seem ripe

to extend the concepts of foetal distress into the ante-natal period (Chapter 3) as the newer technology now allows.

1.5. Foetal assessment - Monitoring of the foetus during delivery only covers a part of the period at risk. Ante-natal assessment must undoubtedly become a valuable asset to modern obstetric practice.

Several approaches are already available - ultrasonic estimation of foetal growth (Donald et al, 1958), urinary oestriol assay (Coyle and Brown, 1964) foetal scalp blood biochemistry (Sahling, 1966) and physical examination of the foetal heart. Each has its part to play and it seems likely that, as in most branches of medicine, no single technique can provide all the answers.

1.6. Aims of this study - The foetal circulatory system is one system which can be investigated without surgical assault upon the mother. Foetal heart information has proved of value in the past and will no doubt do so in the future.

This thesis follows on from that already published by this author (M.Sc. Thesis, University of Strathclyde, 1969 - referred to as Vol. 1.) and will cover the following topics.

a. The methods currently available for study of the foetal heart will be described and their relative clinical usefulness discussed.

b. The very considerable recent advances in electronics will be applied to the improvement and refinement of a practical FECG system.

c. The training of non-specialist operators and the introduction of the technique into the clinical situation will be described.

d. An analysis of the results obtained from the above will be made particularly to assess whether prognostic information can be had from ante-natal examination of the foetal heart.

2. LITERATURE REVIEW

2.1. Introduction - In a review of foetal heart monitoring it becomes necessary to distinguish between advances in technology and instrumentation and advances in clinical application of the knowledge gained. To accommodate such an appraisal this review will firstly consider the development of the several physical approaches to the foetal heart and then the clinical usefullness of the information obtained.

In planning this review the author intended to summarise quite briefly earlier work (which has been previously reviewed, Goodyer, et al 1942, Southern, 1957, Hellman, 1965, Shenker, 1966 and Curran, 1969) and to concentrate on the last few years' literature on a world-wide basis. To facilitate this a MEDLARS current awareness search was constructed (see Apprendix D) and monthly print-outs obtained.

By carefully delineating the search a manageable number of references were obtained. Many of these are in foreign languages of which the majority have been translated or summarised.

2.2. Physical Techniques - A few years ago it was thought impossible to apply all the methods described for adult cardiology to the foetus. Nevertheless recent developments have overcome earlier problems to the extent that electrocardiography, phonocardiography, ultrasonography, ballistocardiography, impedance plethysmography and displacement kinetography have all been described in the context of foetal heart monitoring.

2.2.1. Foetal electrocardiography (FECG) - The FECG was the first method (apart from the stethescope) of foetal monitoring to be described. The original credit is rightly given to Cremer about 1906. There is however, a widespread misconception that his original case was both isolated and accidental. Reference to the original paper (Cremer, 1906)

makes it clear that this was the first in a carefully planned series.

The major milestones in technique were the application of the radio-valve amplifier by Maekawa and Toyoshima in 1930 and the use of a balanced "differential amplifier" by Bell in 1938. Although the electronic components have undergone enormous changes in the years since then the basic form of the differential amplifier lies at the heart of all FECG systems.

The upsurge in electronics since the second world war soon made it clear that the demonstration of the FECG was, of itself, valueless and that clinically useful information would have to be demonstrated.

In-labour monitoring of the FECG presents few technical difficulties today. Once the membranes are ruptured and some slight dilatation of the cervix has occurred an electrode can be attached to the foetal scalp and a very satisfactory FECG obtained by a simple differential amplifier. Hon (1963) described a very suitable clip electrode for this purpose. Basically this is a well insulated clip, with bare points, a positive wire leading to the amplifier and a bare "earth" wire wound round the clip. (See Fig. 5.1.)

Other but similar electrodes have been described by Hunter et al, (1960), Vasicka et al, (1963), Rosen and Scibettar, (1969) and Unger and Goodwin, (1972). Electrodes held on by suction are also described such as that of Ross, (1961), but these do tend to fall off and have not found favour in practice.

The other popular type of electrode is similar to that of Torbet (1970). In this case a fine stainless steel wire is covered with a teflon or shelac sheath. The last $\frac{1}{2}$ centimetre or so of wire is bared and placed in the subcutaneous layers of the foetal scalp via a fine hypodermic needle. No "earth" is provided.

Each of these electrodes has its advantages and drawbacks. The Hon Clip is big and interferes with scalp blood taps for biochemistry, it does tend to fall out rather easily and it is expensive. The teflon wire electrode is smaller, cheaper and probably more firmly attached. Electrically the Hon clip is certainly safer (see Chapter 6.7). Surgically neither leaves a wound of any significance and fear of wound infection etc., need not, in practice, cause any alarm.

It is in ante-natal monitoring of the FECG that electronic technology is stretched to its limits. Leaving aside surgical assault upon the mother, before labour commences the FECG has to be obtained from the maternal body surface. This means that the foetal signal has the much larger maternal ECG superimposed upon it. Several workers (Dressler and Mokowitz, 1941, Goodyer et al, 1942, Southern, 1957, Novotney et al, 1959, Mattingly and Larks, 1963, Buxton et al, 1963, Friedman and Eckering, 1964, Storer et al, 1964, Neilsen & Moelstrop , 1968 and Battle, 1970) have described clinical information derived from study of such combined ECG traces. The value of such information is dubious. The effort and time involved in interpreting the trace far outweights any benefits. Such traces are not suited for automated counting or processing.

Clearly a trace relatively free of maternal elements is desirable.

The first method of achieving this is cancellation of the maternal element by electronic subtraction of a maternal ECG derived from a part of the mother's body where little or no foetal ECG is present. Hon and Hess, (1957) described such a system in 1957 although they never again referred to it. Walden and Birnbaum (1966) described a very similar system using three differential amplifiers

for the maternal and foetal ECG, one for the maternal only ECG and a third to subtract the two signals. The degree of subtraction was controlled by the gain control on the maternal only channel. They published no clinical results and unfortunately the only example they showed does not require cancellation anyway as the foetal elements are well clear of the maternal elements in the original trace.

Both these systems used amplifiers whose current cost is in excess of £150 each. Two channel cancellation of this type has not proved popular yet there is adequate evidence that at least in the hands of enthusiasts, perfectly satisfactory results can be obtained (Sureau and Trocellier, 1961, Curran and MacGregor, 1968). To achieve adequate cancellation not only must the amplitudes of the two signals be comparable but the phase relationship (i.e. the shape of the ECG) must match exactly. Sureau (1961) achieves this by a multi-electrode switchable array but careful placement of the electrodes can be adequate (Curran, 1969).

It must be admitted that cancellation procedures require almost obsessional care on the part of the operator but results can be economically and realistically obtained.

More complex forms of cancellation have also been described. Goodard et al (1966) described one technique in which 11 channels were used. This method is clinically unrealistic as described because of its unwieldiness.

There is a little known but extremely attractive multichannel method described by Schuler et al (1968) which this author has found to be of value (see Chapter 6.5). Again no clinical results are detailed and the authors do not seem to have published anything further.

The other commonly used technique to remove maternal signals

has been that of "gating" (Offner and Moisland, 1966). In this form a second maternal only signal is used to switch off the combined trace over the time interval of the maternal R wave. This means that coincident foetal beats are lost and in extreme examples this could lead to loss of 25% to 50% of foetal beats.

Maternal elements can of course be quite easily removed from a combined trace by a large digital computer. Such programs are described by Favrett and Caputo (1963) and Favrett and Marchetti (1966). These however are "off line" procedures, both cumbersome and expensive.

To date these remain the general principles involved in the detection of the FECG from the mother's abdomen.

Modern electronics and particularly integrated circuits have so simplified the amplifier problem that new amplifiers are not commonly described.

The other major technical aspect is that of radio-telemetry. Normal labour is not conducted with a patient flat on her back wired to a battery of monitoring devices. Radio-telemetry removes the patient from any electrical hazard and allows a degree of mobilisation. Single channel foetal ECGs can be radio-telemetered by quite simple means - (Hess, 1962, Kendal et al, 1962, Lepage et al, 1966, S. Dubini et al, 1971, Unger and Goodwin, 1972). The foetal scalp ECG can be telemetered by the very neat concept of Tazawa et al (1968) who place their miniature transmitter in the vagina (membranes need not be ruptured). No clinical results have as yet been published by them.

2.2.2. Phonocardiography (FPCG) - The FPCG was first introduced in 1923 by Rockwood and Falls. Since then many attempts have been made to use the FPCG clinically but

the electronic and microphone requirements are stringent and until lately few useful results have appeared.

The FPCG is usually adulterated by sounds arising from the maternal abdomen and it has been customary to use electronic filters to reduce their effect. Considering the enthusiasm with which the FPCG has been studied it is surprising that few serious attempts have been made to define the "electronic" characteristics of the signal.

Basing his assumptions on adult work Smith (1957) set his filters at between 60 and 80 Hz but he carefully noted that this was not based on analysis of foetal signals.

The first recorded analysis was that of Green and Wood (1953). They found that the energy from the FPCG was over the frequencies 55 to 330 Hz. Unfortunately they did not give the vital characteristics of their amplifying and filtering systems and others cannot interpret their data.

A second analysis was carried out by Sawyer (1959) who decided that the range was 30 to 80 Hz. He however, used a pen recorder whose response could not have exceeded 80 Hz which certainly negates the upper limit. Shelly (1969) carried out a painstaking and thorough analysis which set the ideal limits at 60 to 120 Hz. Using these his recorder could detect every foetal heart audible to the foetal stethoscope.

A similar range was decided upon by Hammacher (1966) who has done more to popularise the FPCG than any other contributer. The commercial development of his instrument (Hewlet-Packard) has brought a new standard of care to many labour wards. Unfortunately many of the details of his equipment are not available for, no doubt sound, commercial reasons.

Intra-vaginal phonocardiography has been described by Feruglio and Rieppi (1969) who combined their microphone with an ECG electrode and, it seems quite unwittingly, demonstrated the complete inadequacy of the FPCG for automatic processing. Computer recognition of the FPCG has been described (Vahl, 1967) but expense would militate against general introduction of such a technique.

Phonocardiography remains a difficult technical problem which may account for the paucity of published information in recent years following Hammacher's "success". Bearing in mind that it is both physically and electrically safe it may yet prove of inestimable value for routine use.

2.2.3. Ultrasonic foetal cardiography.

2.2.3.1. Pulsed ultrasound - The use of pulsed ultrasound in obstetrics was first established by Donald, McVicar and Brown (1958). The use of the A and B scan for monitoring foetal growth and for diagnostic purposes is outwith the scope of this review but the method has been adapted for examination of the foetal heart.

Bang and Holm (1968) described a method for demonstration of foetal heart movement in early pregnancy and suggest that this method is the method of choice for the demonstration of foetal life. In this they have been slightly overtaken by progress as the most accurate method seems to be localisation of the embryo by B-scan and then detection of the foetal heart by ultrasonic Doppler. (See 2.2.3.2.) Similar work has been reported by Murata et al (1971) from Japan.

Garrett and Robinson (1970), from Sydney, describe a method for measuring the area of the foetal heart on a cross section scan of the foetal chest. They conclude that the heart occupies 21% of the chest area in a normal baby. They also

demonstrated the foetal kidneys and liver. In their method the dose of ultrasound to which the patient is exposed is much higher than that used in Britain.

The safety of diagnostic ultrasound is also beyond the scope of this review. However the Lancet for May 30th, 1970 contains two interesting articles. The first is a paper by Hellman et al attesting the safety of diagnostic ultrasound in a multicentre trial and the second a leading article which points out that while there are no demonstrable bad cellular effects at 1 Watt/sq. cm for 1 μ sec. there are obvious effects at 200 Watts/sq. cm. It concludes that "there will be no evidence of genetic safety for generations yet".

2.2.3.2. Ultrasonic Doppler effect. - The ultrasonic Doppler device is a newcomer to the field of obstetrics. The earliest description seems to be that of Callagan et al (1964) from the Bethesda National Naval Medical Center. They give no clinical details but describe the electronics and principles involved.

The following year Johnson and Lein (1965) described the adaptation of a subcutaneous blood-flow detector for foetal heart detection. Again there were no clinical results.

This early trend towards technical rather than clinical description continued and in 1966 Bishop described the commercial instrument called the Doptone (Smith Kline Instruments, U.S.A.). In 1968 Fielder gave the description of the first British instrument (Sonicaid) and Brown and Robertson described the Ultradop (Ames Ltd., U.S.A.).

Clinical descriptions have largely dealt with the usefulness of the device in early pregnancy. Bernstein and Callagan (1966) describe their failure to detect the foetal heart as only 1.7% over 307 cases. Muller and Osler (1969) and Hunter and Robinson (1970) found similar success. From these and many

other similar papers from all over the world it can certainly be safely concluded that the Ultrasonic Doppler is the most effective instrument available for the demonstration of foetal heart action at all stages of pregnancy.

Linking these doppler devices to automated foetal monitoring however has proved an entirely different problem. (See Chapter 5). There are a few descriptions of systems such as these of Bishop (1968) and Mosler (1969) and one commercially available system from Sonicaid. At present there seems no simple system for recording accurate heart rate continuously by ultrasound.

2.2.4. Ballistocardiography - The concept of ballistocardiography was first described by Starr in 1939. The principle is attractive in that, as enthusiasts say, the heart is not intended to produce electrical signals but to drive blood around the body.

Despite a mass of adult literature and several apophrical stories there is only one reference in the world literature to a successful foetal ballistocardiogram. (Curran, McGregor and Kerr, 1969). The techniques involved will be described elsewhere in this thesis (Chapter 5.3.) but most certainly not enough evidence of clinical effectiveness has yet been amassed.

2.2.5. Impedance Plethysmography - In the adult the impedance plethysmograph measures the changes in electrical impedance of a body segment as flood flows through it.

The first successful attempt to measure the foetal impedance plethysmograph arose out of personal contact between this author and Prof. J. Nyboer of Detroit. His work is described in a paper by Nyboer, Khalafalla and Spyker (1970). Again the only reference discovered). The paper describes

perfectly reasonable techniques for obtaining the impedance measurements and for isolating a foetal ECG to trigger computer analysis but is badly spoiled by quite unreasonable attempts to quantitate the results and to arrive at a foetal stroke volume of 3.5 ml by making too many invalid assumptions.

2.2.6. Displacement Kinetography - The adult displacement kinetograph has only recently been introduced (Sharf et al, 1969). There is some promise of foetal information by computer analysis but to date no reports are found in the literature.

2.3. Data Presentation - The problems of foetal heart monitoring most certainly do not end with the successful detection of some aspect of foetal heart action. If the data is to be used as part of the decision making process it must be presented realistically and promptly.

2.3.1. Rate information - The presentation of foetal heart action over a loudspeaker or on an oscilloscope screen offers little advantage over intelligent use of the stethescope. A permanent record is usually required.

The most popular form of presentation has been that introduced by Hon (1959) and Caldeyro-Barcia (1961) in which foetal heart rate is plotted against time on a paper strip recorder. A second trace on the same paper depicts uterine action either from a tocodynomometer or intra-uterine catheter. This form of presentation, though probably still the most adequate available, suffers several drawbacks. In terms of material it is expensive on paper - at 1 cm per minute a twelve hour labour consumes will over 7 metres of paper. This apart even a fairly short labour produces such a mass of data that interpretation becomes an art in itself (B.M.J. 1971).

It is apt, though not quite fair, to say that that the diagnostic skill of the obstetrician is transferred from the patient to a long piece of paper Attempts to reduce this form of data to numerical values have been made. These are based on the time relationships between uterine contractions and variation in foetal heart rate and the extent of that variation. Shelley (1971) showed that the total "area" of heart rate slowing over an hour of labour was highly predictive of the neonatal outcome.

Time-lapse techniques such as that of Marshall and Shubeck (1961) in which the recorder is switched on for 5 minutes in every 15 could more correctly be called data rejection than data reduction.

The demand for prompt information makes much more sophisticated methods for dealing with the data largely impractical. Van Bemmel (1969) described a Cluster technique which reduces many hours of labour to a single graph which takes into account the sequence of events and Forsyth et al (1969) carried out time-series analysis of labour records to express the changes mathematically. While both these techniques are well grounded and have been demonstrated as suitable for prediction of the outcome of labour their cost in computer time is high and it seems unlikely that on-line systems, which would be necessary, could be economical.

It is worth noting here that many of the "ratemeters" used in clinical studies are wildly inaccurate and a precise description of the ratemeter used is mandatory if other workers are to compare results.

2.3.2. Waveform information - The study of electronic waveforms is a complex and difficult business. A trace flashing across an oscilloscope screen can hardly be claimed as ideal for this purpose yet the human eye is so adept that quite

useful information can be gained. Traces can also be written out on recorders but a major problem is that few recorders have the frequency response to record faithfully these biological signals.

These methods had such obvious limitations in foetal monitoring that other ways of presenting the data were sought.

By far the most successful method is that of transient averaging introduced to foetal monitoring by Hon and Lee (1963). This method uses computer technology which can be achieved with a small comparatively cheap (£2,000) machine. Hon and Lee (1963) used the Mnemtron C.A.T. and Curran (1968) used the Nuclear Chicago 7100 C., which are essentially similar devices to recover the FECG.

Rhyne (1969) used a conventional digital computer with the added, if expensive, advantage that earlier complexes could be dropped as new ones entered.

The technique (described in detail in Vol. 1., Chapter 4) has since been used to recover the FBCG (Curran, Kerr and McGregor, 1970) and the foetal impedance plethysmogram (Nyboer, 1972). It is also used in the recovery of the foetal EEG (Kasabe and Arayama, 1969). Cross and auto-correlation have also been used (Van Bemmel, 1968) but these techniques depend heavily on a signal which is not only repetitive but regular which the foetal heart is not.

The FECG has been the usual object of attention but the PCG waveform has also been studied. (Van Bemmel, 1968, McRae, 1923). Van Bemmel (1968) found that the FECG to FPCG delay time was affected by Rhesus incompatibility but there is little other evidence of its usefulness.

2.4. Clinical Studies based on Foetal Heart Rate.

2.4.1. Ante-natal - That the foetal heart rate could be an indicator of foetal state was first suggested by Von Winkle at the beginning of this century. Since then the foetal heart rate has been the object of many investigations. Recent years have seen a swing to in-labour monitoring but interesting and valuable work on ante-natal foetal heart rate changes conti nues to be reported.

There is ample evidence that the ante-natal foetal heart rate is relevant to the state of the infant at birth.

Welford et al (1967) made the interesting statement that

> "there is clear evidence that by the last month of gestation the fetus has already developed a pattern of heart rate variation which is relatively stable and characteristic of the individual".

In truth their evidence is far from "clear" as it was based on 13 cases whose heart rates were calculated by hand from strip recordings of uncancelled abdominal FECG signals. Nevertheless, other work supports the conclusion. Benson et al (1968) calculated statistical parameters of foetal heart rate on 25,000 births. They measured the mean rate, the standard deviation about the mean, the maximum drop, the lowest value and the frequency of consecutive drops. In all they found only the standard deviation to be a statistically significant predictor of infant outcome. They comment that anæsthesia and birth weight do not affect this relationship. These results were obtained by stethescope and must be subject to considerable variation. Nevertheless it is a large series and shows a real result. Takemura (1966) in a report from Japan, discusses ante-natal rate changes in great detail. His major contention is that a basic heart rate (peculiar to any particular foetus) is operated upon by a variety of physiological and pathological

factors which might be mathematically resolved. This would agree with the adult work of Sayers (1968) but no clinical results are yet available.

In past years attempts to use the FECG for diagnosis of foetal cardiac arrythmias have been made. Their lack of success is only too obvious (Vol. 1, Chapter 2) and is again demonstrated by the series of Neilsen and Moelstrup (1968) in which 90 FECGs (do not specify number of patients), from uncancelled maternal abdominal signals were analysed. Their conclusion that foetal heart rate falls with gestational age has not been confirmed.

In the ante-natal period there seems no justification for regarding the FECG as an adult-type exercise in cardiology. The FECG rather can be an indicator (admittedly a poor one) of foetal state.

Bolte et al (1968) used the foetal heart rate derived from the FECG to select children at risk from placental dysfunction. The rationale of their selection is not clear but the results were claimed to be satisfactory.

It is no surprise that in maternal conditions, known to cause poor foetal outcome, the use of foetal cardiac information has been explored. Savenko (1967) reports, from Russia, a series of 165 cases of pre-eclampsia. He divided the foetuses into four groups of increasing severity.

a) Foetal heart rate $\geqslant$ 150/m
b) Foetal heart rate $\geqslant$ 160/m
c) Arrythmia
d) Gross irregularity

He demonstrated an improved condition in the foetus following treatment of the maternal condition. This well presented and seemingly valid paper was spoiled by the references to cupping

as a means of treating pre-eclampsia.

That pregnancy can interfere with maternal hæmodynamics is well known. A well documented case by Reed et al (1970) demonstrates the vena-caval obstruction syndrome. With the mother lying flat her BP was 60/20 mm. Hg and her pulse 110/min. The foetal heart rate was 78/min. When the mother sat up her BP rose to 118/70 mm. Hg. and her pulse fell to 75/min. The foetal heart rate rose to a normal 144/min. This case demonstrated yet again a real danger of foetal monitoring. Normal labour was not intended to take place with the patient laid flat on her back and restricted by monitoring apparatus.

The complete ruthlessness of computer "thinking" was unintentionally demonstrated by an apparently ludicrous article turned up by the Medlars search used for this review. The article bore the intriguing title "Untaxed whiskey and fetal lead exposure". (Palmisano et al 1970). In the event this proved to be a perfectly serious, and in its context worrying, consideration of the dangers of foetal plumbism following maternal consumption of illicit whiskey manufactured in the Southern States of the U.S.A.

Early workers had shown effects on foetal heart rate following administration of drugs to the mother. This led to a fascinating and as yet unfinished search for some form of "placental function test" based upon foetal response. Stander et al (1964) found that intra-venous isoxsuprine to the mother caused an increase in foetal heart rate. This, however, seemed to occur irrespective of placental "condition". Hellman and Fillisti (1965) carefully analysed the effect of atropine in pre-eclampsia and diabetes. In 1964 Morton et al had shown that atropine given to the mother causes first a maternal tachycardia, followed by a foetal tachydycardia. It was hoped that this interval would indicate the ability of the placenta to transfer material from mother to foetus. Although the results seemed

useful, on statistical analysis they were not adequate.

Kretowicz (1968) digressed slightly from this line and demonstrated a very definite anti-arrythmia effect of atropine in the foetus.

De Padua and Gravenstein (1969) examined the effects of the two salts of atropine - the sulphate and the methyl bromide - these two have very different molecular weights and will possibly be transferred at different rates. This proved to be so but embarassingly the larger sulphate molecule (MW 694.82) transferred faster than the bromide (MW 384.29).

In the light of scanning electron microscope studies of the placenta (Millington, 1971) and developments in membrane chemistry for adult artificial kidneys this line of approach still seems promising and work is clearly continuing.

2.4.2. Intra-partum - In-labour study of the foetal heart rate has been by far the most popular form of foetal monitoring. The credit for its development is usually given equally to Hon (1959) and Caldeyro-Barcia (1961). The basis for both these studies was the effect of uterine contraction upon foetal heart rate. The nomenclature of the changes has been debated and extended over the years. Hon (1963) talked of type 1 and type II dips which he later changes to physiologic, head compression, cord compression and pathelogic. Caldeyro-Barcia described these same changes as U and V shaped dips. They came to agreement later and both referred to early and late decelerations with respect to contractions. Commercial development, in Europe at least, was accelerated by the technique of Hammacher (1966) whose phonocardiography technique made simple monitoring possible. The system is however clearly based on previous work and adds little to the clinical picture.

The early work in this field has already been reviewed (Vol. 1)

though it seems very much the case that a few people have written the same things in slightly different forms in a lot of different places.

New writing of any real significance has been hard to come by and mostly consists of comparison of the Hon - Caldeyro-Barcia systems with other means of monitoring such as pH, pO_2 and CO_2 and steroid biochemistry and of monitoring the effects of biochemical and physical interference with labour.

Quilligan et al (1964) attempted to correlate foetal heart rate with blood gasses but claimed to find no significant correlation. Only one of their cases had a very low Apgar score (3) and its heart rate of 124 was by no means abnormal.

Giadina and Bovicelli (1967) presented two cases of intra-partum death monitoring by the Hon system and demonstrated and discussed at length the various deceleration patterns they found. A major point which they did not discuss was that both foetuses started labour with a heart rate of more than 180/min which would indicate a poor prognosis in any case.

Hon himself took up the challenge in 1969 and with others investigated foetal pH measurements in labour. His very large series showed a definite relationship between pH values and Apgar score but with a very large statistical overlap which made pH changes difficult to relate to the individual's progress. While he readily admits to the value of Sahling's (1966) techniques the distinct impression given is that he feels foetal heart rate a more practical individual method of prediction of poor outcome. This view is shared by Schifrin and Dame (1972). Haan et al (1969) and Davidsen (1971) re-emphasised that in labour monitoring of poor risk cases (selected by clinical criteria) was highly desirable.

There has been a feeling that dysmature babies, who are low in glycogen stores might benefit from intra-venous glucose

to the mother during labour. This was investigated by Anderson et al (1970) whose well conducted trial showed no evidence of benefit in either foetal heart rate or pH changes though the strength and frequency of contractions was diminished. They conclude that intra-venous glucose is of little if any value.

2.5. Waveform Information.

2.5.1. Ante-natal - Studies based on waveform analysis have generally been in the ante-natal period - no doubt because of the difficulty in obtaining "clean" waveforms in labour.

The major proponent of FECG waveforms as predictors of foetal condition is Larks. With Anderson he first published his proposals in 1962. This was a catalogue of poor results in 4,500 cases, of which he presented 9 in detail.

His major index of foetal "embarassment" was widening of the QRS complex which is impossible to judge as his illustrations give no time-base. His other index is notching of the foetal R wave. This claim gives the opportunity to drive home a point which most authors have omitted - in such cases it is essential to quote the frequency response characteristics of all sections of the recording apparatus if such claims are to be substantiated. He has not done so and close examination of his published examples show definite though uncommented notching of the maternal S waves which suggest that all the notching is artefact. This early paper was promptly challenged by Lee and Hon (1965) who were unable to reproduce such changes.

Caldeyro-Barcia et al (1966) also examined the possibilities of prognostic information in the FECG waveform by a method which is unlikely to be popular in Britain. They passed a "fish-hook" of nichrome wire through the maternal abdomen into the liquor amnii and fished for the foetal buttocks. This

clearly gave excellent FECG traces if somewhat unconventionally achieved. They found no diagnostic information in examination of the waveform.

This conclusion was confirmed by Takemura (1966) in his Japanese series. The Russian authors Markaryan and Okoev (1966) turned the clock back many years with a description of the use of phono and electrocardiography in the diagnosis of foetal life. This approach has been outdated by the ultrasonic doppler device as was shown by Soberon-Accueda et al (Mexico, 1968) among many others.

The proponents of Larks' theories are still very much in evidence. For example a paper by Eisenberg and Senties (1967) from Mexico claims very similar results but does not give enough technical information for further comment.

Possible variation in FECG waveforms in postmaturity have been recently to the fore in some quarters. Levinson (1968) examined 35 patients known to be 3 weeks past-dates with a contrast group. He found that in the post-mature cases the foetal Q R S complexes were of significantly higher amplitude. Similar claims, based on only 2 cases were made by Serr et al from Israel also in 1968.

It is extremely difficult to accept this evidence. The exact relationship between the foetus and external electrodes is never known and must vary from day to day. Personal experience so strongly enforces this view that despite the obvious enthusiasm of these authors the results can only be viewed with scepticism. The same comments apply to Tomita (Japan, 1968) who compared the ratio of R to S waves with eventual Apgar score.

Despite the enormous criticism of his work, by many more eminent than this author, Larks has continued to publish work

on the FECG. In 1969 he published a comparison of breech and cephalic presentation in which he suggested that the FECG amplitudes related to foetal sex (he earlier claimed that females had greater amplitudes) were reversed in breech presentation. He then proceeded to propose an endocrine basis for presentation. This paper too is likely to attract criticism.

Though the FECG has been the obvious waveform for analysis ante-natally Peters and Van Bemmel have published work on the FPCG (1969) in which they show changes in the hyperdynamic cardiac insufficiency in erythroblastosis foetalis. The work is based on only 3 cases but augurs well for further ballistocardiograph and impedance plethysmograph studies. There are no recorded attempts to analyse the ultrasonic doppler device signals for prognostic purposes.

2.5.2. Intra-partum - The practical difficulties involved in obtaining good waveforms in labour have led to little work being reported. An excellent technique for producing running transient averages exists (Rhyne, 1969) but there are no recent reports of any significance.

2.6. Commercial Developments - As early as 1960 Hon described a commercial version of his monitoring device. Essentially it is a ratemeter driven from the FECG derived from his scalp electrode. At the same time an indication of uterine activity is derived from a tocograph or intra-uterine catheter. Both are displayed on a two channel write-out.

The same device, electronically improved and suited for mass production is recognisable in the report by Paul and Hon (1970) on 252 cases monitored with the device to some advantage. Such was very much the state of the art until the development

of the Hammacher technique by Sanborn (Hewlett-Packard). The up-to-date version of this device accepts the FPCG or FECG as rate trigger and tocodynomometer or intra-uterine catheter transducer signals as "labor" indicators. This device seems set to revolutionise many labour wards though there are as yet no really critical reviews of its usefulness.

By contrast the article published by Weis et al in 1970 is such utter rubbish that one wonders what the editor had in mind when it was accepted. The device "works" on uncancelled abdominally obtained FECG signals, makes no attempt to count the foetal heart rate automatically, and relies upon visual presentation. It is a blatant advert for the Kagey - Frink Instrument Co.

In the ultrasonic field - which has progressed largely by industrial and commercial, rather than academic channels the only monitor which presents more than just the "heart action" is the Sonicaid FM2 which is still undergoing clinical trial. It is undoubtedly reliable, if expensive, and has suffered severely from aspersions cast upon the safety of ultrasound.

3. FOETAL DISTRESS AND ITS SEQUELAE

3.1. Foetal distress. - Foetal distress is generally accepted as the manifestation of hypoxia, or ultimately anoxia, on the foetus. Hypoxia and anoxia have been most convincingly shown to be the major causes of ante-partum and intra-partum foetal death in Britain. (Fig. 1 : 1, British Perinatal Mortality Survey 1958).

If deaths due to hypoxia are to be prevented it is clear that methods for detecting early foetal distress must be developed. This demands some understanding of the mechanisms involved and of the long term results of hypoxia.

3.1.1. Intra-partum foetal distress - Until recently almost all the effort applied to the detection of foetal distress was concentrated on the labouring patient.

In the late 19th century, Von Winkle first described the association of the slow foetal heart rate with poor neonatal results. Since then bradycardia in association with meconium staining has been the mainstay of the diagnosis of foetal distress.

On purely theoretical grounds the first response to hypoxia should be an acceleration of the foetal heart. A fall in circulating oxygen levels requires a faster circulation to supply the vital centres. This tachycardia does in fact occur though it is often missed. The classification of foetal heart rates related to anoxia by Cox (1963) is a good example of current thinking.

1.	Mild anoxia	- tachycardia ($\geq$ 160/m)
2.	Moderate anoxia	- bradycardia ($\leq$ 120/m)
3.	Severe anoxia	- irregularity
4.	Asphyxia	- death.

As Cox himself points out in a later paper (Cox et al 1963) this, even in association with passage of meconium is far from a satisfactory diagnostic technique. Many babies with these signs are born not in any way hypoxic and many without these signs

are hypoxic. In fact he goes so far as to suggest that the accuracy in these signs only approaches 50% (the same odds as tossing a coin).

The more widespread introduction of electronic in-labour monitoring techniques have certainly improved upon this situation (see Chapter 5). Nevertheless much of the hypoxia seen during labour must have its origins in the ante-natal development of the foetus or placenta. The time is now ripe to project the concepts of foetal distress back into earlier pregnancy.

3.1.2. Ante-partum foetal distress - It seems reasonable to suppose that if the foetal heart can indicate foetal distress in labour it can also indicate foetal distress before labour.

The expected changes would be mainly tachycardia and this has been demonstrated (see Chapter 4). This concept of foetal distress extending back into the ante-natal period is embodied in the classification of Gruenwald (1963) which is well worth detailing.

a) Acute perinatal distress. This is of short duration and usually associated with labour and delivery.

b) Subacute foetal distress. This affects a previously normal infant for days or weeks before delivery. It results in loss of subcutaneous tissue.

c) Chronic foetal distress. This affects the whole process of growth for many weeks before birth. It results in the classical premature infant.

3.2. The sequelae of foetal distress (hypoxia) - Foetal distress as a diagnosis only assumes importance if it can be shown to have a prognostic value for the infant. The commonly accepted sequelae of hypoxia of the foetus are death, spasticity and reduction of mental ability.

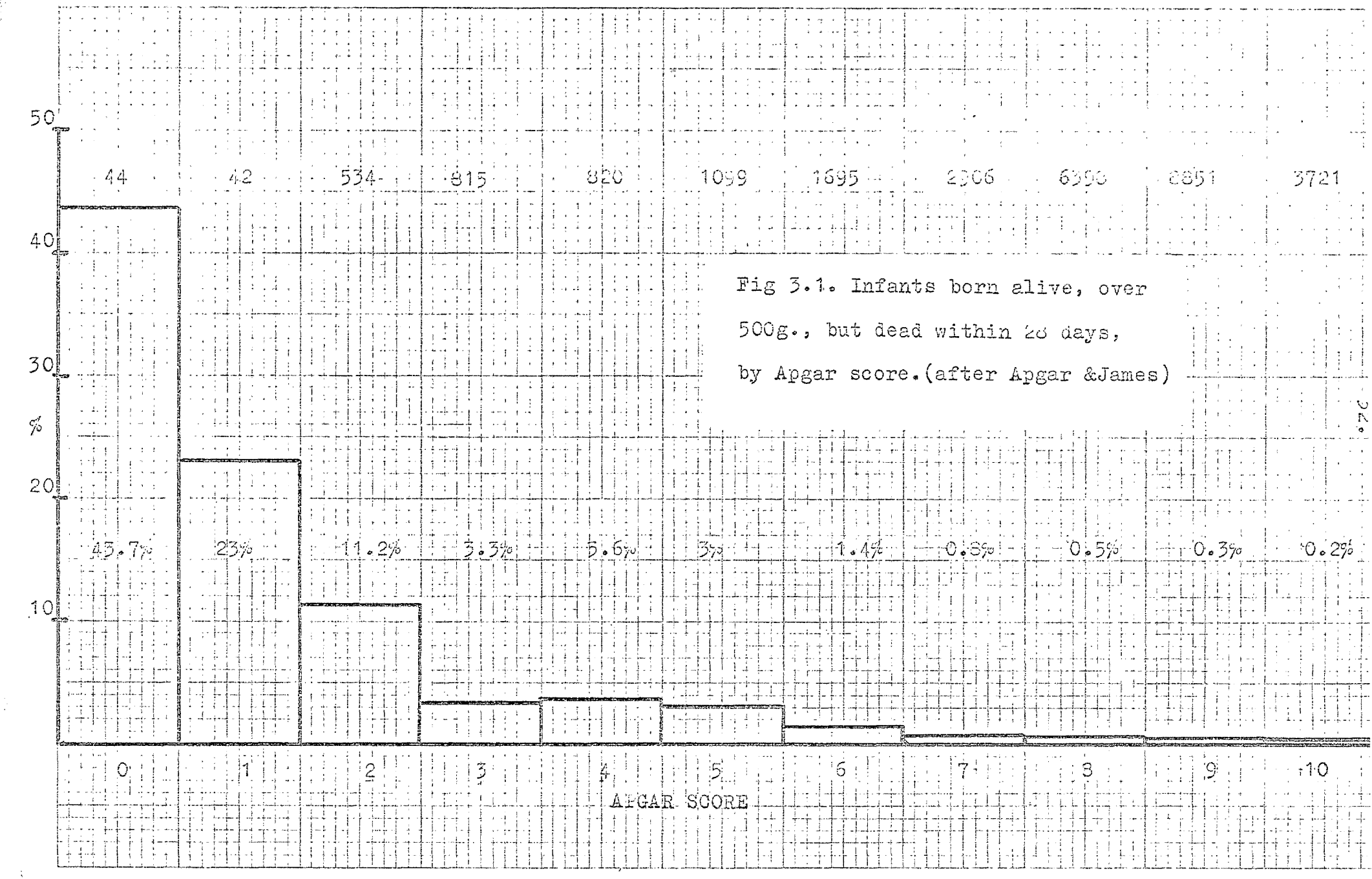


Fig 3.1. Infants born alive, over 500g., but dead within 28 days, by Apgar score. (after Apgar & James)

For the first, death, there is ample evidence that foetal hypoxia is the single most important factor. For the others the evidence is much less substantial - indeed it is quite confusing.

The crucial issue in attempting to apprehend the importance of hypoxia in infants which survive foetal distress lies in the assessment of the child. The Apgar score is the standard method of assessment in most departments. It is not, and was not intended to be, an index of the damage done to a foetus. It is a statistically derived index to indentify groups of babies at risk of death. (Fig. 3 : 1.)

Despite her earlier claim Apgar's most recent publication (Apgar and James 1962) contains this interesting quote:-

> "While we believe the score is useful, it has many limitations. It is no substitute for a careful physical examination or serial observations over the first four hours of life. Nor will it predict death or survival in individual infants. Indeed few signs in medicine give that definite an answer".

It might then be hoped that examinations at one year or older could show some light on the problem. Many reports from American literature support such a correlation (Honzik et al 1965, Lewis and Bartells 1967) but again these are highly statistical analyses and show little of importance in the individual case - indeed in the paper of Honzik et al the child with the worst birth record - an Apgar score of 1 for 23 minutes scored a well above average intelligence quotient.

Animal work in monkeys has shown that CNS damage can be caused by deliberate anoxia (Windle 1967). The type of lesions caused however were not that associated with spasticity in the human. The lesions were almost always confined to the cerebellum and brain stem. In no case did the experimental hypoxia lead to the respiratory distress syndrome (which is seen in monkeys after spontaneous deliveries). The questions raised

by this paper are immensely important but it is difficult to judge their significance because of the highly evocative and emotional style in which it is presented.

The British picture is yet more confused. It can be accepted that low birth weight and prematurity have a demonstrable effect on social and mental development. There is however no evidence that poor condition at birth (i.e. hypoxia) is related to later development.

Several "at risk" registers have been maintained in Britain over the last five to ten years and the figures are now becoming available. Richards (1969) and Knox (1970) reviewing these results demonstrate that absolutely no sequalae of hypoxia at birth - other than death - can be demonstrated. Knox goes so far as to say :-

> "The only sensible action to be taken with respect to At Risk Registers is to abandon them".

The intuition of every obstetrician and parent cries out that surely good oxygenation at birth is the object of most obstetric practice, yet there is no evidence that this need be so.

The author, along with others, is gradually being forced into the view that perhaps this is yet another instance of the "all or nothing law" in human physiology. Either the baby is fit to withstand delivery and survive or he is not and dies.

If this is so then the dice is cast before the onset of labour and ante-natal assessment or monitoring assumes a greater importance over intra partum monitoring.

As a corrollary to this,prediction of the likely progress of labour on the mother's part must also be of great importance but that is a vast subject beyond the scope of this thesis.

As the evidence stands at present it is reasonable to postulate that :-

1. Any child born alive near term has an adequate potential for adult development given effective resuscitation and neo-natal care.
2. Of the babies born dead at least 45% have succumbed to anoxia and must be considered salvageable.

If the reader finds himself confused by the last few pages, he is not alone. The one factor which emerges clearly is that our methods of measuring the results of obstetrical practice (i.e. the baby) are inadequate. It seems mandatory that such indices be developed before any further comparison of monitoring techniques can be validly undertaken.

4. THE FOETAL HEART

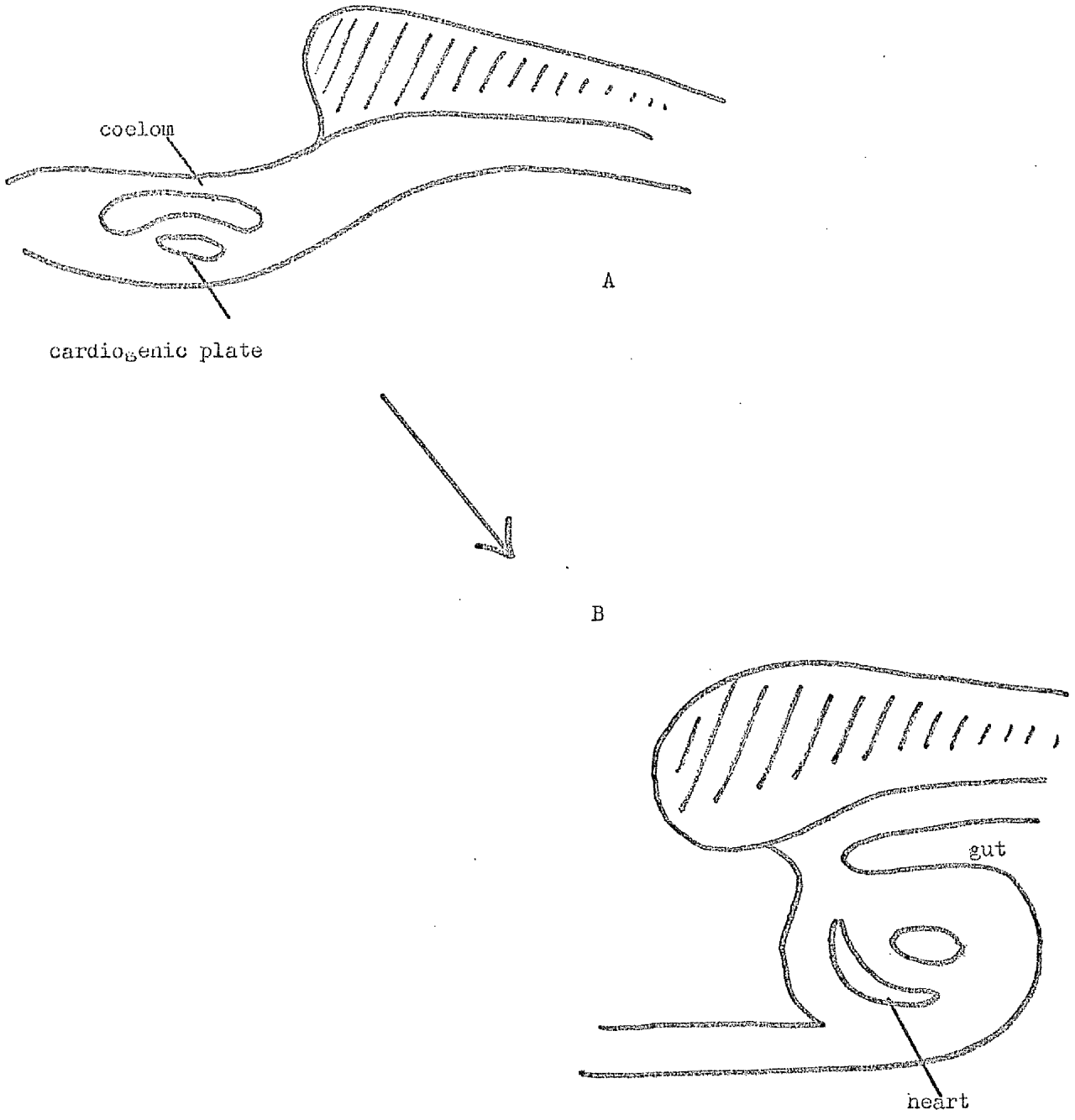


Fig 4.1. The cardiogenic plate.

The foetal heart is the only readily available source of information about the unborn baby. The embryology and anatomy of the human foetal heart are well documented as they can be studied in post-abortum specimens. The situation with regard to physiology and pharmacology is much less satisfactory and depends mainly on inference from animal work.

A brief consideration of these topics is necessary to an understanding of the methods of obtaining foetal heart information. Such is the purpose of this Chapter.

4.1. Embryology - In the embryo the nutritional needs of its growing tissue require that the heart and blood vessels become functional at a very early stage.

4.1.1. Early development - The human heart does not arise simply by the fusion of bilateral halves.

A cardiogenic plate lies beyond the head region and with the forward growth of the head this turns under. It comes to lie in the splanchnic mesoderm beneath the foregut (Fig. 4.1.) at about three weeks. (Davis 1927).

The earliest identifiable cardiac primordia are aggregates of splanchnic mesodermal cells which appear in the cardiogenic plate. They arrange themselves side by side and each grows a cavity just as primordial vessels elsewhere. At the cranial end they rapidly fuse to form a single tube. As the foregut retracts caudally they continue to fuse and complete fusion is achieved by the 16 somite stage. Even while this fusion is proceeding each tube develops cavities which foreshaddow the bulbus, ventricle and atrium on each side. (Fig. 4.2.)

In the fourth week the two bulbar and ventricular regions fuse to form single chambers, leaving paired atria caudally to receive blood from the primitive veins. The sinus venosus

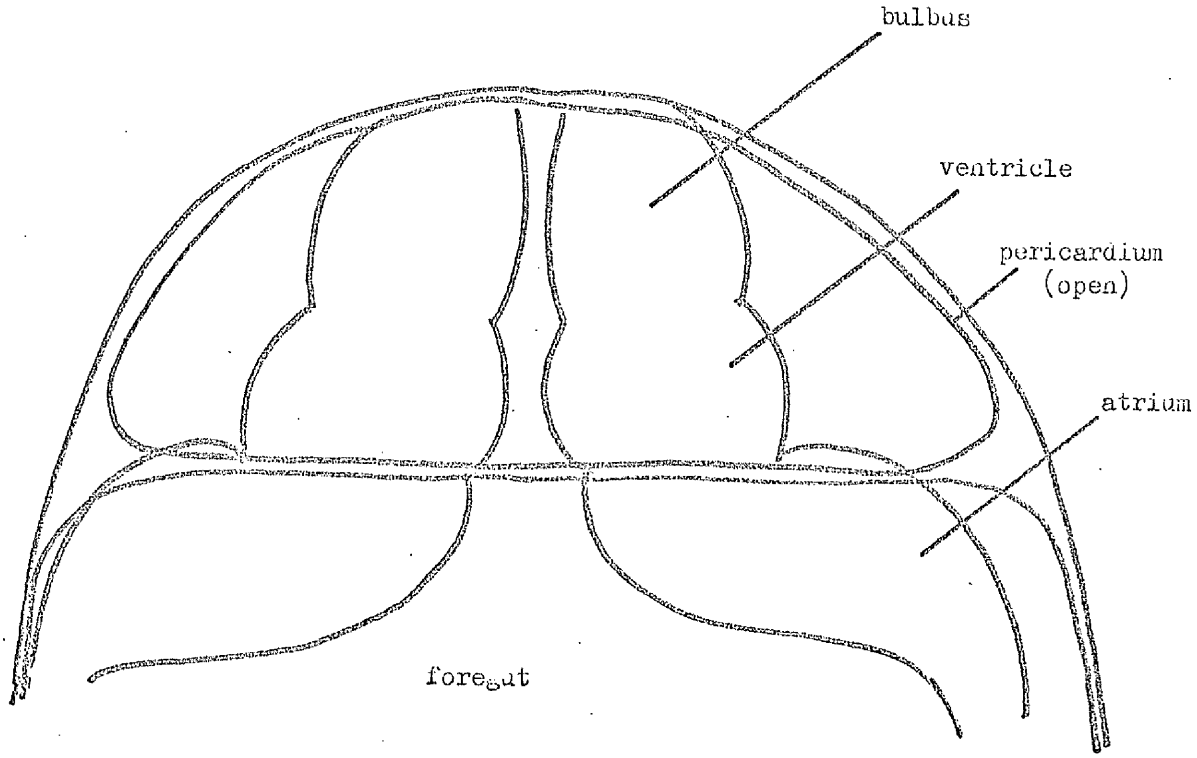


Fig 4.2. The primordial heart cavities.

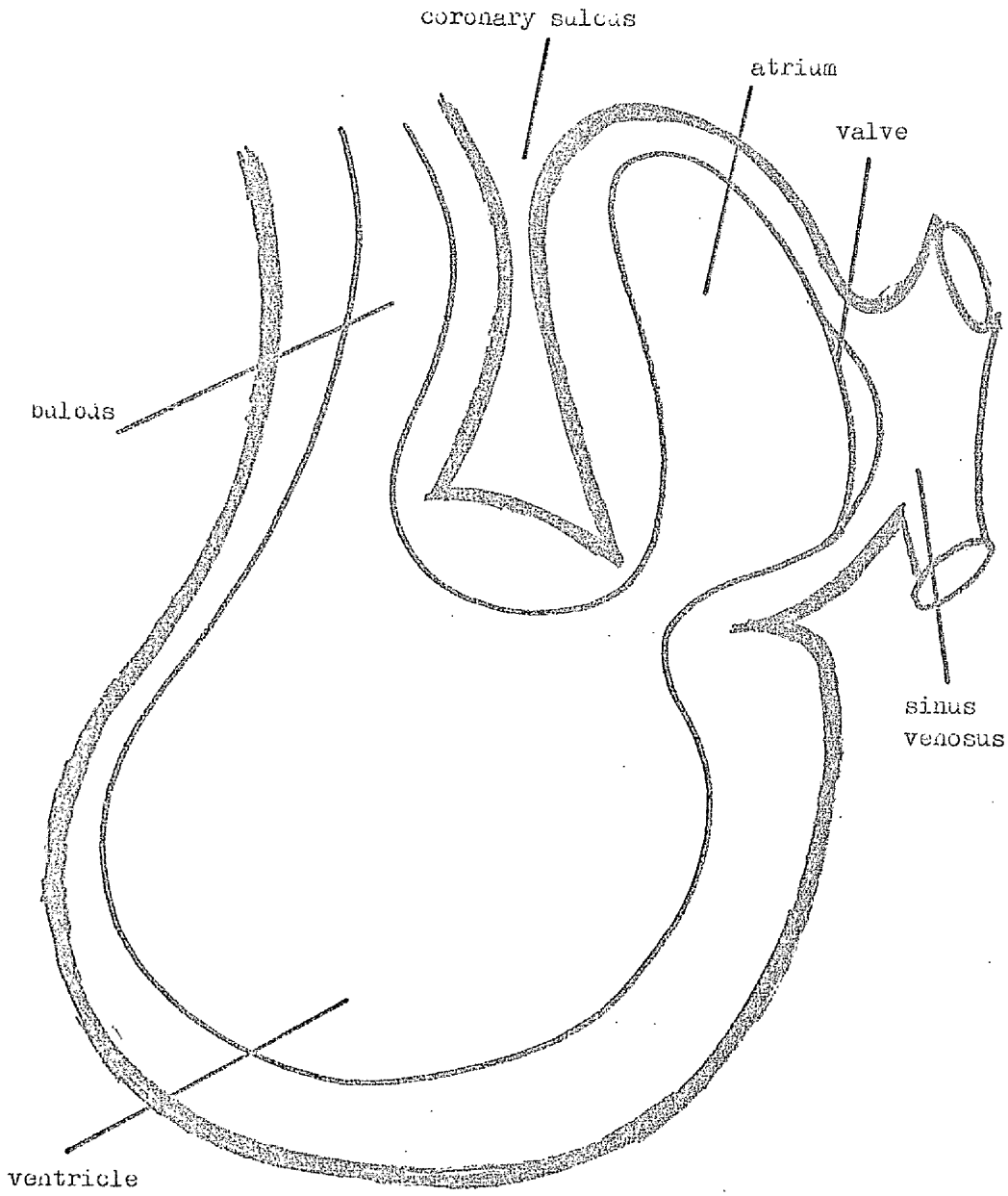


Fig. 4.3. The foetal heart at 5 weeks.

appears about this stage as a caudal specialisation of the atrium and includes sinus valves to prevent backflow during atrial contraction.

4.1.2. Development of external form - At about the fourth to fifth week the external form of the heart is established. By a process of differential growth the entire tube is thrown first into a simple bend and then into a spiralled S and at the same time the, now single, atrium shifts cranially.

These changes result in a reversal of the original orientation of the primitive heart structures and bring the arterial and venous ends close together as in the adult (Fig. 4.3.)

The growing atrium is constricted dorsally by the sinus venosus and ventrally by the bulbus. It is forced to grow laterally and forms two bulges which are the forerunners of the left and right atria.

Meanwhile the sinus enlarges more to its right side because of the increased blood flow up from the liver and the sinus comes to open into the right side of the, still common, atrium.

Both intra-atrial and intra-ventricular septa grow at this stage and by the sixth week the foetal heart exhibits the general external shape of the adult.

The foetal heart has the additional task of maintaining a placental circulation and therefore is larger in proportion to body weight (about X 9) than that of the adult.

4.1.3. Development of internal specialisations - The mamalian heart is required to provide seperate circulations for lungs and body. This is achieved by again dividing the newly fused chambers of the heart.

Between the sixth and eighth week the atria are divided by two parallel septa (septum primum and septum secundum) each of which is imperforate, though in different areas.

This forms a flap effect (Foramen ovale) which allows blood to pass only from left to right. After birth these two structures fuse to form the atrial septum.

The ventricular septum begins to form a little earlier (4 weeks) and progresses more by downwards growth of the ventricles than by enlargement of itself. It is complete by the end of the seventh week.

The bulbus region splits into two tubes - the pulmonary artery and aorta - each with its own tricuspid valve.

The atrio-ventricular valves grow mainly from the endocardial cushion - an area of cells at the junction of the early atria and ventricles. By the end of the eighth week the foetal heart is virtually fully formed and no major changes occur until the reorganisation of the circulation which takes place at birth.

4.1.4. Development of the conducting system - The myocardium is at first continuous throughout the heart but becomes divided by connective tissue at the atrio-ventricular junction. A small bridge of muscle tissue remains and specialises to conduct impulses from atria to ventricles - the Bundle of His. (Walls 1947).

The first beats of the beart are mere spasmodic twitchings which soon gain in force and regularity. In the human these first contractions begin about the fourth week at the slow idiopathic ventricular rate of 60 per minute. This increases to 140 per minute as the higher rates of the atria and sino-atrial node are superimposed.

The development of the electro-cardiogram is considered more fully in Vol. 1., Chapter 3. Mature form ECGs can be recorded direct from the foetus at about 11 weeks although it is some 16 weeks before the signals can be detected at the maternal abdomen.

4.2. Functional Anatomy - The foetal heart from the middle trimester on shows the general form and relationships of the adult. Its function is however somewhat different and it has a few important variations.

The lungs require a very small circulation, only enough for the metabolic needs of the tissues, so the majority of the blood from the right atrium has to find its way directly into the left side of the circulation.

Most of the blood from the lower body shunts directly to the left atrium through the foramen ovale. The blood from the upper vena cava probably passes into the right ventricle. From there it passes up the pulmonary artery and most of the flow short circuits the lungs by passing through the ductus arteriosus to the aorta.

In this arrangement the two sides of the heart pump in parallel (not in series as in the adult) against a common load. The capacity of each ventricle is identical (as in the adult) but so is the thickness of the ventricular wall muscle. The thicker wall of the adult left ventricle does not develop until the relative loads change after birth.

4.3. Physiology - The sheer inaccessibility of the human foetus means that physiological data is hard to come by. Most of the information in this chapter comes from animal work especially on the sheep, and must be interpreted with some care as there is no member of the animal kingdom with a good approximation to human pregnancy.

Arterial pressure rises during foetal life and the more rapid rise late in gestation is probably associated with the development of the autonomic nervous system.

In the lamb exposure to moderate hypoxia causes a rise

in foetal heart rate with very little rise in blood pressure. Severe degrees of asphyxia do however cause a rise in pressure, probably due to a release of nor-adrenaline by direct hypoxia of the adrenal glands. (Comline and Silver 1961).

Injection of hexamethonium causes a fall in both heart rate and blood pressure. Vagal stimulation also causes a profound drop in heart rate but not until near term.

The baroreceptor reflex may develop early in the foetal lamb. Barcroft and Barron (1945) observed that the rise in blood pressure associated with the injection of adrenaline was often also accompanied by a bradycardia. This effect was abolished by vagotomy. Conversely hæmorrhage causes a tachycardia. (Dawes and Mott 1964).

Near term carotid occlusion causes a rise in aterial pressure and there is baroreceptor activity in the afferent nerves from the carotid sinus. (Purves and Biscoe 1966).

There is also evidence of chemoreceptor activity in the foetal lamb. (Cross and Malcolm 1952). As is expected the carotid body receptors, which are more concerned with respiratory activity, are less active than the aortic arch receptors, which are concerned with the distribution of blood flow.

Much of the direct human evidence has been gleaned from observations made within a few hours of birth. What little evidence there is however, supports this general pattern of reflex control over foetal cardio-vascular activity.

Whether these mechanisms are necessary for intra-uterine life and delivery is very debateable. Infants suffering enormous central nervous system defects such as anencephaly or hydrocephaly with meningocele and the like do have an unfortunate habit of surviving the labour process in excellent

cardio-vascular condition.

4.4. In-labour changes of foetal heart rate - Most of the experimental evidence for the causes of foetal heart rate changes once again come from the foetal lamb. This evidence too needs to be interpreted with great care.

The first effect of asphyxia is a tachycardia. Sympathetic tone is developed early in gestation and this rather than the hormonal systems is probably the mechanism for the reflex as it is blocked by hexamethonium.

Even in complete cord occlusion this primary acceleration is always seen.

If the hypoxia is transient then the foetal heart rate returns to normal after 5 to 15 minutes. The mechanism and pathways of the reflex have not been rigorously studied but it seems likely that the medullary centres are involved.

Long periods of asphyxia cause a bradycardia though this does not become gross until the arterial oxygen saturation is reduced to about 15% (normal 50%). The causes of this bradycardia are complex. The two main reflexes involved are probably the aortic chemoreceptor reflex and, if the blood pressure rises, the depressor reflex.

There is also the effect of direct hypoxia on the heart muscle. This causes bradycardia even when automatic ganglion transmission is blocked by hexamethanium.

A short period of severe hypoxia causes a rebound tachycardia probably because of the release of adrenaline from hypoxic adrenals.

The mechanisms for all these effects are far from clear. Nevertheless it remains that they can be observed and put

to very good use in ante-natal and intra-partum care.

The foetal heart is admittedly a poor indicator of overall foetal status but it remains the best we have and seems unlikely to be superseded in the near future.

5. PHYSICAL METHODS OF FOETAL HEART DETECTION

5.1. Introduction - It has been recognised for more than a century that changes in the foetal heart rate can be indicative of the state of health of the foetus. The advent of sophisticated electronic and computer technology has encouraged much more research into the detection and significance of these changes in the clinical situation. The intention of this chapter is to present the technocological possibilities for foetal heart monitoring and to give some guide to their usefulness and interpretation.

5.2. Foetal Heart Detection. - In addition to the stethescope many methods for detection of the foetal heart are available. In general their use falls into two categories, firstly the ante-natal assessment of foetal condition and secondly the intra-partum measurement of foetal reaction to the stresses of labour. The requirements in these two situations are so different that they merit separate consideration.

5.2.1. Ante-natal Assessment - The main aim in ante-natal assessment is to predict the likely outcome of the pregnancy. Direct access to the foetus is rarely available (surgical assault upon the mother is not favoured in U.K.) and non-surgical transabdominal methods are used. In this form of foetal monitoring there is no analogy with adult medicine. The foetal heart is examined almost blindly, not to assess the function of the heart but to assess the status of the whole baby. This remote examination of the foetus forces the use of all the tools of technology in the effort to wring all possible information from meagre data.

It is impossible to make a reliable foetal assessment from any single technique or examination. Nevertheless changes can be detected in the foetal heart, for good or for bad, in such conditions as maternal hypertension, kidney disease, ante-partum haemorrhage and Rhesus iso-immunisation. Deliberate stress to

the foetus, pharmacological or physical has also been shown to affect the foetal heart. Such reactions may prove prognostic (Hellman and Fillisti 1965, Smyth 1965).

The diagnosis of ante-natal difficulties raises the question of ante-natal therapy. This may range from simple repositioning of the mother in bed (to relieve pressure on the cord) to intra-uterine transfusion. Here again changes in the foetal heart can be a most useful index of effectiveness.

5.2.2. Intra-partum Assessment - Once labour is established the problem of foetal assessment assumes a very different nature. With membranes ruptured, direct access to the foetal head allows accurate recording of the foetal EGG, biochemistry and intrauterine pressure. A vast volume of excellent work has been published to relate foetal heart rate patterns and biochemical changes with uterine contractions. (Hon, 1967. Caldeyro - Barcia, 1961. Hammacher, 1966, etc.). That these initial studies have had to use very complex electronic techniques and computer analysis seems to have blinded others to the fact that well-established patterns for prognosis can be obtained without recourse to instrumentation beyond a good midwife and a good stopwatch (Whitfield, 1970).

Foetal heart data relevant to both the ante-natal and intra-partum situation is available from several sources. These are best described and discussed individually.

5.3. Physical Methods.

5.3.1. The foetal electrocardiograph (FECG) - The FECG is the longest established method of foetal heart monitoring (Cremer 1906). It has enjoyed great popularity among researchers for over half a century but has not, as yet, played any significant part in practical clinical management.

In labour the FECG can easily be obtained from a scalp electrode

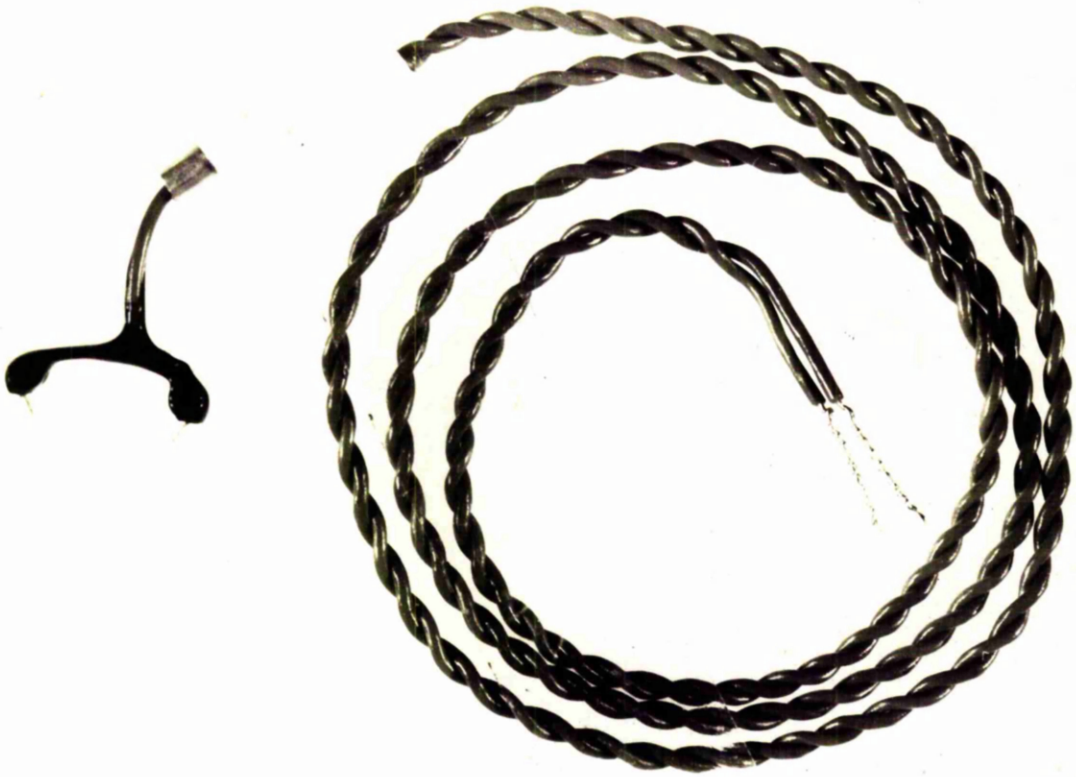


Fig. 5.I. The Hon clip electrode.

of either the Hon Clip type (Hon 1963) (Fig. 5.1.) or the simpler insultated wire type (Torbet 1971). Amplification of the signal is not in any way difficult and the excellent characteristics of the ECG signal make it easy to process further. (See Chapter 6.)

Before the onset of labour the signal is generally much more difficult to isolate. On occasion it is possible to obtain a trace from the maternal abdomen in which the foetal elements predominate over the maternal signal (Fig. 5.2.). This so rarely happens that many methods have been described to isolate the foetal signal. These range from simple cancellation methods (Hon and Hess 1957, Walden and Birnbaum 1966, Curran and MacGregor 1970) through multichannel spacial and temporal summing (Goddard and Newall 1966, Offner and Moisland 1966) to rigorous digital computer analysis (Van Bemmell 1968).

Many clinical uses have been claimed for the abdominally derived FECG. It has been recommended for the detection of foetal life (Dressler and Mokavitz 1941, Hervet et al 1960, Buxton et al 1963, Storer et al 1964), determination of foetal position and presentation (Foa 1911, Goodyear et all 1942, Mattingly and Larks 1963, Larks 1965), diagnosis of multiple pregnancy (Larks 1962, Novotny et all 1959, Friedman and Eckerling 1964) and even for foetal sexing (Larks and Larks 1969).

While all of these uses are of interest they can have little part to play in modern obstetrics. The diagnosis of foetal life and multiple pregnancy has been so convincingly supplied by ultrasonic techniques (Doppler and B-scan) that the FECG has nothing positive to offer. The diagnosis of presentation is <u>not</u> at all accurate by FECG and the laying on of hands is much more effective.

At the present moment only the studies of heart rate, as

Fig. 5.2. Simple ECG traces from maternal abdomen.

measured by the FECG have yielded useful information and this type of monitoring seems likely to hold the field for the immediate future.

Foetal heart rate can be obtained by methods other than FECG but the major advantage of the FECG is its electronic suitability to control more complex methods of data processing and rate analysis. (Chapter 7).

5.3.2. The Foetal Phonocardiograph (FPCG) - Chronologically this falls next in line to the FECG. The electronic problems it posed were, however, greater. Microphones and amplifiers capable of handling its lower frequency components were, and are, difficult to produce. Early developments (McRae, 1959. Smyth and Farrow, 1958) undoubtedly gave greater reassurance to both labour attendants and patients but were probably of little value beyond that.

The FPCG is attractive for ante-natal monitoring because, unlike the FECG, it is not swamped by maternal signals. It is, however, an electronically "untidy" signal consisting of at least two events per cardiac cycle, either of which may be dominant and vary from cycle to cycle. Hammacher's (1966) solution to the problem is a device which counts cardiac events, which occur within a predicted time interval, to control a ratemeter. The information thus gained is used, coupled with some indication of uterine contractions, to detect the patterns of changes in foetal heart rate as described by Hon. (1967). This device, even if expensive, has introduced a new standard of care into many labour wards.

None the less the method has severe limitations. It is often overlooked that the device operates on a very heavily filtered electronic signal. While such active filters do not distort the exact frequency for which they are designed they cause considerable phase-shift in nearby frequencies. Thus while the

system is suitable for average rate estimation it is not suitable for precise measurement of individual cardiac cycles or instantaneous rate indication.

Fortunately the commercial device accepts the FECG as an alternative input which largely obviates these problems and is the recommended procedure for in-labour monitoring.

5.3.3. Ultrasonic Doppler devices - This fairly new addition to the labour ward is of very considerable interest. Leaving aside the question of the safety of ultrasound, such devices are certainly the most effective readily available means for detection of the foetal heart beat.

Their development in Britain has been largely commercial. Although several papers have appeared to attest their effectiveness in general, the principles and uses of the devices are not well documented. Very considerable confusion still exists among the medical and nursing staff who use them and the opportunity will be taken here to summarise the relevant data on the principles and operation of ultrasonic doppler detectors for foetal heart activity.

Ultrasonic Doppler devices detect moving surfaces within the body by measuring the change in frequency of an ultrasonic beam reflected from these surfaces. The information is then presented aurally by a small loudspeaker or earphones. These units must not be confused with the radar-like pulsed ultrasound devices (ultrasonoscope, etc) which detect non-moving surfaces and display the information pictorially.

Ultrasound is formed by creating sound waves at a frequency well above that at which the human ear can hear. These sound waves are capable of penetrating biological tissues, though some portion of their energy is reflected

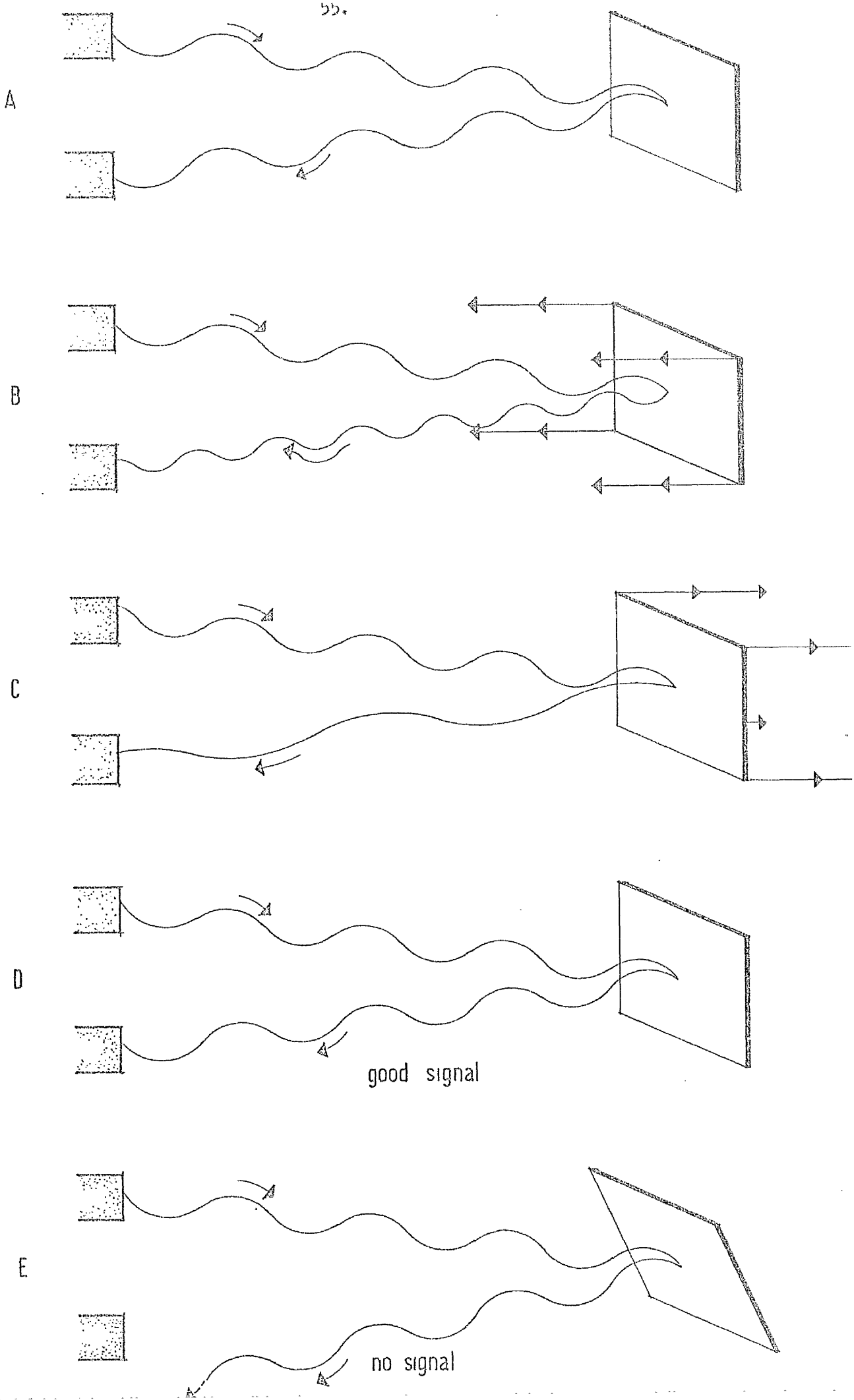


Fig. 5.3. Principles of the ultrasonic Doppler effect.

at every boundary they cross.

In this application ultrasound is formed by electronically causing a crystal to vibrate at a frequency of about two million cycles per second (2M Hz).

The Doppler effect can be simply (if not too accurately) explained by considering a sound wave bouncing off a reflector.

In the first case (Fig. 5.3A) where the reflector is stationary the sound wave will be reflected at exactly the same frequency. Figure B shows that if the reflector is moved towards the sound source, the sound waves will be "crushed up" and reflected at a higher frequency. In the last case (Figure C) where the reflector is moving away from the sound source the reflected wave will be "stretched out" to a lower frequency.

Frequency comparison. If the frequency of the reflected wave is compared with the frequency of the original, the difference in the two frequencies will be related to the speed at which the reflector is moving. In all the ultrasonic doppler units now available, an ultrasonic wave is passed into the patient by a crystal placed on her abdomen. The ultrasonic beam is reflected to some extent by every boundary it crosses but only those which are moving will cause a change in frequency in the reflected wave. The reflected wave is detected by a second crystal (situated beside the first) and the two frequencies subtracted electronically. The greater their difference the higher the note produced at the ear-phones.

It must also be emphasised that these units will only detect moving surfaces which lie at right angles to the ultrasonic beam as otherwise the reflected ultrasound will miss the receiving crystal (Figures D and E).

The practical instruments based on this principle all have an outward similarity though the electronics may be quite

different.

All consist of a control box containing the power supply (rechargeable batteries), most of the electronics and a small loudspeaker. An abdominal probe containing the transmitting and receiving crystals is linked to this by a flexible cable.

Sockets are provided for ear-phones or for tape-recording. Insertion of the ear-phone plug cuts out the loudspeaker. For diagnostic purposes it is best always to use the ear-phones.

It should be clear from the preceding theoretical considerations that ultrasonic doppler units can be used to detect any moving surface within the abdomen of a pregnant woman. Consideration of the anatomy of pregnancy suggests several suitable surfaces and the following are, in practice, easy to detect.

Maternal blood flow. Blood flowing in an artery presents many surfaces to the ultrasonic beam as each red cell in effect acts as a reflector. If the probe is lined up along the path of the uterine artery a strong signal is easily obtained. The fact that this is maternal blood flow is confirmed by simultaneous palpation of the radial pulse. The sound produced by ultrasonic Doppler units detecting blood flow is a characteristic hiss which varies rhythmically with the pulse. Pregnancy apart, blood flow in the radial artery and the arch of the aorta can also be easily detected.

Placental blood flow. Blood flowing in the placenta can be either foetal or maternal. Each can be distinguished by the pulse rate. With practice it is very often possible to localise the placenta to a fair degree of accuracy. However, a placenta on the posterior wall of the uterus is almost impossible to localise this way.

Umbilical cord blood flow. There is a strong flow of foetal blood in the umbilical cord and this is easy to detect. Many users who think they are "listening" to the foetal heart are in fact detecting this. As with maternal blood flow, the characteristic hissing sound is typical. Occasionally it is possible to trace the umbilical cord from the placenta to the baby.

The foetal apex beat. The upsurge of the foetal left ventricle provides an excellent moving reflector for ultrasound which moves both towards and away from the wave and therefore produces a double beat for each heart cycle. This unfortunately "sounds" like the conventional heart sounds and has given rise to many misconceptions about the use of the method.

The foetal mitral valve. The cusps of the foetal mitral valve also reflect ultrasound. Their movement is sudden and short and in fact provides the ideal moving reflector for our purpose. The very sharp "click" of the mitral valve opening is again quite characteristic. The aim of every operator should be to detect this movement as it provides the only signal really suitable for passing to any form of rate meter or counting device.

Technique for operation. As with most things in life, practice makes perfect. There is little to be gained in haphazardly placing an instrument on an abdomen and hoping for the best. It is possibly premature to lay down a search pattern for every occasion but each user should develop a personal routine.

Ultrasound is poorly transmitted in air so care must be taken to exclude all air from between the probe and the patient. This is best achieved by a liberal layer of olive oil. The operator should follow a set search pattern such as each quadrant of the abdomen in turn. Although the information is presented in ear-phones the operator must forget about listening for noises and

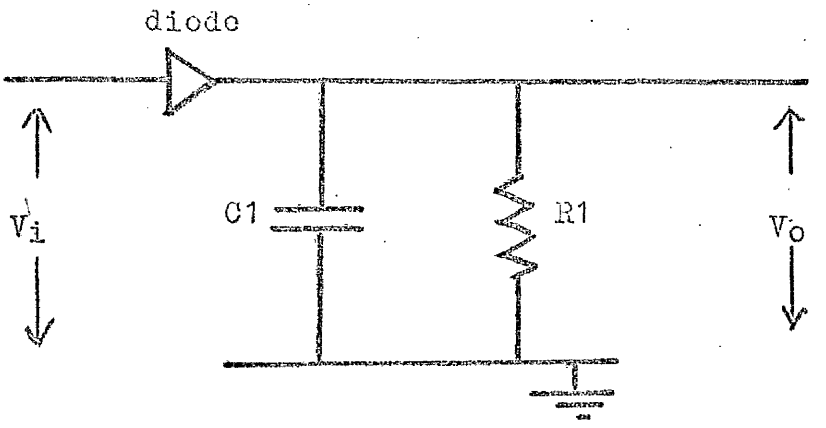


Fig. 5.4. Diode detector circuit.

concentrate on moving the ultrasonic beam around the abdomen like a blind man's stick feeling for movement. While it is often a great relief to hear anything at all, a definite attempt should always be made to identify each signal source and to work towards obtaining the signal caused by movement of the foetal mitral valve. This requires moving the crystals until the ultrasonic beam is reflected at right angles from the valve, and although this may seem difficult a little practice makes it extremely easy in the majority of cases.

As has been emphasised the doppler device detects movement of the foetal heart. While the usual aural presentation bears a comforting resemblence to conventional heart sounds close examination of the signal reveals up to eight events per cycle. This poses even greater problems than the FPCG.

The exact relationship of the transducer to the foetal heart is never constant so that the details of the waveform vary considerably - a simple divide by 8 ratemeter just will not work. The Hammacher technique can be adapted to deal with the problem but not so successfully as to offer any real advantage at reasonable cost.

A simple analog technique developed in the course of this study can be made to work in most cases.

In this method the "envelope" of the signal is detected by a detector circuit (Fig. 5.4.) similar to that used in any AM radio-receiver.

The output waveform (Fig. 5.5.) is not at all satisfactory for precise measurement of cardiac cycle intervals but it can give a fair average rate reading over several minutes.

The exact form of this output depends mostly on the time

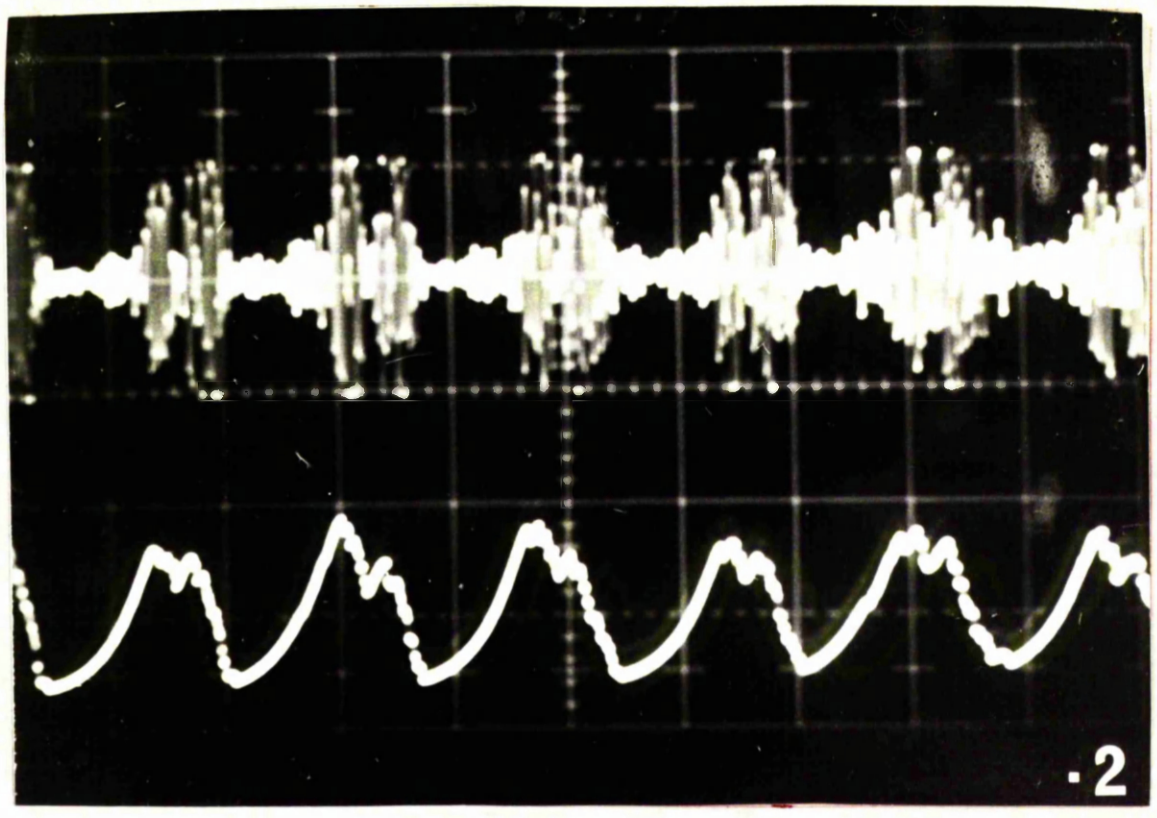


Fig. 5.5. Output of ultrasonic Doppler unit before and after diode detection and smoothing.

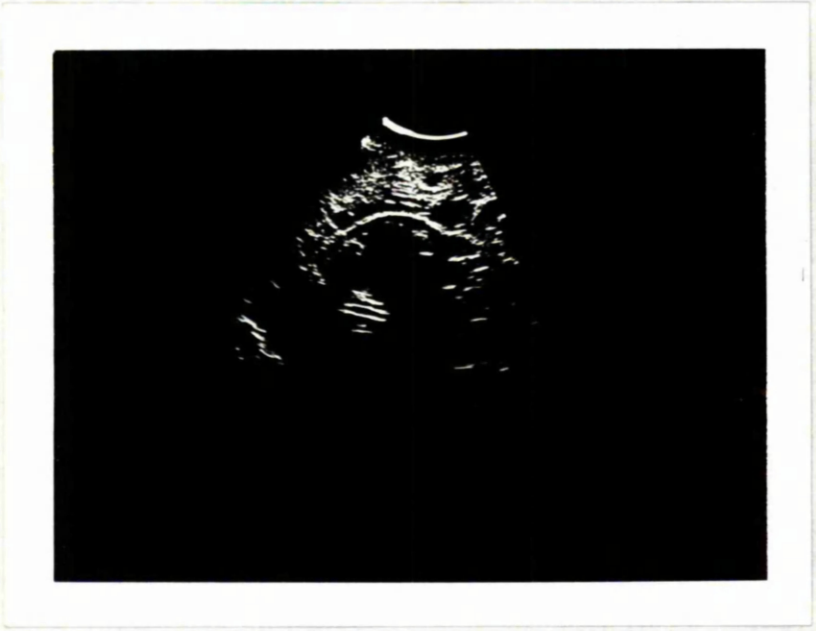


Fig. 5.6. Ultrasonic B-scan showing cross section of foetal thorax.

constant of the capacitor C 1 and resistor R 1. In practice R 1 was made variable and had to be adjusted for each individual case.

The other ultrasonic device used in foetal monitoring is the much larger, more powerful, device the diasonograph. This is an extremely powerful tool in foetal measurement but is not usually thought of in connection with foetal heart monitoring. There are however, two possible uses to which it can be put in this context. Firstly in the conventional B-scan presentation (Fig. 5.6) it is often possible to gain an estimate of the cross sectional area of the foetal heart relative to the cross sectional area of the whole chest. Secondly, in the time - position mode the movement of the ventricles can be detected and measured. Fig. 5.7 shows an example of this form of presentation and it is interesting to note that the general form of the trace is very similar to that of the ballistocardiagram.

Two other sources of information on the foetal heart have been described. At the present time neither has been developed to the stage of clinical usefulness though each bears promise of a new "quantitative" type of information.

Both depend upon the process of transient averaging (Chapter 7) and the securing of an adequate "trigger" impulse from one of the methods already described.

5.3.4. The Foetal Ballistocardiograph. (FBCG) - The adult ballistocardiograph has been used since 1939 (Starr et al). In all its forms the BCG reacts to the flow of blood within the body and this reaction can be quantitatively measured.

In the case of a pregnant woman the BCG will be reacting to both maternal and foetal flows. The concept of foetal

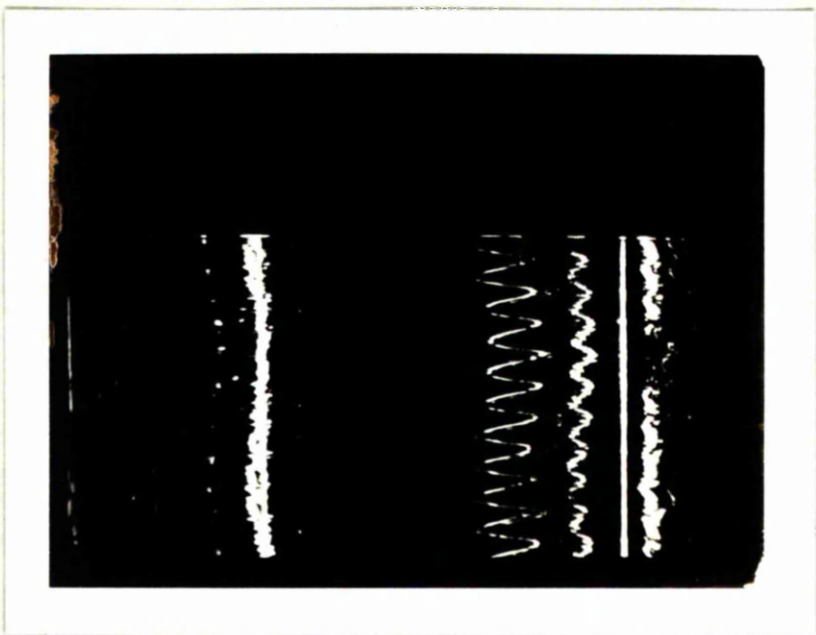


Fig. 5.7. Ultrasonic TP-scan showing movement of the foetal heart.

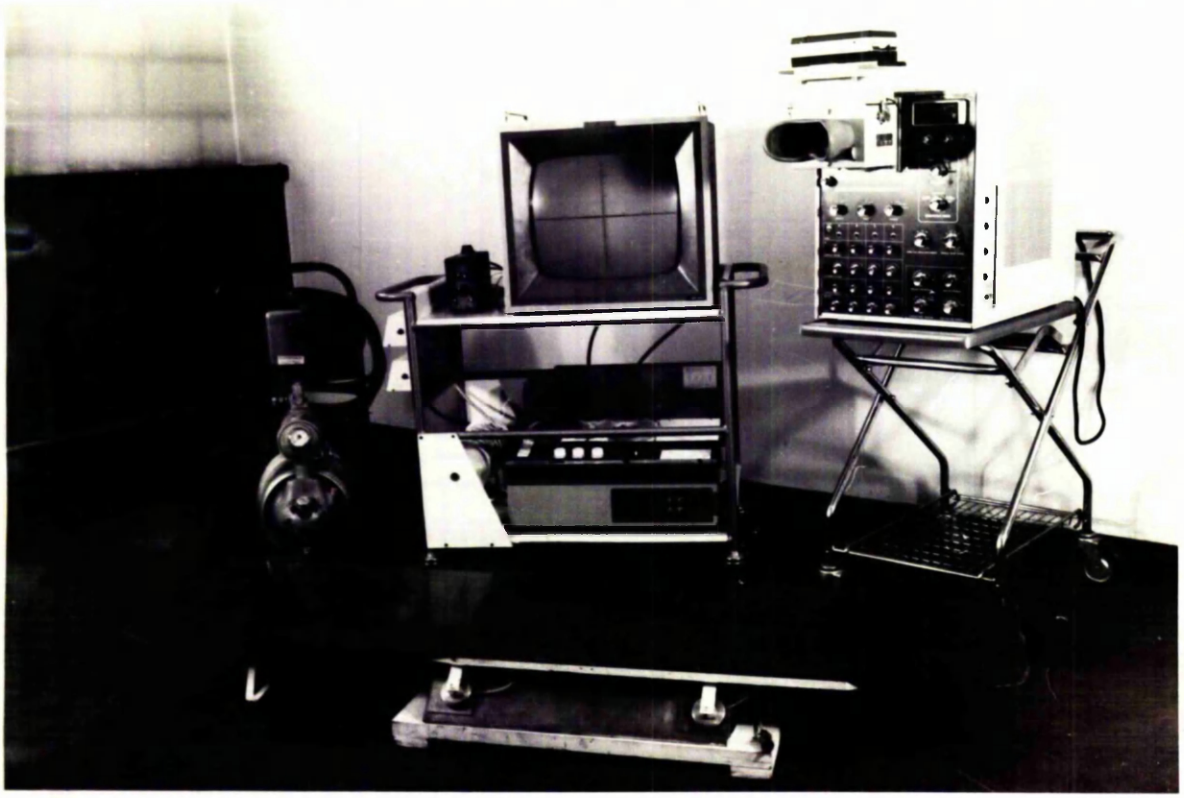


Fig. 5.8. Air-bearing ballistocardiograph.

ballistocardiography has been examined before now but the only report of its successful recovery is that by this author (Curran, Kerr and MacGregor, 1969).

During the course of development of a FECG system (Volume 1) it became clear that the process of transient averaging was an exceptionally powerful tool in bio-medical research.

In theory if a sensitive enough ballistocardiograph could be built to register the tiny foetal pulsation then the computer technique should be able to isolate them from the superimposed maternal elements.

Happily this thought coincided with an upsurge in air-bearing technology at the National Engineering Laboratories (East Kilbride) and a prototype air-bearing ballistocardiograph was constructed there (Fig. 5.8).

(The engineering details and two preliminary forms of analysis are described in Appendix C).

The procedure for examining a patient is similar to that for adult ballistocardiography but she is instrumented for simultaneous foetal electrocardiography.

Trigger signals derived from the FECG are used to control a computer of transient averages and both FECG and FBCG waveform can be computed. (Fig. 5.9).

Maternal waveforms can also be computed for comparison.

While this technique seems to offer a major advance in signal recovery in the research situation it will be some time before clinically useful results will appear. As the method is basically quantitative it seems that numerical information on foetal cardiac output and blood flow is achievable. This information could be of real value in the imminent congestive heart failure of hydropic foetuses or in the early detection of

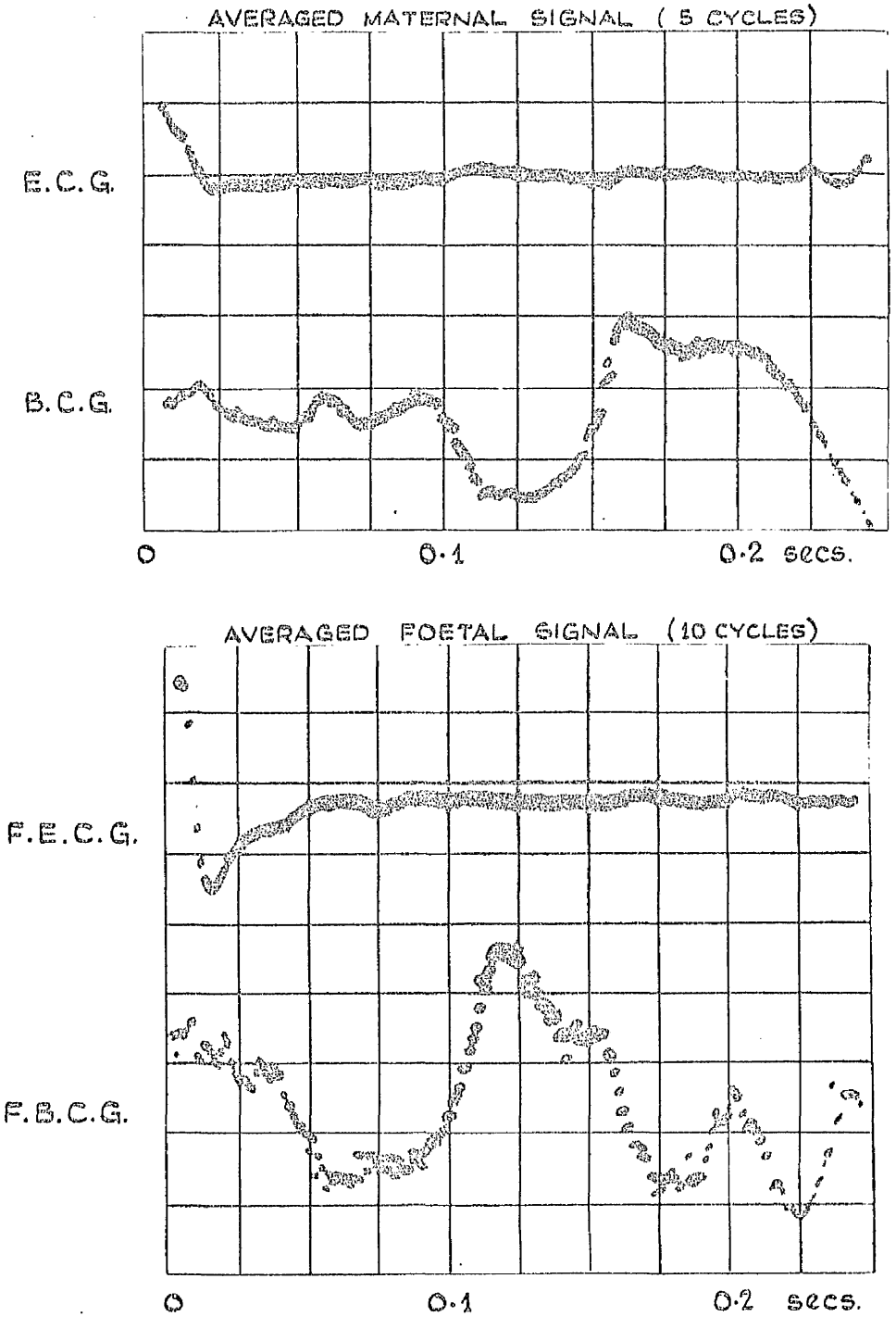


Fig. 5.9. The foetal ballistocardiogram

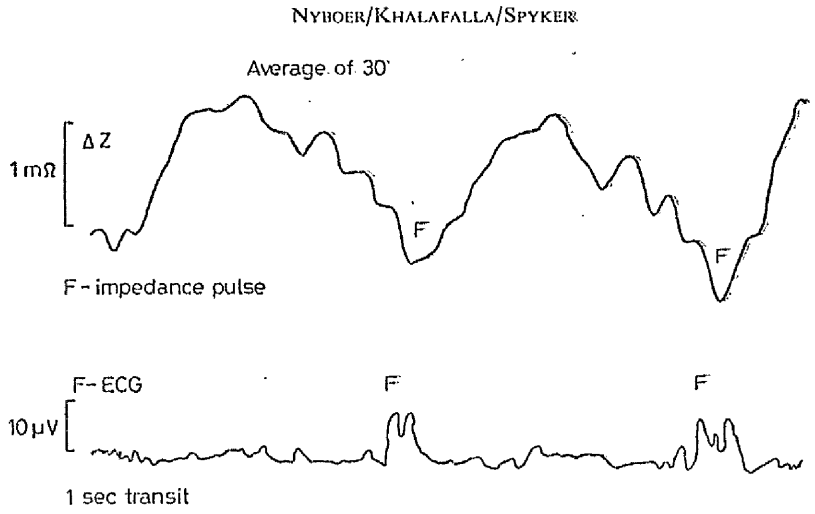


Fig. 3. By the use of computer averaging techniques, the maternal QRS signals are minimized or eliminated. The maximum fetal spike potentials of the fetal ECG are used to trip the computer averaging circuit for existing but small fetal impedance contributions to the impedance baseline measurements. This covers 2 or more successive beats in the study for over a period of 1 sec beyond the triggering signal. Impedance forms vary with the number of pulses averaged. These distinctly show an increase in volume (up) with systole in the lower torso derived from the submerged fetal region. Peak to peak differences are only in the order of 2 mΩ or less and is equivalent to 3.5 ml/beat.

Fig. 5.10. Foetal impedance plethysmogram. (Nyboer)

congenital heart defects.

5.3.5. Impedance Plethysmography - Once it had been demonstrated that foetal ballistocardiography was possible the concept of other approaches to the foetal heart and circulation was opened up. The challenge was taken up by Prof. J. Nyboer of Michigan who succeeded in demonstrating the foetal impedance plethysmogram.

He used a 4 electrode technique in which about 1mA (as a constant current) was applied to the mother at 5 KHz. The changes in impedance measured are due to varying flow in the maternal and foetal circulations. Given a good FECG it again proved possible to recover the foetal components by transient averaging (Fig. 5.10). He has extended the method far enough to calculate the foetal stroke volume at about 3.5 ml per beat. (Details in Appendix C).

While this is extremely encouraging, adult impedance plethysmography has been bedeviled by difficulty in obtaining repeatable results and in quantifying the data. These foetal results must be regarded with considerable care and perhaps a little scepticism.

5.4. The Future - From these considerations it is clear that there are many possible ways to gain information on the foetal heart.

Unfortunately all of them are highly technical and inherently subject to error. Of all the signals available the FECG is certainly the most satisfactory to process provided it can be detected.

The FECG must never be assessed by the standards of adult cardiology but even if it is relatively unhelpful of itself it certainly is the key to unlock a great deal of information

on foetal circulatory physiology.

Progress in the understanding of human foetal physiology and pathology has been slow and hesitant. This is no surprise as the sheer inaccessability of the foetus has already forced obstetricians to wring more information out of meagre data than their colleagues in adult medicine. Computerised medicine may be difficult to justify but surely in this special circumstance we must apply all the tools of our complex technology to advance.

Examination of the foetal heart must rarely be regarded as an exercise in cardiology. The object is, more often,to assess the wellbeing of the whole foetus. In this light the foetal heart rate is somewhat removed from the real problem - that is brain stem oxygen levels - and it can only serve as an indicator of affairs. The foetal heart rate can certainly not be regarded in isolation from biochemistry and clinical evaluation.

The foetal electroencephalograph (EEG) has also been described. This is much more closely related to cerebral oxygen but the technical difficulties in obtaining and quantifying the signal are immense. Once again transient averaging has been useful. If both computer and foetus are triggered at the same time; e.g. by light or noise any repetative response by the foetus can be recovered - even from the maternal abdomen (Kasabe and Arayama, 1969). There is a little encouraging evidence that demonstrable changes are associated with intra-partum anoxia.

One method of moving closer to the foetus is the application of radio-telemetry. It is now technically feasible (though it has not been done) to deliver a small radio-transmitter into the liquor amnii which could relay out information on liquor oxygen, colour, and pressure together with foetal heart rate.

Medicine in the past has rarely paused to count the cost of human life. The introduction of all the techniques described here into obstetric research departments, far less general clinical practice, would be prohibitively expensive. The money could undoubtedly be spent to equal, if not better, effect on other human problems. Foetal monitoring has arrived at the cross-roads and the way ahead is not clear.

To date there is no evidence that foetal heart monitoring per se has reduced perinatal mortality in otherwise good conventional obstetric units. Some argue that an improvement in the quality of infant (as measured by its Apgar score) is the main achievement. This is patently not relevant as several "at risk" register follow ups have shown (Richards and Roberts, 1967, Knox, 1970).

Before assessment of obstetrical practice can continue some accurate method of quantifying the result (i.e. the newborn infant) must be developed. At present no such index exists.

The only "hard" evidence of improvement has come from such centres as Aberdeen where social measures have produced real drops in perinatal mortality (Baird, 1965).

Yet, with all this said, the intuition of every obstetrician and parent cries out that the birth of a well oxygenated infant is the undoubted object of the whole exercise.

6. DESIGN AND DEVELOPMENT OF FECG SYSTEMS

6.1. Introduction - The Foetal Electrocardiograph (FECG) is the longest established electronic method of foetal heart detection (Cremer, 1906). When the FECG is detectable it certainly is the most effective basic signal from which to proceed.

Despite its small voltage (100 μV) the FECG is really quite a large signal by today's electronic standards. Its amplification need no longer be considered greatly troublesome as this Chapter will demonstrate.

Unfortunately the FECG at the surface of the mother's abdomen is always accompanied by the maternal ECG. Recovery of the foetal signal (F) from this combined signal (M + F) can be difficult though rarely impossible.

In an earlier Study (Vol. 1. Chapter 4) many of the points in this chapter were considered in some detail. Since then many considerable advances have occurred, both in the design of amplifiers and in overall electronic systems. This Chapter is intended to explain and describe these improvements.

6.2. Patient preparation and electrodes - The passing years have if anything re-inforced the earlier finding that a relaxed, comfortable patient is the best starting point for successful foetal electrocardiography.

In a trial of 50 out-patient examinations in only 40% was the FECG detected satisfactorily at the first attempt.

This compares with a success rate of at least 75% for the first examination on in-patients. A second examination brings the ward success rate up to at least 90% but makes little improvement on the out-patients.

There remains no doubt that the examination should take place on in-patients in their familiar ward surroundings.

The examination should be presented as a routine technique

and not heralded by "research" trumpets

Likewise no new evidence has been found to change the type of electrode recommended. Five centimetre lead discs were found to be eminently satisfactory in all respects. No electrode has been found to improve upon cost, ease of manufacture, patient comfort or above all effectiveness.

6.3. FECG Amplifiers.

6.3.1. General Considerations - The space-oriented explosion in electronic devices and systems has wrought enormous changes in medical instrumentation. Over the last few years integrated circuits (ICs) have become easily and cheaply available.

This major step allows full play to the "black box" empirical approach to instrumentation which is not dependent on deep electronic knowledge.

Cost, a major problem in widespread use of instrumentation, has fallen dramatically to extremely attractive low levels.

When this Study began (1968) a good commercial FECG amplifier cost in excess of £150.00. The early amplifiers built for the project (based on the Fenlow AD 105) cost just over £50.00. The amplifiers described in this chapter can be built for as little as £5.00 each.

It is a fair criticism that commercial medical electronic equipment built by large electronic concerns tends to be sophisticated for the sake of elegence rather than for its operational requirements.

The requirements for an FECG amplifier are set out in detail in Vol. 1 but can be briefly summarised here.

a. Accept a signal of about 10 μV and amplify this to about 0.5 V.

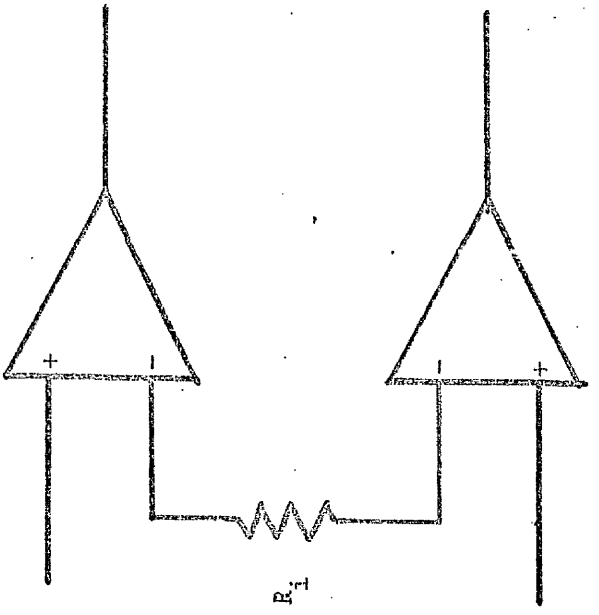


Fig. 6.1. Two operational amplifiers linked as one.

b. Moderate input impedance. e.g. 500 Kohms.

c. Low inherent noise level.

d. Good common mode rejection.

e. Adequate band-width, i.e. 5 - 60 Hz

f. Operational safety.

It will be demonstrated that these can easily be achieved by virtually fireside electronics.

6.3.2. The Practical Amplifier - The first design, which is not particularly novel, is based on the Motorola MC 1435 dual operational amplifier (£3.50). This is a single package 1" x $\frac{1}{2}$" x $\frac{1}{4}$" containing two seperate good quality amplifiers.

To obtain reasonable input impedence two amplifiers are linked as one by their inverting (negative) inputs. (Fig. 6.1.).

The overall gain of this first stage is determined by conventional negative feedback to the inverting inputs and is kept small (x 10 or x 15).

This is determined by the ratio of $\frac{R_f}{R_i}$ (Fig. 6.2.)

Differential amplifiers operate best if the impedence between each input and earth is the same. This can be virtually achieved by inserting large resistors in this position. (Fig. 6.3.) Note that the system negative goes to an amplifier positive

At this point no attempt has been made to shape the bandwidth of the system. Only stability with moderate gain has been achieved. To obtain best results this stage is physically kept close to the patient - so that only short electrode leads are required. The remainder of the electronics can easily be situated some distance away.

Further gain and bandwidth shaping is achieved by another pair of amplifiers (again a single Motorola MC 1435 device).

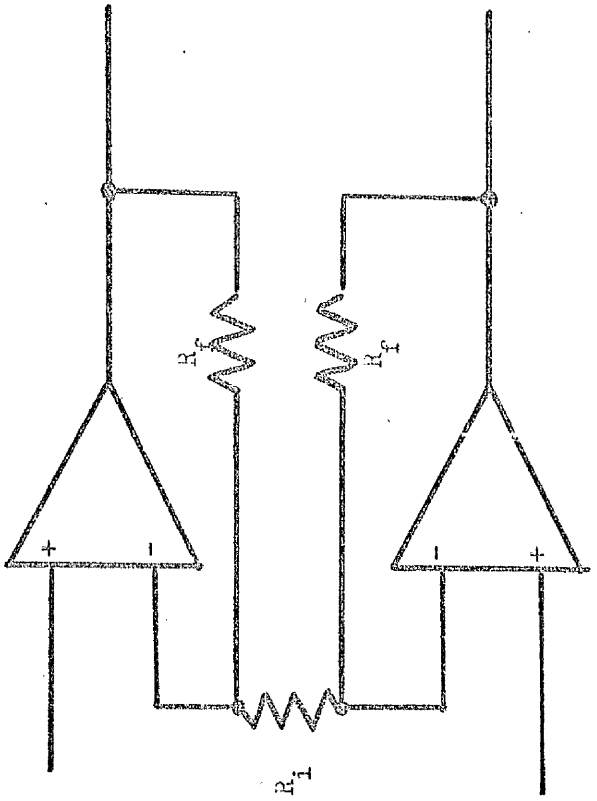


Fig. 6.2. Negative feedback circuit.

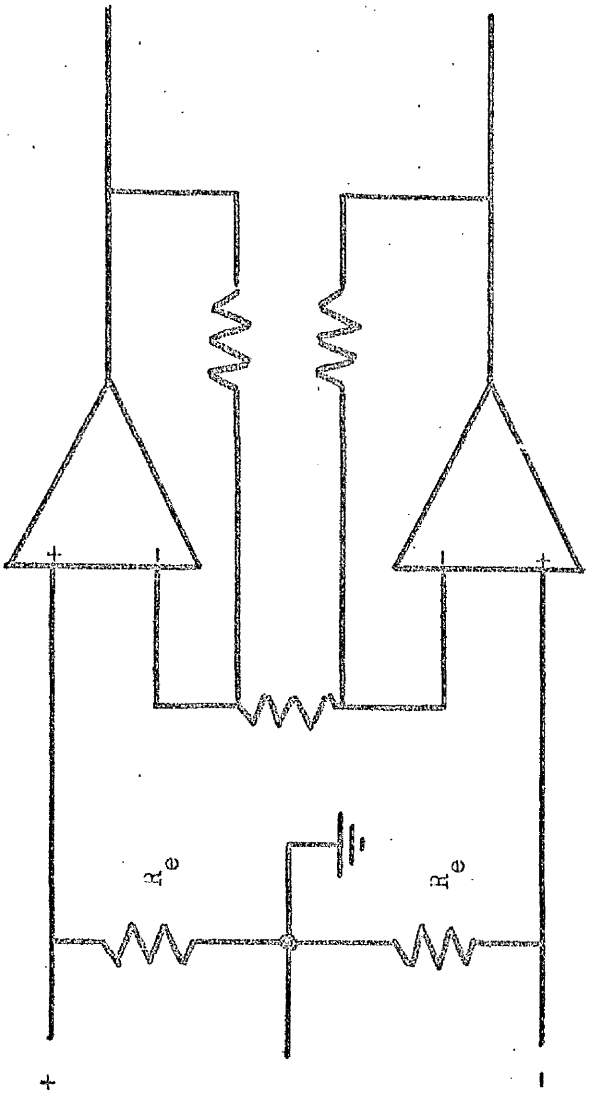


Fig. 6.3. Input balance resistors.

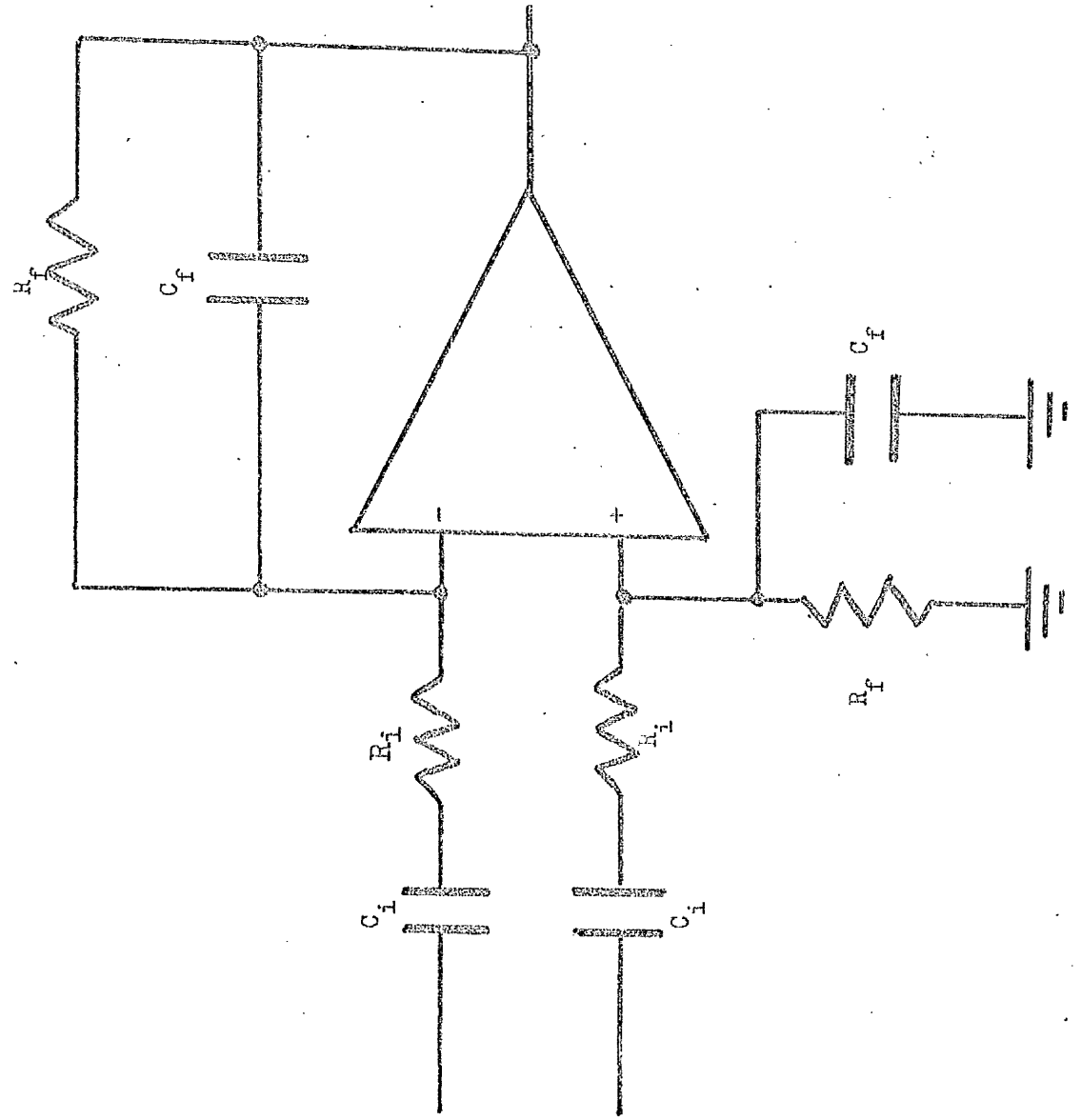


Fig. 6.4. Circuit to determine bandwidth.

The outputs of the first stage are connected to the second stage by a capacitor and a resistor in series. The resistor value is determined by the gain requirements of the stage so the value of capacitor depends upon the lower limit of bandwidth required. The response of the amplifier will be 3dB down at the frequency for which the impedance of the capacitor equals the set resistor. This is calculated from the formula.

$$I = \frac{1}{2\pi f C}$$

where I = impedance (Ohms.)
f = frequency (Hz)
C = capacity (Farads.)

In this case R = 2.2 Kohms and C = 6 μF for a frequency of 15 Hz.

The other element which determines gain is the feedback resistor Rf and it too is set for the required gain. The upper bandwidth limit is set by a capacitor in parallel to this. The amplifier response will be 3 d B where the impedance of this capacitor at the required frequency equals Rf.

Again by $I = \frac{1}{2\pi f C}$ for a frequency of 50 Hz C = 0.1 μF.

Feedback is of course only taken back to the inverting input. For best results an identical network should be inserted between the non-inverting input and earth. (Fig. 6.4.)

Still greater gain can be obtained from the fourth amplifier and this if required can be made variable by including a variable resistor. (Fig. 6.5.)

The theoretical system for one channel is now complete and the whole circuit is presented in Fig. 6.6.

While this represents enough information for the electronics

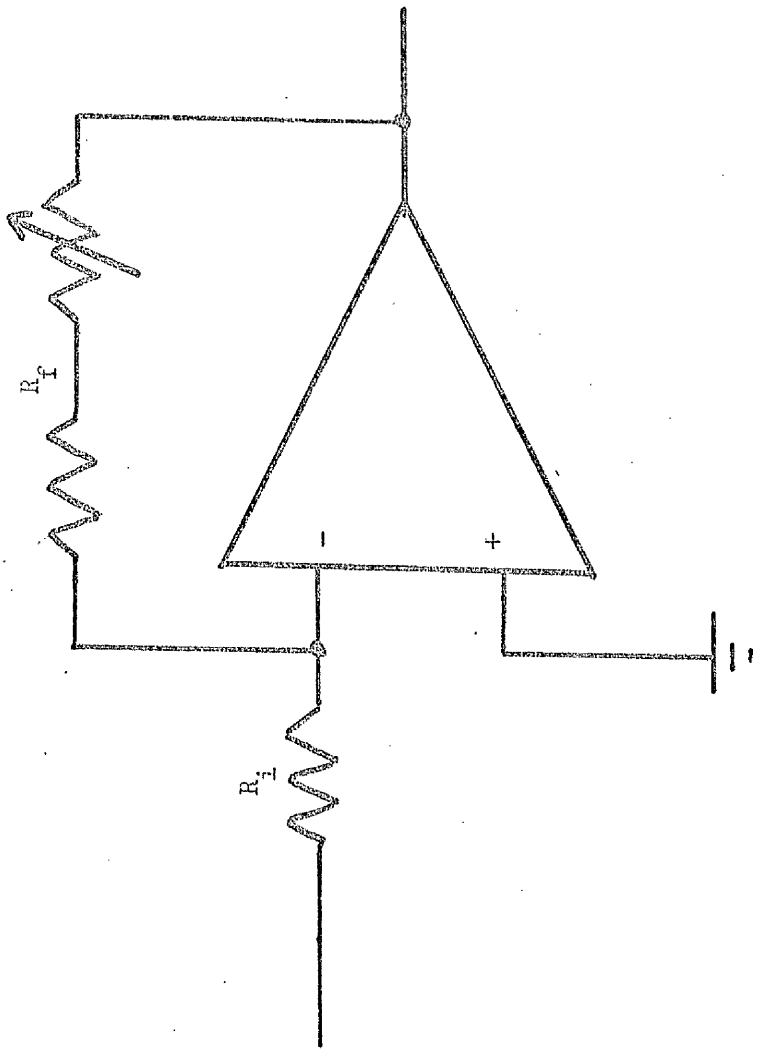


Fig. 6.5. Variable gain amplifier.

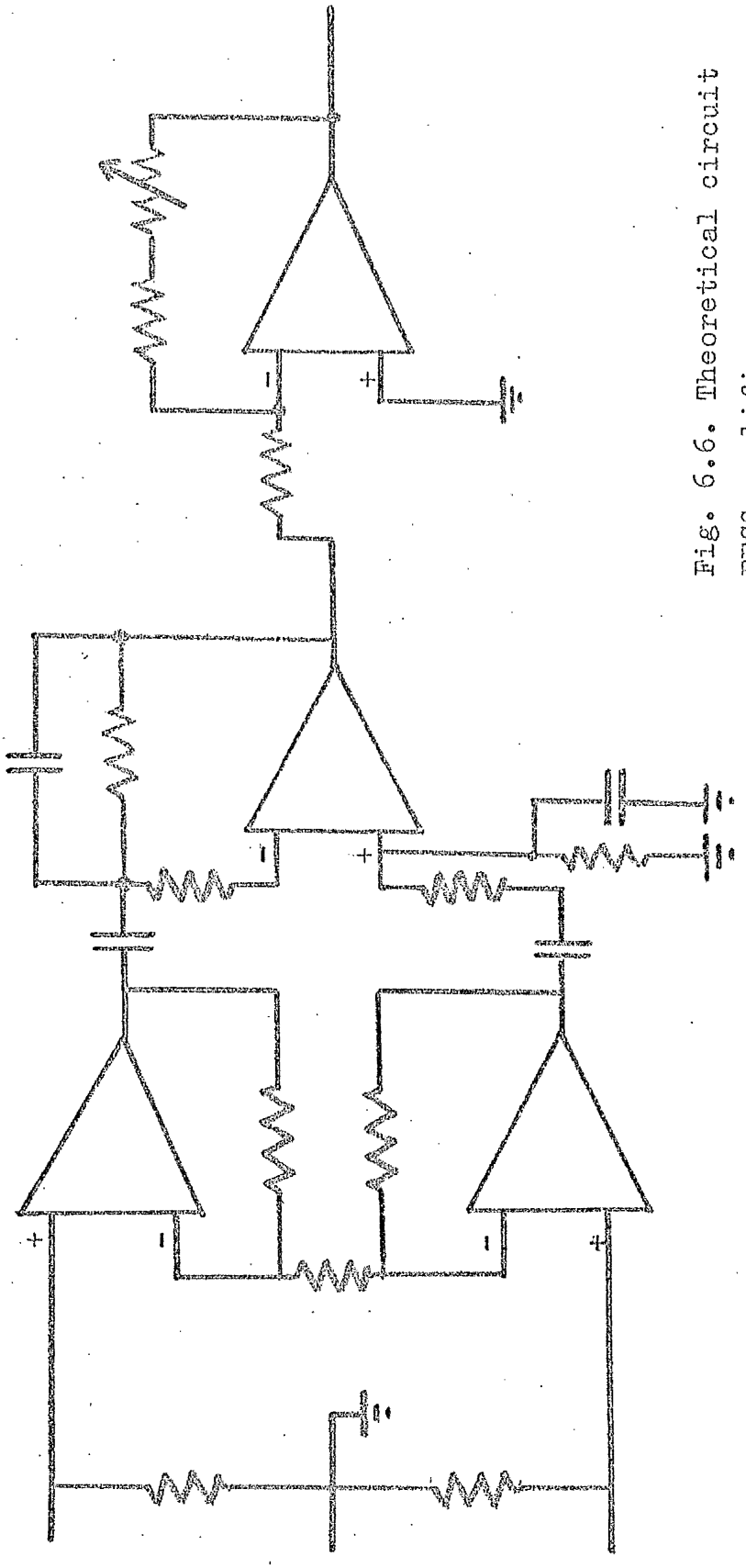


Fig. 6.6. Theoretical circuit FECG amplifier.

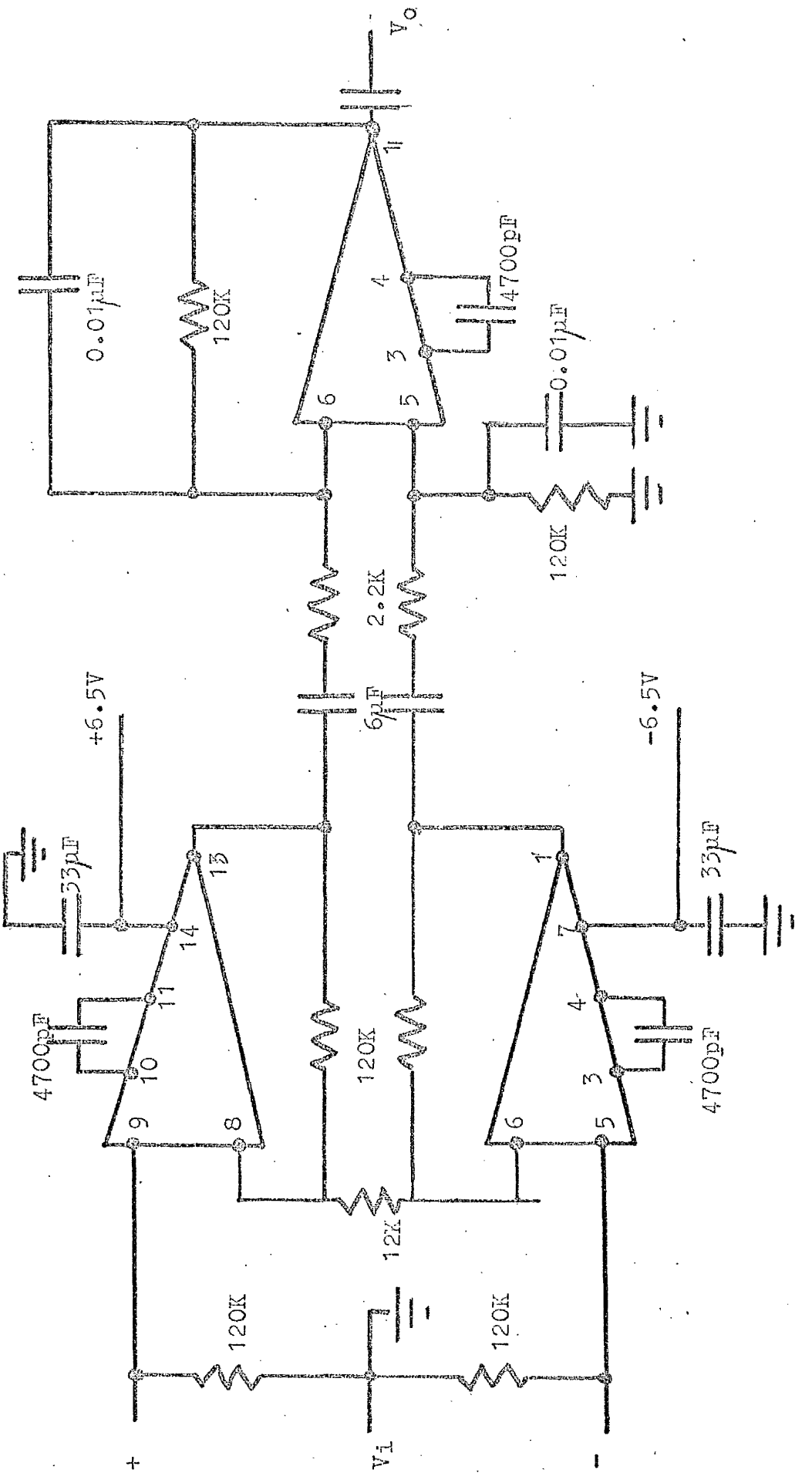


Fig. 6.7. Practical FECG amplifier using Motorola MC1435 integrated circuits.

engineer to construct the system it is not complete enough for the "amateur" constructor. A few practical points have to be included.

The Motorola MC 1435 amplifiers are not equally efficient at all frequencies and external frequency compensating components are required. In this case they are simply 4700pF capacitors inserted at the relevent points.

It is also essential that the power supply to the amplifiers be decoupled as near as physically possible to the amplifiers - this is especially so at the first stage which is quite remote from the power supply. This again is a capacitor, but a much larger one, of say 30 μF between each power line and earth. The amplifiers require both positive and negative supplies at 6.5 V. Particularly in the interests of safety this is best supplied from two 6.5 V batteries.

A resistor of 1 Kohm in series with the final output is a very useful addition as even with the output terminal accidentally shorted the amplifiers cannot be damaged.

The complete practical circuit is shown in Fig. 6.7.

This was the basic amplifier constructed and used for the experiments described in this thesis. Not surprisingly electronics continued to advance even over the next year or so and prices fell even further. So much so that a major modification of the system is worth describing.

The theoretical system remains the same but by use of new amplifiers - the Radio-spares OPA 741 at 90p considerable savings in time, components and cost can be achieved.

This amplifier is internally frequency compensated and so requires no external components. Each amplifier is seperately packaged which allows a more flexible layout of the parts and a printed circuit board is not really necessary. A small piece (4" x 5") of perforated paxolin board (Radiospares) will suffice.

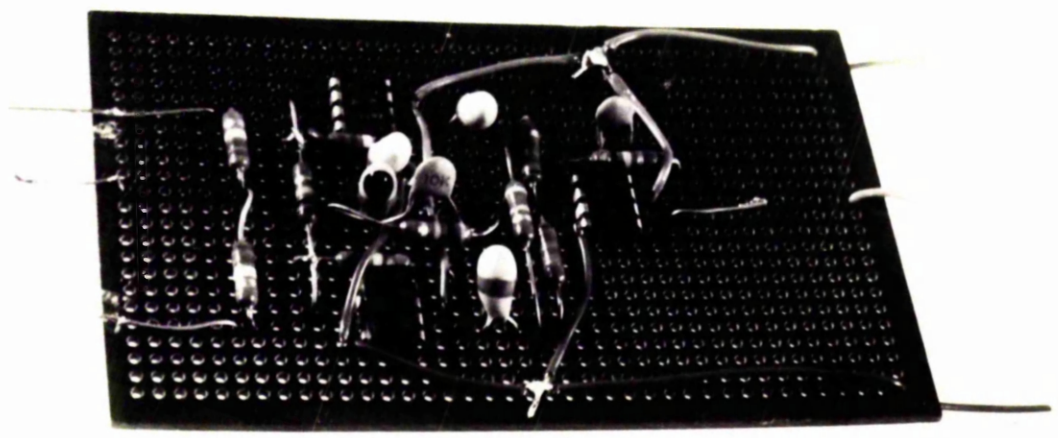


Fig. 6.8. A prototype FECG amplifier.

The prototype (Fig. 6.8.) was genuinely built in one evening at the fire-side using only a soldering bolt and a pair of pliers. The practical circuit is given in Fig. 6.9.

In passing, the circuit is also perfectly suitable for use in adult cardiology with allowance made for the slightly wider bandwidth required (i.e. 5 - 100 Hz) This circuit is shown in Fig. 6.10.

Such basic amplifiers are the building blocks for the more complex systems required for adequate recovery and processing of the FECG. Their further use will now be described.

6.4 Two Channel Systems - This is the method of recovering the FECG used in most of the clinical studies described in this thesis. Its use is fully described in Chapter 8.

Earlier work (Vol. 1) had concluded with a two channel system in which each channel's output was seperately variable and passively added. With that system the electrode connections had to be carefully arranged so that the maternal element in each channel was of opposite polarity at the input (and of course the output) so that addition actually achieved cancellation. The operation of the system proved to be such a personal skill that others had great difficulty in obtaining useful results.

Some method of return to a single central knob system seemed necessary. The problem with the even earlier single potentiometer system (Fig. 6.11) was that variation of the potentiometer changed the load on each amplifier which resulted in some instability. The solution lay in a small operational amplifier - again the Motorola MC 1435.

The use of a differential amplifier meant that two channels could be genuinely subtracted and so identical channels and electrode connections could be used.

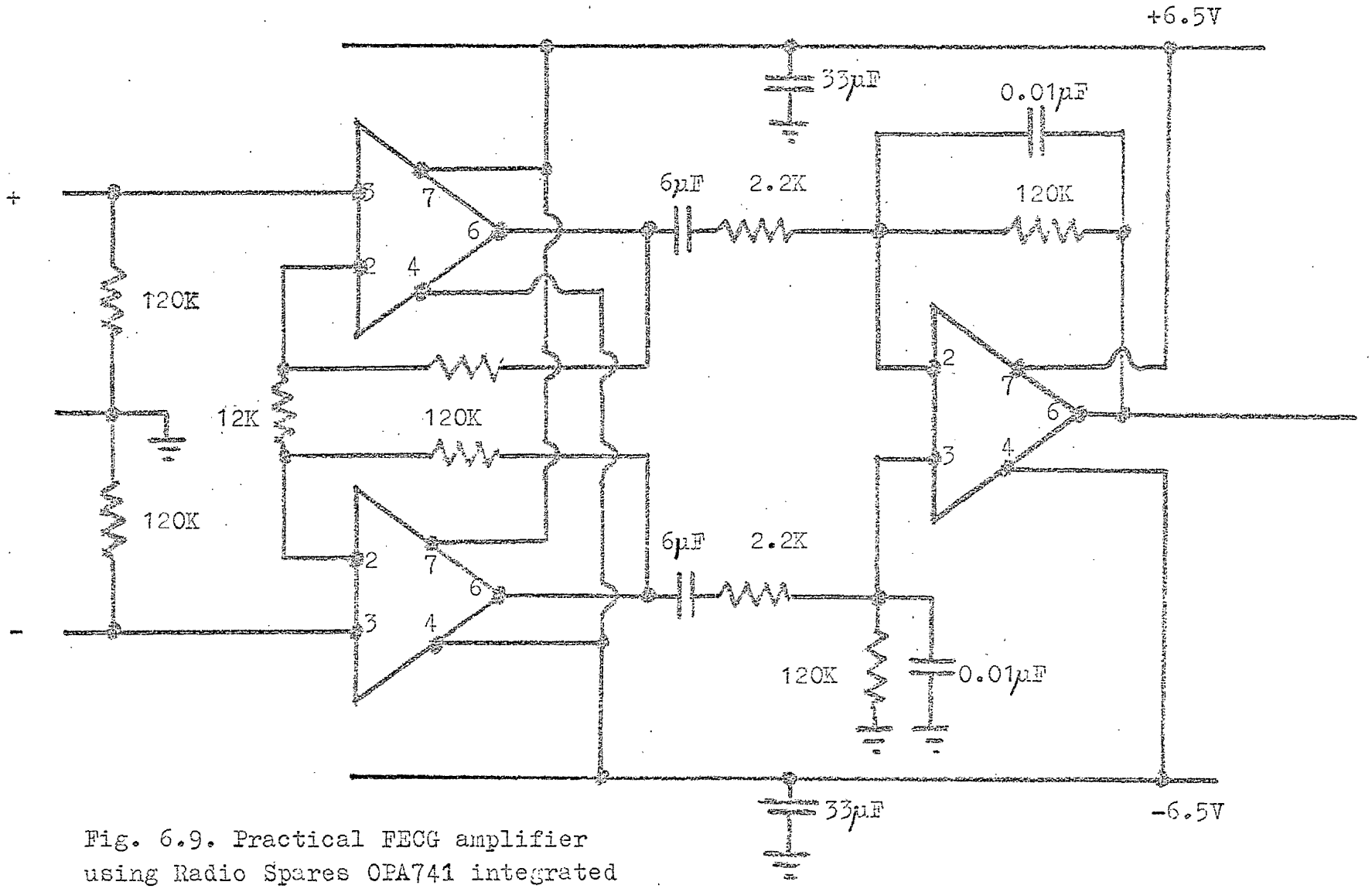


Fig. 6.9. Practical FECG amplifier using Radio Spares OPA741 integrated circuits.

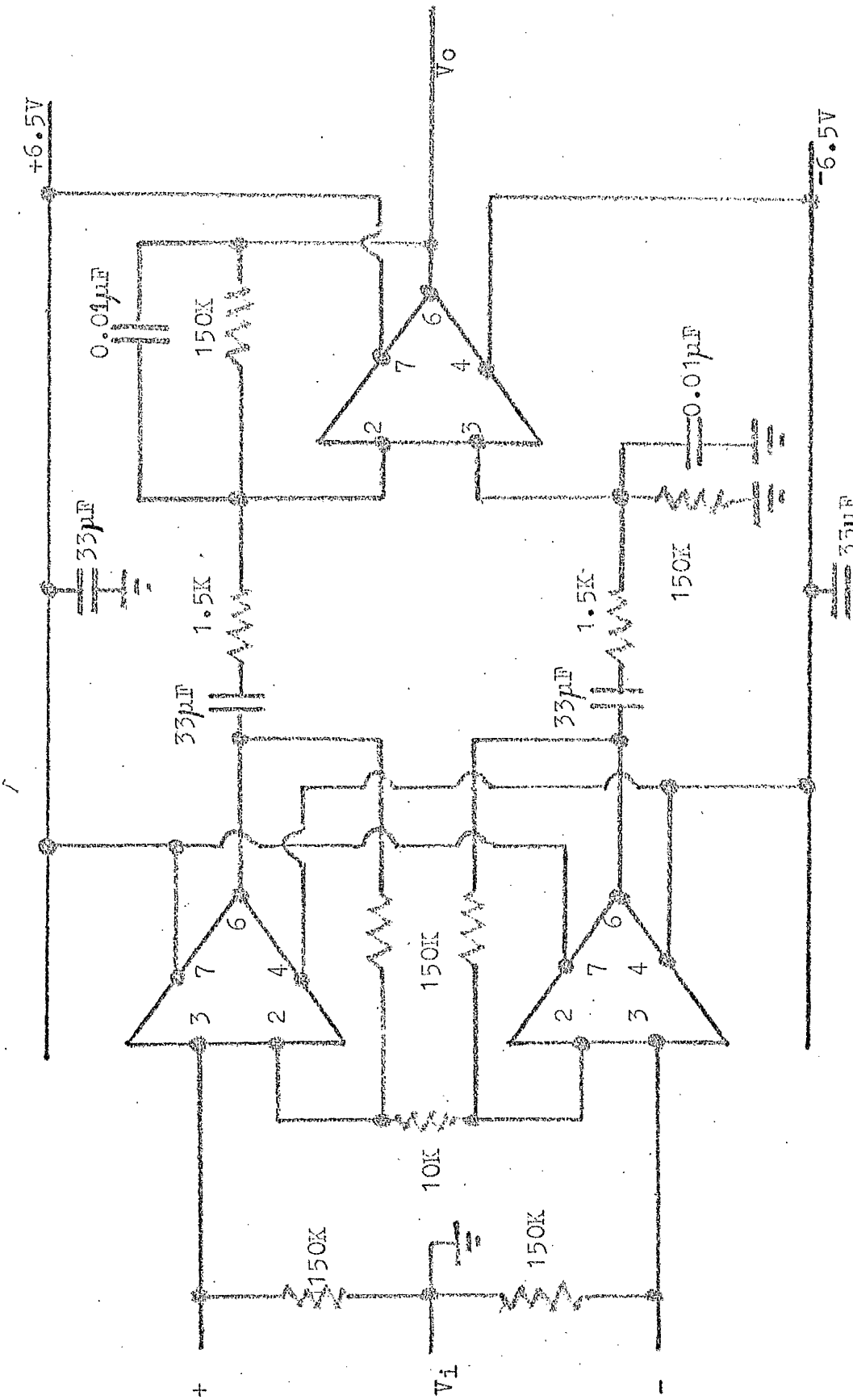


Fig. 6.10. Practical adult ECG amplifier using Radio Spares OPA741 integrated circuits.

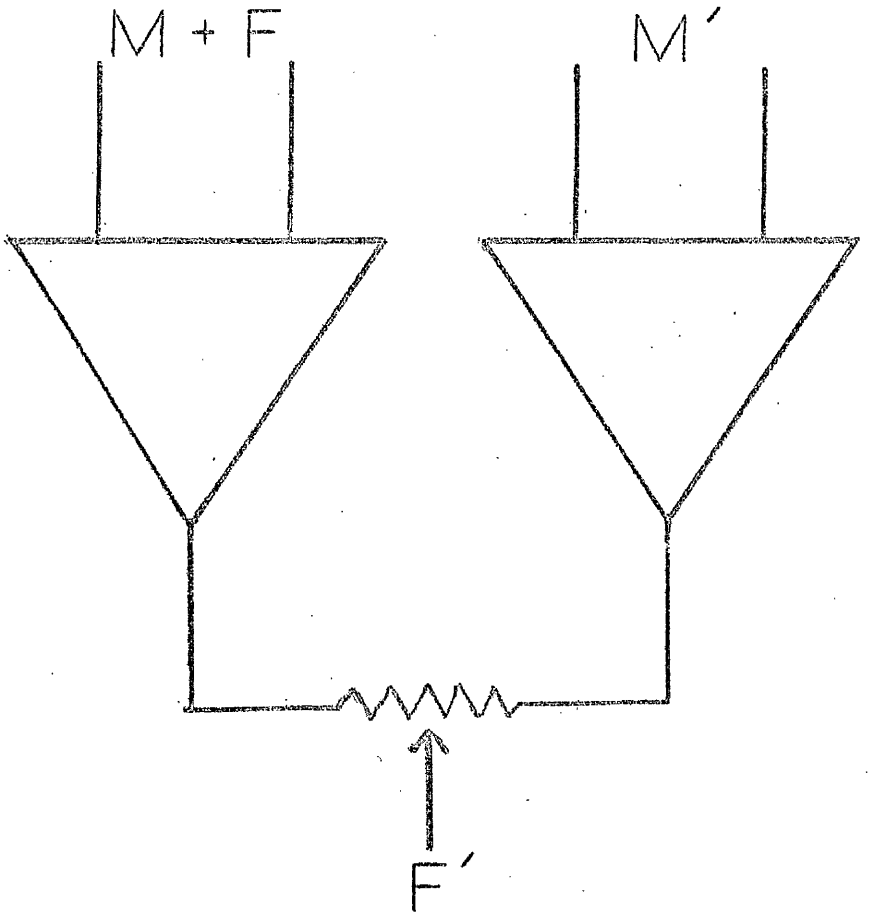


Fig. 6.11. Single potentiometer 'balance' system.

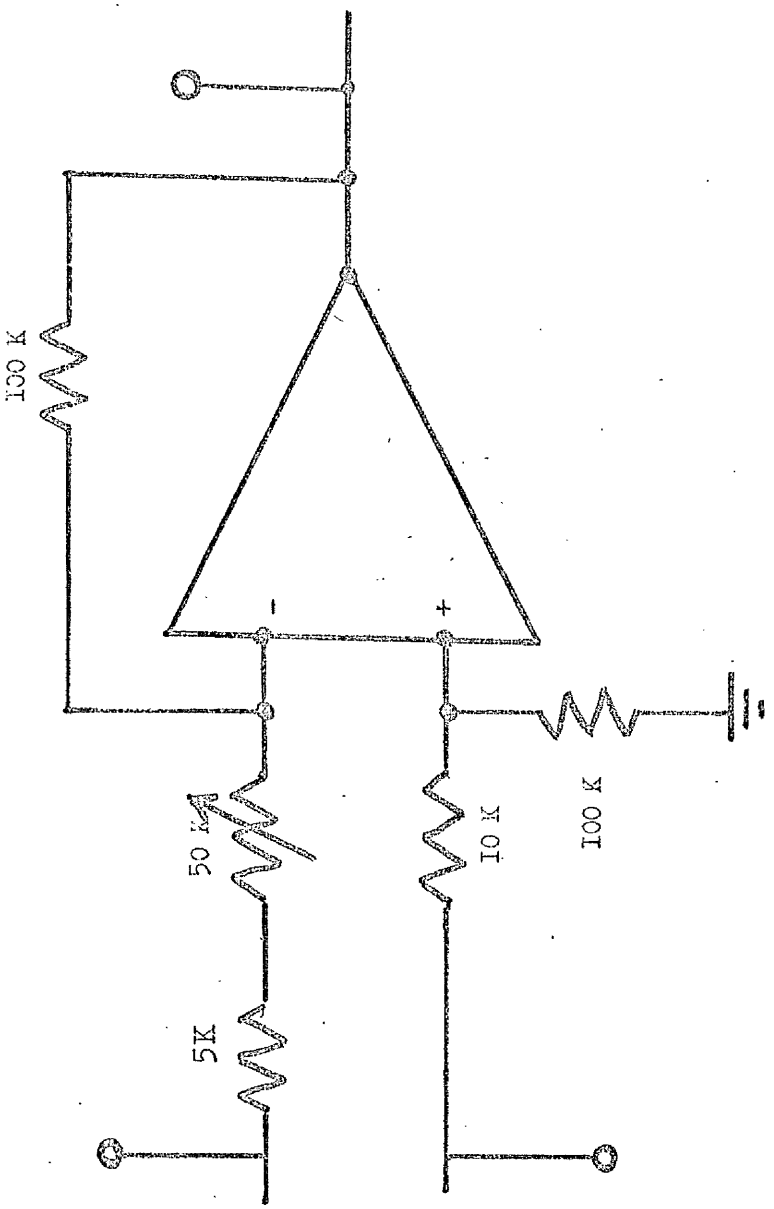


Fig. 6.12. Operational amplifier 'balance system.

It is a simple matter to adjust the gain of the differential amplifier with respect to each input signal so that variation in their amplitudes can easily be accommodated. (Fig. 6.12) As the foetal + maternal channel contains the smaller maternal element it was connected to the non-inverting (positive) input and its gain fixed at 10 (by R_1 and R_2). The other, maternal only channel was taken to the inverting (negative) input and provision made to vary its gain from 2 to 20. This variable control is a 50 Kohm potentiometer and it is well worth the added expense of using a 10 turn model which allows very fine "balancing" of the signals.

This system completely isolates the channels from each other and from the recording system which follows. The Radio-Spares OPA 741 is also perfectly suitable for this system but in practice the extra amplifier of the MC 1435 block was used to provide even more gain in switched stops. (Fig. 6.13)

Provision has also to be made for monitoring the output of each channel and the final output. This was done on a small oscilloscope which had provision for simultaneous monitoring of two signals. The system was arranged to continuously monitor the final output and allow switching to either channel seperately.

This system has worked well and it has been possible to train other non-technical personnel to operate it with considerable success. A typical example of the cancellation possible is shown in Fig. 6.14.

Recording the further processing of the output signal is dealt with in the following chapter. (Chapter 7).

6.5. An Eight Channel System - Experience with simple cancellation shows that in about 75% of cases an adequate FECG can be recovered. To identify the FECG in the remaining 25% a modification of the technique of

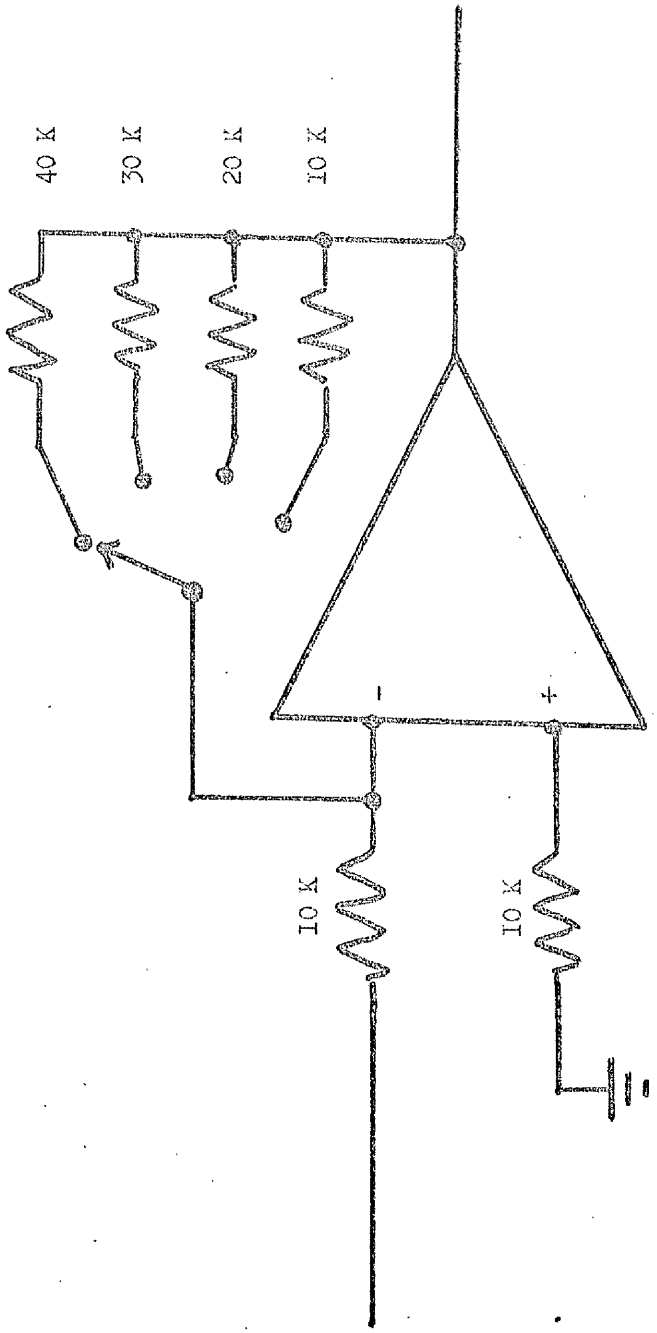


Fig. 6.13. Switched gain amplifier.

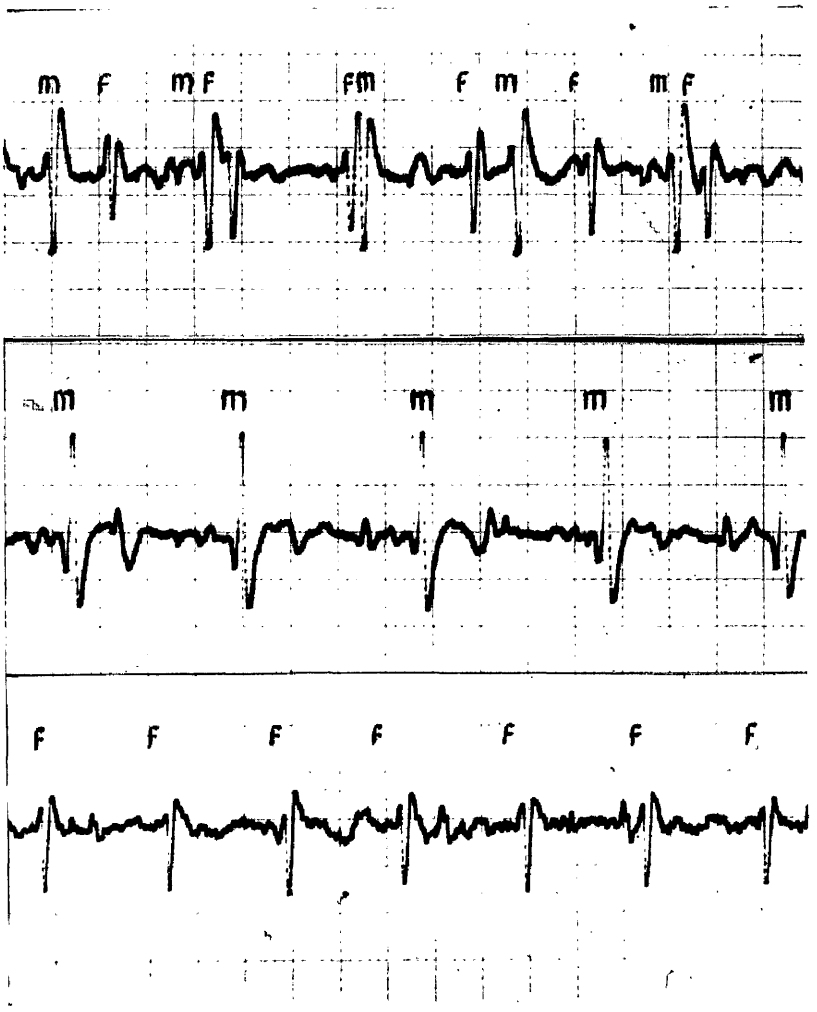


Fig. 9.14. Example of two channel cancellation.

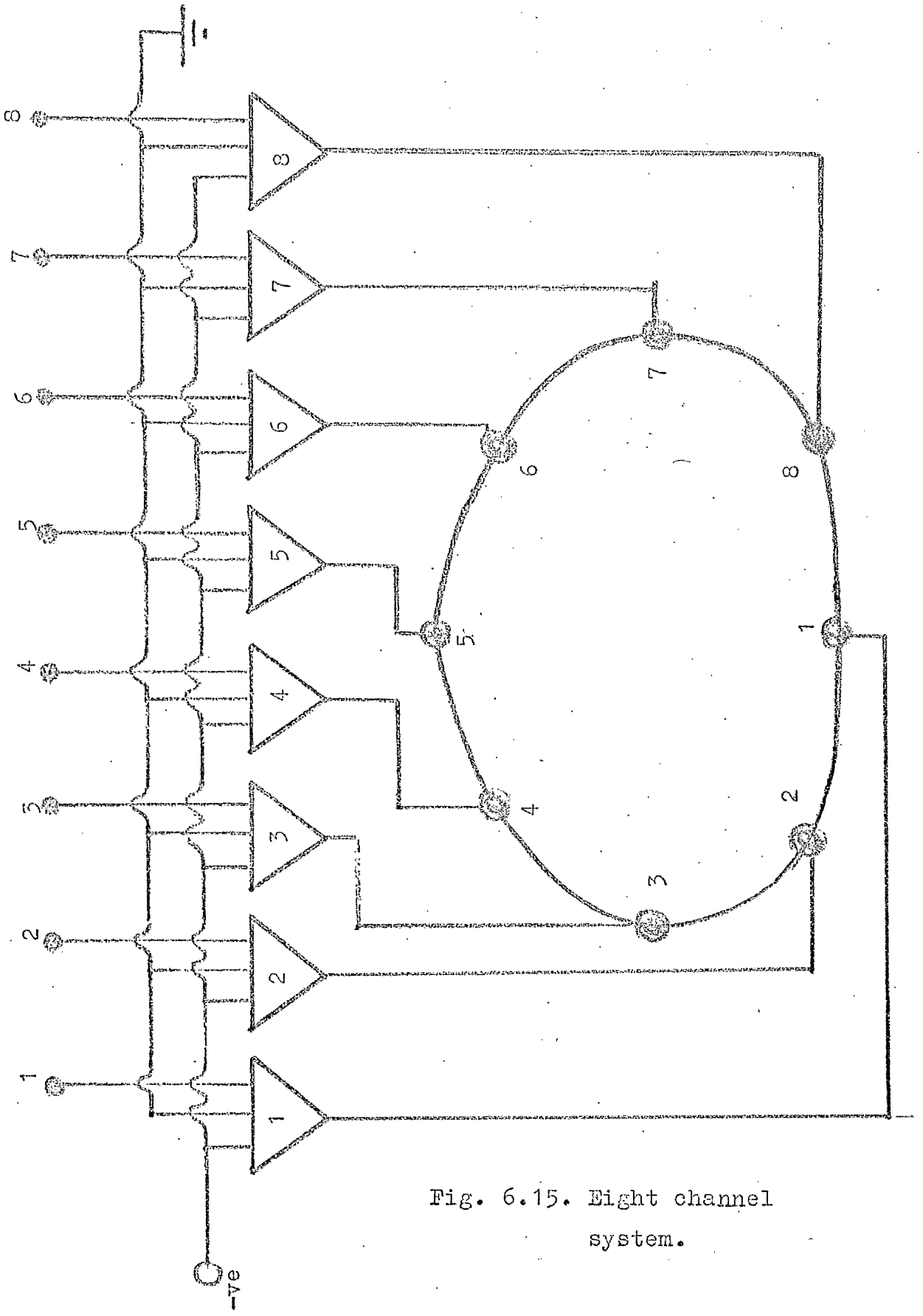


Fig. 6.15. Eight channel system.

(Schuler et al) was evaluated.

The basis of this method is that the best possible FECG signal would be that available between the foetal head and buttocks. An electrode placed at the maternal pubis will approximate to the foetal head (in a vertex presentation) or buttocks (in a breech). The upper pole of the foetus is however much deeper within the maternal body.

To simulate an electrode in the position it is possible to use a simple analogue technique.

A ring of eight electrodes is placed around the maternal abdomen cross section at the level of the upper foetal pole. The signal between each electrode and the suprapubic one is amplified and passed to the corresponding point on a resistance mat (Teledeltus paper) cut to an approximate cross section of a pregnant abdomen.

In theory this form of analogue addition will recreate at some point on the surface of the mat, the original foetal signal at some point apparently within the depths of the maternal tissues.

Eight FECG amplifiers could represent a very considerable financial investment. The ones used here were those as described above (6.3.)

All eight amplifiers are mounted in one case with a common battery power supply. The negative inputs are collected together and connected to a single suprapubic "indifferent" electrode. The earth of each amplifier is connected to a common earth electrode in the mother's R thigh. The eight electrodes around the maternal abdomen are connected to the corresponding amplifiers. (Fig. 6.15). The amplifier outputs are connected to a carefully prepared terminal posts mounted around the periphery of a sheet of teledeltus paper cut to the

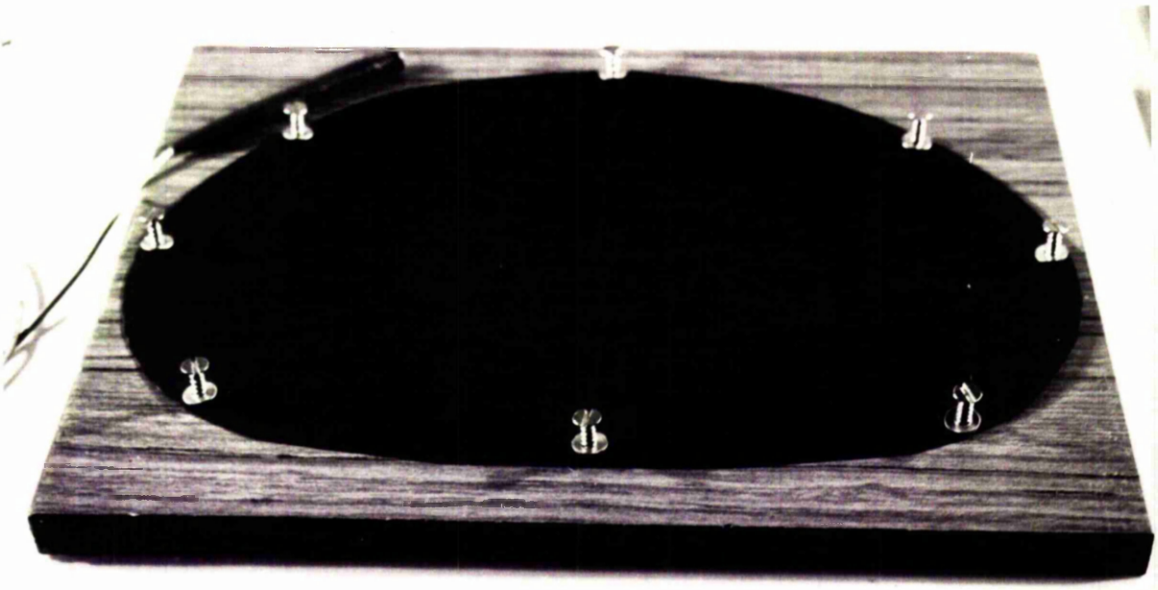


Fig. 6.16. Teledeltus paper analog.

approximate cross section of a pregnant abdomen and glued to a piece of plywood (Fig. 6.16).

The final signal is detected by a free hand-held probe moved over the surface of the paper.

All the electrodes are 5cms. diameter lead discs.

Results were surprisingly easy to obtain. From the very first it was obvious that a marked improvement in previously poor FECGs could be obtained. A typical example is given in (Figs. 6.17A and 6.17B). The signal from each "channel" is shown and on none is the FECG above the rest of the signal - in fact only on channel 1 can its FECG be seen at all.

The signal from each quadrant of the mat shows some improvement in the situation but that from the "area of best signal" is convincingly adequate. This area of best signal is remarkably critical, though not difficult to find by routine search. As little as 2cms. in any direction causes a dramatic fall in clarity.

Though this method is admittedly clumsy to use it is not greatly time-consuming and it offers a method of obtaining a good reliable trigger from those cases in which other, simpler cancellation techniques have failed.

6.6. Radio-telemetry - The theoretical aspects of radio-telemetry of bio-medical data are well established. The unfortunate fact seems to be that fully adequate systems capable of operating in the hospital environment have not been achieved at reasonable cost.

It would seem fitting here to describe briefly the sad tale of the author's only attempt at radio-telemetry of the FECG and to point out the pit-falls.

Once convinced that normal early labour takes place in the upright position, not attached to monitoring devices, the concept

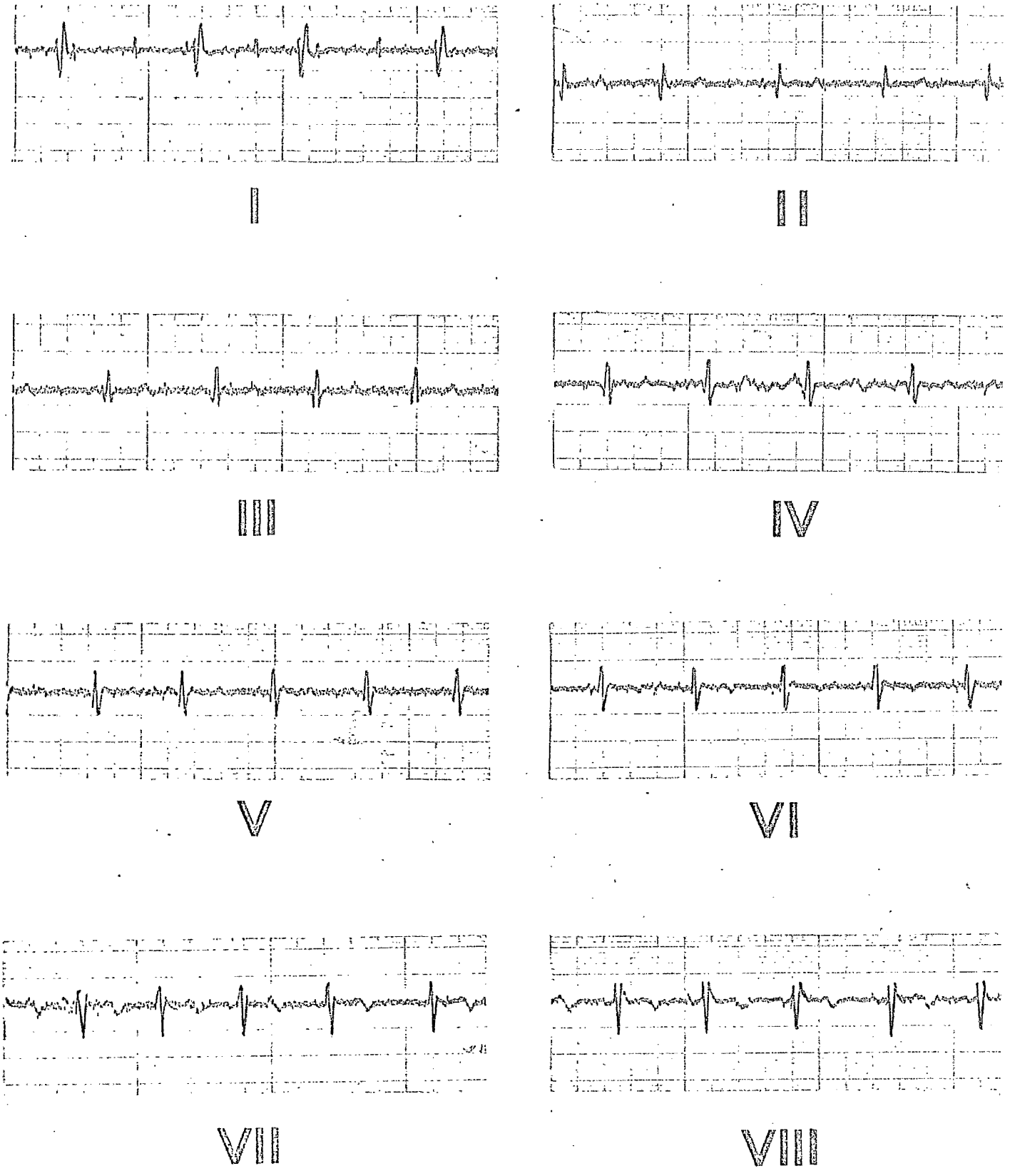


Fig. 6.16a. Example of eight channel cancellation.

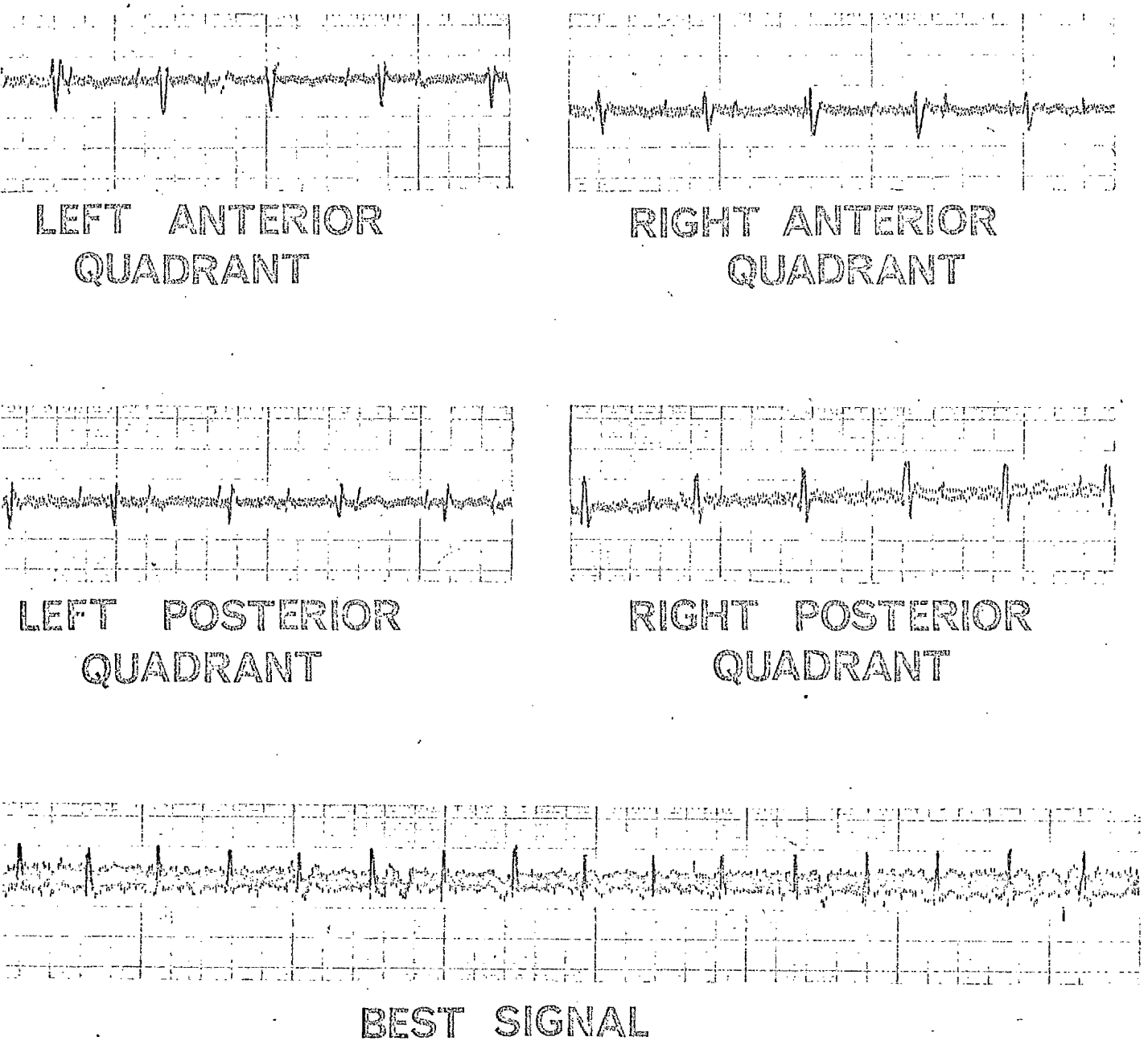


Fig. 6.16b. Example of eight channel cancellation.

of radio-telemetry of the FECG from ambulant patients seems extremely attractive. To test this a pilot trial on cheap commercial equipment showed that the adult ECG or the maternal plus foetal ECG could easily be transmitted over the length of a large ward.

The next step was to transmit separately the maternal and maternal plus foetal signals and cancel them at the receiving console.

We were fortunate to obtain the use of the prototype of a multichannel telemetry system being developed at the University of Strathclyde. The simultaneous transmission of the two channels was deceptively easy but cancellation of the maternal elements at the receiver proved impossible.

The explanation for this is applicable to many other situations and is worth considering here.

Radio-telemetry, and other, systems make use of passive and active electronic filters. Such filters allow the passage of desired frequencies and prevent passage of unwanted frequencies. In addition they cause some degree of phase shift at the passing signal.

The problem is that this phase shift is frequency dependent - i.e. different frequencies shift phase by different amounts. When examined closely the adult or foetal ECG has been considerably distorted by passage through a telemetry system. In a two channel system different filters must be used, the two output signals cannot be made to match exactly.

The Hammacher phonocardiograph and the Sonicaid ultrasonic monitor, for example, both rely on heavy filtering of the original signal. This filtering must cause considerable variation in the time relationships of the events within and between cardiac cycles. It seems to be the case that accuracies better than plus or minus five beats per minute cannot be obtained by

such systems.

6.7. Safety - A complete consideration of the electrical safety of medical instrumentation is obviously outwith the scope of this thesis. Nevertheless, some important points must be made.

The major problem in electrical safety of electronic equipment lies not in the design of individual items but in chance misconnection and unforseen interaction.

A good example of the kind of disaster which can occur, and has occurred,is the hypothetical case of an adult patient with an intra-cardiac pacemaker catheter. Such instrumentation is carefully designed and very well earthed. Of itself there is no hazard. Suppose the patient's wife visits him and decides to shave him with his electric razor. Almost all electric razors are not earthed and depending upon which way up the mains plug is inserted their chassis can achieve a few volts above earth. This is not normally in any way dangerous. In our case however a very good earth is available through the myocardium and the very few micro-amps of current which will flow can be fatal. In fact the wife stands a 50% chance of killing her husband

The electrical safety of foetal monitoring apparatus, especially in the research situation. has received little attention. Instrumentation attached to the patient's abdomen is unlikely to cause danger if the elementary procedures of adequate construction, assembly and earthing are observed.

Intra-uterine instrumentation, however, creates a much more complex situation. An electrode attached to the foetal scalp ensures that any electrical disaster is transmitted direct to the foetus. The added presence of a saline filled catheter ensures an excellent return path. All the current will have passed through the foetus probably with deletrious effect. The major

difficulty lies not in the design of individual items of apparatus, which is almost always impeccable but in the combination of equipment and in chance misconnection.

The potential user of monitoring equipment must consider not only possible faults in his apparatus but also faults in the environment. The mains electrical wiring in many of our older hospitals is nothing short of laughable. The supposed earth connection may be totally inadequate and neutral and live wires transposed.

It must be most strongly recommended that all electrical equipment (and this includes infusion pumps, drip counters etc.) be connected to a single specially installed power supply and that that be checked frequently for faults. Other power points in the vicinity of the patient should be disconnected.

The possibility of unforseen problems in the interconnection of equipment demands that such assemblies be installed and checked by persons fully aware of the complicated issues involved.

The Medical Defence Societies advise that they are prepared to cover members for misuse of equipment but not for misdesign.

From the point of view of the non-commercial constructor of FECG Amplifiers safety can be assured by two simple expedients. Firstly, the amplifiers should be battery powered - the battery pack should be quite seperate from the power supplies of recording instruments etc. Secondly, the output from the amplifiers should be completely isolated from the input to the recorders. At first sight this last seems a tall order - the commercial manufacturer's solution has been to modulate a radio-frequency signal with the output, transfer this across a transformer and then demodulate the signal for further processing. Fortunately recent developments in opto-electrics have by-passed this problem. A single small device TIXL 101 , cost

£5.00, is now available.

In this device the output of the amplifiers modulates a tiny photo-diode (a light source) - this tiny light is focussed onto a photo-transistor thereby controlling the current through the transistor and supplying a suitable input for the recording system.

There is NO electrical or mechanical pathway from input to output.

These devices must find more and more applications in both foetal and adult monitoring, especially in these situations where the mains electrical system is open to criticism.

7. DATA RECORDING AND DISPLAY

7.1. Introduction - The stage is long past where the mere demonstration of the FECG can be considered an achievement. The technicalities of detection of the FECG are now well documented, if not well understood, the area where knowledge is sadly lacking is in the interpretation and application of the information contained in the FECG. The first step in rational use of the FECG is clearly to find a suitable method for presenting the information. Many methods have been used by this, and other authors, each of which will be considered in turn.

7.2. Data Recording - This is the area of the man-machine interface. For the FECG or any other signal to be meaningful it must be presented intelligibly.

7.2.1. Loudspeakers - The F H is easily presented by loudspeaker. The FPCG, Doppler or FECG can all be used to provide drive for this. The mechanical design of loudspeakers is now so good that they certainly are not the limiting factor in the electronics of FPCG and good quality sound can be obtained. With the FECG or Doppler the loudspeaker is not a direct representation of the source signal but only indicates the occurrence of a beat.

The loudspeaker represents little advantage over the foetal stethescope as the record is not permanent nor any easier to count or assess for regularity. The sound of the foetal heart over a loudspeaker may well be comforting to the patient and occasionally to the staff but it has little practical value.

7.2.2. Oscilloscopes - A good oscilloscope is invaluable in foetal cardiology. It provides a rapid method for checking the function of the individual parts of the whole electronic system.

As a display for the final output it is very convenient for setting up and adjusting the optimal situation. Like the

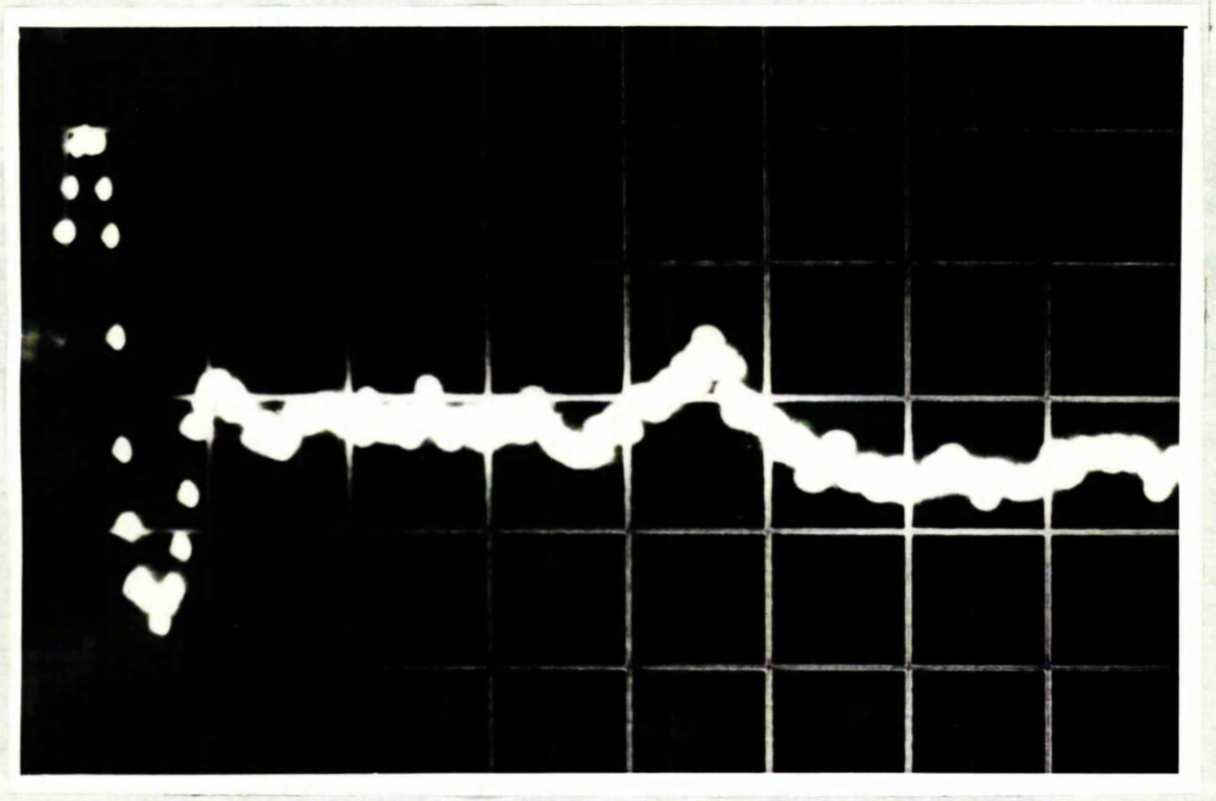


Fig. 7.I. Photograph of oscilloscope trace.

loudspeaker its display is not usually permanent and it is rarely useful as a diagnostic instrument. It is possible to obtain a permanent record of a small time interval of the display by photographing the screen (Fig. 7.1.) or much more expensively by investing in a storage oscillascope. Both these methods are useful but should be viewed with economic prudence

For some mysterious reason oscilloscopes sold for "medical" applications are much more expensive than their industrial equivalents. The potential user is advised to peruse the industrial catalogues before buying.

7.2.3. Strip Recorders - These are by far the most popular devices used in medical electronics. Basically a roll of paper is moved past a writing mechanism which moves at right angles to the paper in response to the input signal. The record is permanent and immediately available (Fig. 7.2.)

The major drawback of this method is the enormous length of paper generated by continuous monitoring. At the very slow speed of 1 cms/min a 10 hour labour would yield 6 metres of output.

There are a few other drawbacks to this class of mechanism though these are not very significant in foetal monitoring. The upper frequency response of the usual device is about 100 Hz which really is adequate. The majority of mechanisms depend upon a hot wire stylus writing on heat sensitive paper which is quite expensive. Both ink and biro nibs are obtainable but these are messy. The ultraviolet recorder is another variant in which the writing arm is a beam of UV light striking light sensitive paper (Fig. 7.3.). These are excellent recorders but tend to be heavy and temperamental. Their frequency response is excellent up to thousands of cycles.

7.2.4. Tape Recorders - Tape recording is an extremely

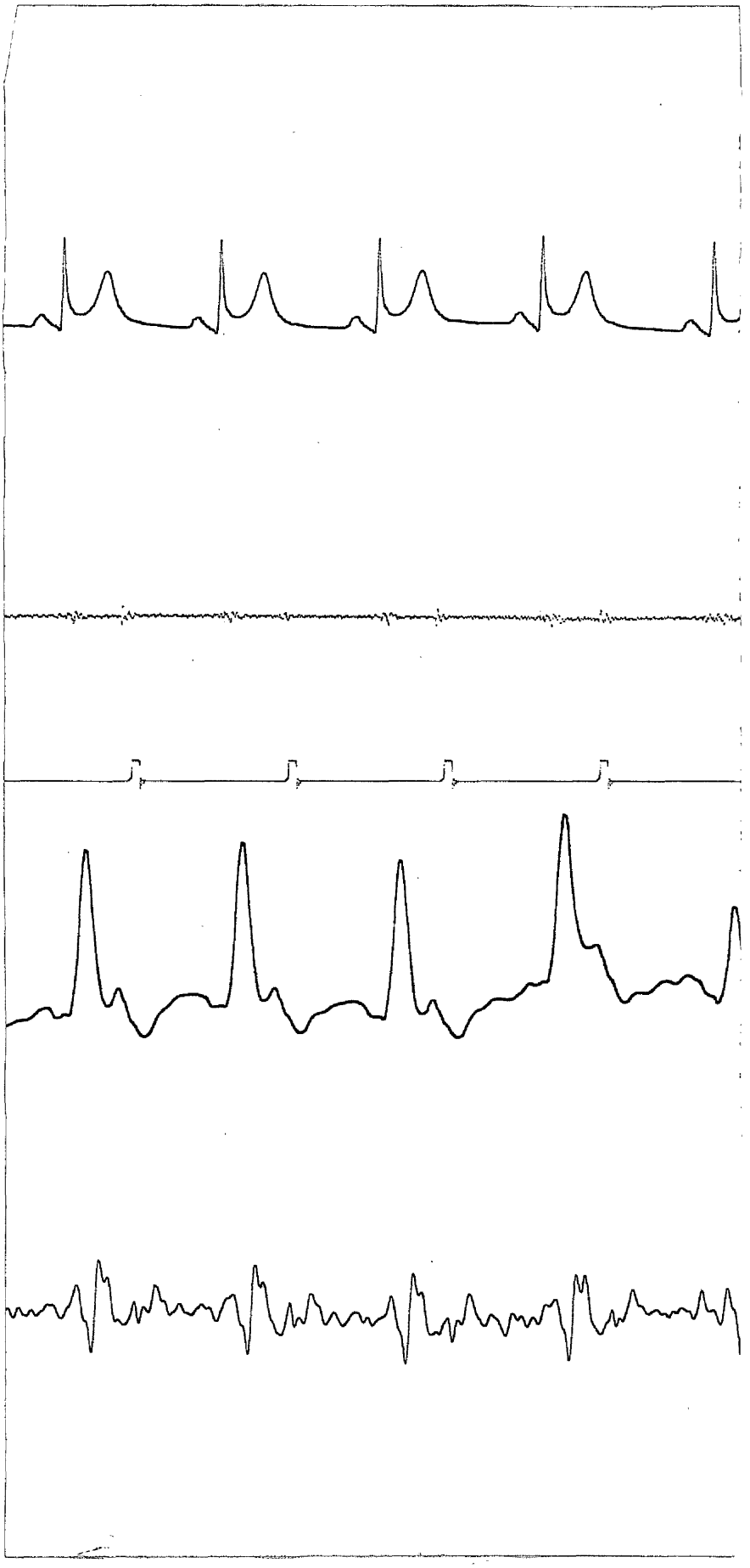


Fig. 7.2. Paper strip recording.

Fig. 7.3. Ultra-violet recording.

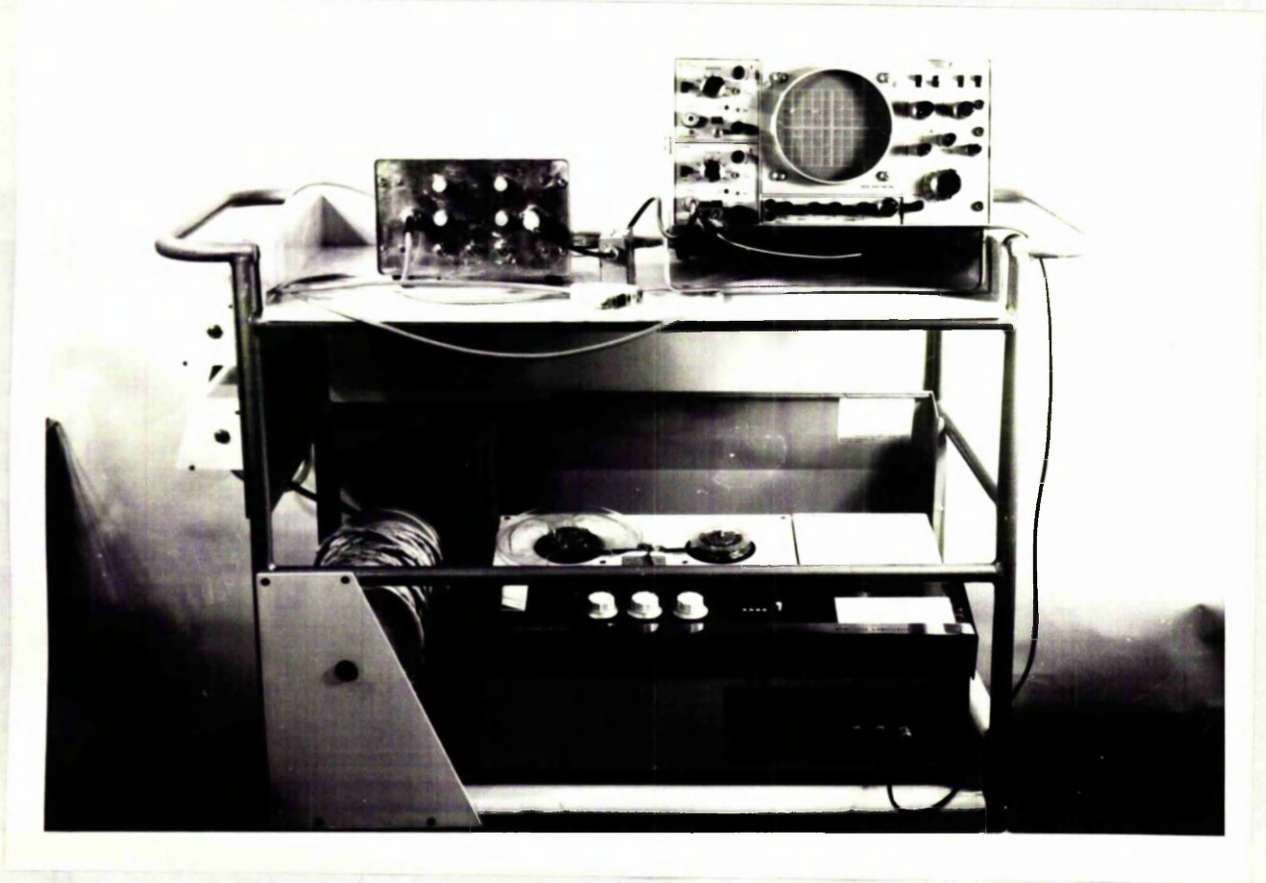


Fig. 7.4. Epsylon tape recorder.

attractive way of preserving an FECG session. As the electronic signal itself can be reproduced analysis can be undertaken at a different place and time. The record is virtually permanent, which allows re-analysis of old recordings by new methods. Probably most important of all, most modern tape recorders have the magical quality of being "computer compatible".

The pitfalls of tape recording are however serious and the solutions tend to be expensive.

The conventional domestic tape recorder - even from the most expensive range - is just not suitable. The electronics of it are such that the lower frequencies (usually below 60 Hz) are not well recorded. This means that most of the FECG is grossly distorted.

The electronic solution lies in frequency modulation for recording. In this the input signal (from the cardiograph) is converted into a signal whose frequency varies with the amplitude of the input. This variation can be arranged to occur about any suitable centre frequency - e.g. 1000 Hz so that accurate recording is now possible. Such a recorder (Fig. 7.4.) based on a good quality domestic mechanical tape deck was used in this study. The machine cost £600 but must be used bearing in mind its extreme limitations.

These limitations lie in the reproduction of the signal. If a frequency modulated signal is to be reproduced then it follows that the speed of the magnetic tape past the reproduce head must be the same as the recording speed. This is very difficult to ensure over long periods of time. For example, playback of a year old tape is unlikely to be accurate because of mechanical changes in the system. Suitable recorders are available but the cost is a considerable jump to £5,000 or more.

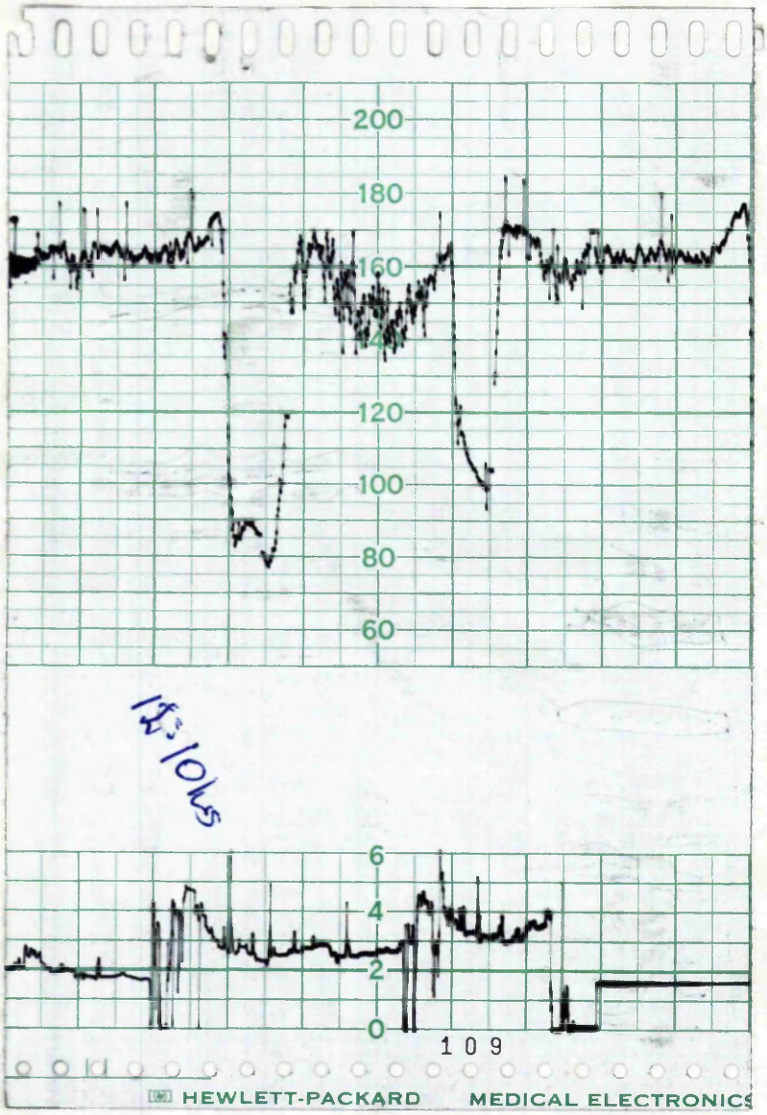


Fig. 7.5. Foetal heart rate and uterine contractions.

It is then unwise to depend upon precise measurements of the usual quality of tape recorded data.

In this study the data was recorded on tape but analysis took place in real time at the patient's bedside.

7.3. Data Presentation - The demonstration of the foetal heart beat is of little value in itself and certainly does not justify the large expenditure of complex electronic equipment.

The information contained in the foetal heart data must be processed sensibly and presented in such a way as to be of clinical value at the time. This precludes many of the popular concepts of computer processing as these generally are undertaken "off line" at a point distant in space and time from the labouring patient.

A very important maxim which seems to have escaped the manufacturer's engineers is that the information must be presented to show the Minimum Charge Capable of Convincing a Clinician to Change his Mind (MCCCCCM, Wolf). Many electronic systems produce - apparently for the sake of electronic sophistication - information by far too accurate for reasonable interpretation.

The following presentations have been described and are in current use.

7.3.1. Foetal Heart Rate and Uterine Contractions - The form of the FECG and FPCG have proven of little value to date. Both these signals are usually converted to rate information. By far the most popular presentation is that of variation of foetal heart rate presented in parallel with an indication of uterine contractions. (Fig. 7.5.). Such systems tend to be linked with Hammacher though Hon and Caldeyro-Barcia should really share the honour. Hammacher's contribution was in the

utilisation of the FPCG to obtain rate information.

As has already been described the method produces a long length of paper which requires manual examination and interpretation. It can legitimately be claimed that it removes the clinician's traditional skills from the patient and transfers them to a bit of paper. This is an extreme view and undoubtedly the method is of great value in some cases. Estimates of its value are however impossible at this stage. The method is always applied by enthusiasts who of themselves will improve results and it requires the personal attention of the medical staff in the labour ward which again will improve results.

Electronically there are a few important points. The choice of ratemeter is important. Many ratemeters are of the "averaging" type which yield a figure over say 5 or 10 beats. These ratemeters cannot reflect the variation between individual foetal heart beats which seems to be of some importance. The ratemeter of choice is the "instantaneous" ratemeter which presents each individual cardiac cycle interval as rate. Enthusiasm for this type of meter may have to be temepered against the cost of £1,000 for a good one.

Despite the maker's claims most users now agree that the FPCG cannot be processed to yield foetal heart rate at a better accuracy than $\pm$ 5 BPM. The FECG however can be precisely accurate and coupled with an instantaneous ratemeter is the method of choice for in-labour monitoring.

7.3.2. Interval Histogram - The major drawback of the preceeding method is the sheer volume of data produced. Clearly some method which condenses the data is desirable. The interval histogram presentation developed by this author (Vol. 1.) and used in this study is one such method.

Briefly the interval between foetal R waves is measured and stored in a small computer. The computer builds up a picture

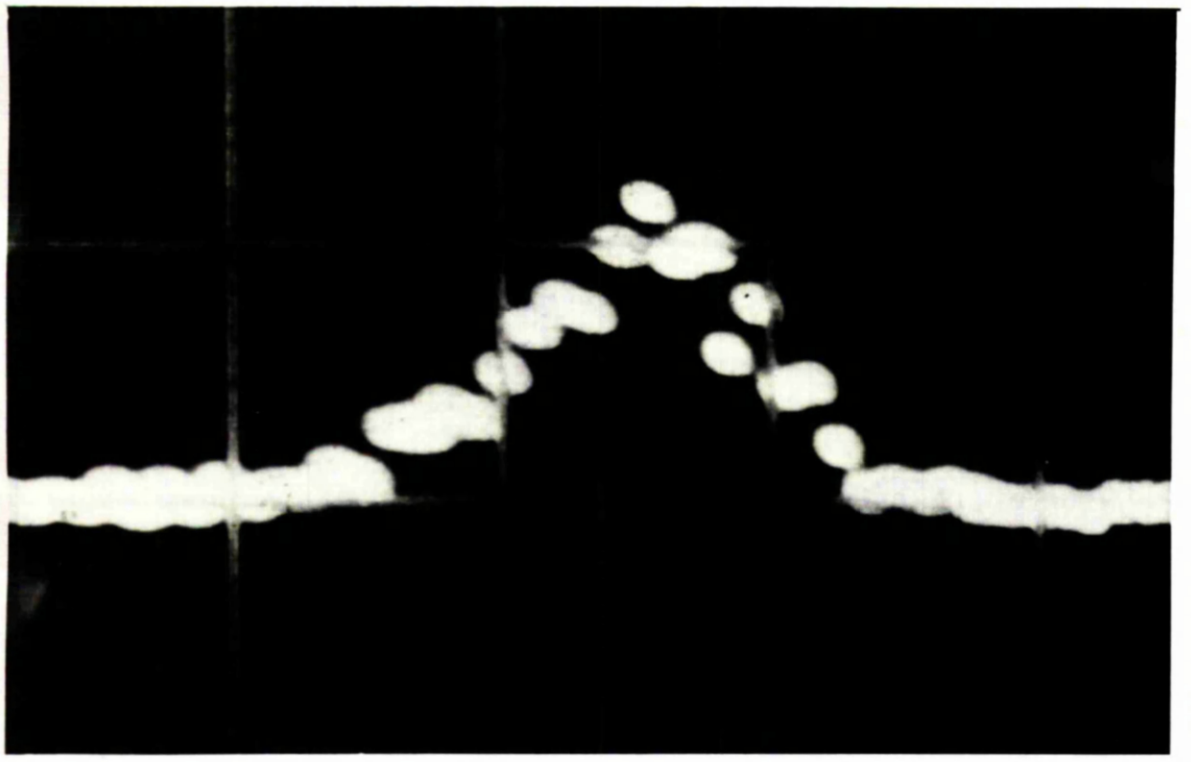


Fig. 7.6. Interval histogram.

of the number of beats which occur at any one interval (or rate) (Fig. 7.6.). This is the familiar histogram or bar diagram. This form of presentation of several hundred or thousand beats in a single diagram lends itself to simple statistical analysis and such values as the mean, standard deviation and coefficient of variation (SD/MEAN %), can easily be calculated. The value of these indices has already been considered (Vol. 1. Chapter 7).

It must however be emphasised that the method was developed for ante-natal prognosis of foetal viability and not as a monitor of the reaction of the foetus to the stress of labour - for this it is of no use.

The cost of such an apparatus is not excessive - the computer used cost £3,000 but it is a versatile device capable of other functions. A single purpose commercial device could be made available for about £1,000.

Although the method largely condenses information - as opposed to time lapse techniques which discard information - it suffers the drawback of no longer indicating the time relationship between events.

7.3.3. Scatter Diagrams - The major drawback of the previous method is that all time relationship between cardiac cycles is lost. Even the variance around the mean gives no measure of the short term irregularity of the heart beat. The advantage of second order histograms (scatter diagrams) is claimed (Van Bemmel, 1969) to condense inverval information into a single picture in which some relationship to the time domain is retained. (Fig. 7.7.)

This approach allows very essoteric mathematics full sway. It was not intended to be a routine method for clinical use but as yet another attempt to wring all possible information

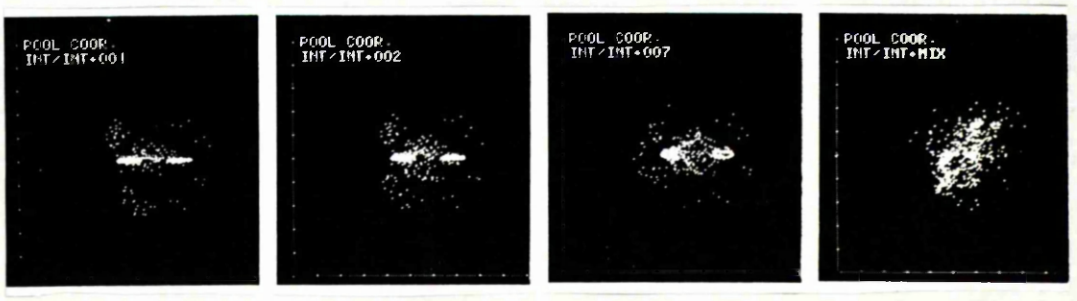


Fig. 7.7. Scatter diagrams. (Van Bemmel)

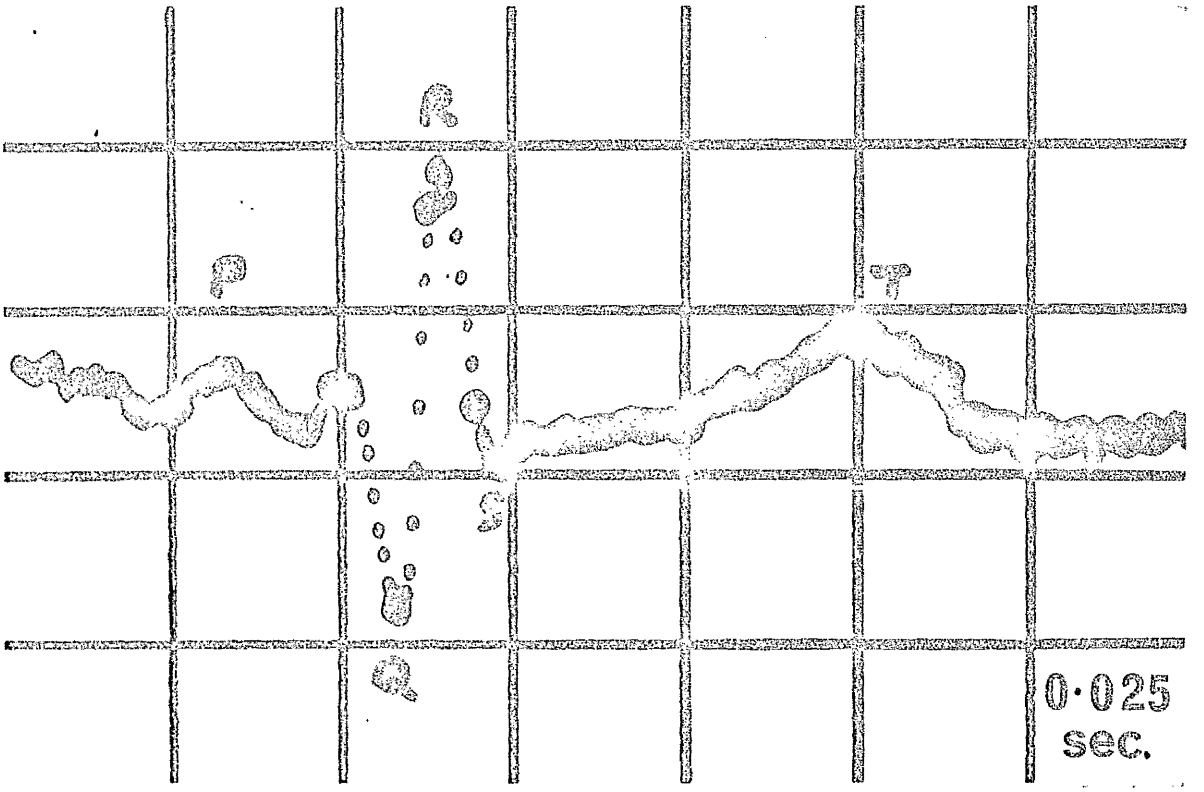


Fig. 7.8. Averaged FECG complex

out of the meagre data available on the unborn infant. It certainly requires access to a moderate computing facility and if clinically useful data were required on an individual case on-line analysis would be necessary. In Britain this seems unrealistic in the near future.

7.3.4. Time Series Analysis - This is yet another computer statistical approach to data reduction (Forsyth, Greenberg and Hon, 1969). The method reduces the data to a single mathematical expression which it is hoped will be predictive of foetal outcome. It is based on spectral and cross-spectral analysis which requires a large computing facility.

This, and the last, method (7.3.3.) is expensive and time consuming. This author's opinion as to their usefulness is biased by his complete inability to understand them. The interested reader is directed to the original papers.

7.3.5. Transient Averaging - This method is concerned not with reducing data but with construction of an average waveform from a repetitive signal buried in "noise" (Fig. 7.8) The technique was already well established in the communication industry before it was applied to the foetal situation. (Hon, 1963). A detailed mathematical analysis has already been given (Vol. 1. Chapter 4) but further points have evolved since.

For good results a precise and electrically neat trigger signal is required. In foetal cardiology irrespective of the signal to be analysed (e.g. FECG, FPCG, Doppler, FBCG, impedance plethysmogram, etc.) the FECG is the only suitable trigger signal.

There are other, in many ways simpler, methods of recovering signal burried in noise. These are often suggested by the

uninitiated communications engineer but none is suited for the adequate recovery of a repetitive but irregular event.

The usefulness of the recovered FECG waveform is quite another problem. Hon is certainly of the opinion that the little use it has barely justifies the trouble in processing it. This view is shared by this author and many others. Despite this others are continuing to evaluate the problem and a definitive assessment is not yet possible.

These then are the main methods of data presentation in use. As this study was set up to continue the evaluation of the interval histogram clearly this method is the one used in the majority of the work described.

8. THE MAIN EXPERIMENT

8.1. Preamble - This study formed a part of a continuing, much larger study of the processes of pregnancy and delivery.

The specific objective was to examine the information content of foetal cardiac cycle interval histograms and to test whether these could be used in clinical practice to prognose the state of the infant at birth.

The foetal electrocardiograph (FECG) was considered still to be the best and safest signal to use for such precision measurement of foetal heart activity. A basic technique (Vol. 1) was already available, though now re-engineered to higher standards and far easier operation, and there was preliminary evidence that good prognostic indices (the standard deviation and coefficient of variation) could be obtained.

It now remained to test three closely linked hypotheses -

a. Could the previous indices, especially the coefficient of variation, be shown to be applicable to a larger group of patients?

b. Could these indices be improved or superceeded?

c. Could the FECG technique be taught to others (with widely differing professional backgrounds) and still achieve reproductable results?

8.2. Statistical Design - The original trial (Vol. 1, Chapter 6) was very closely defined and rigorously controlled. In this trial the net was deliberately cast very wide and by necessity such strict control was not possible.

The basic concept of this trial was to train as many operators as possible, obtain as many FECG examinations from as many patients as possible within the time available and to carry out analyses along previously established lines.

8.2.1. Source of material. - This trial was conducted in its entirety in the Glasgow Royal Maternity Hospital (GRMH), Rottenrow, Glasgow. All the consultant obstetricians agreed to make their hospital in-patients available for the study without let or hindrance.

8.2.2. Selection of patients - For traditional and historical reasons the GRMH operates in an area with a very poor obstetrical population. The hospital specialises in abnormal obstetrics. Clearly almost every in-patient in the hospital is at risk and as the impracticability of out-patient examinations has been demonstrated (Chapter 6.2) it has again been impossible to conduct a trial with a "normal" control group.

In the previous study a deliberate attempt was made to select high risk cases. In this study no such attempt was made. Patients were selected only by their being near term and not in labour. Wherever possible serial examinations were carried out at weekly intervals.

8.2.3. Selection of operators - All the members of the Clinical Measurement Group at the Bio-engineering Unit were trained to operate the equipment. This proved to be a fairly heterogenous group consisting of the following:-

medical	2
physiologist	1
electrical engineer	1
communications engineer	1
mechanical engineers	2
statistician	1
computer operators	2
midwives	2

In addition two of the hospital's junior medical staff learned the technique.

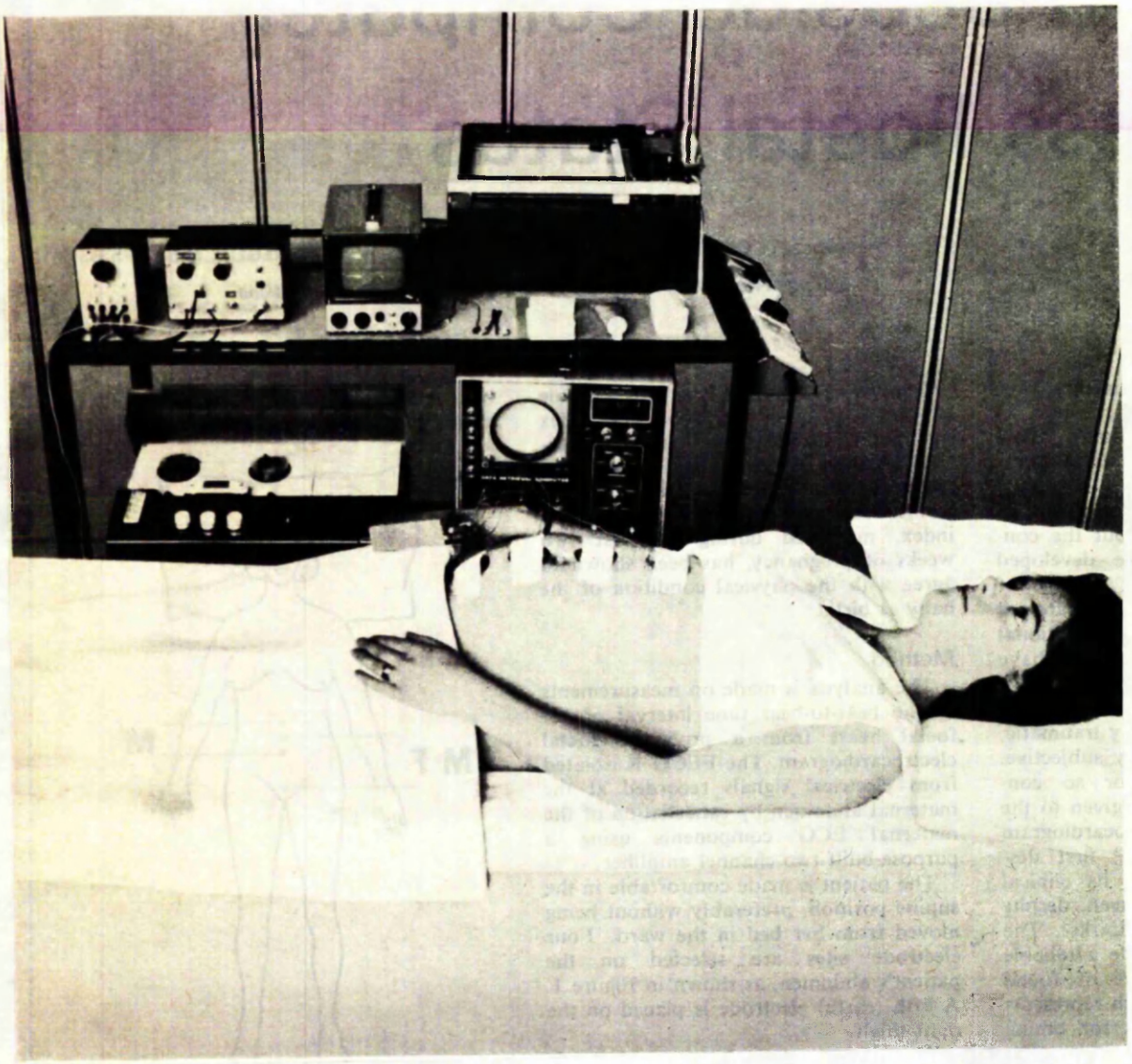


Fig. 8.I. The FECG insrumentation in use.

Despite these widely differing backgrounds every member of the group learned the technique satisfactorily and although results clearly improved with practice no one failed to achieve adequate competance.

8.3. Data Collection - All the equipment required for collection of FECG data was assembled on a trolley (Fig. 8.1.) which could easily be wheeled about the hospital.

8.3.1. Equipment - The following equipment was used (Fig. 8. 1) -

Top Tray (left to right)

a) switching box
b) FECG amplifiers
c) two channel oscilloscope (Nihon - Koden)
d) X . Y plotter (Houston Instruments)
e) mains socket bus box.

Lower Tray

a) F M tape recorder (Epsylon)
b) Data Retraval Computer (Nuclear Chicago)
c) cable drum.

8.3.2. Method Summary - Further details of the method will be given later in this Chapter (8.6.)

Briefly, the patient was examined in her own bed and familiar surroundings. The technique was very superficially explained to the patients (who all seemed delighted to meet such complex instrumentation). The examination was always presented very much as part of the hospital routine and not as a "special" research project.

The electrodes were applied and adjusted as necessary to obtain a good working signal and adequate cancellation of the maternal ECG.

The switch box was used to display the combined, foetal only or maternal only signals on the oscilloscope as required for setting up.

The tape recorder was so wired as to record the two traces displayed on the oscilloscope, normally the combined and foetal only signals.

Once a suitable foetal only signal was obtained the computer input discriminator was set at a suitable level (positive or negative) so that the computer triggered once on every foetal ECG complex.

The tape recorder was started and a run of ten minutes commenced. Note that although a tape recording was taken the actual computer analysis took place in real time.

The interval histogram can be seen to build up on the computer's own display tube but at the end of the run the histogram was printed out on the X.Y plotter. This print out takes 64 seconds.

This concluded the operation at the bedside. The tape recording was filed and the output graph taken to a desk calculating machine (IME Digicorder) for calculation of the mean standard deviation and coefficient of variation - no more than 3 minutes work. As the mode and the range had been previously shown to be of little value they were not calculated.

8.3.3. Operator training - As has been previously described the operators came from very different professional backgrounds. It was therefore necessary for the non-clinical members to start with the basic approach to the patient, introduction of the examination and general decorum and chaperoning arrangements.

This, I suspect, for several proved more awkward than the operation of the equipment.

Each operator was individually taught to use the equipment at the bedside until sufficient confidence and ability were achieved. Thereafter they were encouraged to spend as much time as possible practicing the art for themselves.

Fortunately the large store (almost 300) of tape recordings made it possible to practice using the computer and its output without recourse to actual patients.

8.4. Data Logging - The results of the FECG examination together with a few selected clinical details were entered on the same pro-forma as previously used. The flexible design allowed the insertion of three further items (Appendix A). The size of paper was also increased to leave more room for free text and general comments.

As the analysis programs required numerical data (see 8.5) the entries were coded using the same codes as before (Appendix A).

8.4.1. Patient identification and general information - The mother's serial number, hospital number and age were noted for identification purposes. Although her name appears on the pro-forma, it was not entered into the computer file.

The parity of the mother (i.e. the number of previous children and abortions) was recorded as there is evidence that first babies do not fare so well as subsequent ones.

The expected date of delivery was recorded so that it could be compared with the actual date of delivery and birth weight to assess pre or post maturity. It was also used to calculate the gestation at the time of examination which was also recorded.

The space left for item 16 was used in this series to enter

the error in the estimated dates, i.e. the actual date of delivery (item 17) less the estimated date (item 5).

8.4.2. Medical and obstetrical conditions were noted as some of these in themselves may prejudice the outcome.

8.4.3. Details of delivery - The type of delivery, duration of each stage, occurrence of complications and whether induction had been required were recorded to allow assessment of the effectiveness of labour.

8.4.4. Details of infant - The sex of the infant was recorded as there is evidence that male infants tend to succumb more easily than female.

The health of the infant at birth was assessed by the Apgar score recorded at 1, 5 and 10 minutes. As the aim of this project has been to predict foetal outcome, this method of assessing the infant will be described in detail.

The Apgar Score

This scoring method was introduced by Dr. V. Apgar in 1953. She intended it as a means of assessing the state of oxygenisation of the newborn infant. The scoring process is simple to apply and has been universally accepted. The method assigns a score of 0, 1 or 2 to each of five signs as follows:-

APGAR SCORE AT 1 MINUTE

Sign	*Score*		
	0	1	2
Heart rate	Absent	Slow (below 100)	Over 100
Respiratory effort	Absent	Slow, irregular	Good, crying
Muscle tone	Limp	Some flexion of extremities	Active motion
Response to catheter in nostril (tested after oropharynx is clear)	No response	Grimace	Cough or sneeze
Colour	Blue, pale	Body pink extremities blue	Completely pink

A total score of 10 is ideal and a score of 0 is hopeless. As used in the Glasgow Royal Maternity Hospital, the Apgar score has been found to be a fair reflection of the infant's state. It is always assessed within 1 minute of birth and if at that time the score is less than 8 it is repeated at 5 and 10 minutes.

The value of the 5 and 10 minute scores is debateable in the present context. If the 1 minute Apgar is 10, then no further scores are recorded. If the 1 minute Apgar is less than 6, then oxygen therapy is immediately applied so that the 5 and 10 minute readings are artificially high.

The Apgar method can be criticised on several counts - the main one being observer variation. However, in a very busy labour ward with highly experienced midwives, this variation is small.

8.4.5. Statistical measures - The mean, standard deviation and coefficient of variation were calculated and entered. The mode and range were not calculated but were entered as missing data so that uniformity with the original series was maintained.

Items 30 onward were left blank at the time but in retrospect item 32 was used to store the log of the mean and item 33 for the new logarithmic index SD x 10 / log mean.

8.4.6. Final outcome - Finally, the eventual outcome, i.e. whether the child went home, remained in sick nursery or came to PM, was recorded.

8.5. Storage and Analysis of Data - As the data were collected they were punched onto paper tape and used to update a magnetic tape file on the University's ICL 1905 Computer. The punching of data onto paper tape is a tedious and time consuming business but the author has found it well

worth while to do this personally, at least in the research field, as obvious errors can be corrected immediately and accurately.

The SCAN (Scheme for Computer Analysis of Numerical data) suite of programs was already available within the Bio-engineering unit. This invaluable scheme accepts numerical data and can carry out complex correlations and analysis.

The scheme was designed for clinical data and has a most useful facility for outputing data in graphical form to give the user a "feel" for his data.

Programs are available to calculate, means, standard deviations, standard errors, t tests, chi squared tests and regressions.

As the authors of the SCAN system (Jordon and McGregor) so rightly point out the system is capable of producing results at an alarming rate. The user is well advised to think carefully before deciding on the type of analyses he wishes to have.

8.6. Operator's Manual - The remainder of this Chapter is a copy of the manual produced for the operators trained in the course of this study. It was, of course, supplemented by tutorials and practical instruction.

Errata. Pages I3I - I39 are to be omitted.

8.6. FECG OPERATOR'S MANUAL

I INTRODUCTION

The foetal ECG can be a valuable tool in the assessment of foetal status. It has the enormous advantage of being utterly harmless to both mother and child and to present an electrical waveform which is easy to manipulate. The electrical potentials recorded at the surface of the body are the result of electrical activity in the heart muscle immediately preceding a contraction. At source these potentials are in the region of 90 millivolts but by the time they have been attenuated by passage through the body, in the adult they are in the region of 1 millivolt and from the foetus in the region of 100 microvolts. Note that the amplitude at source was the same in both cases.

Two electrodes placed on the abdomen of a pregnant patient will therefore record the ECG of the baby and her own ECG. Obviously the patient's own ECG will be of a much larger voltage and will dominate the picture. If the foetal ECG is to be used advantageously it must be recovered from this combined signal and this is possible by the cancellation method described in this manual, in which another ECG channel containing "maternal only" information is inverted and electrically added to the original combined signal.

The recovered foetal ECG is now suitable for analysis in a variety of ways and the method of interval histogram analysis will be described in detail.

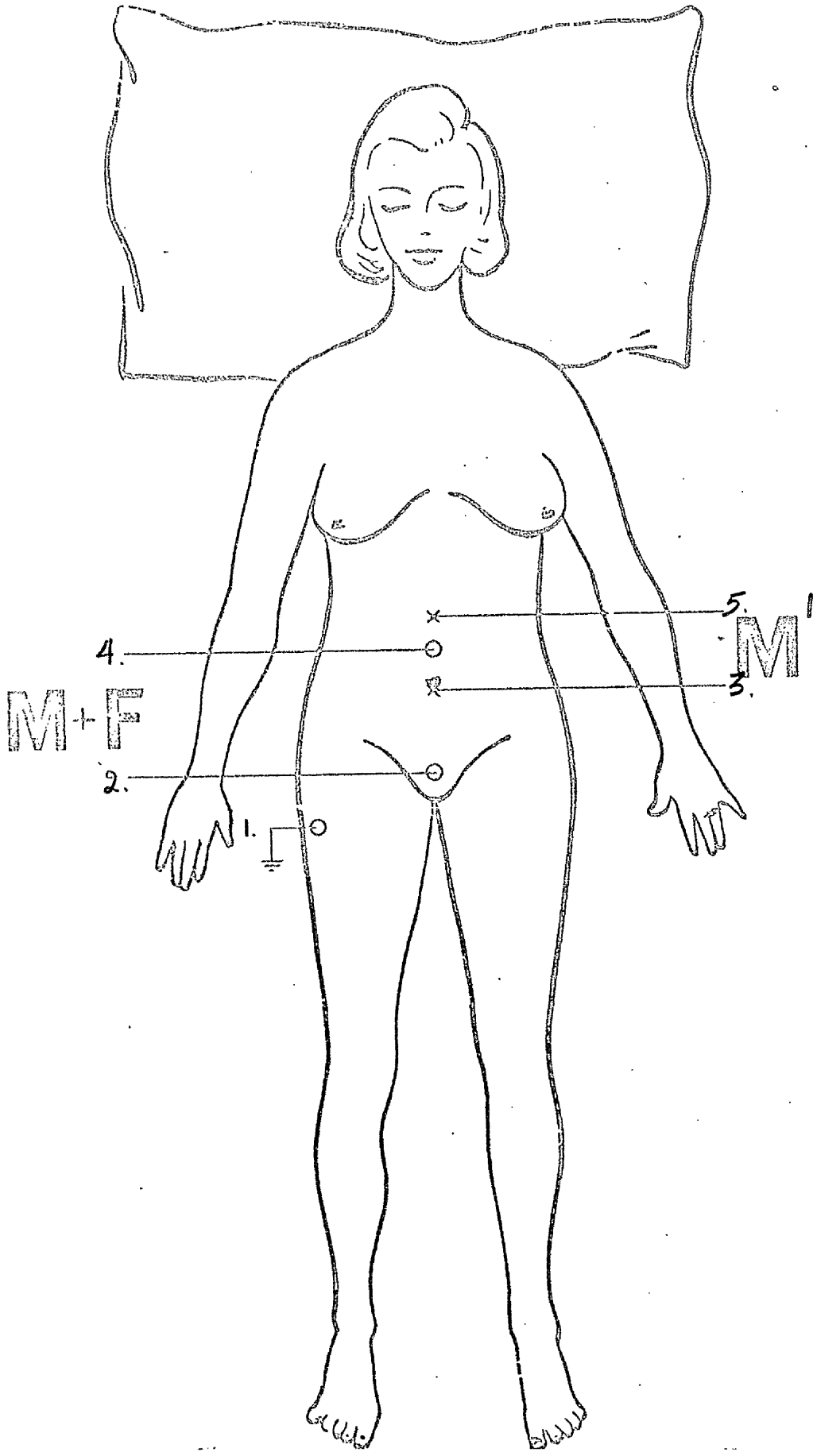


Fig. 8.6.1. FECG electrode positions

II PLACING OF THE ELECTRODES

The proper preparation of the patient and the placement of the electrodes on her abdomen are of the utmost importance in foetal electrocardiography. For preference, the patient should be in a familiar bed in familiar surroundings and as relaxed as possible. Five electrode sites are required and these are indicated roughly in Figure 1. Over-elaborate preparation of the site is not indicated and a brief, brisk rub with Cambridge electrode jelly is quite sufficient. The earth electrode on the right thigh should be placed first, followed by the four abdominal electrodes in order from the pubis up. Note that these abdominal electrodes must be in a straight line. There is very considerable scope for adjustment of the electrodes spacings to suit the individual case and this is a matter for practice and personal experience. In general electrodes 2 and 4 will contain the maternal and foetal signals and electrodes 3 and 5 will contain the maternal only signal. The combination of pairs is best decided by trial and error but the important point remains that all four electrodes must lie in the same straight line. It is sometimes found that moving the upper electrode of the maternal plus foetal pair away from the midline will improve the amplitude of the foetal signal. However, this leads to such considerable difficulty with cancellation that it is rarely worthwhile.

The electrodes themselves are 5 cm. diameter lead and should be covered with a moderate layer of electrode jelly before being "bedded in" at each site. They are attached to the abdomen with a strip of 2" wide elastoplast under gentle tension. Care must be taken in the handling of these electrodes as the solder join between the electrode and the wire lead is fairly fragile and cannot tolerate repeated bending. The electrode leads can now be connected to the amplifier junction box which has five colour coded sockets. The central white socket is the earth connection and should be connected to the right thigh lead. The maternal plus foetal pair of electrodes should be connected to the blue (for a boy) and yellow pair of sockets and the maternal only leads connected to the black and red sockets. If the electrodes are connected from below upwards in order it will be found that the maternal only signal is already inverted but if, on checking, this is found not to be the case, the leads to the black and red sockets need only be interchanged.

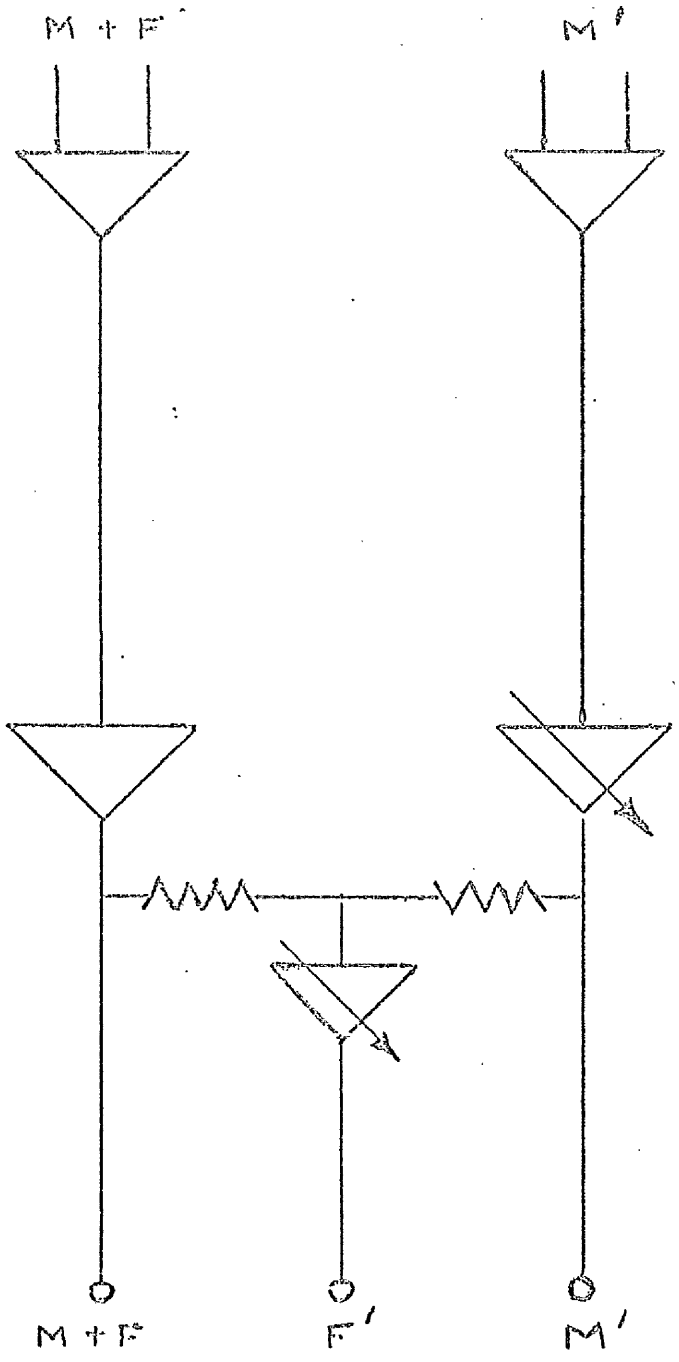


Fig. 8.6.2. Schematic of two channel amplifier system.

III OPERATION OF THE FECG AMPLIFIERS

As has already been explained the method depends upon obtaining two ECG channels, one with maternal and foetal information, the other with maternal only information. These two channels have to be amplified separately and finally mixed to produce the foetal ECG on its own. The circuit diagram of amplifier system is shown in figure 2 from which it is clear that the maternal plus foetal ECG channel is a series of two amplifiers with a fixed gain. The maternal only channel is a similar series of two amplifiers in which the second amplifier has a variable gain covering the range roughly from half to twice that of the maternal plus foetal. The gain control of this amplifier is the "balance" control on the panel of the amplifier box. The output from these two channels is tapped and resistively added at the input of a fifth amplifier whose gain is variable in steps x1, x2, x3, x4. Three outputs are therefore available, maternal plus foetal, maternal only and foetal only.

The first amplifier in each channel is contained within the terminal box at the patient end of the main electrode lead. This is to reduce pick up of extraneous electrical signals in the lead system. All the other components of the amplifier system are contained within the amplifier box. The controls in the front panels of this box are shown in figure 3 and are as follows:-

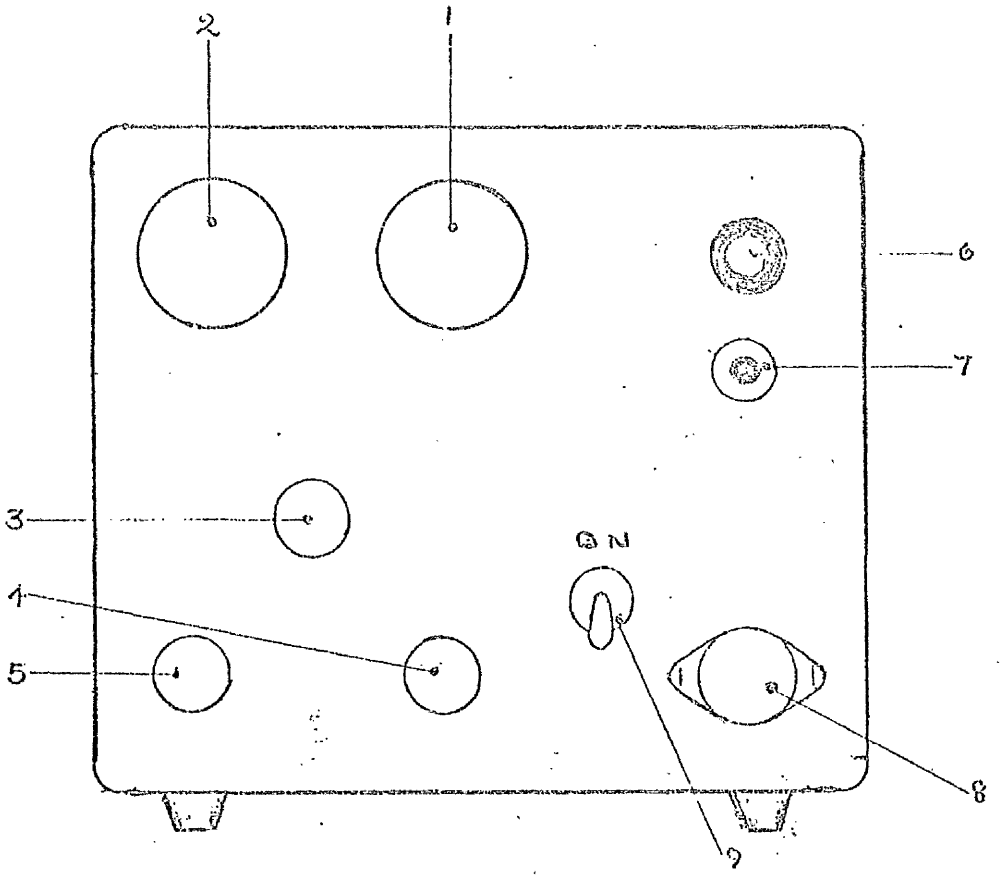


Fig. 8.6.3. FECG amplifier controls.

1. Gain Control - this is the stepped gain control of the final amplifier on the foetal only channel and produces a gain of x1, x2, x3 or x4 as required. The function of this control is to produce a foetal signal of sufficient amplitude to match the taperecorder and a signal of $\pm$1 volt is optimum.

2. Balance Control - this control corresponds to the gain on the second maternal only amplifier and provides the control for varying the amount of maternal only signals subtracted from the combined maternal plus foetal signals. It is a ten turn potentiometer and this allows for a very fine adjustment of the balance between the two channels. While some practice is required in the matter of balancing the two channels it is not a difficult procedure and this is a convenient point to remind potential operators that total cancellation is not required only that some part of the foetal signal should stand above or below the general signal level.

3. Output socket for the foetal only signal.

4. Output socket for the maternal only signal.

5. Output socket for the maternal + foetal signal. These three outputs can be displayed on the oscilloscope and provision is made for switching between outputs 4 and 5 without interfering with the socket connection.

6. Battery Test - Light.

7. Battery Test - Pushbutton - when this pushbutton is pressed the battery test light (6) will light

up provided the full battery voltage is available. This control is only operative when main on/off switch (9) is on.

8. Input socket - this socket connects the cable to the terminal box at the patient and carries the necessary input wires from all the electrodes and also a power supply for the two pre-amplifiers.

9. On/Off Switch - this switch obeys the American convention of down for off. The reason for adopting this convention on our instrumentation is that in general it is easier to knock a switch down in an emergency than to pull it up.

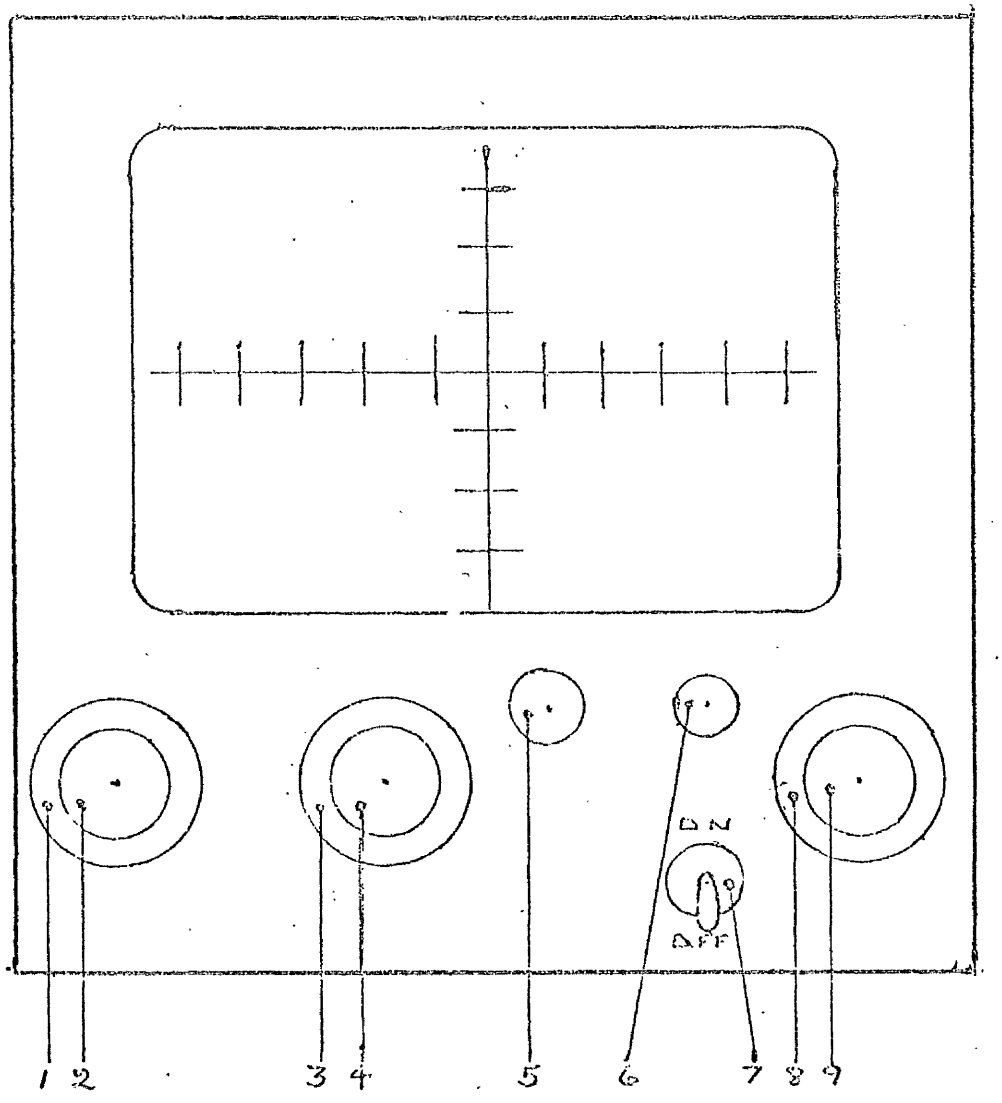


Fig. 8.6.4. Monitor oscilloscope.

IV OPERATION OF THE MONITOR OSCILLOSCOPE

This oscilloscope is a small dual beam oscilloscope with a long persistance tube. In this application it is prewired so that the foetal only ECG channel is always displayed on the upper trace (trace 1) and either the maternal + foetal or maternal only channel can be switched to the lower trace (trace 2). This switching is described in Chapter V. The controls of the oscilloscope are all clearly marked on the instrument and are demonstrated in Figure 4. They are as follows:-

1. Chanel 1 Y gain. This control, the outer knob of the two concentric controls 1 and 2, controls the amplitude of the signal on the screen. Although the scale is not calibrated the position corresponding to one volt per centimetre is marked.
2. Chanel 1 Y displacement. This is the inner of the two concentric controls and controls the position of the trace on the screen.
3. Channel 2 Y gain control.
4. Channel 2 Y displacement control.
5. Intensity control. This controls the brightness of both traces on the screen.
6. The mains indicator lamp. This little light is illuminated when the mains switch is on.
7. On/Off switch. This is the mains on/off switch controlling only the oscilloscope. It again obeys the American convention of down for off.
8. The Sweep Speed Control. This is the outer of the concentric controls 8 and 9 and controls the speed at which both signals cross the screen.

9. The x position control is not required in normal operation. It positions the width of the sweep within the screen area.

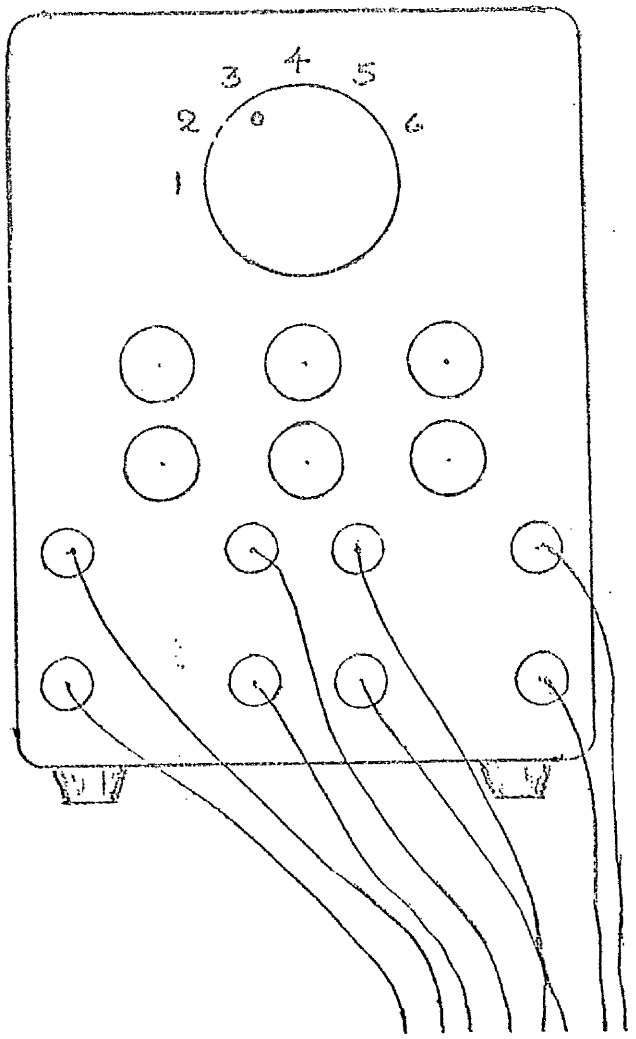


Fig. 8.6.5. FECG switching box.

V OPERATION OF THE SWITCHING BOX

The switching box is included in the apparatus for convenience to enable switching of the various amplifier outputs to other equipment without interfering with the terminal connections. It includes several output sockets which allow access to the signals at various parts of the system but these are usually required only for servicing and are not used in normal operation. The major control in this box is a multi-position wafer switch, the positions are clockwise:

1) connects the maternal only output of the amplifier system to the lower channel (channel 2) of the oscilloscope.
2) connects the maternal + foetal channel to the lower channel of the oscilloscope.
3) connects the output of the taperecorder (see chapter VI) to both channels of the oscilloscope.
4)
5) Not yet in use.
6)

Note that in both positions 1 and 2 the foetal only ECG is always connected to the upper channel and that the taperecorder will record precisely what is displayed on the oscilloscope.

VI OPERATION OF THE TAPERECORDER

The taperecorder is the standard, unmodified Epsylon taperecorder and for full details the Epsylon manual can be consulted. In this application the taperecorder is run at $1\frac{7}{8}$" per second (this enables fast play back at 15" per second if necessary) with the inputs corresponding to the signals on the monitoring oscilloscope (Chapter IV) on the two FM channels. The voice and time marker channels are both available and may be freely used. At no stage is there any need to interfere with the input or output leads to the taperecorder as these are controlled from the switching box (Chapter V). The only difficulty with this particular machine lies in threading the tape through the tape heads. It is all too easy to lay the tape on the wrong side of the positioning posts which apply the tape to the tapeheads during record/playback. This should be checked very carefully at each operation.

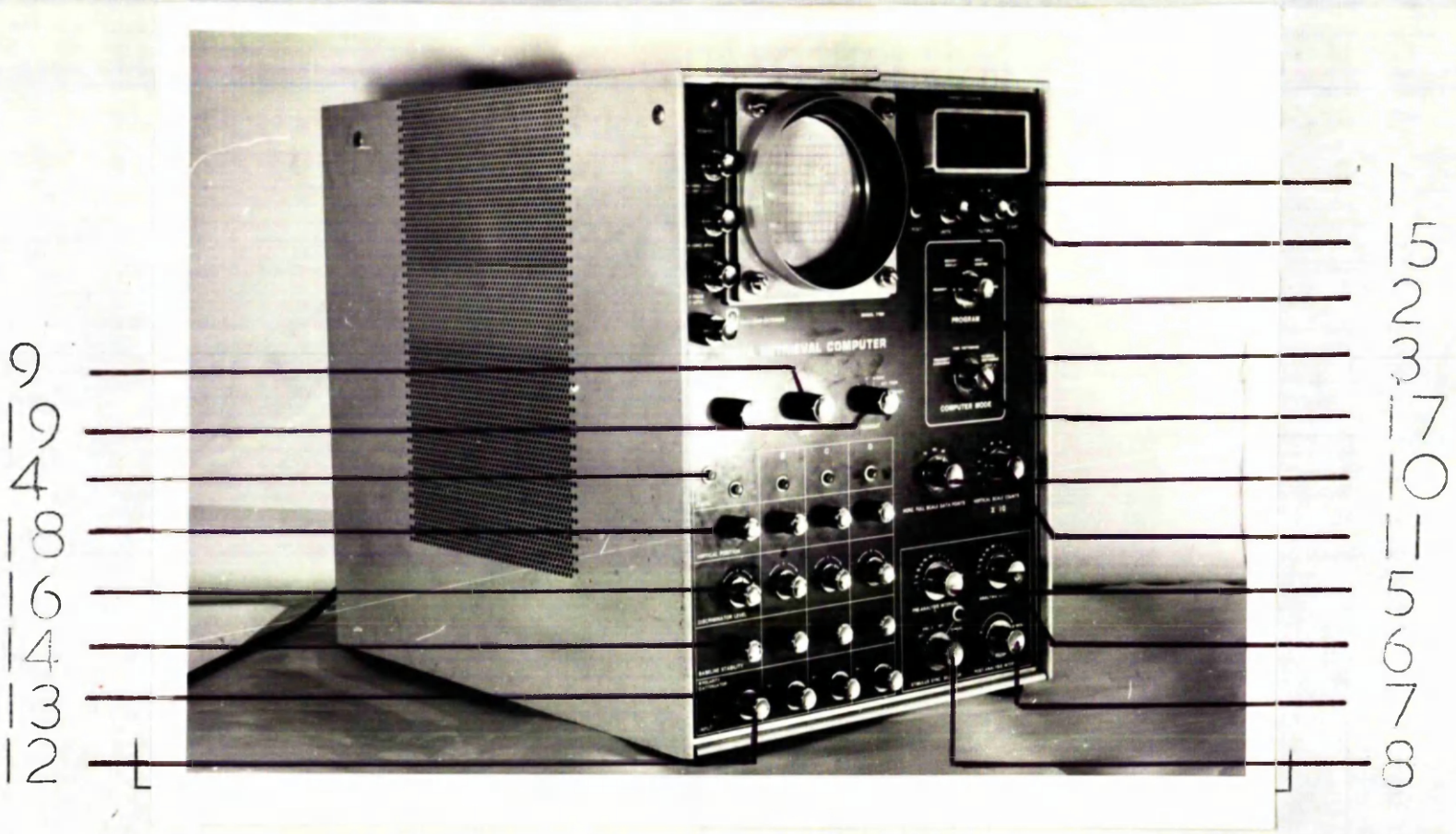


Fig. 8.6.6. Nuclear Chicago Data Retrieval Computer.

VII OPERATION OF THE COMPUTER

The computer used here is a standard Nuclear Chicago Retrieval computer Model 7100C and for full details the manual is available for consultation. Only those controls necessary for operation in the present context will be described. They are shown in Figure 6 and are as follows:

1. Counter reset. The computer will count the number of events it has dealt with up to 999 and this can be set at zero by this control.
2. Maximum count control. The computer can be set to cease its operation after any number of events but in this context it is usual to set the control at infinity so that the computer does not in fact stop until the operator decides.
3. Program selector. This control has four positions which are clockwise:
   (a) Readout - in this position the memory stores of the computerare available for output to line printers, X-Y plotter, tapepunch, etc. It is always operated in conjunction with control 16.
   (b) Memory display. In this position the memory stores of the computer are displayed on its own oscilloscope screen. This control is often operated in conjunction with controls 11 and 19.
   (c) Input monitor. In this position it is possible to monitor the input signal to the computer and this is operated in conjunction with controls 12 and 13.

(d) Compute. In this position the computer will execute any of the programs decided by control 18.

4. Master erase. This button will erase the memories of the computer only when control 3 is in the memory display position. In conjunction with controls 9 and 10 the slave erase buttons A, B, C and D can be used to erase small portions of the memory. None of the erase buttons will operate in any other position of control 3.

5. Pre-analysis interval. In some circumstances it is desirable to allow a delay before analysis commences but in this application care must be taken to set this control at zero.

6. Analysis Interval. The interval over which analysis takes place is variable over wide limits but in this application the time of one second is optimal.

7. Post Analysis Interval. In some physiological experiments it is desirable to have a resting phase after each analysis. This is not applicable here and again care should be taken that this control is set at zero.

8. Stimulus Synchronisation Selector. This control decides the trigger for the computers operation and here it must be set at the discriminator A position. The other positions are not applicable.

9. Input Channel Control. This computer is capable of operating on one, two or four channels. These can be selected by this control but here channel A is used for normal operation.

10. Horizontal Full-scale Data Points. This control is complementary to Control 9 and must be set to 400 for channel A, 200 for channel A and B, or 100 for channels, A, B, C and D. The major use in this application is to split the memory into four parts after analysis to allow for erasing of noisy parts of the base-line (control 4).

11. Vertical Scale Count. This control has been modified and the vertical scale count is only 1/10th of that indicated. This control can be changed during analysis and on memory display but a reasonable starting point is the 2K position.

12. Input Polarity Control. The computer only operates on a signal whose main deflection is upwards on the oscilloscope screen. Should it be required to deal with a signal in which the main deflection is downwards, this control can be set to reverse the input terminals thereby producing an apparent upward deflecting signal.

13. Input Attenuator. This control which is concentric with the input polarity control (12) has four positions by which the amplitude of the input signal can be varied to match the requirements of the computer. With the program control (3) in the input monitor position, this attenuator control should be set so that the maximum deflection of the signal is about 2 cm.

14. Base Line Stability. This control is used to centre the base level of the input signal to the required part of the computer's oscilloscope. It is also used during transient averaging control (18) but this is not pertinent to the present situation.

15. Start Button. Once all the computer controls have been set to the desired positions pressing the button commences the operations of the computer.

16. Discriminator Level. This control determines the voltage of the input signal which will trigger the operations of the computer. It should normally be set at zero and then moved clockwise, or anti-clockwise until the desired trigger level is achieved. This can be checked either by examination of the input monitor (Control 3) with the computing mode switch (17) at the time histogram position or alternatively, with the computer running in the interval histogram position the discriminator level may be adjusted until intervals compatible with foetal ECG intervals are achieved.

17. Computer Mode Selection. This control has three positions of which only the interval histogram is of any interest here. The time histogram position can be used in conjunction with controls 3 and 16 but this is rarely necessary.

18. Vertical Position. This control only operates in the memory display position of control 3 and can be used to move the display up and down the

oscilloscope screen.

19. Read-out. This switch selects the speed at which the computer will read out the information of its memory stores to accessory equipment. In this application it is always set at 64 seconds so as to match best the XY plotter employed. Note that the start button (15) is the control which initiates read-out when the program selector (3) is set at read-out position.

This computer undoubtedly presents the most bewildering array of knobs of any of the equipment in this assembly and there can be no possible substitute for experience and practice in its operation.

VIII OPERATION OF THE XY PLOTTER

This plotter is the standard Houston Instruments plotter and the manual is available for further study The controls of this plotter are of little relevance here as they can remain permanently set at their present position because the computer generates both the X and Y information.

In the usual read-out mode of the computer a 64 second sweep represents 8 inches on this plotter. We have here a useful check on the accuracy of the plotter as the completed graph should occupy exactly 8 inches. Should this not be the case a very slight adjustment of the fine Y gain control can be undertaken but this is extremely delicate.

The practical points to note about the use of this plotter are the difficulties in inserting the graph paper into the channels as it is indeed a tight fit and that if the pen is allowed to over-run in any direction it is very susceptible to damage.

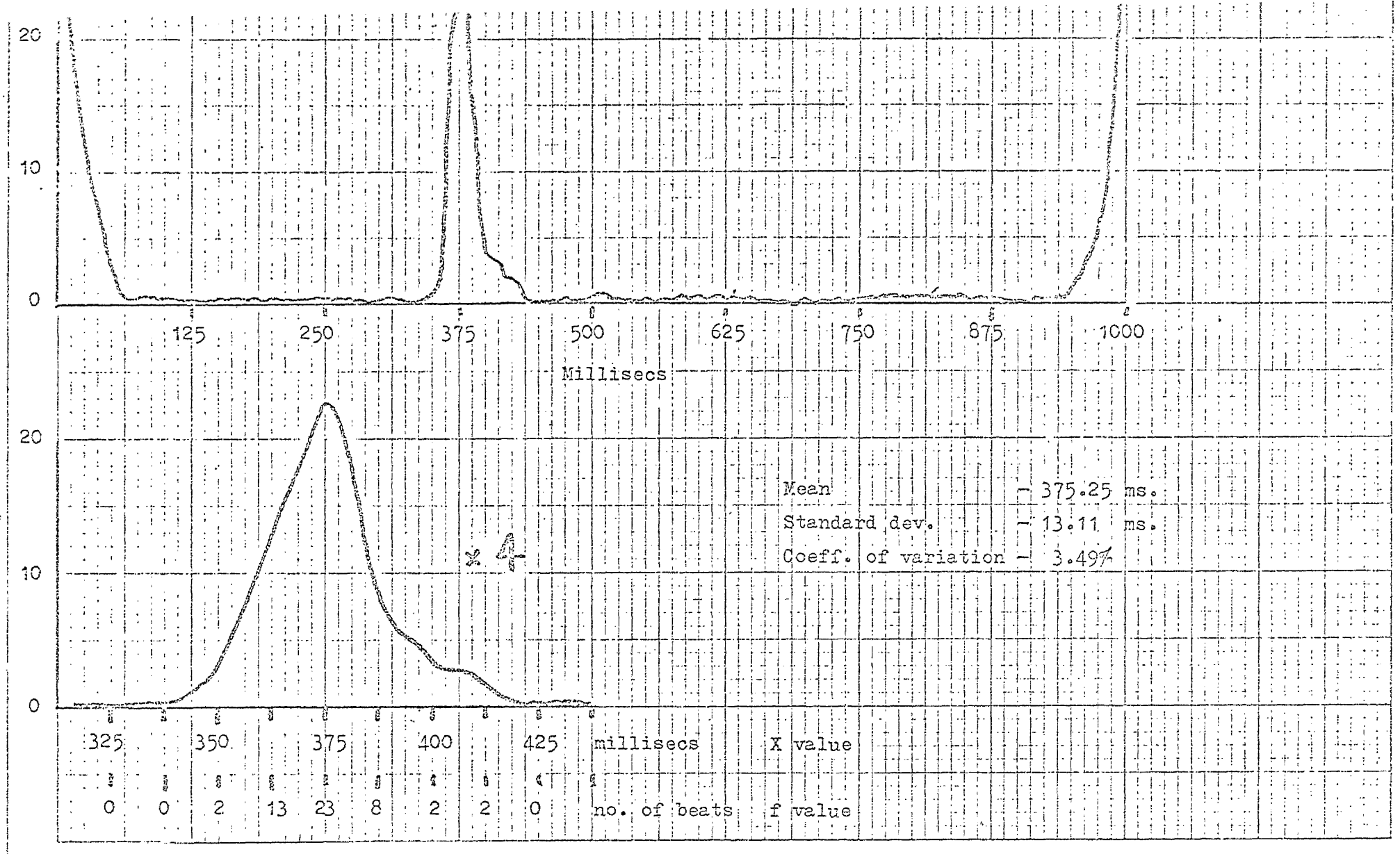


Fig. 8.6.7. Typical interval histogram output from the computer

IX ANALYSIS OF THE INTERVAL HISTOGRAM

The general form of histogram produced by the XY plotter (chapter 8) is shown in Fig. 7. From this it can be seen that 8 inches represents the full time scale of 1 second. It follows then that each small tenth-inch square represents 12.5 millisecs. The units on the Y axis do not have to be identified as the mean and standard deviation calculations depend upon proportion rather than upon absolute value. It is sufficient then to express the Y values as numbers of small squares. The graph is constructed by joining the crests plotted by the XY plotter and the value of Y decided for each value of X (i.e. time) over the appropriate section of the graph.

Further calculation is carried out on an I.M.E. Digi-recorder which is so programmed that only the first value of X is required, the machine supplying sub-sequent values of its own accord. Please note here that the value of Y = 0 is the instruction to the calculator to commence its calculations and that the first value of Y must never be zero; it may well be .001.

Instructions for the operation of the I.M.E. Digi-recorder are available with the machine and the points to note here are that only the first X value (i.e. time) is required and that the Y values are punched

in sequence ending with Y = 0 which is the instruction for the computer to compute the mean, standard deviation and coefficient of variation in order. These three parameters are then available for comparison with the state of the infant at birth.

9. RESULTS

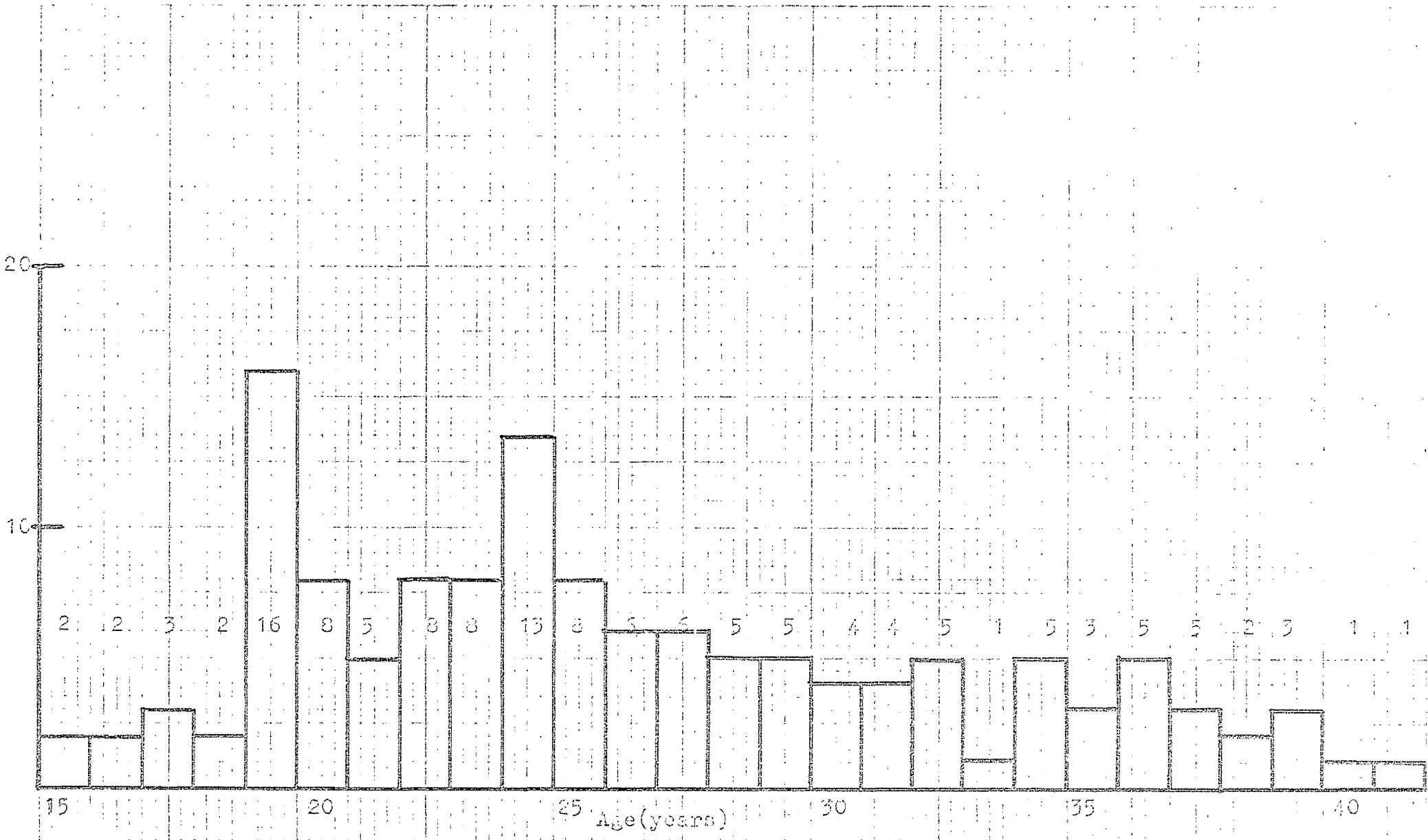


Fig. 9.1. Distribution of maternal age.

9.1. Introduction - In this series the net was deliberately cast much more widely than in the previous series. No attempt was made to select patients other than the factors causing their admission to the hospital. By the nature of the Glasgow Royal Maternity Hospital this still represents very considerable selection. Most patients are of social class 4 and 5, many are unmarried and high parity is common. These, however, are the very groups in which perinatal loss is high and where scope exists for real improvement.

In all 162 FECG examinations were carried out on 135 patients in the last few weeks of pregnancy. None of the records were obtained in labour.

The complete data on every patient is listed in Appendices A and B . This Chapter will examine the more pertinent data both on the population and individual basis.

9.2. General description of the population studied - Before embarking on a detailed statistical study of the results in a trial such as this it is very necessary to take an overall view of the population studied to ensure that the population itself is not so unusual as to invalidate the results obtained from it.

9.2.1. Maternal age and parity - As maternal age and parity are well known to contribute towards the outcome of pregnancy these two factors were the obvious general points to consider first. Fig. 9.1. shows the histogram of the ages of all the mothers in the series by one year intervals, irrespective of parity. It demonstrates clearly the expected "humps" at ages 19 and 24 and agrees with the overall U.K. pattern.

Figs. 9.2 and 9.3 show the distribution for primiparous and

Fig. 9.2. Distribution of maternal age. Primigravid patients.

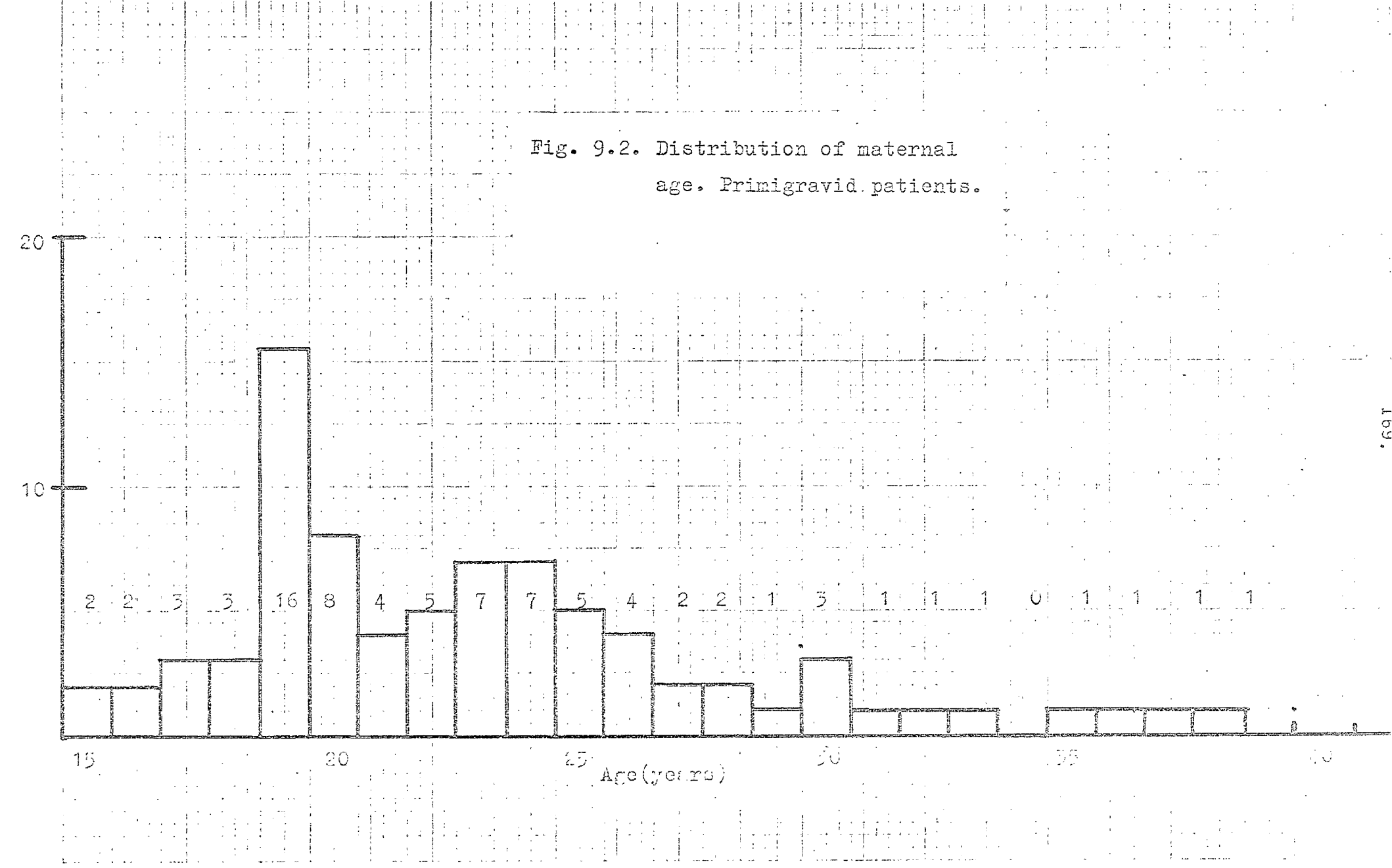


Fig. 9.3. Distribution of maternal age. Multiparous patients.

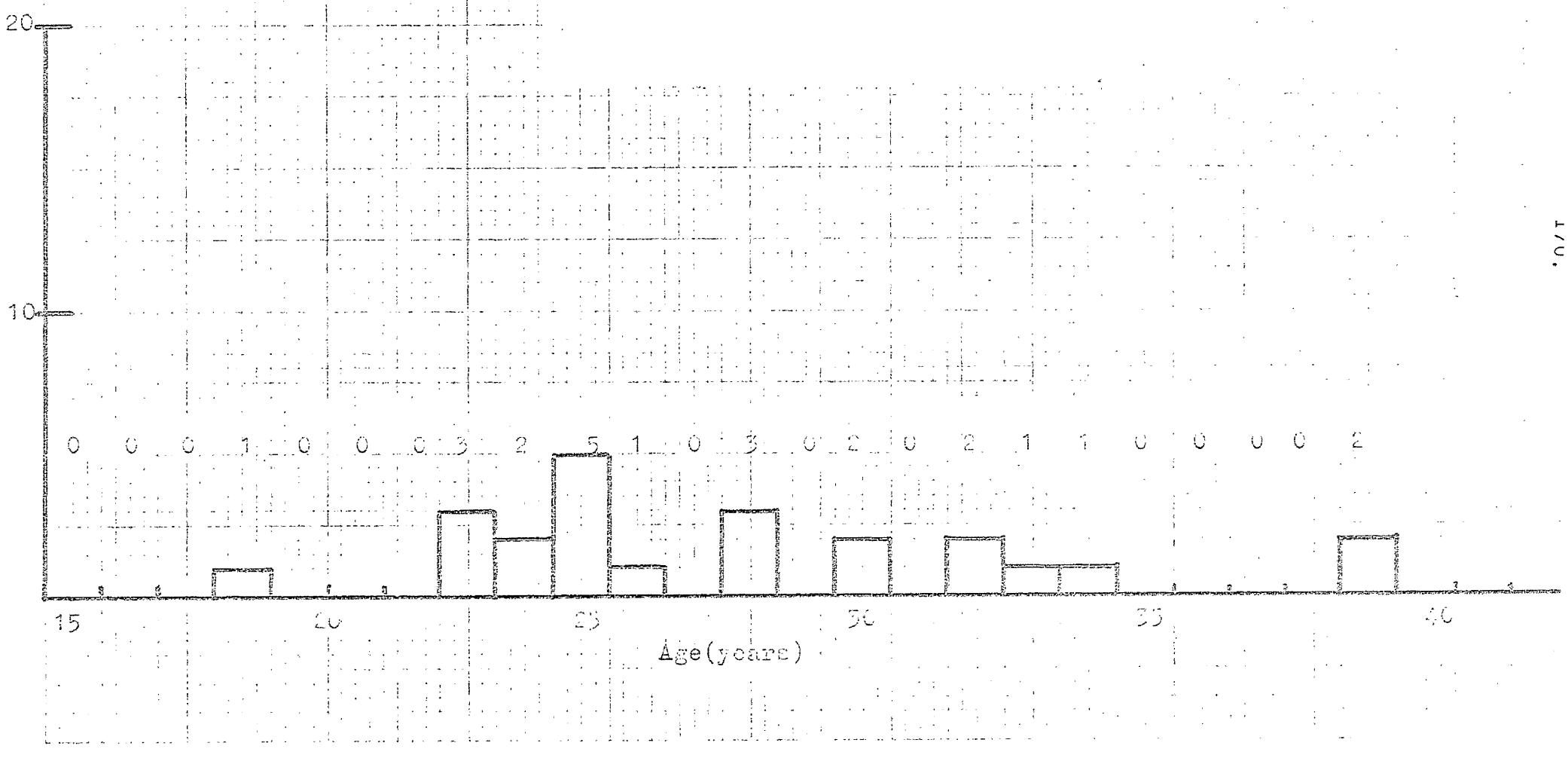
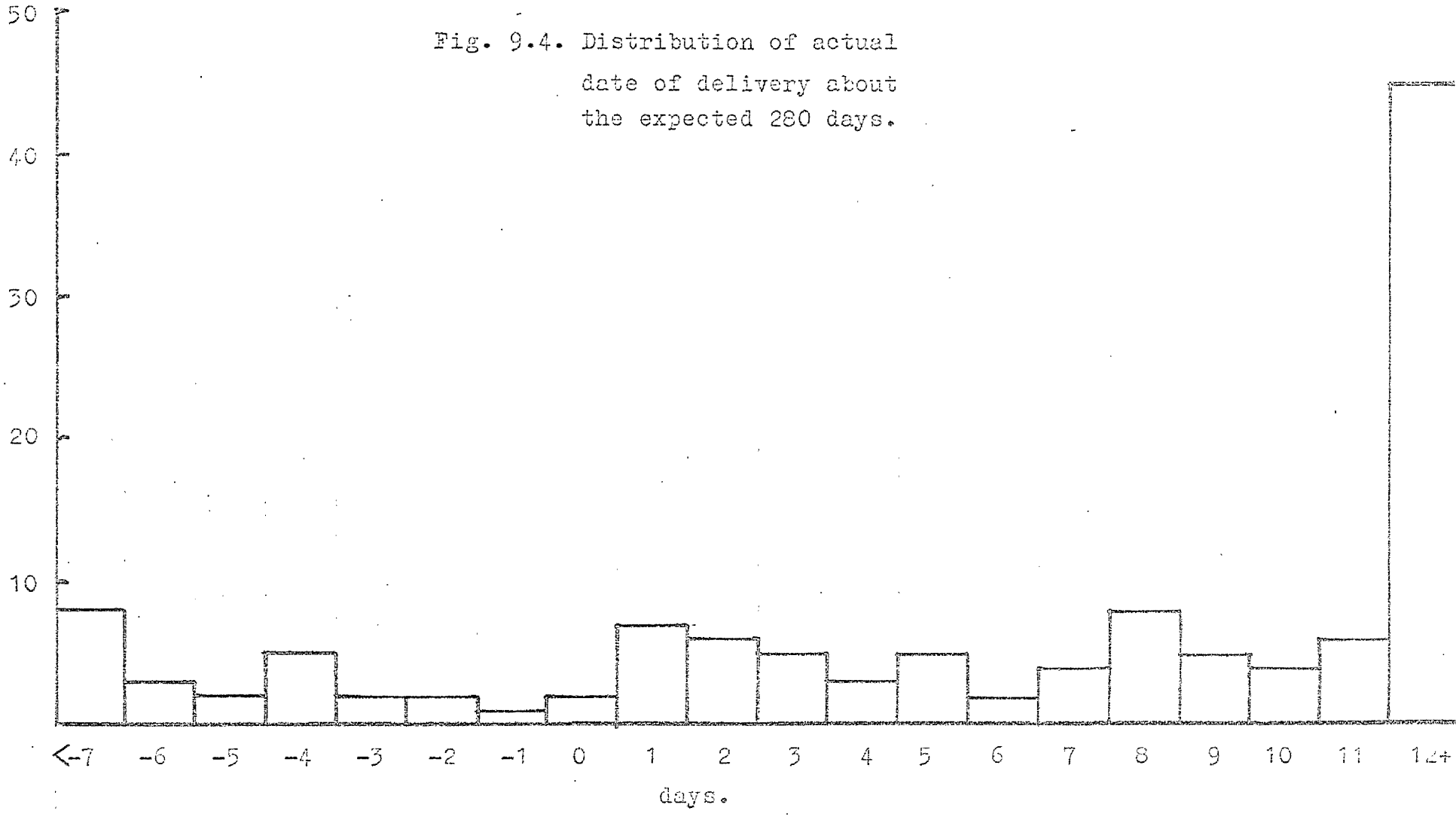


Fig. 9.4. Distribution of actual date of delivery about the expected 280 days.



multiparous mothers. From these two it can be seen that the first peak at 19 is due (not surprisingly) to first pregnancies and the second peak at 24 is due to a combination of some of the first group having a subsequent baby and another group of primiparous patients.

These are easily explained - and indeed expected - by the pattern of marriage and pregnancy in our society. Social groups IV and V tend to marry and reproduce early, about 18 to 20, while the professional group tend to marry later (after University etc.) at 24 to 25.

At least in these two respects, age and parity, this group of mothers can be assumed not to be unusual.

9.2.2. Duration of pregnancy - The problems of the diagnosis of maturity and duration of pregnancy are not strictly relevant to this thesis. Nevertheless, as the information was collected and the data surprising, it seems justifiable to digress a little. The expected date of delivery was calculated in the usual manner but only in those cases where the menstrual history was reliable. Fig. 9.4. shows the distribution of the actual duration of pregnancy about the nominal 280 days. The mean duration is 287 days and no less than 45 patients (36%) were over 12 days late.

This finding, of course, reflects the induction policy of the obstetricians concerned. In the unit where this study was conducted induction was not common. Both in this study and in another (Jordan, 1971) the adherence to this policy has not affected the perinatal death rates adversely. Here it is 22.22 per 1000 compared with the hospital average of 27.25 per 1000

This author was intrigued to the extent of attempting to test the hypothesis that pregnancy may be tending to last longer - after all the ages of menarche and menopause are changing rapidly.

	Number	Mean	Standard deviation S.D.
Hospital series	125	7.7	11.5
G.P. series	320	1.3	13.1

degrees of freedon = 443.

t = 4.8

P < 0.001

Table 9.1.

A problem with any hospital population is that it is highly selected. Some other source of data is clearly required. It proved quite possible to check the expected and actual dates of delivery of all cases from the author's present general practice records. As the practice operates in the same area as the hospital the same social factors apply. No attempt was made to distinguish between home or hospital deliveries or spontaneous or induced labour. Of 320 cases (1968 - 71) the average duration of pregnancy was 281 days. The wide difference between this group and the hospital group was confirmed by the Student t test (Table 9.1.). This shows a highly significant difference between the populations.

Elucidation of this finding could well require a thesis in its own right and unfortunately cannot be considered further here.

9.2.3. Weight of babies - The birth weight of infants is generally recognised as being significant to their survival and development. In this series it is only possible to demonstrate that the weights fall within accepted limits at birth as an unusually effective neonatal pædiatric unit is responsible for resuscitation and after-care.

The general distribution of birth weights is shown in Fig. 9.5. and can clearly be seen to be normal. The relationship between birth weight and Apgar score is shown in Fig. 9.6. While the two heaviest babies did very well, the lightest was by no means the worst and the three dead babies do not occupy any unusual position.

9.2.4. Apgar Scores - The method used for calculating the Apgar score is detailed in Chapter 8 and its use is further discussed in Chapter 3.2. Fig. 9.7 shows the distribution of the 1 minute Apgar Scores in the present series.

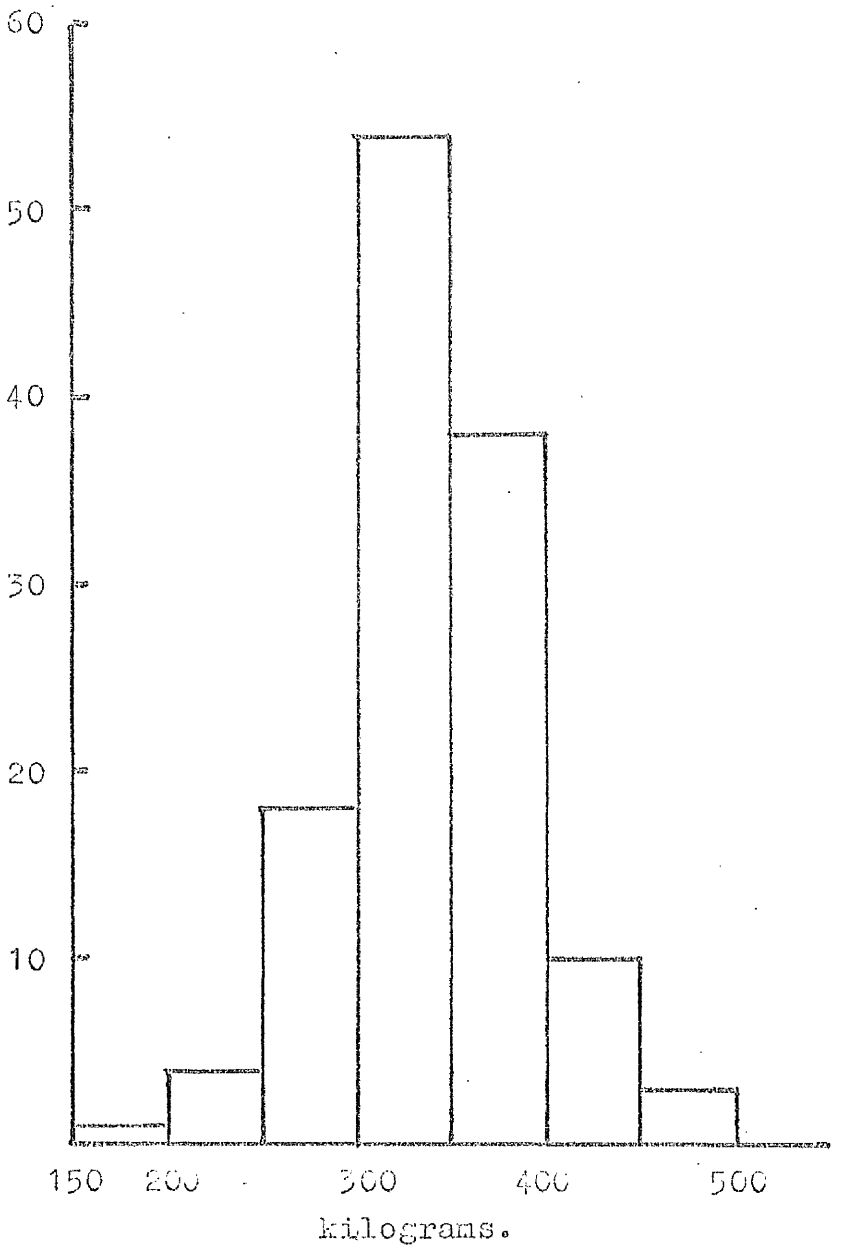


Fig. 9.5. Distribution of infant's birth weights.

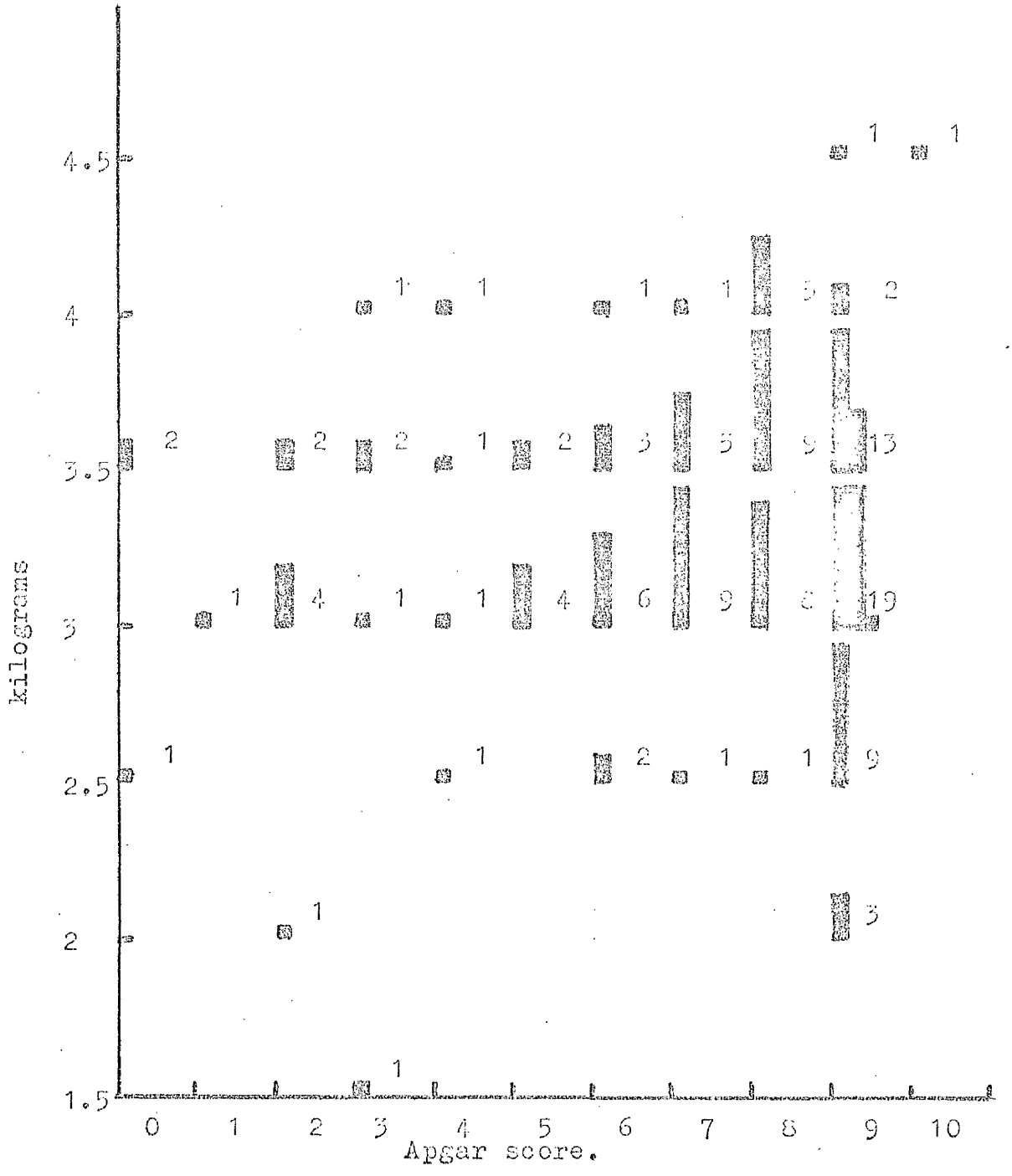


Fig. 9.6. Relationship between Apgar score and birth weight. (by 500g classes)

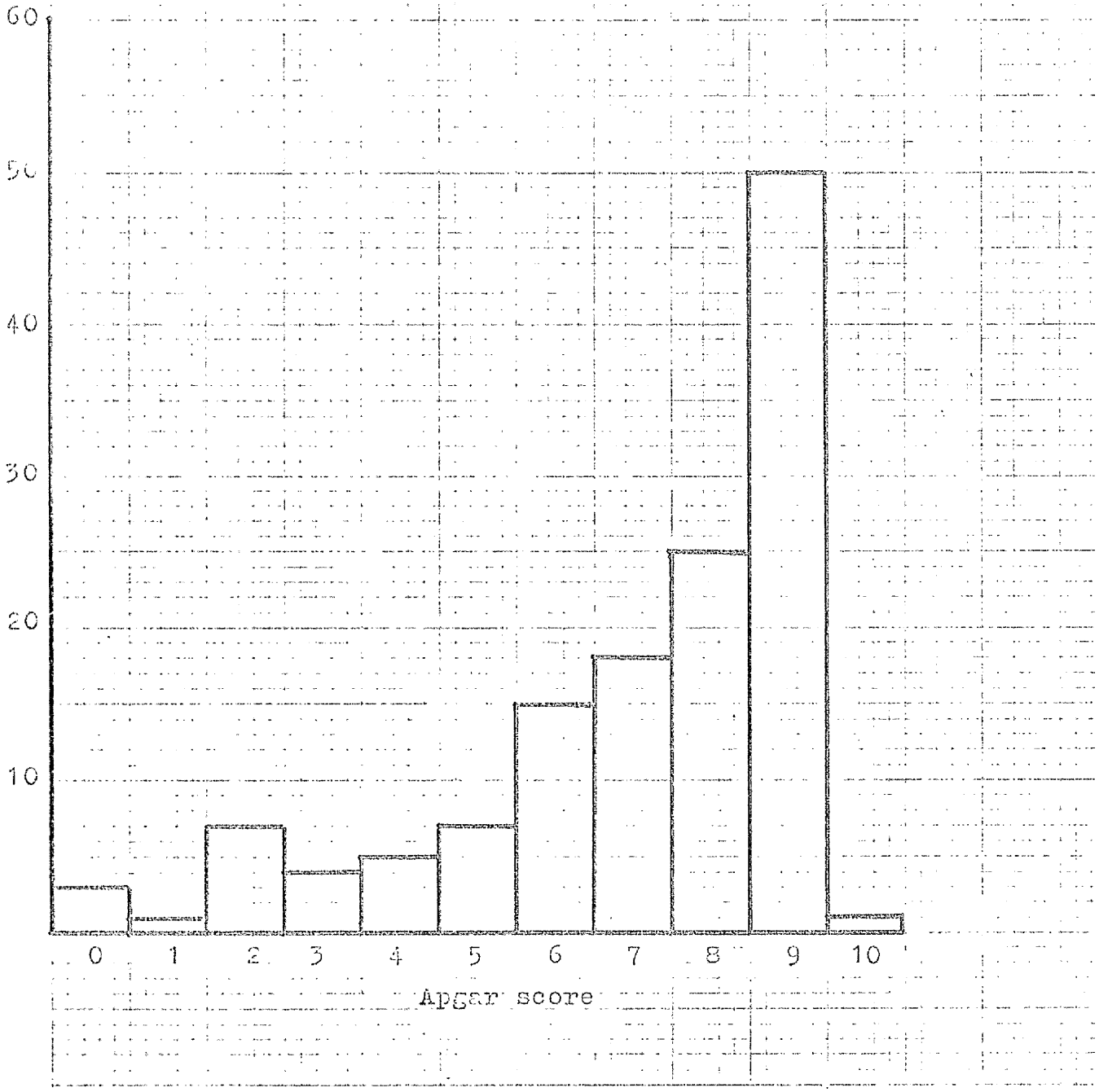


Fig. 9.7. Distribution of Apgar scores.

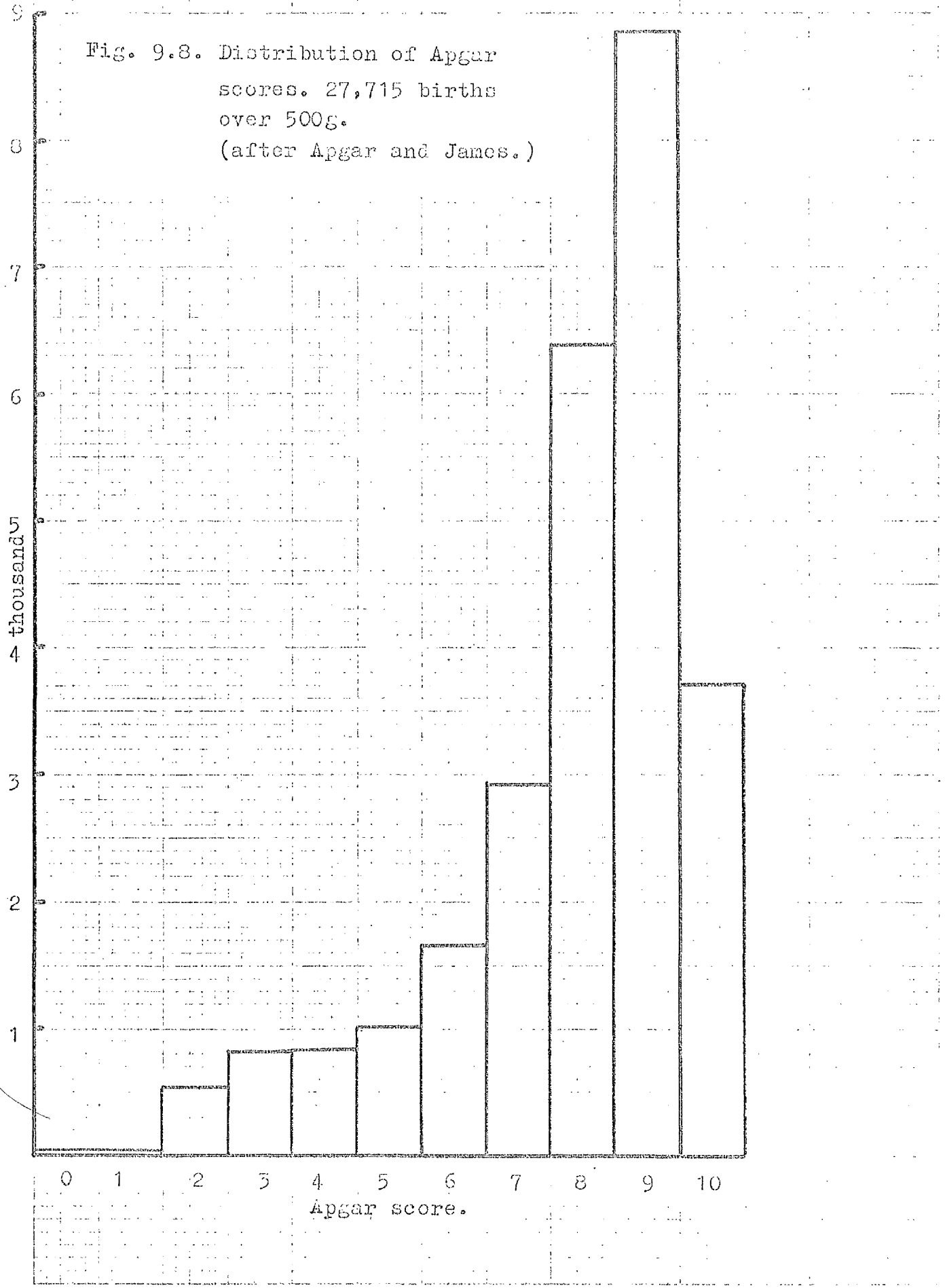


Fig. 9.8. Distribution of Apgar scores. 27,715 births over 500g. (after Apgar and James.)

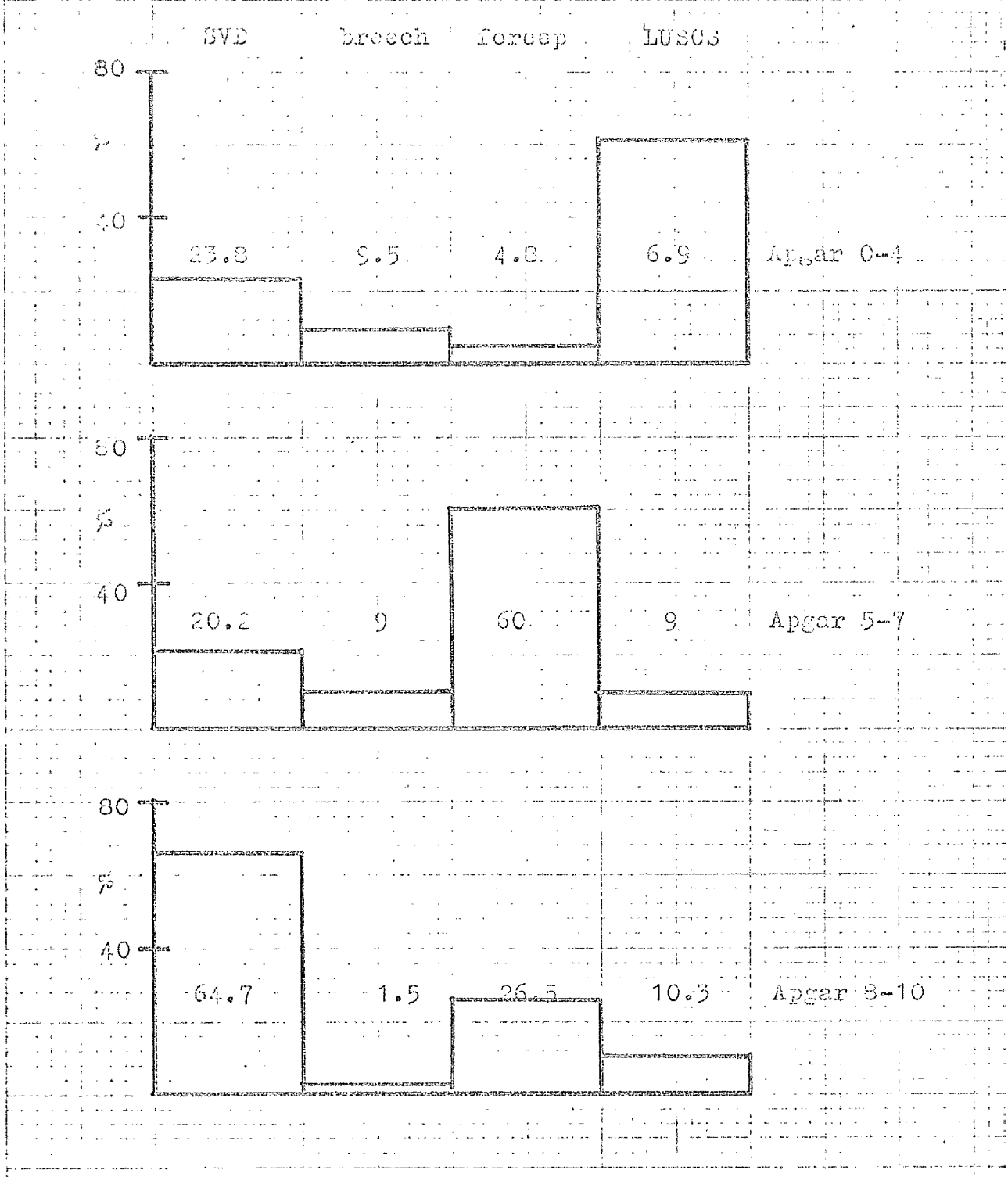


Fig. 9.9. The relationship between delivery method and Apgar score.

Comparison with Fig. 9.8 (after Apgar and James, 1962) shows that it follows very much the expected pattern except for the absence of scores of 10. This may be explained by the rigorous and enthusiastic application of the Score in the labour ward concerned.

Both Apgar and James' and our own distributions are shown here not only to demonstrate their similarity but to emphasise an extremely important point which seems to be generally misunderstood.

By no stretch of imagination can these distributions be considered "normal". In addition the score jumps in discrete steps and cannot be considered continuous. Under these circumstances the concept of average Apgar Score is slightly dubious but the use of means, standard deviations, t-tests and related statistical concepts cannot be applied. These terms have been used in the current literature, doubtless there is no intention to deceive, but these authors have been grossly misled by their statistical advisers.

The relationship between delivery method and Apgar Score is a fascinating one. Fig. 9.9 shows the relative incidence of delivery method. (SVD, breech, forceps, LUSCS) within the Apgar groups 0 - 4 (poor) 5 - 7 (medium) and 8 - 10 (good). This clearly shows that the majority of the low Apgar score infants were delivered by Cæsarean section (LUSCS), the medium score infants by forceps and the good ones by spontaneous vertex delivery (SVD). This immediately raises the "chicken or egg" argument. Were the poor risk babies so well identified that they were sectioned? Or does Cæsarean Section cause low Apgar scores? Fortunately, this thesis was not set up to find that answer and it will not be attempted.

The distribution of Apgar Scores within parity groups is also

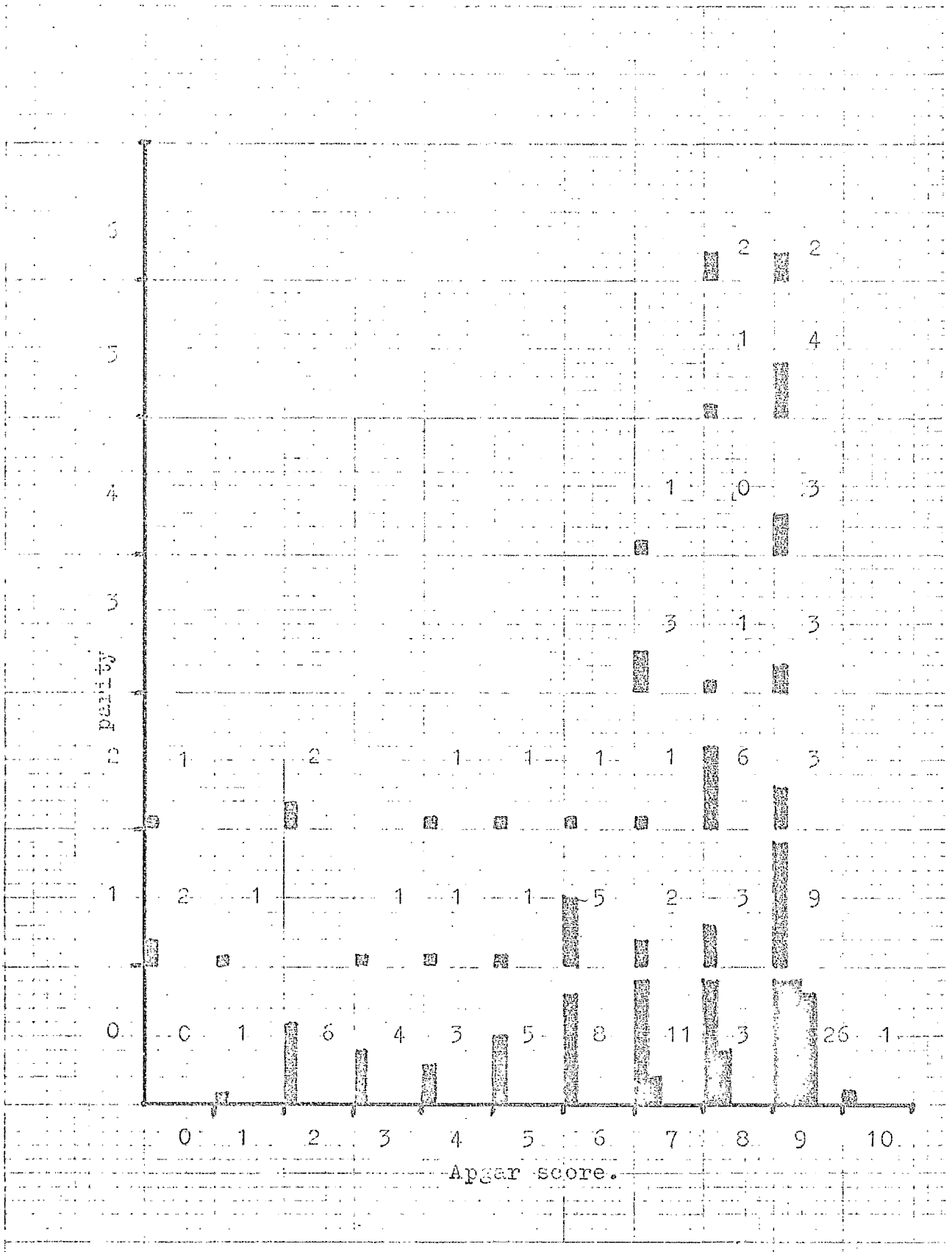


Fig. 9.10. Apgar scores within parity groups.

interesting (Fig. 9.10). All the poor Apgar score infants were delivered of mothers of parity 3 or less. There were no poor Apgar scores above parity 3.

The above general description of the population under study has been given to demonstrate that, although it may have its idiosyncrasies, it is not an unusual population in the statistical sense. Were it a very unusual population there would be no point in continuing to examine the details envisaged in this thesis.

9.3. Results of statistical analysis of cardiac cycle interval - From general considerations and the evidence from the previous study (Vol. 1.) it was expected that statistical analysis of the cardiac cycle interval would yield information which would be useful in the diagnosis of foetal status.

Several statistical indices were used to compare groups of babies. The babies were grouped according to Apgar score at birth. In general they were divided into two groups (Apgar 0 - 5 and 6 - 10) or three groups (Apgars 0 - 4, 5 - 7 and 8 - 10). The results of these comparisons will now be examined in detail.

9.3.1. Mean interval of cardiac cycle - This is simply the average cardiac cycle interval taken over the whole recording. It is the index nearest to the aurally obtained foetal heart rate. From the published data and the great mass of obstetrical experience over the years it can be expected to reflect foetal status to some degree.

Before continuing any further operations upon the means it is necessary to ensure that such operations will be valid. Fig. 9.11 shows the distribution of the means within the population of the experiment. This is demonstrably "normal". Conventional Gaussian statistics can then be undertaken.

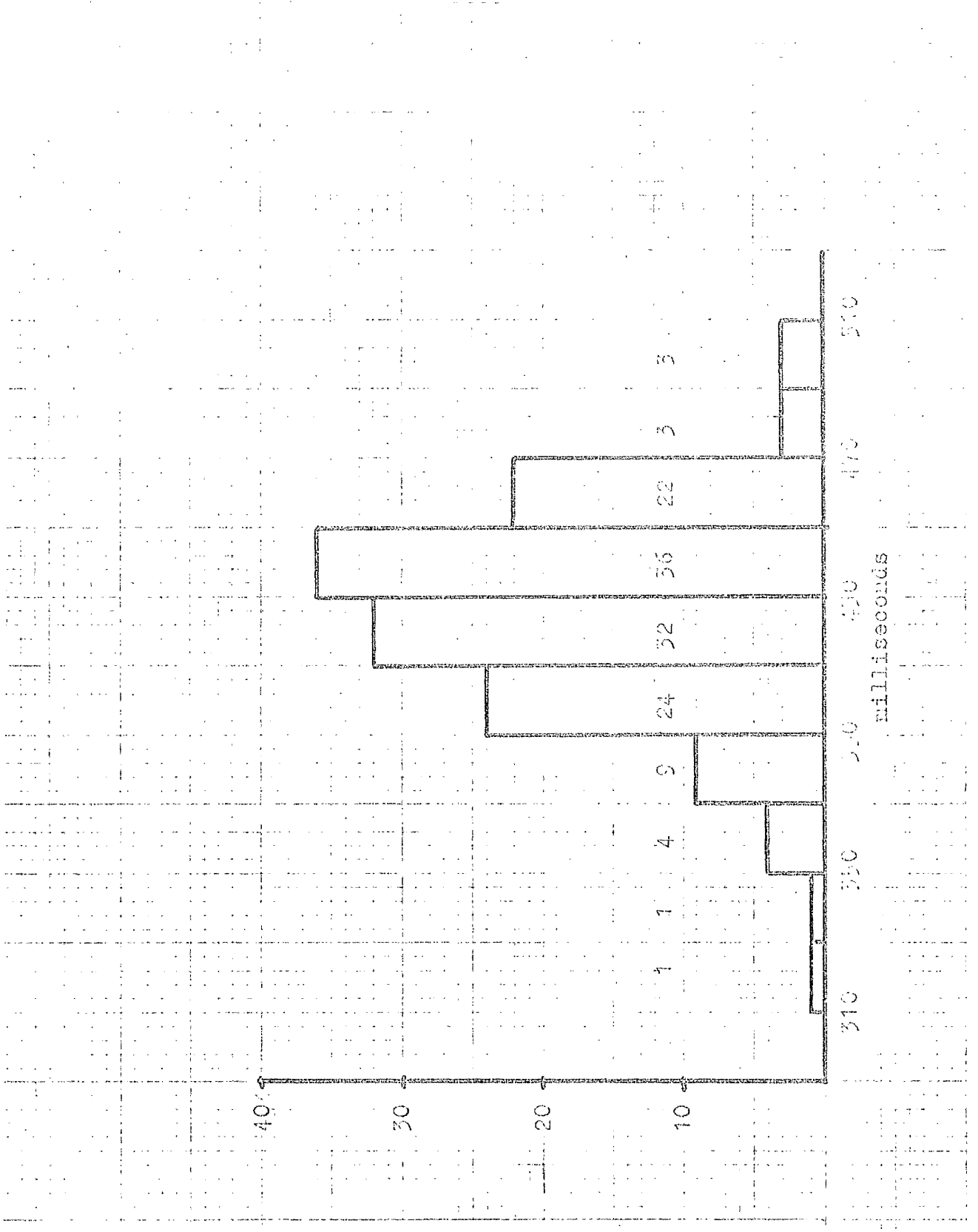


Fig. 9.11. Distribution of the means of cardiac cycle intervals.

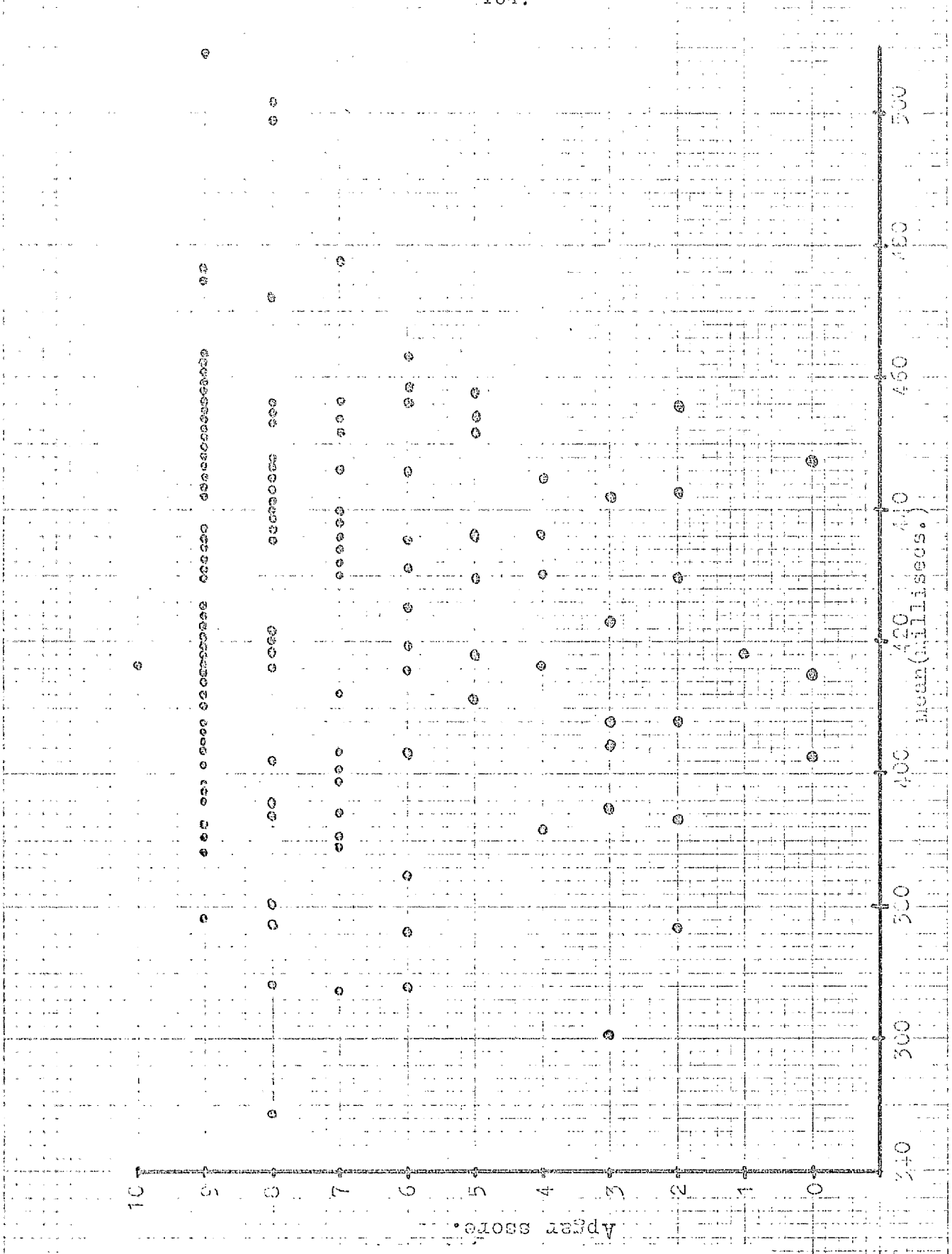


Fig. 9.12. Apgar score versus mean of cardiac cycle interval. (all cases)

The values for the means were first plotted against Apgar score - Fig. 9.12. At first sight this seems very disappointing as the three dead babies occupy a very central position. However, in general the low Apgar babies are towards the small intervals (i.e. fast rate). Fig. 9.13 is the same plot with the instrumental deliveries removed - it is essentially the same.

The values of the means were compared for several groups of babies. Firstly, a simple high and low Apgar grouping (10 - 6 and 5 - 0) and secondly, by three groups, good (10 - 8, fair (7 - 5) and poor (4 - 0).

Fig. 9.14 shows the results of this exercise with the mean and 2 standard error limits plotted for each group.

From these the trends are quite clear. The low Apgar groups tend to have small cardiac cycle intervals.

Further comparison of the groups was undertaken by Student's t test. Table 9.2 shows the results.

Between the high and low groups (10 - 6 and 5 - 0) the difference in the means is not statistically significant. Between the good and poor groups (10 - 8 and 4 - 0) the t test shows a significant difference. The level of significance reached ($P < 0.1, > 0.05$) is just barely adequate but it does confirm the expected trends.

The differences in the averages of heart rate for the good (10 - 8) and poor (4 - 0) is quite marked at 140 beats per minute and 168 beats per minute respectively.

There has been reported recently a fixed slow heart rate in babies very near to death in labour. This author has not seen this effect outwith labour.

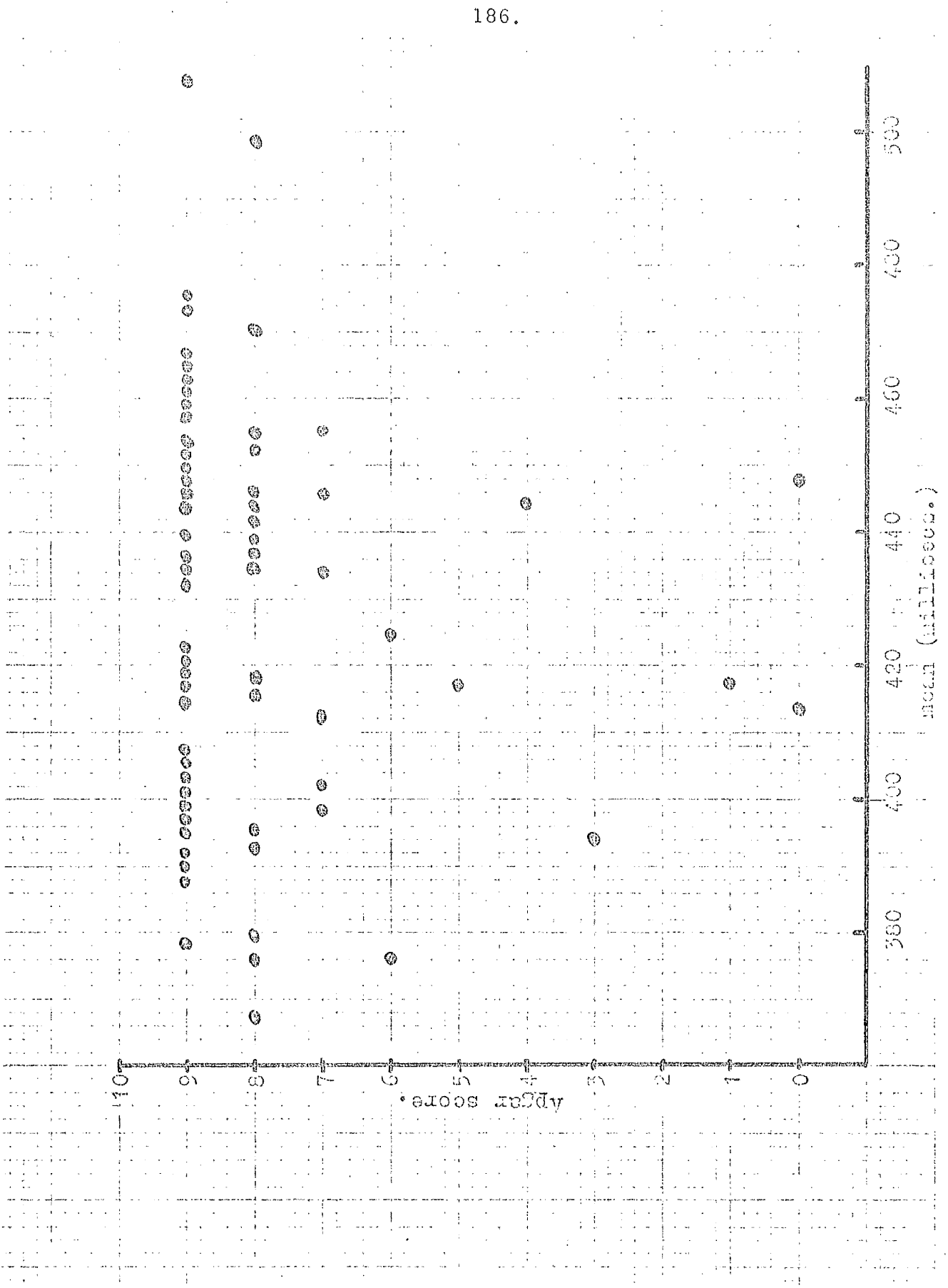
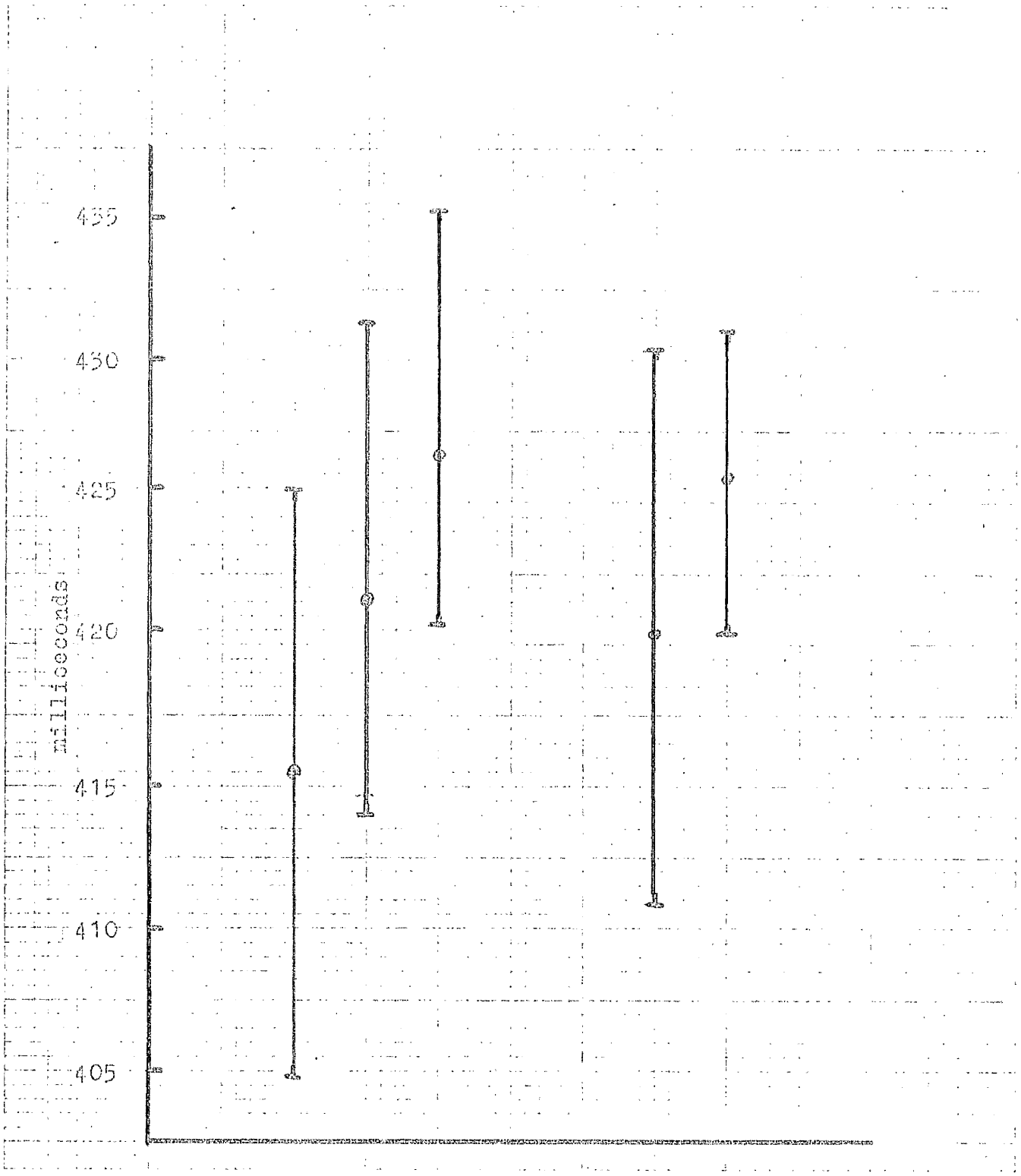


Fig. 9.13. Apgar score versus mean of cardiac cycle interval (SVDs only)



	Apgar	+2SE	Mean	-2SE
○	0-4	426.3	415.7	404.6
●	5-7	432.3	423.3	414.4
●	8-10	436.2	428.7	421.1
●	0-5	430.3	420.8	411.3
●	6-10	432.4	426.3	420.1

Fig. 9.14. Comparison of means of cardiac cycle intervals. Divided by Apgar groups.

	Number	Mean	Standard deviation
Apgar 10 - 6	107	426.3	31.5
Apgar 5 - 0	28	420.8	24.7

degrees of freedom = 133

t = 0.98

P < 0.4, > 0.3

	Number	Mean	Standard deviation
Apgar 10 - 8	75	428.7	32.5
Apgar 4 - 0	21	415.7	24.8

degrees of freedom = 94

t = 1.68

P < 0.1, > 0.05

Table 9.2

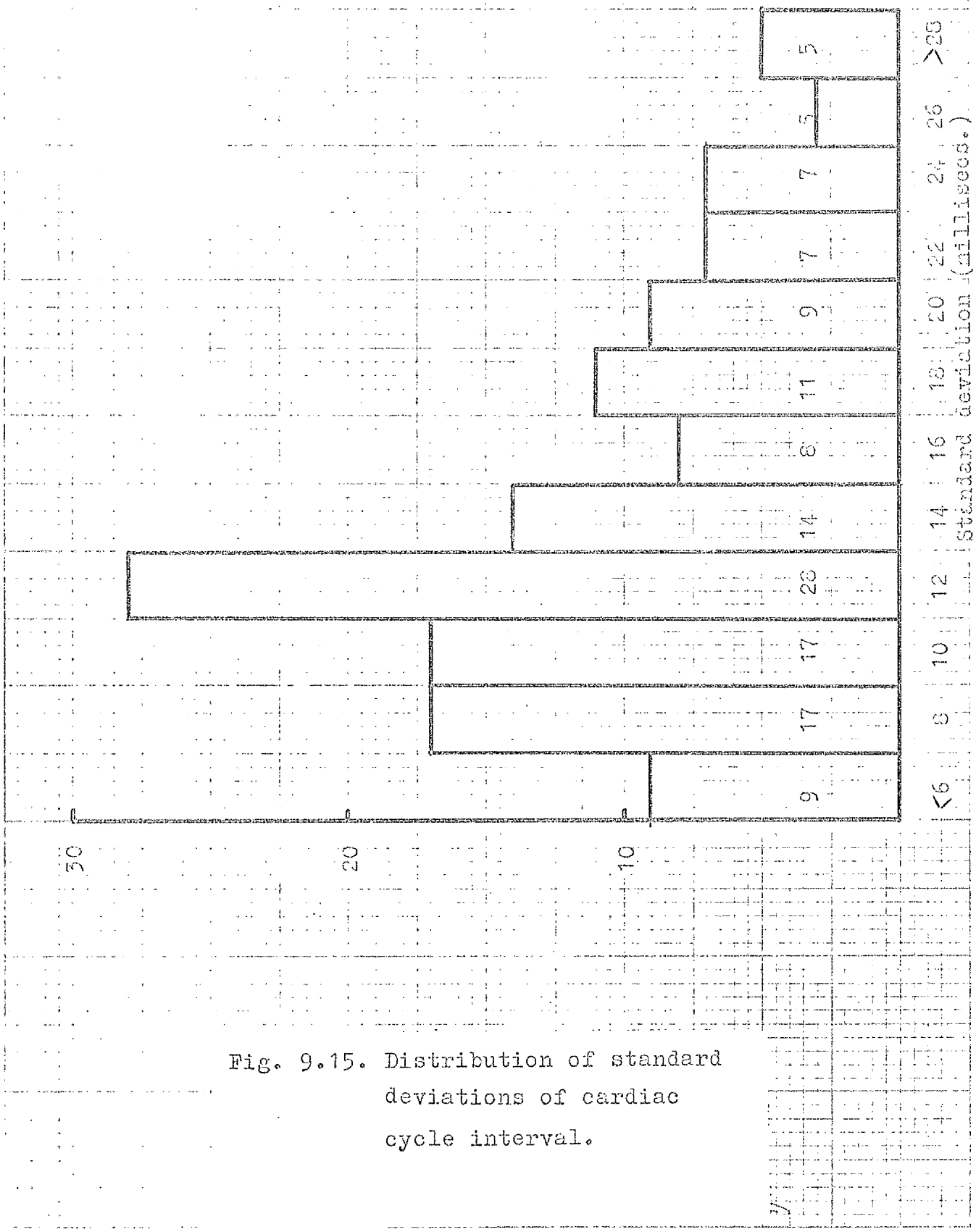


Fig. 9.15. Distribution of standard deviations of cardiac cycle interval.

To summarise, the mean cardiac cycle interval as a predictor of foetal status follows the expected trends, both from the published literature and the physiology of the foetus, and although it achieves statistical significance in prediction it does not achieve high significance.

9.3.2. Standard deviation of cardiac cycle interval (SD) - Like the adult heart rate the foetal heart rate is not entirely regular. The degree of irregularity is recognised to be important in foetal prognosis but it is difficult to measure. The Standard deviation of cardiac cycle interval about the mean is one method of measuring this. It does not take into account the sequence of events (like the method of Van Bemmel, 1970) but merely indicates the distribution of longer or shorter cycles about the mean. It is expected from the previous series (Vol. 1) that the Standard deviation will have some value in identifying poor risk babies. As in the last section it is necessary to look at the distribution of the data before proceeding with statistical analysis. Fig. 9.15 shows this distribution.

This is not nearly so convincingly Gaussian as the means were. There does seem to be an additional peak about 18 millisecs., which could be caused by a second population superimposed.

Fig. 9.16 shows the individual cases with the SD plotted against the Apgar score. There is no obviously startling trend here but the "good" babies are grouped towards the small values and the "poor" babies towards the large.

As before the groups of babies were considered as high (10 - 6) and low (5 - 0) Apgars and good (10 - 8), fair (7 - 5) and poor (4 - 0).

Fig. 9.17 shows the comparison of these groups from which it can be seen that there might be some real difference between the high and low and good and poor groups.

These were compared by the "t" test (bearing in mind the

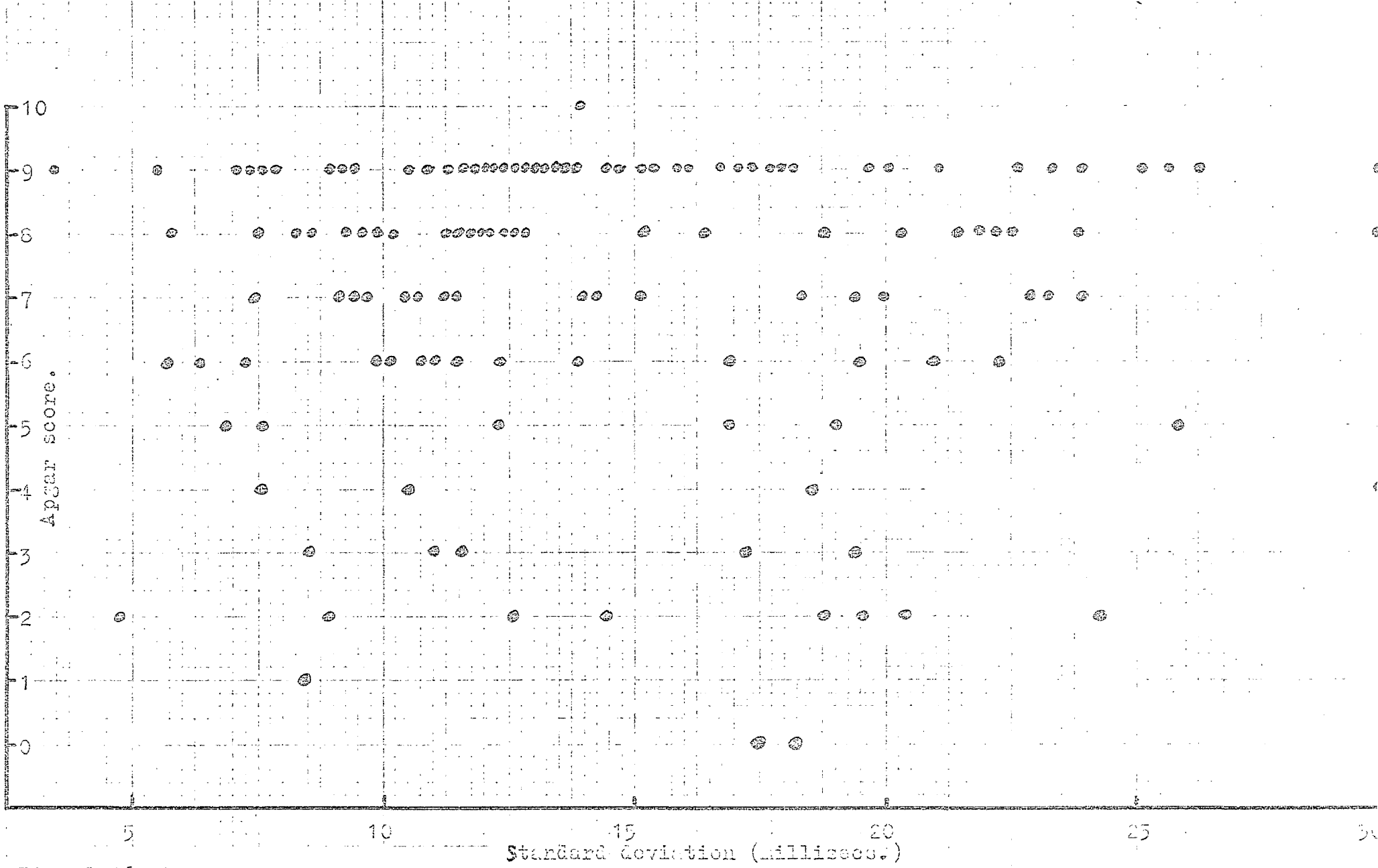
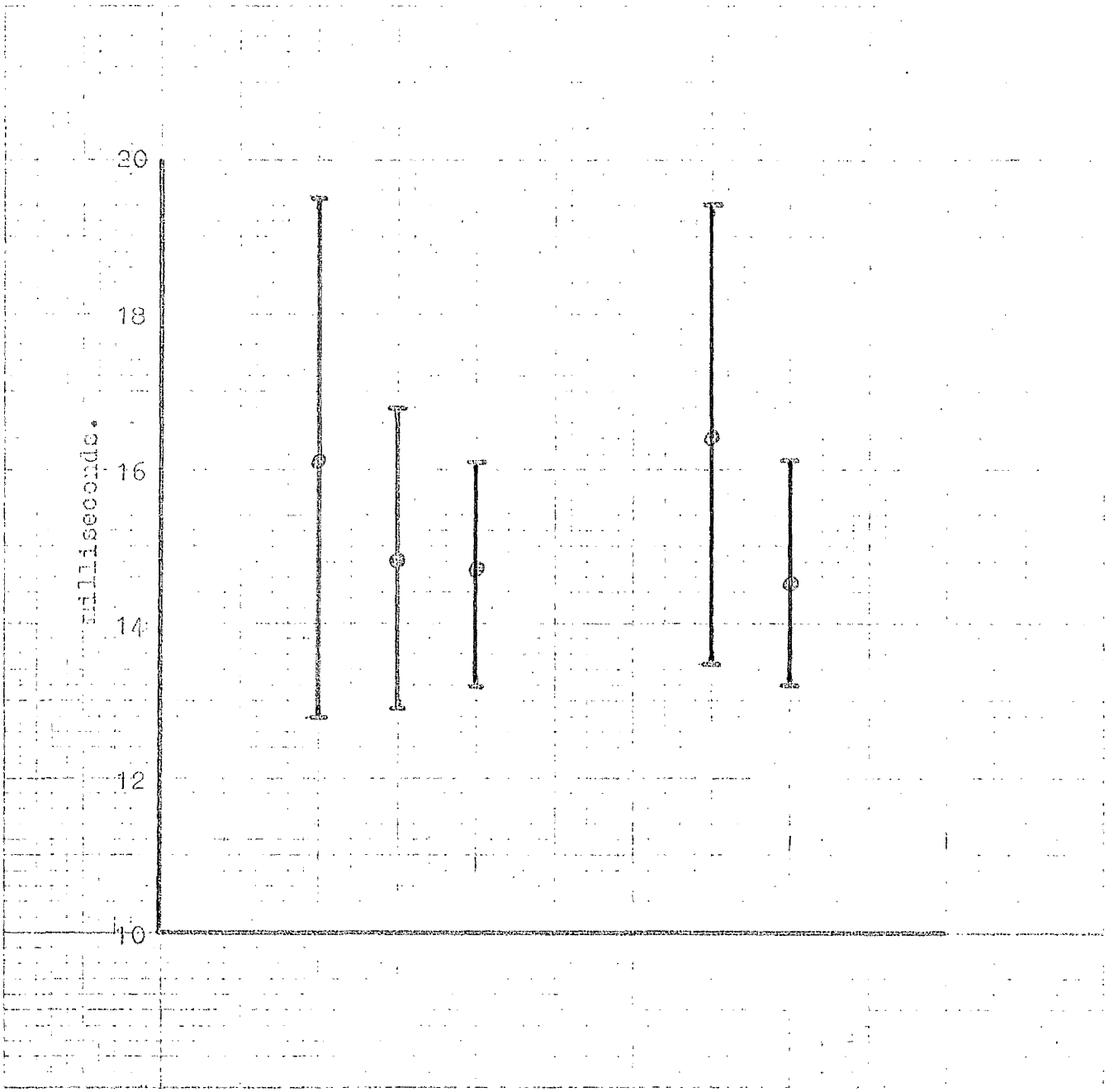


Fig. 9.16. Apgar score versus standard deviation of cardiac cycle interval.



	Apgar	+2SE	Mean	-2SE
◍	0-4	19.5	16.1	12.8
●	5-7	16.8	14.8	12.9
●	8-10	16.1	14.7	13.2
◍	0-5	19.4	16.4	13.5
●	6-10	15.8	14.5	13.4

Fig. 9.17. Comparison of standard deviations of cardiac cycle interval. Divided by Apgar score.

	Number	Mean	Standard deviation
Apgar 10.-6	107	14.6	6.1
Apgar 5 - 0	28	16.5	7.7

degrees of freedom = 133

t = 1.38

P < 0.2 , > 0.1

	Number	Mean	Standard deviation
Apgar 10 - 8	75	14.7	6.4
Apgar 4 - 0	21	16.2	7.5

degrees of freedom = 94.

t = 0.91

P < 0.4 , > 0.3

Table 9.3.

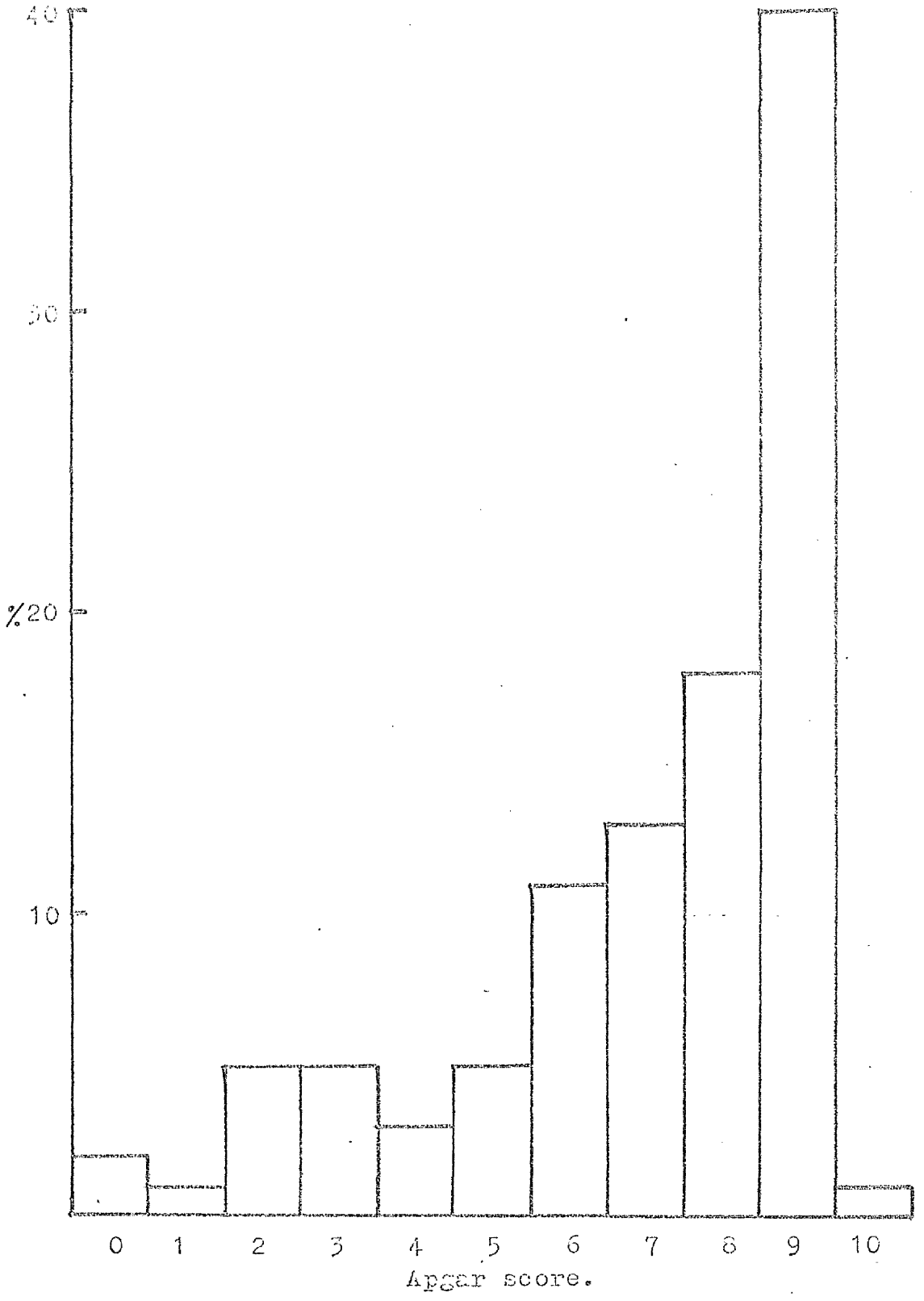


Fig. 9.18. Distribution of Apgar scores. Standard deviation of cardiac cycle interval less than 20 milliseconds.

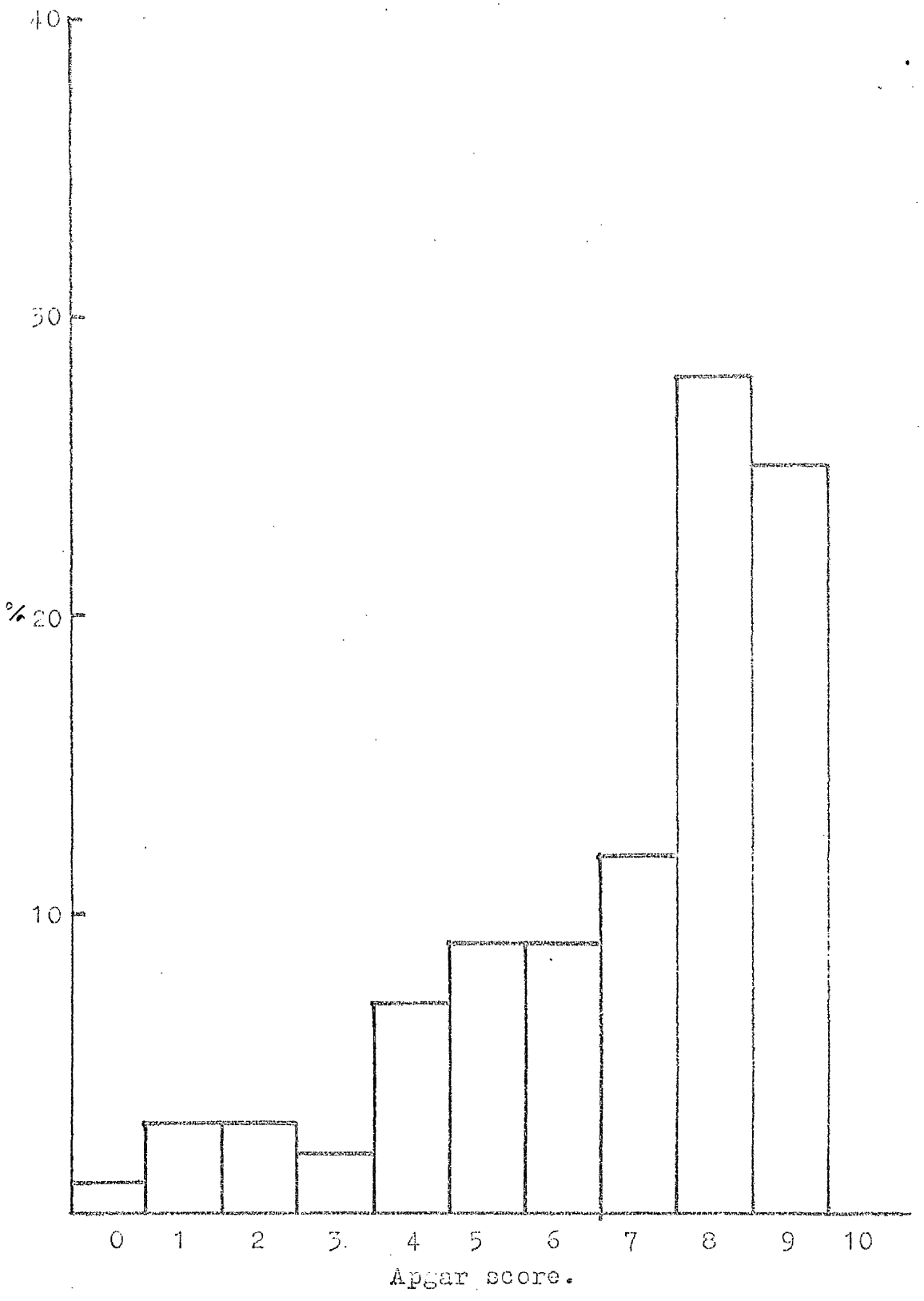


Fig. 9.19. Distribution of Apgar scores. Standard deviation of cardiac cycle interval more than 20 milliseconds.

distribution of the data). Table 9.3 shows the results and in neither case is a significant difference demonstrated. Despite the lack of statistical significance the trend is clearly towards higher values (i.e. more irregularity) in the poorer babies.

Another way of looking at the same data is suggested by the double peak in Fig. 9.15. That is to divide the cases by standard deviation and look at the Apgar scores. Dividing the cases at the level of 20 millisecs. seems a reasonable grouping. The average Apgar for the high group is 6.85 and for the low group is 7.05. While this is certainly a trend in the expected direction it cannot be considered very convincing.

The distribution of the Apgars in the two groups is shown in Figs. 9.18 and 9.19.

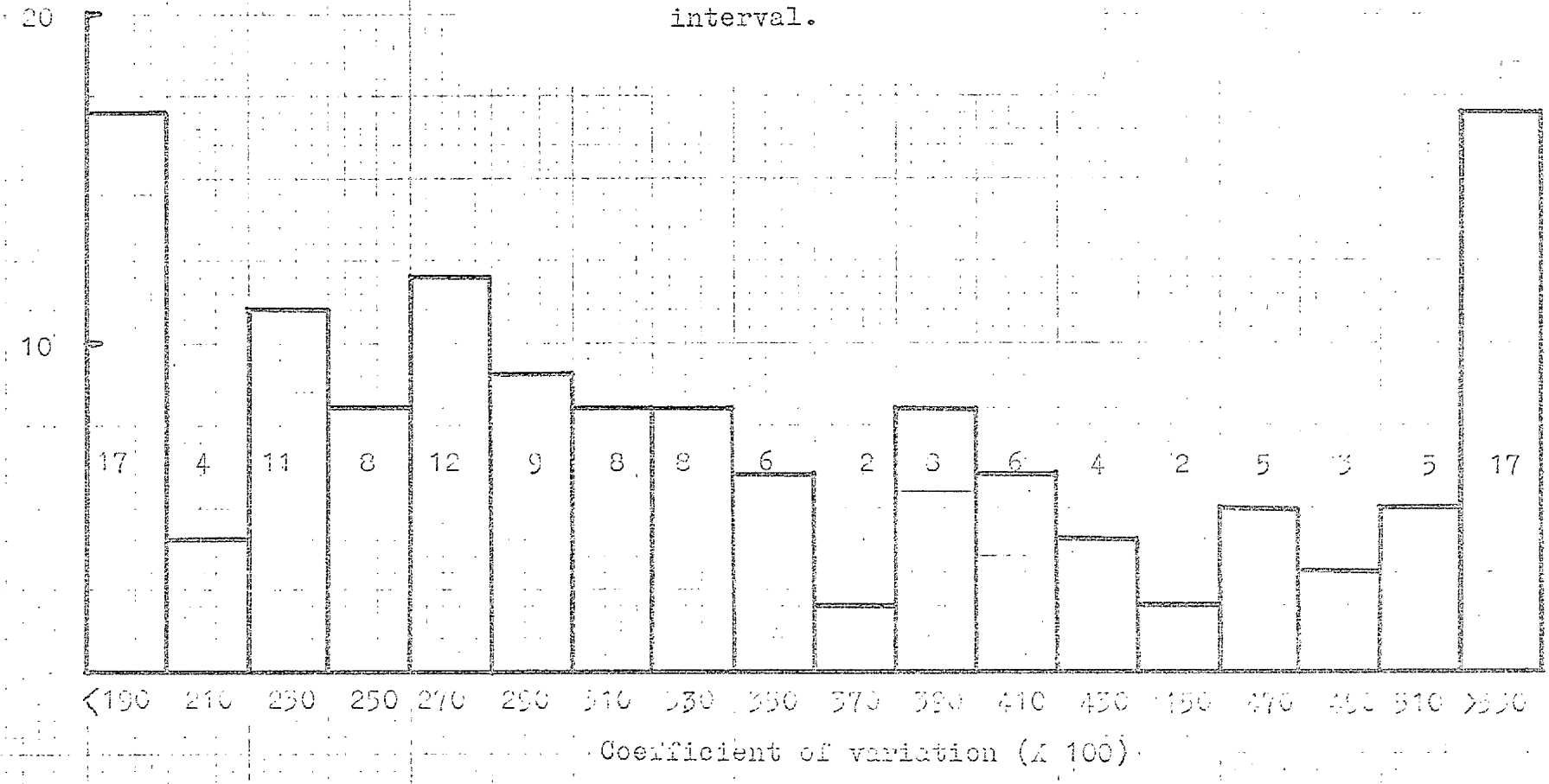
As was found in Vol. 1 the standard deviation of cardiac cycle interval shows a trend towards being high in the group of babies which have low Apgar scores at birth. This trend is not of itself significant enough for accurate prognosis of condition at birth.

9.3.3. Coefficient of Variation of cardiac cycle interval. (C.V.) - This index is a standard statistical index. It is arrived at by expressing the standard deviation as a percentage of the mean. (SD/Mean %). It is intended as an index for comparing two samples whose means are different. It always seemed a suitable index for comparing the interval histograms of foetal heart cycles.

Previous work (Vol. 1) demonstrated that this was indeed so in a carefully controlled series.

The first step, as before, was to look at the distribution of the index over the cases. This is shown in Fig. 9.20.

Fig. 9.20. Distribution of coefficient of variation of cardiac cycle interval.



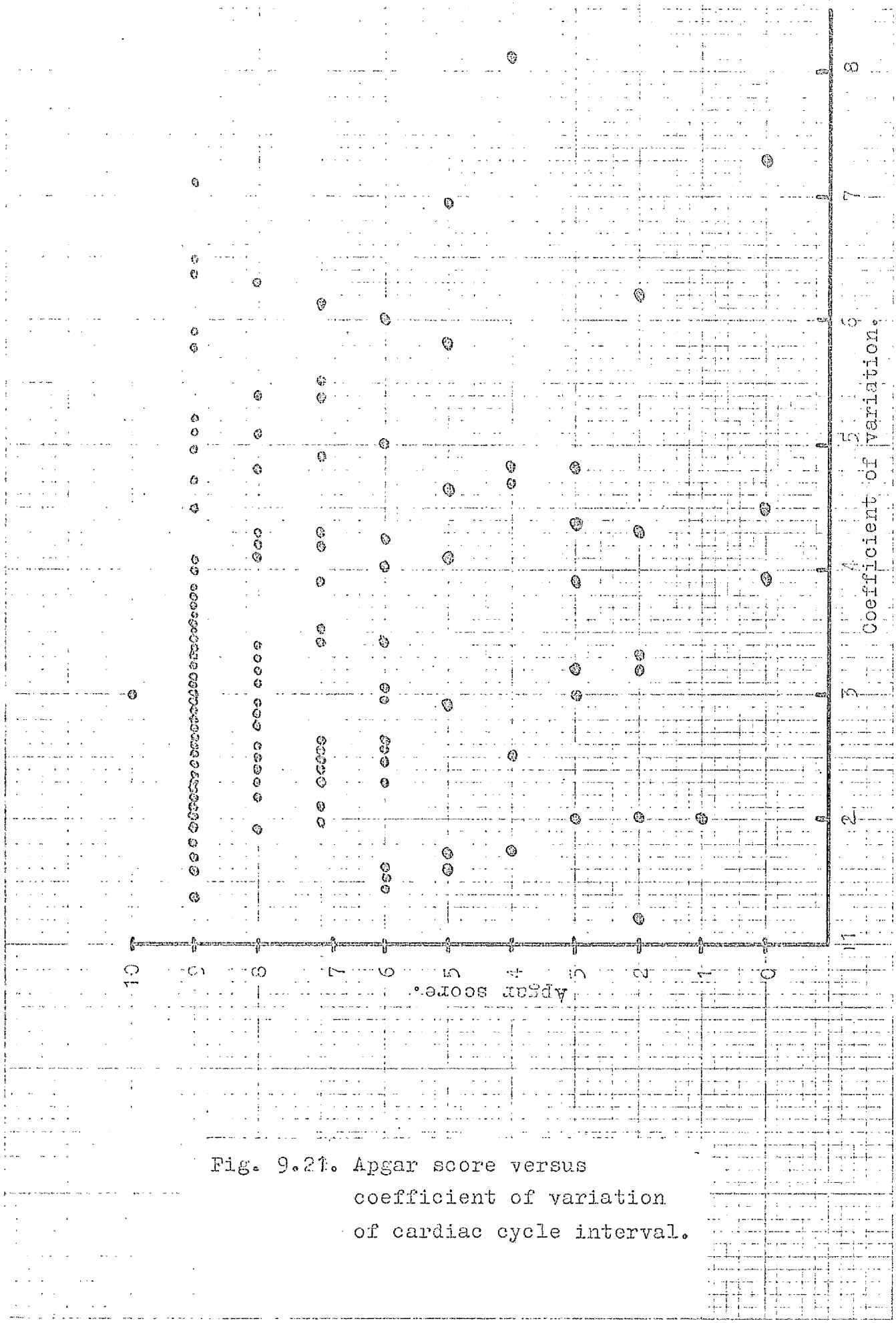


Fig. 9.21. Apgar score versus coefficient of variation of cardiac cycle interval.

This is as confusing as it is surprising. The distribution is clearly so odd as to invalidate normal statistical procedures.

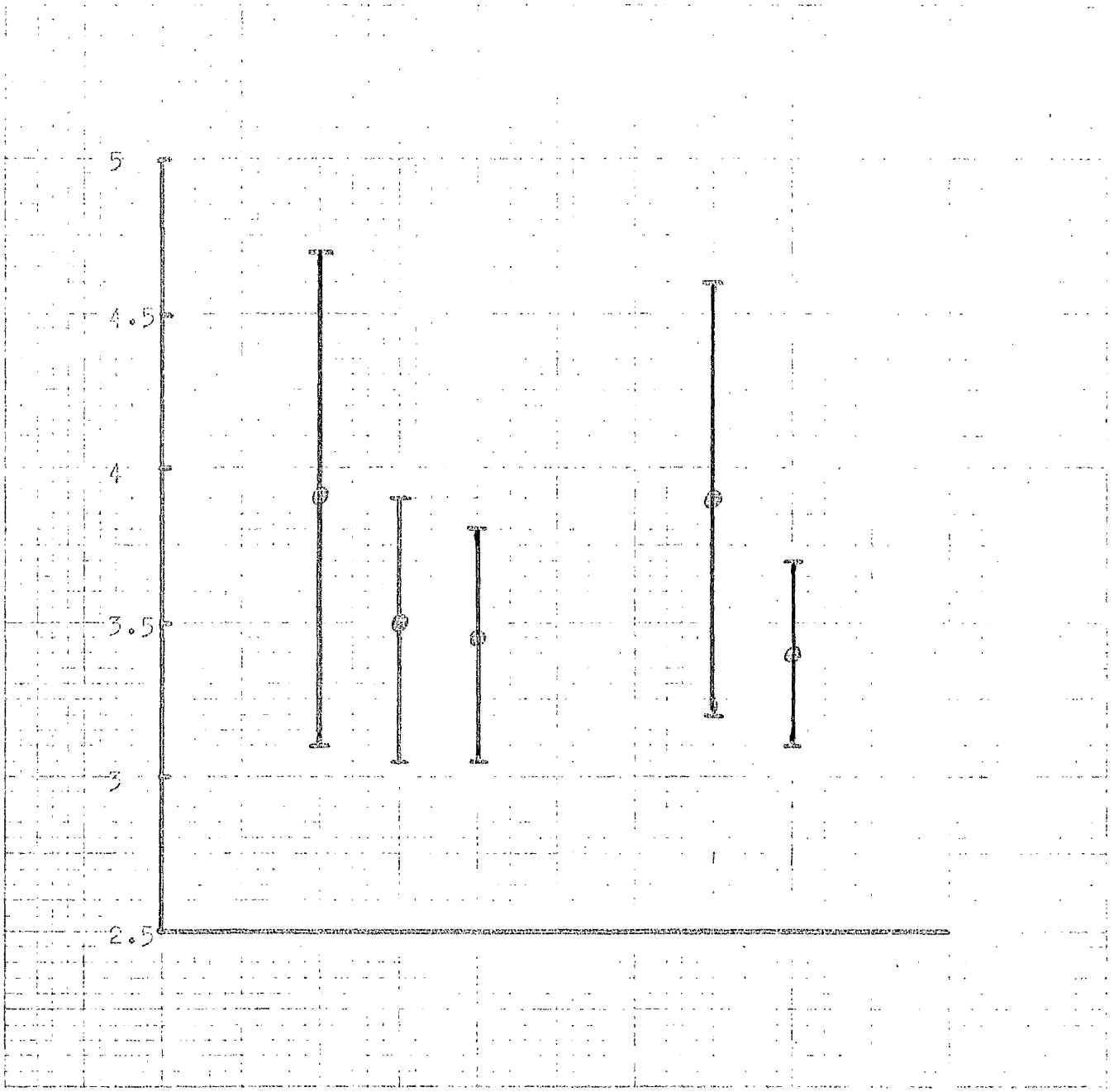
The plot of individual cases against Apgar score (Fig. 9.21) follows the expected pattern with the high Apgar infants grouped at the low values and the low Apgars tending towards higher values.

As previously explained the application of t tests to this kind of distribution is probably quite meaningless. For what little they are worth the means $\pm$ 2 standard errors for the groups high (10 - 6) and low (5 - 0) Apgars and good (8 - 10) fair (5 - 7) and poor (0 - 4) Apgars are shown in Fig. 9.22. The t tests are shown in Table 9.4. These all show the expected trends and the t test does achieve significance between the high and low Apgar groups. The other approach of dividing the cases by C.V. and plotting the Apgars is also shown.

The cases were divided at C.V. 3.4. The good prognosis group Apgars are shown in Fig. 9.23 and the poor prognosis group in Fig. 9.24. The average Apgar for the good group is 7.2 and for the poor group 6.9. These are essentially no different and the index has clearly failed to divide the cases as dramatically as was expected.

9.3.4. <u>A new index</u> - Despite the failure of the previous indices to perform as well as was expected, perusal of the data on each individual case still gave the impression that useful information was available. The previously most satisfactory index was the coefficient of variation. This is calculated as the standard deviation divided by the mean expressed as a percentage -

$$\frac{S\ D}{\text{mean}} \times \frac{100}{1}$$



	Apgar	+2SE	Mean	-2SE
○	0–4	4.7	3.9	3.1
●	5–7	3.9	3.5	3.1
●	8–10	4.6	3.4	3.1
●	0–5	4.6	3.9	3.2
●	6–10	3.7	3.4	3.1

Fig. 9.22. Comparison of coefficients of variation of cardiac cycle interval. Divided by Apgar score.

	Number	Mean	Standard deviation
Apgar 10 - 6	170	3.4	1.3
Apgar 5 - 0	28	3.9	1.8

degrees of freedom = 133

t = 1.66

P < 0.1 , > 0.05

	Number	Mean	Standard deviation
Apgar 10 - 8	75	3.4	1.4
Apgar 4 - 0	21	3.9	1.8

degrees of freedom = 94

t = 1.34

P < 0.2 , > 0.1

Table 9.4

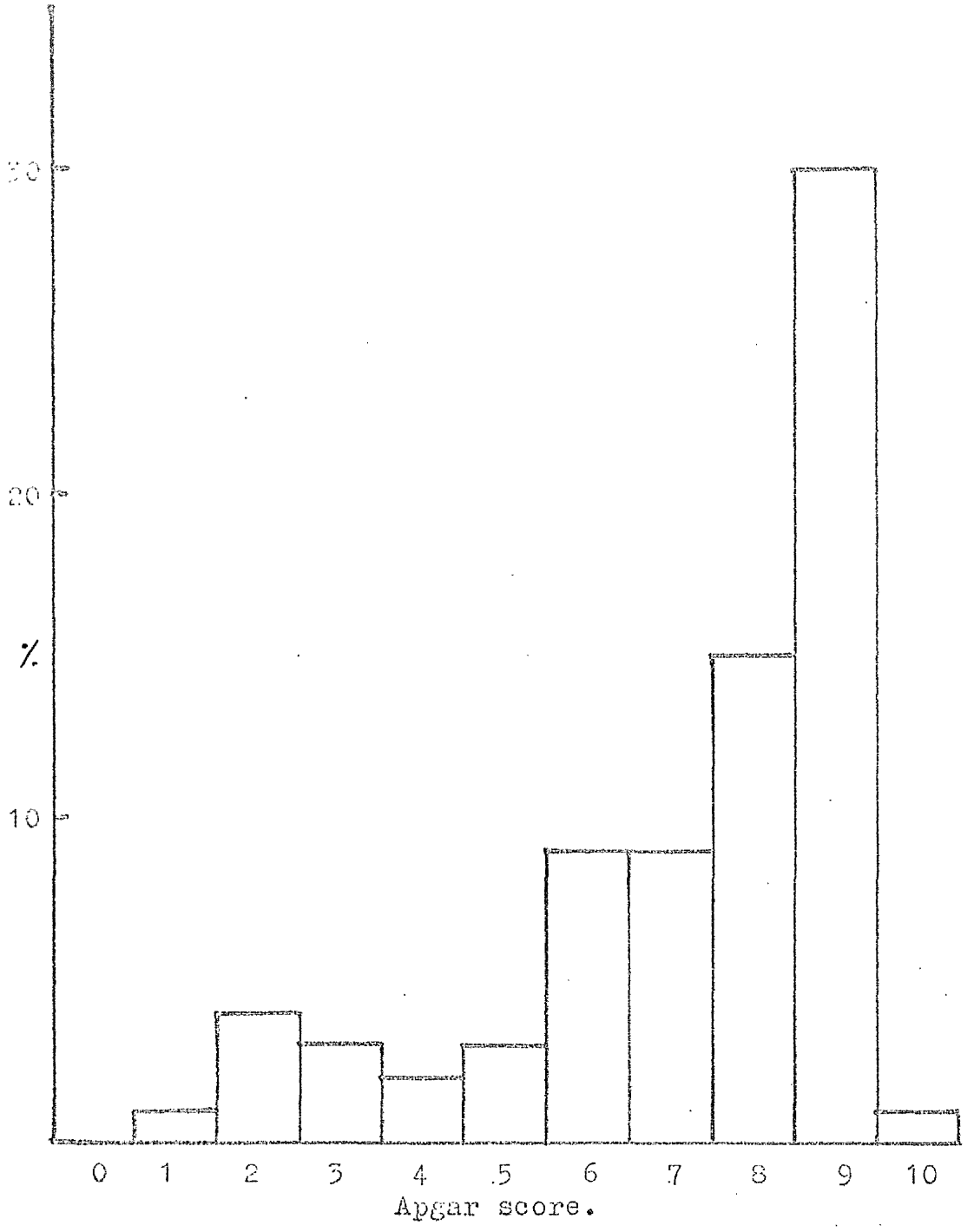


Fig. 9.23. Distribution of Apgar scores. Coefficient of variation of cardiac cycle interval less than 3.4

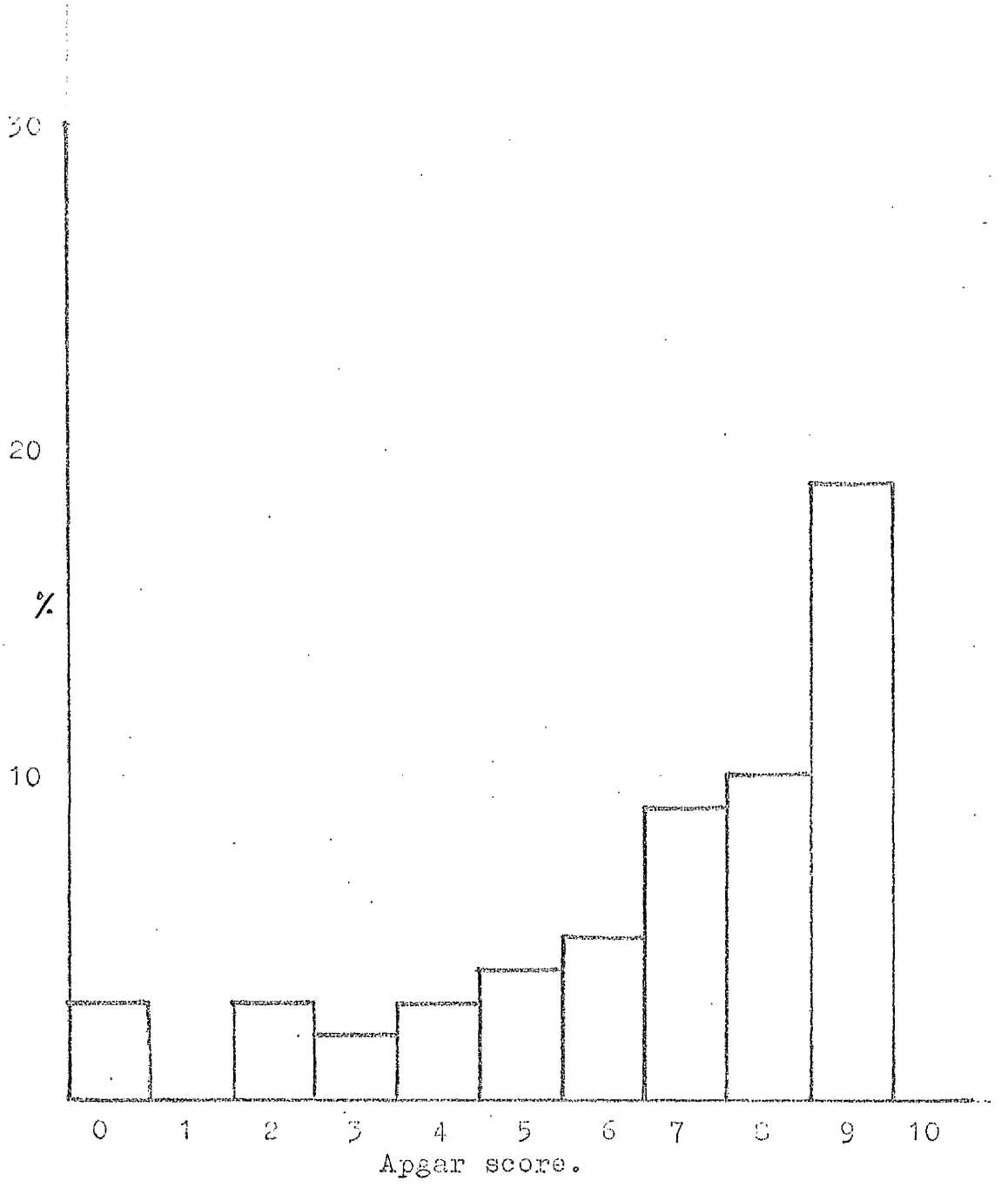


Fig. 9.24. Distribution of Apgar scores. Coefficient of variation of cardiac cycle interval more than 3.4

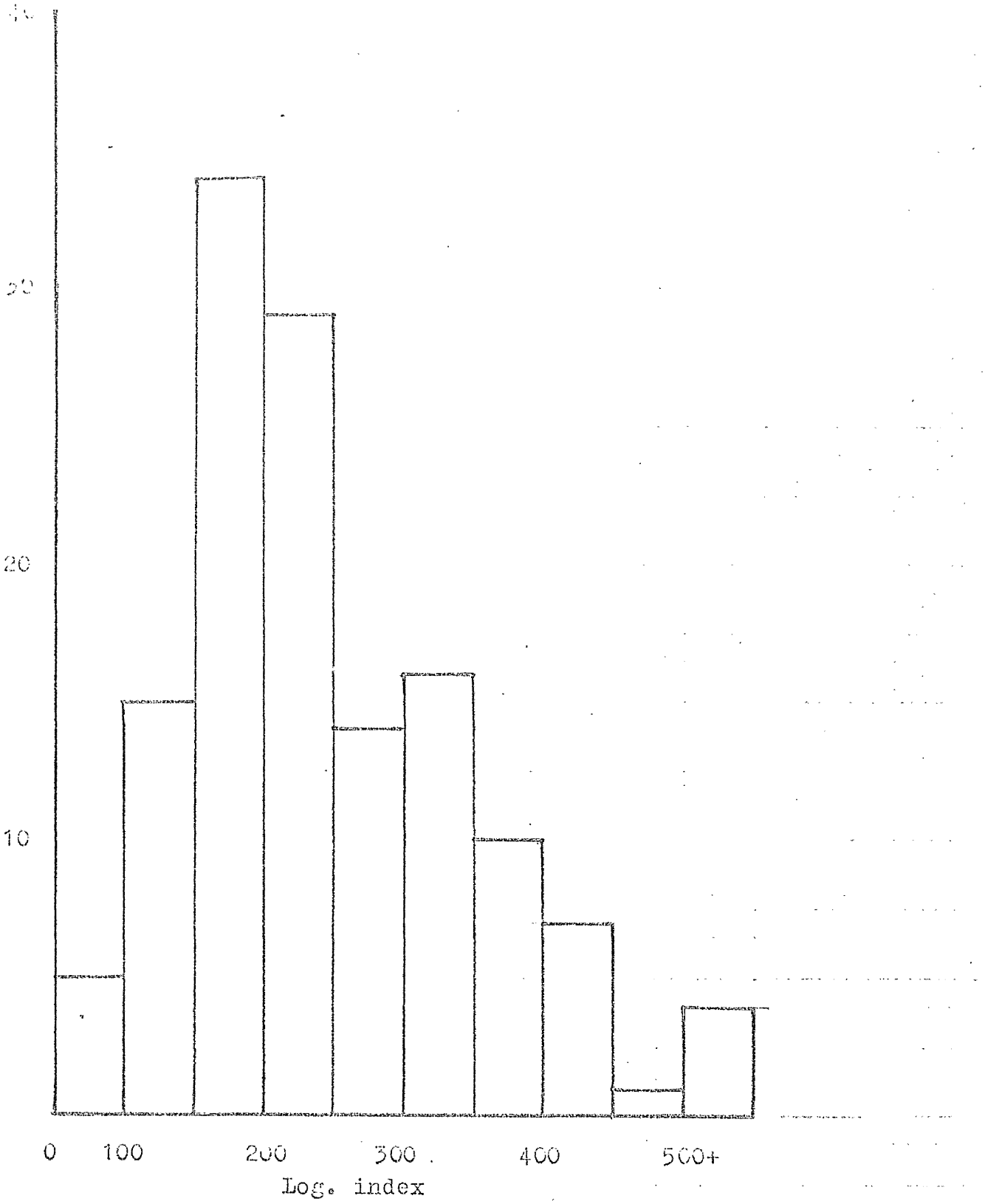


Fig. 9.25. The distribution of the log. index of cardiac cycle interval.

In this index a fall in the mean (i.e. a rise in heart rate) or a rise in Standard deviation (i.e. irregularity) gave a higher index and worse prognosis.

It seemed that a diminishing mean was not giving enough weight to the change in index. That is to say for a given S D a normal mean is much less important than a low mean.

To express this mathematically the expression used was

$$\frac{S\,D \times 100}{\log_e (\text{mean})}$$

In this expression once again a rising S D (irregularity) raises the index but a falling mean (rising rate) raises the index only a little within the normal range but much more as the mean moves out of the normal. The numerator is multiplied by 100 merely for convenience in calculation - this makes no difference to the distribution of the index. This new index will be referred to as the Log. Index. (L I).

The distribution of the log.index immediately gives a much better impression (Fig. 9.25). This is much nearer a normal distribution which allows realistic use of statistical procedures.

The plot of L I against Apgar score for all deliveries is shown in Fig. 9.26 and for S V Ds only in Fig. 9.27.

Examination of Fig. 9.26 shows that the good results tend to be grouped at the low values of L I and less impressively the poor results towards the high values.

Dividing the cases by Apgar score into the same groups as before, high (10 - 6), low (5 - 0), good (10 - 8), fair (7 - 5) and poor (4 - 0) enables t tests to be carried out.

The means $\pm$ 2 standard errors are shown in Fig. 9.28 and

Fig. 9.26. Apgar score versus log. index of cardiac cycle interval.

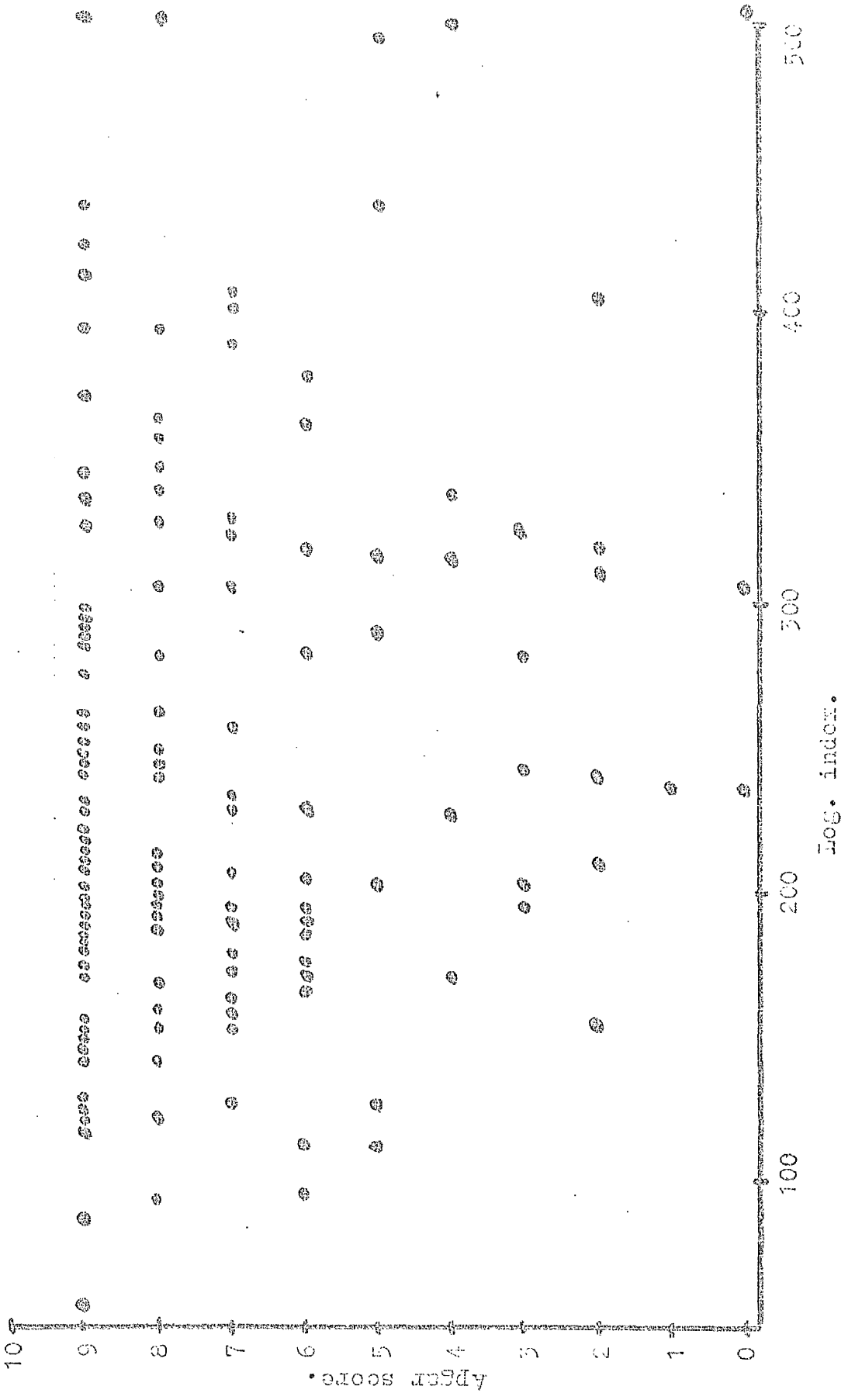
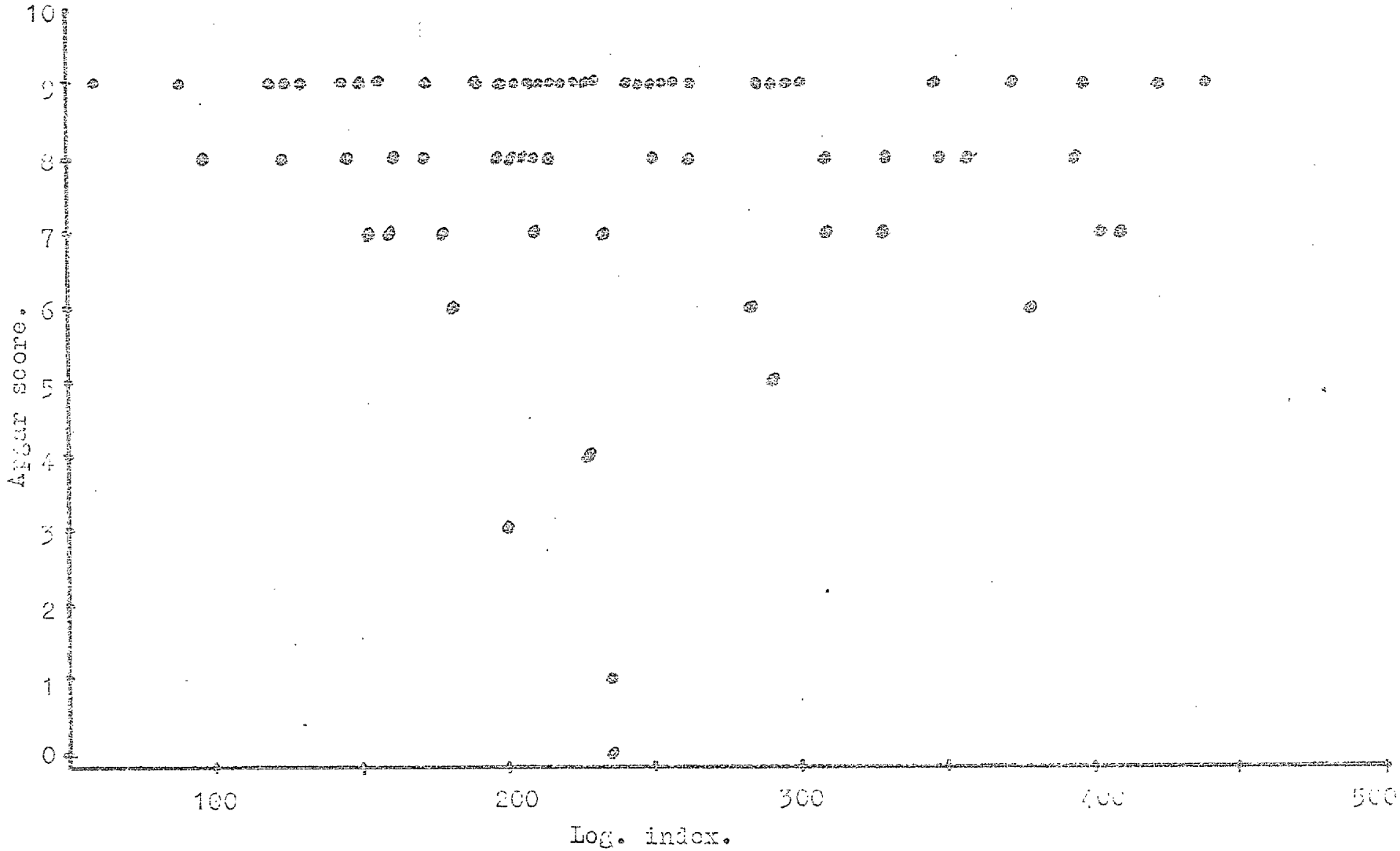
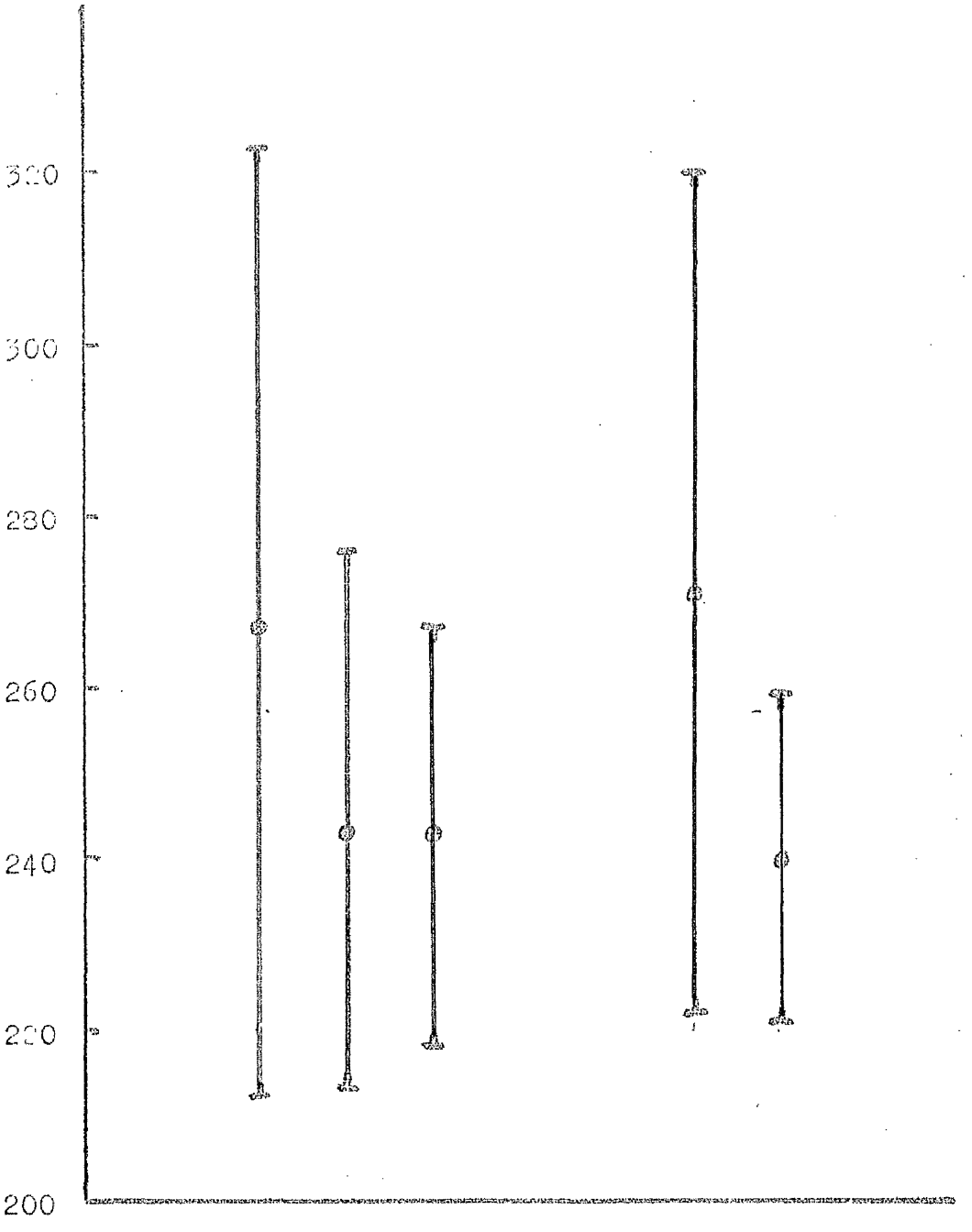


Fig. 9.27. Apgar score versus log. index of cardiac cycle interval. (SVDs only)





	Apgar	+2SE	Mean	-2SE
o	0-4	323	267	212
•	5-7	276	243	211
•	8-10	267	243	218
o	0-5	320	271	222
•	6-10	259	240	221

Fig. 9.28. Comparison of log. indices of cardiac cycle interval. Divided by Apgar score.

	Number	Mean	Standard deviation
Apgar 10 - 6	107	240	99
Apgar 5 - 0	28	271	127

degrees of freedom = 133

t = 1.38

P < 0.2, > 1.0

	Number	Mean	Standard deviation
Apgar 10 - 8	75	242	104
Apgar 4 - 0	21	267	124

degrees of freedom = 94

t = 0.92

P < 0.4, > 0.3

Table 9.5

the calculations of the t test in Table 9.5.

Unfortunately once again this fails to reach any really high degree of significance in seperating the groups although the expected trends still show strongly. The other approach of dividing the cases by an arbitery value of L I and examining the Apgar Scores is also very relevant.

A value for LI of 300 was chosen by examination of the total distribution (Fig. 9.25) and the LI v Apgar plot (Fig. 9.26). Fig. 9.29 shows the distribution of Apgar Scores for cases with L I less than 300 and Fig. 9.30 shows the distribution for L I more than 300.

As has been repeatedly emphasised it is very dangerous to proceed with tests of significance on such clearly non Gaussian distributions. The average Apgar in these figures is 6.2 for the low values and 7.2 for the high values. Standard deviations can be calculated easily enough but are meaningless. (Low L I $\pm$ 2.6 , high L I $\pm$ 2.2) What is striking here is the definite change in the distributions. Both are biased towards the high Apgar scores - as is the overall distribution of Apgar scores - but the low L I values (Fig. 9.29) show the clear absence of the highest Apgar values and increased presence of low Apgar values.

Statistics aside, common sense indicates that the index has seperated out two entirely different prognostic groups. Division of the original data (Fig. 9.26) into four quadrants by good and poor prognosis (L I less than 300 and more than 300) and good and poor results (Apgar 10 - 6 and 5 - 0) is shown in Fig. 9.31. Of the 98 cases with a good prognosis only 16 (16%) had a poor result with one death. The one death was a baby which died before the onset of

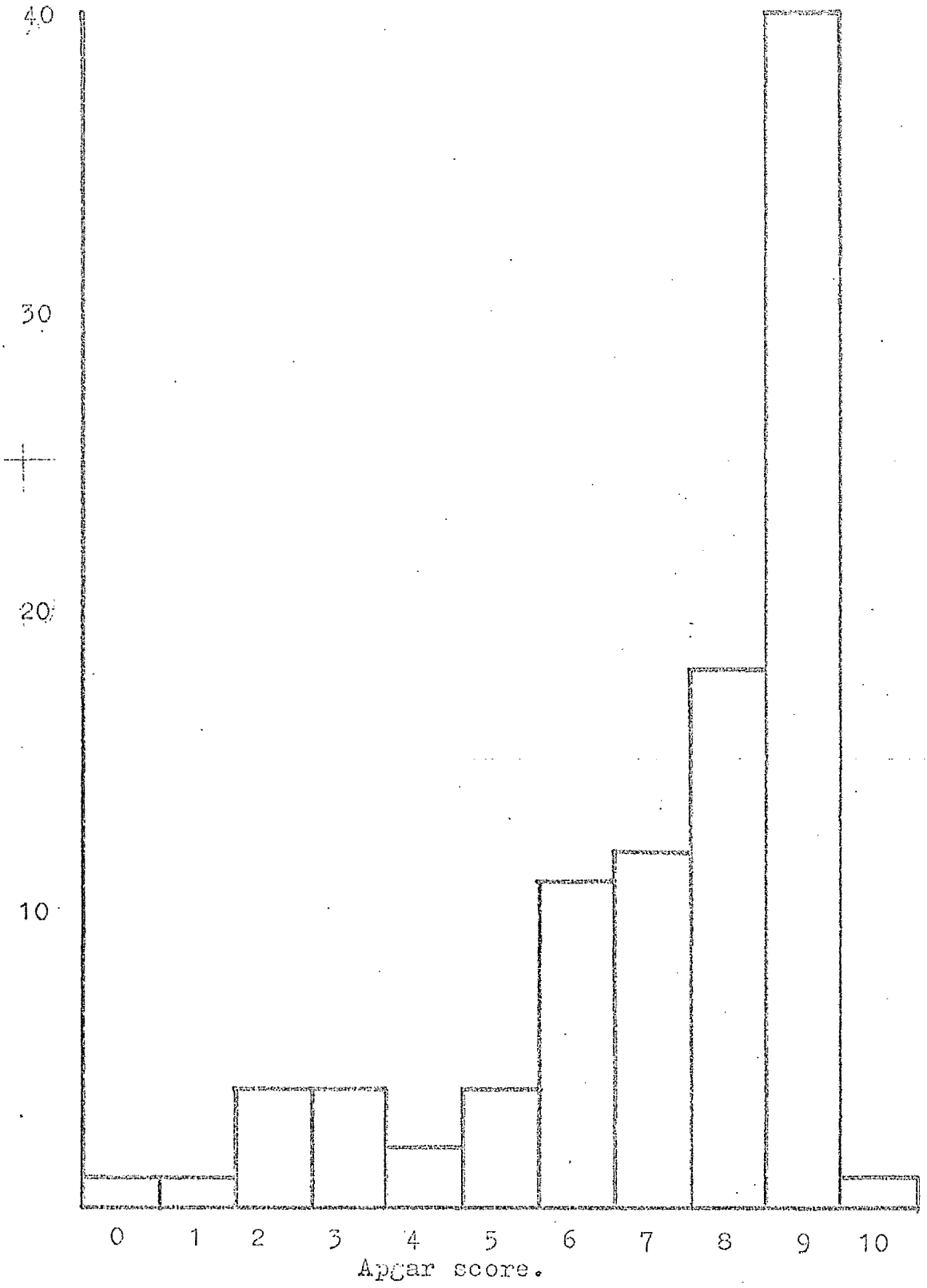


Fig. 9.29. Distribution of Apgar score. Log. index less than 300.

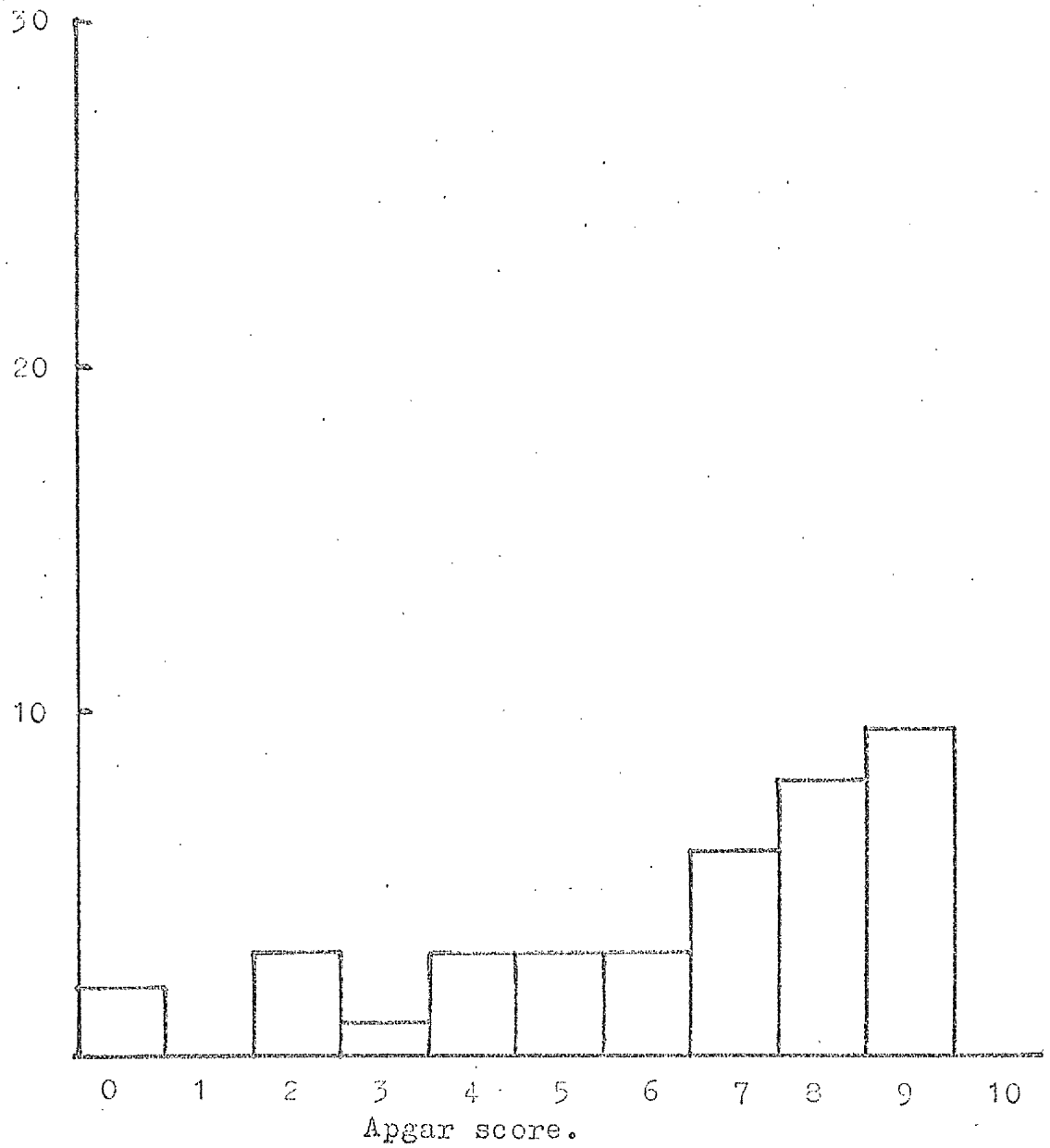


Fig. 9.30. Distribution of Apgar score. Log. index more than 300.

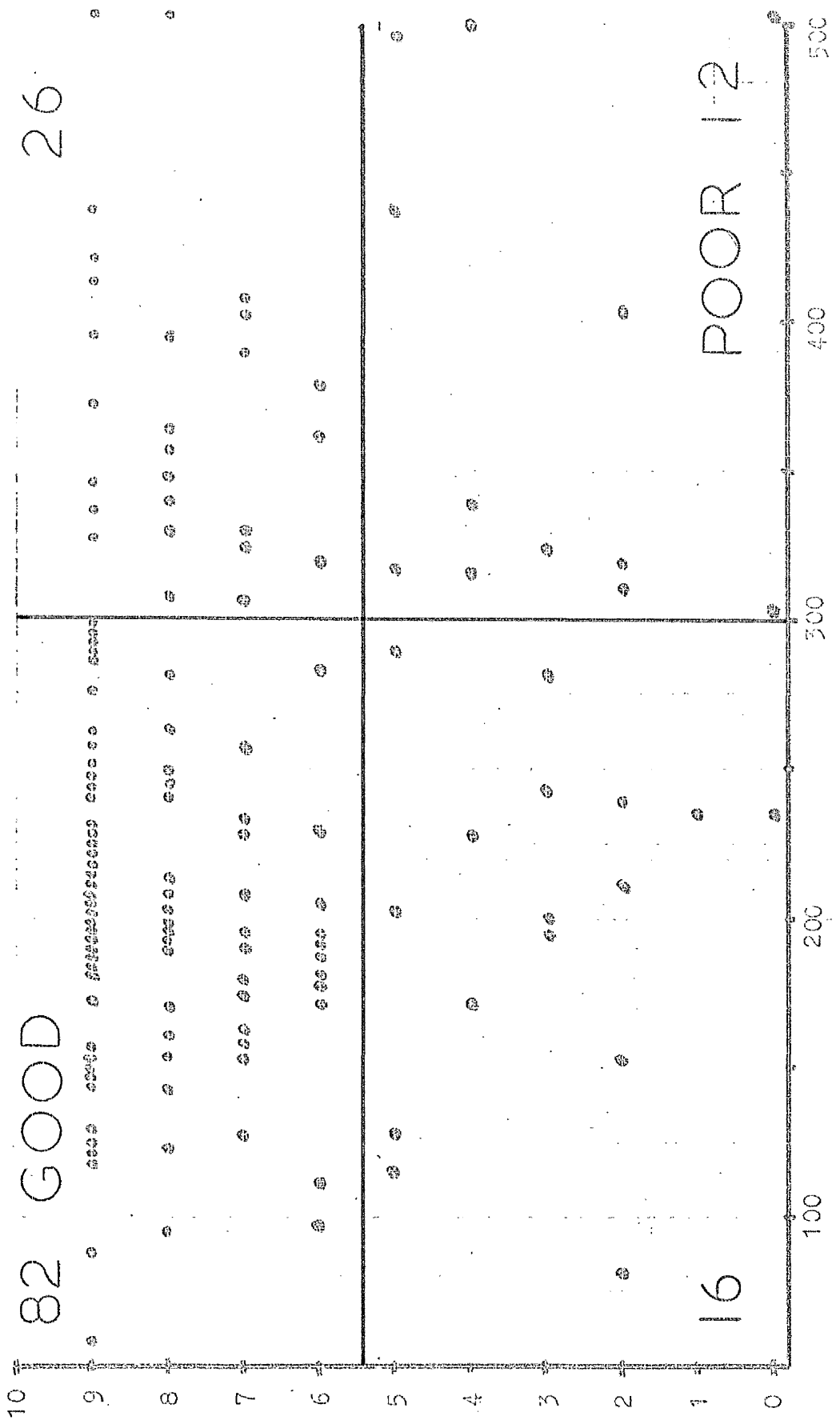


Fig. 9.31. Prognosis of Apgar score by log. index.

labour and was found at post mortem to have a twisted necrosed umbilical cord.

Of the 38 with a poor prognosis 12 (32%) had a poor result with 2 deaths.

In pure statistical terms the index does not seem very accurate but in the human situation, with which we have to deal, little is lost by wrongly labelling a foetus as being at increased risk. A practical index must always err on the side of pessimism.

This new index shows very little advantage over the previous best index, the coefficient of variation. However its distribution is much more acceptible and it is, of the two, the better for studies on groups of babies.

9.4. Results of serial examinations - In this series it proved possible to obtain two or more examinations at weekly intervals on 25 patients. The degree to which both the coefficient of variation and the log index followed the clinical course of events was striking enough to justify considering these cases briefly here (the case summaries are to be found at Appendix B).

Case 204.

A primiparous patient, past dates with a frank breech presentation. On admission her C V was 4.52 and after several failed attempts at version fell to 2.24. After an assisted breech delivery the child's Apgar, not surprisingly, was 2. It responded well and was discharged fit. The log index also fell over the week from 312 to 152. Both indices failed to give any indication of the result but in fairness the method of delivery presents too great a challenge to any prognostic index.

Case 206.

This primigravid patient was admitted when 7 days past her expected date. At that point the CV was 2.2. She was left for one week and the CV rose to 4.31. A poor labour followed induction and she came to LUSCS. The baby's Apgar was 2. The log index followed a similar pattern rising from 161 to 319.

Case 209.

Pre-eclampsia. This case was admitted for rest and induction at term. Her BP was $^{150}/_{90}$ and fell to $^{130}/_{90}$. The CV also fell though not dramatically from 3.8 to 3.3. The log index also fell slightly from 278 to 238. Foetal distress was diagnosed in labour and after a LUSCS the baby's Apgar was only 2. It responded well and was discharged fit.

Case 235.

This woman had had a previous LUSCS for foetal distress and was now past her dates. The CV was 2.71 and fell to 1.6. The log index also fell from 189 to 119. The baby's Apgar was 6.

Case 241.

This patient was presumed to have essential hypertension. Her BP remained at $^{160}/_{100}$ during her hospital stay and after delivery. The CV fell from 4.2 to 3.44 over a week of bed rest. The log index also fell from 319 to 223. The baby's Apgar was 6 after an elective section.

Case 242.

A case of pre-eclampsia . On admission the maternal BP was $^{130}/_{80}$ and the CV was 2.02. Despite bed rest and sedation the BP rose to $^{135}/_{85}$ and the CV to 2.53. The log index followed the rising pattern as well going from 149 to 176. The patient was induced and the baby born with an Apgar of 6. It subsequently collapsed and required resuscitation.

Case 243.

Iron deficiency anaemia. The mother's Hb was 8.0 G and she was admitted to total dose imferon infusion. The CV was 4.8. After 10 days the Hb was 10 G and the CV had fallen to 2.6. The log index reflected the improvement by falling from 301 to 182. The baby was born with an Apgar of 6 and did well.

Case 245.

Pre-eclampsia. Patient admitted with a BP of $^{160}/_{110}$. The CV was 3.04. After a week's bed rest and sedation her BP fell to $^{130}/_{90}$ and the CV to 1.95. The log index fell from 207 to 127. The baby was born with an Apgar of 7 and did well.

Case 247.

Pre-eclampsia. Mother admitted with BP of $^{130}/_{90}$. The CV was 4.2. After a week the BP fell to $^{110}/_{70}$ and the CV to 3.9. In this case the log index went against the trend and rose very slightly from 252 to 256. It seems to have predicted the outcome reasonably well but not followed the clinical improvement as did the CV. The baby had an Apgar of 7.

Case 257.

This was a case of pre-eclamsia with minimal BP rise but considerable oedema. The BP was $^{130}/_{90}$ and the CV 2.43. After a week the BP was still $^{130}/_{90}$ but the oedema gone. The CV fell to 1.51. Likewise the log index fell from 153 to 98. The baby's Apgar was 6.

Case 270.

This patient was admitted merely because of an unstable lie. With a weeks bed rest the already good CV of 2.1 and log index of 144 fell to 1.41 and 98 respectively. The baby's Apgar after a normal delivery was 8.

Case 271.

Pre-eclampsia. Patient admitted with BP of $^{145}/_{90}$. The CV was 2.70. This fell to 2.40 over the week as the BP fell to $^{110}/_{65}$. The log index fell very slightly from 179 to 171. The baby did well.

Case 273.

This patient was admitted because of rising anti-Kell antibodies. With steadily rising anti-bodies the CV rose from 2.32 to. 2.40 and on to 2.54. Delivery was undertaken before the anti-bodies rose to danger levels and did well. It is interesting to compare this case with case No. 40 in Vol. 1., where the CV reflected improvement in a case of Rh sensitisation after intra-uterine transfusion. In this case the log index did not reflect the clinical pattern as it fell from 174 to 146 then rose to 172. Nevertheless, all three readings place the baby in the good prognosis group.

Case 284.

Pre-eclampsia. The mother's BP was $^{170}/_{90}$ on admission. The CV was 2.54. The BP fell to $^{120}/_{80}$ after treatment and the CV fell to 1.90. The log index fell from 188 to 141. The baby did well.

Case 286.

This patient was admitted with a moderate APH. On admission the CV was 6.0 and the log index 423, both poor. With rest and sedation the bleeding stopped and the BP fell from $^{150}/_{90}$ to $^{130}/_{80}$. The CV fell to 3.7 and the log index more convincingly to 243. After a normal delivery the baby's Apgar was 9.

Case 297.

A para 2 + 0 mother with Rhesus negative blood but no antibodies. She also had a severe urinary infection. Both the CV and log index varied but little over 2 weeks. Log index was 176, 159

and 194. The baby was born perfectly well with an Apgar of 8.

Case 308.

Post maturity. This patient was reputed to be 24 days past her dates on admission. CV was 2.71. This rose to 4.02 over a further week when the child was delivered. The baby was postmature. The log index also rose from 203 to 287.

Case 310.

Mild pre-eclampsia. On admission the maternal BP was $^{115}/_{75}$ (it had been higher at the Clinic) and the CV was 3.30. The BP fell slightly to $^{110}/_{70}$ and the CV to 2.96. Likewise the log index fell from 237 to 206. The baby's Apgar was 9.

Case 318.

This grade IV cardiac mother sought medical attention for the first time at 36 weeks. She was immediately admitted in congestive heart failure with a CV of 5.02. After a weeks bed rest and medical care the mother had improved greatly and the CV fell to 2.00. The log index also reflected the improvement by falling from 366 to 150. The baby was born with an Apgar of 9.

Case 322.

This woman had a previous stillbirth due to placental insufficiency. She was admitted with a BP of $^{150}/_{95}$ and a CV of 6.5. The BP fell to $^{140}/_{90}$ and the CV to 4.55. Despite these high readings the baby did well. The log index however did fall into the normal range by dropping from 430 to 290.

Case 323.

A case of pre-eclampsia. The maternal BP fell from $^{170}/_{90}$ to $^{110}/_{90}$ over a week. The improvement was reflected by

the CV falling from 4.8 to 3.2 and the log index falling from 324 to 213. The baby's Apgar was 9.

Case 324.

Pre-eclampsia. On admission the mother's BP was $^{130}/_{95}$ and the CV 4.9. This fell to a BP of $^{110}/_{90}$ and a CV of 3.20. The log index also fell from 323 to 223. The baby did well.

Case 326.

There was no pathology in this case. The mother, a para 6 + 0, was admitted for social reasons. There was no change in BP over the week. The first CV was 4.1 and the second 4.2. The log index too changed very little from 297 to 287. The baby did well.

Case 330.

Pre-eclampsia. This mother's BP was $^{150}/_{100}$ on admission. The CV was 2.02. The BP fell to $^{110}/_{80}$ and the CV to 1.70. The log index fell from 149 to 123. The baby did well.

These results in individual cases are much more encouraging. It certainly seems that, like many other tests in obstetrics such as urinary oesterial levels and bi-parietal diameters (ultrasonic), a single reading does not give the greatest amount of information but that serial estimations can be of real value.

In virtually every case the CV follows the clinical progress. The LI also follows this progress generally but apparently not so faithfully.

These results and the conclusions drawn from them will be discussed in the following Chapter. (Chapter 10).

10. DISCUSSION OF RESULTS AND CONCLUSIONS.

10.1. Introduction - This study has demonstrated, yet again, the enormous difficulties involved in taking a laboratory research technique into the rough and tumble of the hospital environment. The pilot study (Vol. 1) was conducted entirely by the author on a series of carefully selected poor risk patients. The results of that study were demonstrably significant. In this study several more operators were involved and a much wider selection of patients examined. In retrospect it was inevitable that some degeneration of the data would occur. Despite this the previously established trends continue to show very strongly and suggest that the method is highly relevant to foetal assessment.

As the results of the FECG examinations were not available to the clinical staff they were not able to influence the management of the patients.

10.2. Discussion of Results - The results presented in the previous Chapter (Chapter 9) do not achieve the high statistical significance it was hoped to demonstrate. It was possibly naive to expect to do so in this very widely based trial. The outcome of labour clearly depends on maternal factors as well as foetal ones. The fact that these maternal factors were not taken into account at all makes it all the more remarkable that strong trends have been demonstrated on foetal prognosis alone.

10.2.1. Mean of cardiac cycle interval - It is no surprise that this index, the equivalent of foetal heart rate, shows some ability to prognose foetal outcome. There is a wealth of obstetrical experience to that observation. What has emerged clearly is that the initial effect of foetal embarrassment is a rise in foetal heart rate, mediated by the brain stem centres. The very slow rate of classical foetal distress in labour is not seen ante-natally.

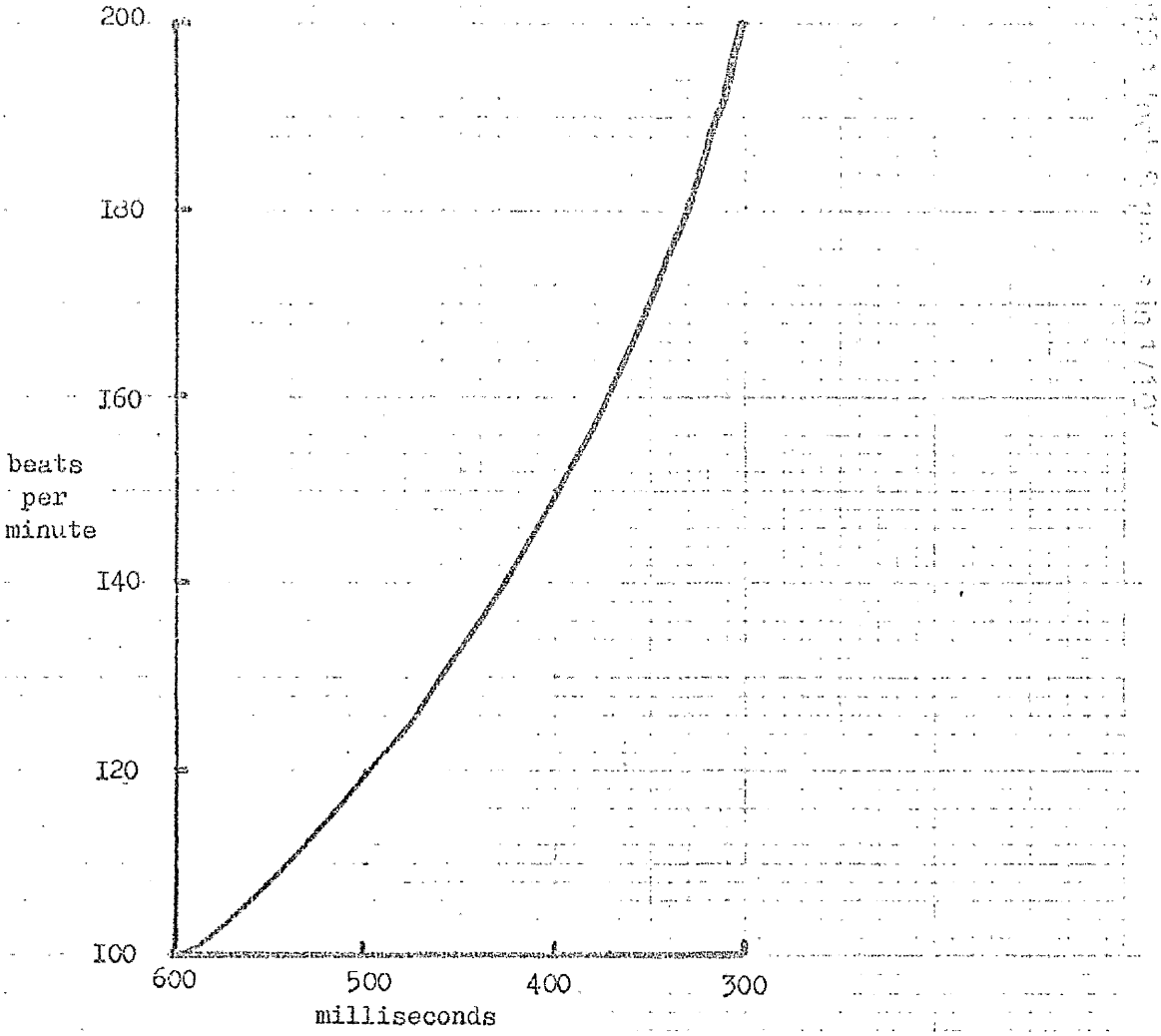


Fig. 10.1. Conversion of cardiac cycle interval to heart rate.

Cardiac cycle interval is often meaningless to those not accustomed to the concept and Fig. 10.1 is a simple graph to assist in conversion to heart rate.

There is certainly no need for computer methods to obtain an approximation to heart rate but the results obtained here and elsewhere certainly suggest that, with the mother at rest in bed, any foetus with a heart rate in excess of 160 /min (interval less than 370 millisecs.) is compromised. Such information is readily available to anyone who cares to listen to the foetal heart and practice the art of accurate counting.

10.2.2. Standard deviation of cardiac cycle interval - Variability of the foetal heart rate is an established poor prognostic sign. Measurement of this variability is however virtually impossible by subjective means. It is difficult enough to count the very fast heart rate of the foetus far less assess its irregularity.

The standard deviation about the mean is an ideal objective measure of the phenomenon but can only be obtained by methods such as that described in this thesis. The range between maximum and minimum intervals is no substitute for the standard deviation as the range gives no indication of the distribution of the intervals within the range.

On its own it has failed to reach any measure of statistical significance but it certainly follows a distinct trend of rising with an increasingly poor prognosis.

It would seem at a standard deviation of cardiac cycle interval greater than 20 millisecs, is a poor sign. As 95% of intervals lie within $\pm$ 2 S.D. this represents a variation in rate of about 30 beats per minute.

More importantly it has been shown that a falling S.D.

over two or more examinations is a good prognostic sign.

10.2.3. The coefficient of variation of cardiac cycle interval - This index combines the information of the previous two in a useful form. It condenses both the foetal heart rate and its irregularity into one number.

It was hoped to demonstrate again the very highly significant prognostic value of this index. This has not been achieved.

Minimal statistical significance has been achieved but the distribution of the index is so unusual as to make tests of significance meaningless.

The trend however is exactly as expected. A high coefficient of variation is a poor prognostic sign. The range of values found in this study is greater than that in Vol. 1 and it has been necessary to revise the dividing value upwards to 3.4. This has been caused by an unsuspected, though fortunately constant, poor calibration within the computer.

Population studies with this index have been difficult but it has been shown to bear a very close relationship with the changing clinical pattern of events over serial examinations.

10.2.4. The log. index (SD x $10/\log_e$ mean) - This index contains essentially the same information as the previous one. It was constructed in this unusual form in an effort to achieve a more satisfactory weighting for changes in the mean cardiac cycle interval.

The fact that its distribution within the study population was virtually Gaussian was immediately heartening. Disappointingly it fails to distinguish between "good" and "poor" prognostic groups with any greater significance.

Dividing the population at a value of 300 for the log. index does however select two entirely different risk populations. The population with high log. indices is demonstrably much more at risk of foetal death and poor oxygenation at birth.

The log. index has also been shown to follow the clinical pattern of events in serial examinations. In this it has not been quite so faithful as the coefficient of variation. From the theoretical viewpoint it is the more satisfactory index for comparison between babies but it has little to add as a practical index of prognosis in the individual.

10.2.5. The next step ? - These results have not been as convincing as was hoped. The fact that the expected trends are very much in evidence is nevertheless reassuring.

A major problem, and probably a major cause of the deterioration, has been the electronic instrumentation used in the analysis of the FECG output. The Computer of Average Transients presents such a bewildering array of chrome plated knobs that non-technical personel had the greatest difficulty comprehending it. There are too many possibilities for incorrect settings which still appear superficially to give a correct result.

It seems, at first, a daunting thought to design a special purpose computer for this work but such a device with the very minimum of controls is what is needed. The very reasonable quote of £1,000 pounds has been suggested by one British manufacturer. This is in fact less than the cost of a good tape recorder and makes it possible to consider the several sets of instrumentation which would be required for a definative trial.

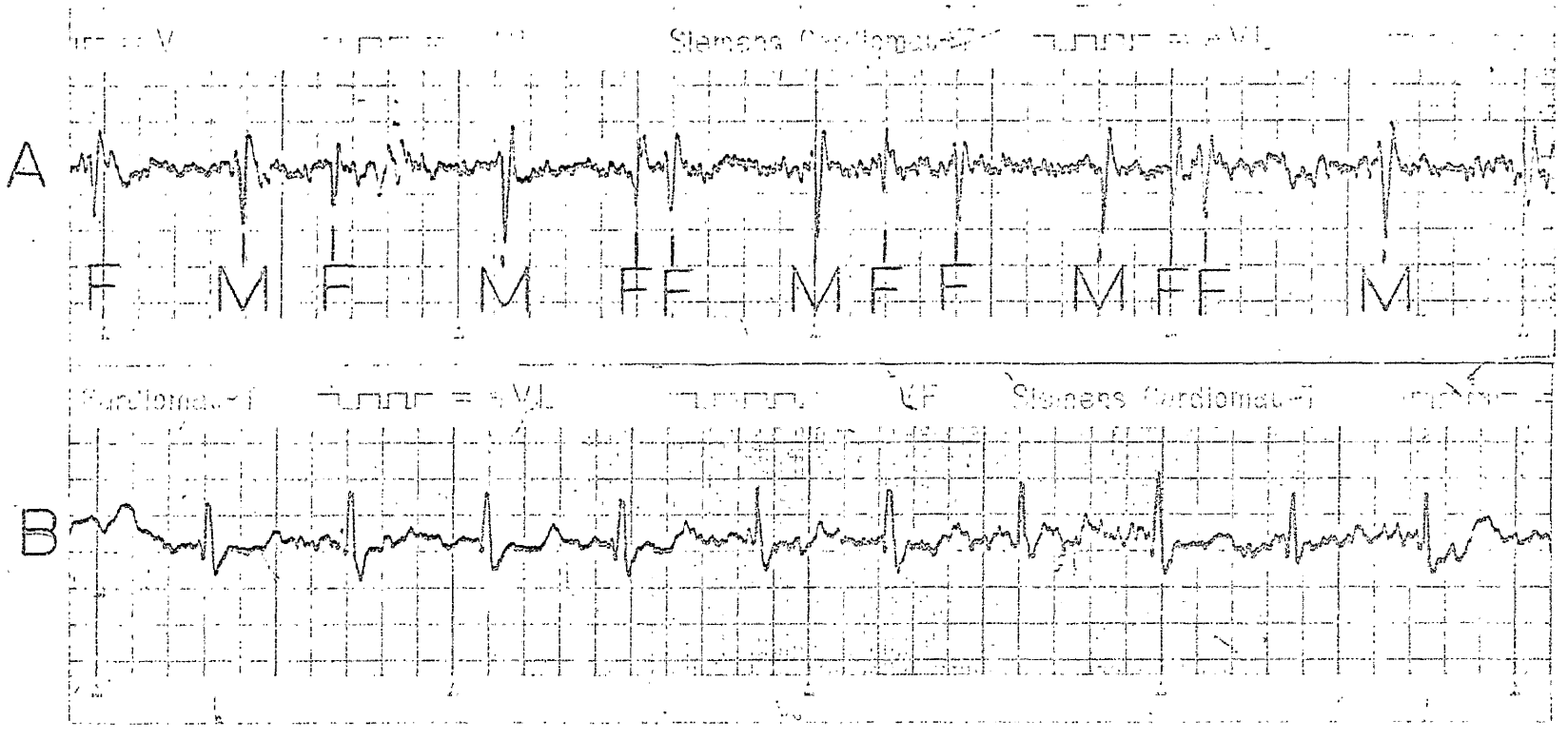
10.3. Points Arising from the Literature (Chapter 2) - The last few year's literature on the FECG has on the

whole been disappointing. There has been a steady, if not large, stream of articles from all over the world but very little by way of original contributions. The majority of reports continue to eminate from the U.S.A. and the other English speaking nations. For this study translations were made or obtained from the following countries, Austria, Germany, Holland, Hungary, Italy, Israel, Japan, Mexico, Poland, Russia, Scandinavia and Spain. The overall impression is that the general "state of the art" in these countries is a little behind that of N. America. The clear exception is Japan. Japanese translations are difficult and expensive to obtain. Several Japanese journals publish English editions but these are not translations of the Japanese editions. The pool of information is so fascinating and forward looking that I can only express regret that I cannot afford to read more. The Russian situation is also fascinating. Russia is such a closed book to Western Europeans that it was very illuminating to read their articles. As a practical point the Russian Embassy will supply, free, translations of any scientific paper less than five years old. The impression here is that Russian medicine is well in arrears of the West but with flashes of absolutely up to date technology - where else could the foetal ECG and cupping be discussed in the same paper?

10.4. Incidental Points Arising - The earlier uses for the FECG such as diagnosis of foetal life, detection of twins, determination of presentation and the like are no longer relevant. Ultrasonics, both in the form of the Doppler unit and the Diasonograph, has completely supersceded it. There can be no doubt that the Doppler unit is the most effective method of detection of foetal heart action generally available. Unfortunately its

Fig. IO.2A Foetal extasystoles.

B Normal neonatal ECG.



suitability for detection is not matched by its suitability for automated analysis.

The FECG has been disappointing as an outpatient procedure. Successful detection of the signal requires an utterly relaxed mother. This seems only practical on an in-patient basis.

Radio-telemetry of the FECG has also been unrewarding. A simple signal can easily be transmitted and received but the more complex procedures used here have not, as yet, been amenable to such a solution.

Only one case of foetal extrasystoles was detected in the course of this study. (Fig. 10.2A). The baby's ECG at birth was normal (Fig. 10.2B). This agrees with Hon's contention that foetal extrasystoles are benign.

It has been interesting to observe the changing attitudes of the nursing staff towards electronic equipment. Admittedly the early prototype instrumentation was a little disconcerting but the initial attitude of complete disassociation has changed to one of ready acceptance and willingness to learn.

10.5. Comparison with Other Methods of Foetal Assessment - It is inevitable that this method of foetal assessment will be compared with the other methods now in use. The two most popular methods, ultrasonic cephalometry and urinary oestriol estimation, were not routinely available at the GRMH when this study was done. It has therefore not been possible to compare them directly by experiment.

10.5.1. Cost - An FECG system need not be expensive. The FECG amplifiers can be very cheap (£5) and a special purpose computer could be made available

for about £1000. It is only a small addition to include a hard wired program for calculation of the mean, SD, CV etc.

This compares very favourably with the cost of an auto-analyser or Diasonagraph though these devices can be used for many other purposes.

10.5.2. Safety - Of the three methods the oestriol estimation is obviously totally safe. Provided electrical safety is assured the FECG is a passive system and cannot harm the patient. The debate on the safety of ultrasound continues and it would be impossible to present any conclusion here.

It never was the intention to develop the FECG in competition with these other methods. FECG information can only be regarded as yet another piece or data to be used in arriving at a rational decision on clinical management.

10.6. The Value of the Apgar Score -

> "While we believe the score is useful, it has many limitations. It is no substitute for a careful physical examination or serial observations over the first few hours of life. Nor will it predict neonatal death or survival in individual infants". (Apgar & James, 1962).

A great deal of foetal monitoring has been based on the Apgar score of the resulting infant. In retrospect this now seems unfortunate. The score is not a good enough indicator of the individual baby's use to the community as the "at risk" registers have shown. To date we have no satisfactory alternative. Until such time as our pædiatric colleagues produce a satisfactory measure we

have no basis for comparison of monitoring or obstetric practice other than the simple perinatal mortality. The claim that better Apgar scores means better babies has not been substantiated.

It is also unfortunate that the Apgar score is a number. This encourages people to use it in erroneously based mathematics. It might be worth considering replacing these numerical values with the alphabetic scale A - J which would prevent that possibility.

10.7. The Future. - As has just been pointed out it is very difficult to decide just where the future lies in the absence of a reliable method of assessing the quality of the infant delivered.

The foetus is so well protected from investigators that it's secrets can only be unlocked at ever increasing complexity and expense. There is a very valid argument that such expense may not be cost effective and that the money could be spent to better advantage elsewhere. (I understand that even Hon has had difficulty in obtaining further finance). Doctors have never been trained to count the financial cost of human suffering and particularly in the very emotive area of foetal survival this kind of decision seems impossible.

As to the other physical methods of assessing foetal function such as the foetal ballistocardiograph, impedance plethysmograph and electro-encephalograph these are at the moment only at the very frontiers of technology. None has as yet been engineered to the point where valid clinical trials could be undertaken. Such work is however, progressing and the results may be well worth the wait.

The "stress test" approach to foetal assessment has been mentioned in this thesis. Such an approach where the foetus is stressed by chemical or physical factors and its reaction

measured is extremely attractive. This author has not, as yet, had the opportunity to attempt such an approach but is certainly very intrigued by it.

The foetal heart rate is of course only a very small factor in the equation of labour. Work is progressing on the prediction of maternal performance in labour. This is a mamoth task but once both maternal and foetal predictions can be combined, perhaps labour will bring forth fewer surprises.

10.8. Conclusions - The sheer complexity of mankind (or more correctly, womankind) makes it difficult to form absolute opinions on medical problems. This thesis has assessed the role of ante-natal monitoring of the foetal heart, by the FECG, in the prognosis of foetal health.

The following conclusions have been reached.

10.8.1. The diagnosis of foetal distress need not be confined to the labouring patient. Ante-natally fewer factors operate in the baby and an assessment of it's "viability" is technically easier. The foetal heart rate is one of the few parameters of viability available.

10.8.2. Of the many methods available the foetal electrocardiograph is the only method which can yield accurate foetal heart rate information. It's waveform is precise and is easy to process electronically.

10.8.3. FECG amplifiers are the cheapest available apparatus for the detection of the foetal heart. Their construction is well within the scope of the amateur electronics experimenter.

10.8.4. A two channel cancellation system is suitable for the removal of unwanted maternal ECG complexes in most cases. An eight channel analog addition system can be used where the two channel method fails.

10.8.5. Study of FECG waveforms has to date been unrewarding but the technique of transient averaging developed for these studies has opened the way to foetal ballistocardiography and impedance plethysmography. The FECG is still essential to trigger these averaging techniques.

10.8.6. The interval histogram is a suitable method for condensing information on foetal cardiac cycle interval obtained ante-natally by the FECG. The histogram can be described by standard statistical terms such as the mean, standard deviation and coefficient of variation. These indices can be of real value in the diagnosis and prognosis of foetal status, particularly where serial examinations can be performed.

10.8.7. The new log. index affords a more correct index for the comparison of babies but is of no greater value in individual cases.

It may be that in years to come "family planning" in its widest sense will eliminate many of our present obstetrical problems. Nevertheless, major problems of foetal viability and quality of child exist today and require solutions now. This study has only been a small part of the search for more and better information on the foetus.

That it has not been so dramatically successful as I would have liked is more a tribute to the biological system which protects the baby than a reflection on modern technology.

11. SUMMARY

1. Ante-natal assessment of the health of the foetus has been identified as a problem. The foetal heart rate has been selected as a parameter of measurement of foetal condition.

2. A review of pertinent literature, in brief from 1906 to 1968 and in detail thereafter has been made.

3. The problems of foetal distress and its sequelae have been considered.

4. The developmental anatomy and physiology of the human foetal heart have been described.

5. The physical methods for obtaining information from the foetal heart have been evaluated and the FECG studied in detail.

6. Amplifiers have been designed, constructed and used in two and eight channel systems for removal of the unwanted maternal ECG signals superimposed on the FECG obtained from the mother's abdomen.

7. Methods for the acquisition, manipulation and display of data from the foetal heart have been detailed.

8. A clinical trial of the FECG system linked to an existing interval histogram method for the display of cardiac cycle intervals has been successfully undertaken.

9. The results of the trial have been presented and the condition of the newborn correlated with the ante-natal assessment.

10. This thesis has shown that the FECG is a satisfactory method for obtaining information about the foetal cardiac cycle which can be of real value in ante-natal assessment of foetal viability.

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APPENDIX A

1. Pro forma

2. Numerical codes

3. Table of results

Specimen of pro-forma on which data was logged. The items are not consecutively numbered to maintain conformity with a previous series.

MOTHER.

1.	Serial no.	1
2.	Hospital no.	2
	Name	
3.	Age	3
4.	Parity	4
5.	E.D.D.	5
7.	Gestation at FECG	7
8.	Medical condition (code)	8
9.	Obstetrical condition (code)	9
10.	Induced ? (1 = Yes, O = No)	10
11.	Duration of 1st stage.	11
12.	Duration of 2nd stage.	12
13.	Delivery (code)	13
14.	Dysmature ? (1 = Yes, O = No)	14
15.	Error in estimated dates	15

BABY.

17.	Date of delivery	17
18.	Weight at delivery (Kgs).	18
19.	Sex (1 = Male, 2 = Female)	19
20.	Apgar at 1 min.	20
21.	Apgar at 5 mins.	21
22.	Apgar at 10 mins.	22
23.	Complications (code)	23
26.	Mean of int. hist.	26
27.	S.D. of int. hist.	27
28.	Disposal.	28
29.	Coefficient of variation.	29
33.	Log index.	33

As the SCAN system only handles numerical data, the non-numerical data was coded as follows:

Item 8 - MEDICAL CONDITIONS

0 Nil
1 Rh-Antibodies present
2 Cardiac disease (maternal)
3 Anaemia
4 Respiratory disease
5 Diabetis mellitus
6 Contracted pelvis
7 Epilepsy
8 Ulcerative colitis
9 Urinary infection

Item 9 - OBSTETRICAL CONDITION

0 Nil
1 Pre-eclamptic toxaemia
2 Past dates
3 Bad obstetric history
4 Previous forceps delivery
5 Antepartum haemorrhage
6 Hydramnics
7 Premature rupture of membranes
8 Variable lie
9 Previous caesarean section
10 Foetal distress
11 Threatened abortion
12 Low oestriols

Item 13 - DELIVERY

1 Spontaneous vertex delivery
2 Breech
3 Forceps
4 Caesarean section
5 Venteuse extraction

Item 23 - COMPLICATIONS

0 Nil

1 Rhesus affected

2 Cord round neck and twisted cord - short cord in cases

3 Post-partum haemorrhage

4 Meconium aspiration

5 Congenital abnormality

6 Jaundice

7 Prematurity

8 Hypoglycaemia

9 Urinary tract enfection

Item 28 - FINAL RESULT

1 Home

2 Paediatric nursery

3 Post mortem room.

These codes were deliberately left open-ended so that unforseen items could easily be added.

In the table of results 99999 represents missing data. The fictitious Apgar score of 11 is used where Apgar is assumed to be 10 but not recorded.

200	201	202	203	204A	204B	Serial number
80482	82722	81453	81609	81261		Hospital number
25	32	19	25	25		Age
0+2	1+0	0+0	1+0	0+0		Parity
1.10.70	15.7.70	19.9.70	22.6.70	21.9.70		Expected date of delivery
39	41+	44	42+	41	42	Gestation at FECG (weeks)
0	9	0	0	0		Medical condition
3	10	2	4	2		Obstetrical condition
1	0	1	1	1		Induction
3.25	9	99999	11	13		Duration of 1st. stage (hrs)
0.75	0.25	99999	0.5	0.5		Duration of 2nd. stage (hrs)
1	1	4	1	2		Delivery
0	0	0	0	1		Dysmaturity
1	14	38	20	16		Error in dates
2.10.70	29.7.70	27.10.70	11.7.70	7.10.70		Date of delivery
2.86	3.11	3.74	3.65	2.41		Weight at delivery (Kgs)
2	2	2	1	2		Sex
4	1	3	0	2		Apgar at 1 min.
8	9	8	0	8		Apgar at 5 min.
11	11	11	0	11		Apgar at 10 min.
10	2	10	11	10		Complications
443.7	417.3	420.96	414.1	415.12	407.0	Mean of int. nist.(millisecs)
7.74	8.4	8.6	30.25	18.8	9.11	Standard deviation („)
1	1	1	3	1		Disposal
1.74	2.0	2.03	7.30	4.52	2.24	Coefficient of variation
127	139	142	502	312	152	Log index

205	206	207	208	209A	209B	Serial number
8I959	8I93I	82723	82020	8I792		Hospital number
42	I7	36	20	22		Age
I+I	0+0	2+0	0+0	0+0		Parity
99999	5.9.70	99999	I9.I0.70	3.I0.70		Expected date of delivery
40	43	99999	38	39	40	Gestation at FECG (weeks)
0	0	0	6	0		Medical condition
0	2	6	I	I		Obstetrical condition
I	I	I	I	I		Induction
99999	I8	4.25	34	9.5		Duration of Ist. stage (hrs)
99999	99999	6.25	0.25	99999		Duration of 2nd. stage (hrs)
4	4	2	4	4		Delivery
0	0	0	0	0		Dysmaturity
99999	23	99999	3	I		Error in dates
2.8.70	28.9.70	8.8.70	22.I0.70	4.I0.70		Date of delivery
3.74	3.II	3.88	3.62	3.06		Weight at delivery (Kgs)
I	2	I	I	2		Sex
2	2	0	3	2		Apgar at I min.
9	8	0	6	8		Apgar at 5 min.
II	II	0	9	II		Apgar at I0 min.
0	I0	II	3	I0		Complications
429.7	455.7	402.6	360.II	44I.92	442.43	Mean of int. nist.(millisecs)
I8.9	I9.54	I8.I2	II.5I	I6.95	I4.5I	Standard deviation (")
I	I	3	I	I		Disposal
4.4	4.3I	4.5	3.2	3.83	3.3	Coefficient of variation
3I2	3I9	302	I96	278	238	Log index

210	211	212	213	214	215	Serial number
80976	78128	80486	79373	81734	76023	Hospital number
24	26	15	34	24	38	Age
1+0	0+0	0+0	0+0	0+0	1+0	Parity
17.7.70	2.4.70	9.3.70	1.5.70	26.9.70	99999	Expected date of delivery
40	41	40	40	39	38	Gestation at FECG (weeks)
0	6	0	6	0	3	Medical condition
9	8	10	2	10	0	Obstetrical condition
0	1	1	0	1	1	Induction
30	26	0	4.5	0	2	Duration of 1st. stage (hrs)
0	0	0	0.75	0	0.75	Duration of 2nd. stage (hrs)
4	4	4	3	4	1	Delivery
1	0	0	0	0	0	Dysmaturity
6	-19	30	26	7	99999	Error in dates
23.7.70	5.3.70	9.4.70	27.5.70	3.10.70	21.6.69	Date of delivery
3.45	2.9	4.3	3.5	4.56	2.51	Weight at delivery (Kgs)
2	1	1	1	2	2	Sex
4	4	4	3	2	0	Apgar at 1 min.
9	99999	7	99999	7	0	Apgar at 5 min.
11	99999	9	99999	11	0	Apgar at 10 min.
0	0	4	10	10	2	Complications
435.42	391.4	415.1	403.22	376.9	447.99	Mean of int. nist.(millisecs)
20.56	18.82	10.4	19.44	12.6	17.41	Standard deviation (")
1	1	2	1	1	3	Disposal
4.72	4.8	2.5	4.82	3.33	3.90	Coefficient of variation
338	315	173	324	212	285	Log index

216	217	218	219	220	221	Serial number
80921	78950	75951	76276	82157	77609	Hospital number
27	28	20	31	16	31	Age
2+1	2+0	0+0	1+1	0+0	2+0	Parity
12.6.70	18.4.70	22.7.69	14.9.69	7.9.70	12.11.69	Expected date of delivery
40	38	37	38	33	36	Gestation at FECG (weeks)
6	3	0	0	0	3	Medical condition
9	9	2	3	5	5	Obstetrical condition
0	0	1	0	0	1	Induction
0	0	24	12.5	7.75	1.75	Duration of 1st. stage (hrs)
0	0	0	0	0.25	0.5	Duration of 2nd. stage (hrs)
4	4	4	4	1	1	Delivery
0	0	0	0	0	0	Dysmaturity
-1	-9	15	-17	-43	26	Error in dates
11.6.70	9.4.70	7.8.69	31.8.69	25.7.70	8.12.69	Date of delivery
3.37	3.5	3.8	3.2	1.84	3.2	Weight at delivery (Kgs)
1	2	1	1	1	1	Sex
2	4	2	3	3	5	Apgar at 1 min.
1	8	7	9	7	7	Apgar at 5 min.
8	11	10	11	11	11	Apgar at 10 min.
10	0	10	0	3	2	Complications
407.4	429.9	392141	441.6	394.4	417.82	Mean of int. nist.(millisecs)
4.8	34.99	24.14	17.1	11.75	17.25	Standard deviation (")
1	1	1	1	2	1	Disposal
1.2	8.14	6.2	3.9	3	4.12	Coefficient of variation
80	577	404	281	197	290	Log index

222	223	224	225	226	227	Serial number
81008	81800	76495	79397	76426	82758	Hospital number
35	19	28	27	22	17	Age
4+0	0+0	3+0	1+0	0+0	0+0	Parity
16.6.70	26.5.70	29.9.69	2.3.70	99999	25.9.70	Expected date of delivery
40	40	38	38	99999	40	Gestation at FECG (weeks)
10	0	0	0	0	0	Medical condition
2	6	4	1	10	1	Obstetrical condition
0	1	0	0	1	0	Induction
18.5	6	5	5	14	10.75	Duration of 1st. stage (hrs)
0.25	0.75	0.25	0.25	1.25	1	Duration of 2nd. stage (hrs)
1	3	2	2	3	1	Delivery
0	0	0	0	0	0	Dysmaturity
8	10	1	10	99999	8	Error in dates
24.6.70	6.6.70	30.9.69	12.3.70	21.10.69	2.10.70	Date of delivery
3.79	3.3	99999	3.6	3.26	99999	Weight at delivery (Kgs)
2	2	2	2	2	1	Sex
7	6	7	5	7	7	Apgar at 1 min.
11	9	9	10	9	11	Apgar at 5 min.
11	10	11	11	11	11	Apgar at 10 min.
4	0	0	0	2	0	Complications
393.2	430.02	427.23	410.01	477.45	434.10	Mean of int. hist.(millisecs)
9.19	17.2	24.33	19.0	20.02	12.61	Standard deviation (")
1	1	1	1	1	1	Disposal
2.31	4	5.7	4.63	4.2	2.9	Coefficient of variation
154	284	402	316	325	208	Log index

228	229	230	231	232	233	Serial number
80857	79256	81896	82394	79386	40674	Hospital number
20	35	29	16	22	27	Age
1+0	0+1	1+0	0+0	0+0	1+1	Parity
24.2.70	6.3.70	8.6.70	99999	7.4.70	5.5.70	Expected date of delivery
41	41	42	99999	40	38	Gestation at FECG (weeks)
3	0	3	0	3	6	Medical condition
8	2	5	1	3	9	Obstetrical condition
1	1	0	1	1	1	Induction
9	19.5	6.75	15	10	11	Duration of 1st. stage (hrs)
3.25	0.75	99999	0.75	1.	0.75	Duration of 2nd. stage (hrs)
3	3	5	3	3	3	Delivery
0	0	0	0	0	0	Dysmaturity
31	20	7	99999	8	-6	Error in dates
27.3.70	26.3.70	15.6.70	17.7.70	15.4.70	30.4.70	Date of delivery
3.51	3.4	3.5	3.48	99999	3.4	Weight at delivery (Kgs)
2	1	1	2	1	2	Sex
7	7	6	7	5	7	Apgar at 1 min.
9	10	9	11	99999	10	Apgar at 5 min.
10	11	11	11	99999	11	Apgar at 10 min.
0	0	0	0	0	0	Complications
452.35	429.45	434.85	451.4	451.8	434.1	Mean of int. nist.(millisecs)
9.63	18.6	6.8	10.65	7.78	23.7	Standard deviation (")
1	1	1	1	1	1	Disposal
2.13	4.33	1.55	2.4	1.72	5.45	Coefficient of variation
157	307	112	147	127	290	Log index

234	235A	235B	236	237	238	Serial number
77678	40470		8II69	82I65	79226	Hospital number
22	22		20	I9	29	Age
0+0	I+0		0+0	0+0	2+0	Parity
I2.7.69	22.8.70		99999	99999	I9.3.70	Expected date of delivery
40	40		45	40	4I	Gestation at FECG (weeks)
0	0		0	0	0	Medical condition
I	9		2	I	2	Obstetrical condition
I	I		I	I	I	Induction
8.25	5.25		II	4.75	9	Duration of Ist. stage (hrs)
I	2.25		I.75	0.5	99999	Duration of 2nd. stage (hrs)
3	3		3	I	I	Delivery
0	0		0	0	0	Dysmaturity
0	9		99999	99999	I0	Error in dates
I2.7.69	3I.8.70		2.7.70	I5.6.70	27.3.70	Date of delivery
3.5	4.2		3.6I	3.5	3.4	Weight at delivery (Kgs)
I	I		2	2	2	Sex
6	6		6	7	7	Apgar at I min.
II	II		I0	I0	99999	Apgar at 5 min.
II	II		II	II	99999	Apgar at I0 min.
0	0		0	2	4	Complications
455.I4	4I9.I2	455.75	402.24	4II.8	402.2	Mean of int. nist.(millisecs)
I0.5	II.4	7.3	I3.75	I3.9I	I9.56	Standard deviation (")
I	I		I	I	I	Disposal
2.3	2.7I	I.60	3.42	3.4I	4.9	Coefficient of variation
I72	I89	II9	229	23I	326	Log index

239	240	241A	241B	242A	242B	Serial number
82018	40935	40826		76610		Hospital number
18	19	38		31		Age
1+1	0+0	1+1		0+1		Parity
1.9.70	11.7.70	13.7.70		16.10.70		Expected date of delivery
40	42	38	39	39	40	Gestation at FECG (weeks)
12	0	10		0		Medical condition
5	2	3		1		Obstetrical condition
0	1	0		1		Induction
99999	54	99999		8.5		Duration of 1st. stage (hrs)
99999	1.5	99999		0.5		Duration of 2nd. stage (hrs)
4	1	4		3		Delivery
0	0	0		0		Dysmaturity
3	22	-4		-1		Error in dates
4.9.70	2.8.70	9.7.70		15.10.70		Date of delivery
3.34	99999	3.57		2.6		Weight at delivery (Kgs)
2	2	2		2		Sex
6	6	6		6		Apgar at 1 min.
8	7	9		8		Apgar at 5 min.
11	11	11		11		Apgar at 10 min.
0	2	0		0		Complications
444.5	375.2	386.3	462.5	450.43	418.5	Mean of int. nist.(millisecs)
11.65	22.41	13.3	19.6	9.12	10.6	Standard deviation (")
1	1	1		1		Disposal
2.62	6.0	3.44	4.2	2.02	2.53	Coefficient of variation
191	378	223	319	149	176	Log index

243A	243B	243C	245A	245B	246	Serial number
80306			81998		80993	Hospital number
21			17		20	Age
2+0			0+0		0+0	Parity
23.7.70			21.9.70		22.8.70	Expected date of delivery
38	39	40	39	40	40	Gestation at FECG (weeks)
3			0		0	Medical condition
0			1		1	Obstetrical condition
1			1		1	Induction
3.5			9		6.75	Duration of Ist. stage (hrs)
0.5			1		1	Duration of 2nd. stage (hrs)
1			3		3	Delivery
0			0		0	Dysmaturity
3			3		10	Error in dates
26.7.70			24.9.70		1.9.70	Date of delivery
3.6			3.96		3.3	Weight at delivery (Kgs)
2			2		2	Sex
6			7		7	Apgar at 1 min.
8			10		10	Apgar at 5 min.
10			11		11	Apgar at 10 min.
2			0		0	Complications
424.4	373.6	424.39	408.45	383.34	436.6	Mean of int. nist.(millisecs)
12.4	17.85	11	12.42	7.60	11.56	Standard deviation (")
1			1		1	Disposal
2.9	4.8	2.6	3.04	1.95	2.64	Coefficient of variation
205	301	182	207	127	190	Log index

247A	247B	248	249	250	251	Serial number
82083		8088I	8I979	8I07I	79672	Hospital number
24		23	I9	23	28	Age
0+I		I+0	0+0	0+0	0+0	Parity
I3.I0.70		7.9.70	25.8.70	23.9.70	I4.5.70	Expected date of delivery
39	40	4I	4I	4I	42	Gestation at FECG (weeks)
0		0	II	6	0	Medical condition
I		I	2	I0	I	Obstetrical condition
I		0	0	I	I	Induction
I2		99999	7	20	26.5	Duration of Ist. stage (hrs)
I		99999	2.25	99999	I.25	Duration of 2nd. stage (hrs)
3		4	3	4	3	Delivery
0		0	0	0	0	Dysmaturity
I5		8	8	I4	22	Error in dates
28.I0.70		I5.9.70	2.9.70	7.I0.70	6.I.70	Date of delivery
3.57		2.77	3.45	3.79	3.4	Weight at delivery (Kgs)
2		I	I	2	2	Sex
7		6	5	7	5	Apgar at I min.
I0		I0	9	I0	I0	Apgar at 5 min.
II		II	II	II	II	Apgar at I0 min.
0		2	0	0	4	Complications
352.7	393.04	4I5.9	45I.4	430.35	457.75	Mean of int. nist.(millisecs)
I4.8I	I5.32	I2.4I	7	II.74	26.8	Standard deviation (")
I		I	I	I	I	Disposal
4.2	3.9	3	I.54	2.72	5.84	Coefficient of variation
252	256	206	II5	I94	437	Log index

252	253	254	255	256	257A	Serial number
83476	80561	81712	81105	80369	82562	Hospital number
34	25	29	25	23	20	Age
3+0	0+3	0+0	3+1	0+0	0+0	Parity
10.11.70	27.10.70	24.10.70	12.4.70	99999	5.10.70	Expected date of delivery
39	41	41	42	99999	40	Gestation at FECG (weeks)
0	0	0	3	0	0	Medical condition
1	3	1	2	1	1	Obstetrical condition
1	1	1	0	1	1	Induction
4	6.25	22	2	12.5	5	Duration of 1st. stage (hrs)
0.5	0.5	0.5	99999	1.08	1	Duration of 2nd. stage (hrs)
3	3	5	1	3	3	Delivery
0	0	0	0	0	0	Dysmaturity
9	20	29	20	99999	9	Error in dates
19.11.70	16.11.70	22.11.70	2.5.70	14.7.70	14.10.70	Date of delivery
3.4	3.09	3.31	4.4	3.79	99999	Weight at delivery (Kgs)
1	2	2	1	2	1	Sex
7	7	6	7	5	6	Apgar at 1 min.
9	10	10	10	10	7	Apgar at 5 min.
11	11	11	11	11	8	Apgar at 10 min.
0	0	0	0	0	2	Complications
388.9	366.9	367.33	455.45	435.5	401.8	Mean of int. nist.(millisecs)
13.62	9.52	11.14	10.85	30.6	5.11	Standard deviation (")
1	1	1	1	1	1	Disposal
3.5	2.6	3.03	2.4	6.9	1.3	Coefficient of variation
228	161	185	177	494	85	Log index

257B	257C	258	259	260	261	Serial number
82562		80744	80640	81548	79466	Hospital number
		26	I9	I5	37	Age
		0+0	0+I	0+0	5+3	Parity
		2.8.70	24.8.70	99999	4.4.70	Expected date of delivery
40	4I	42	39	99999	40	Gestation at FECG (weeks)
		0	0	0	0	Medical condition
		2	0	0	3	Obstetrical condition
		I	I	I	0	Induction
		9	3.5	I9.75	0.75	Duration of Ist. stage (hrs)
		0.5	I	I.75	99999	Duration of 2nd. stage (hrs)
		I	2	3	I	Delivery
		0	0	0	0	Dysmaturity
		I8	I	99999	4	Error in dates
		20.8.70	23.8.70	I6.7.70	8.4.70	Date of delivery
		2.86	3.3I	3.5	4.I	Weight at delivery (Kgs)
		I	2	2	2	Sex
		7	5	6	8	Apgar at I min.
		I0	9	I0	I0	Apgar at 5 min.
		II	I0	II	II	Apgar at I0 min.
		2	0	0	0	Complications
372.5	384.I	445.9	428.55	399.55	444.74	Mean of int. nist.(millisecs)
9.I	5.8I	24.74	I2.32	2I.74	I8.8I	Standard deviation (")
I		I	I	I	I	Disposal
2.43	I.5I	5.54	2.9	5.4	4.22	Coefficient of variation
I53	98	406	203	362	308	Log index

262	263	264	265	266	267	Serial number
80267	81258	80581	81152	73678	79343	Hospital number
23	18	21	20	19	26	Age
0+0	0+0	0+0	0+0	0+0	0+0	Parity
28.6.70	15.5.70	10.8.70	25.8.70	9.3.70	23.4.70	Expected date of delivery
42	40	38	42	38	41	Gestation at FECG (weeks)
0	6	0	0	4	4	Medical condition
5	0	1	10	1	0	Obstetrical condition
1	0	0	1	0	0	Induction
99999	14.5	6	12.5	12.25	29	Duration of 1st. stage (hrs)
99999	0.5	2	0.5	0.75	1	Duration of 2nd. stage (hrs)
4	1	3	3	3	1	Delivery
0	0	0	0	0	0	Dysmaturity
25	3	6	13	4	14	Error in dates
23.7.70	12.5.70	4.8.70	9.9.70	5.3.70	7.5.70	Date of delivery
3.37	3.4	3.34	4.05	4	4	Weight at delivery (Kgs)
1	2	2	2	1	1	Sex
9	9	8	8	9	8	Apgar at 1 min.
10	10	10	10	10	10	Apgar at 5 min.
11	11	11	11	11	11	Apgar at 10 min.
0	0	0	0	0	0	Complications
429.5	398.5	400.7	500.24	456.97	442.74	Mean of int. hist.(millisecs)
25.2	26.1	21.8	31.37	41.02	11.97	Standard deviation (")
1	1	1	1	1	1	Disposal
5.9	6.54	5.4	6.34	8.97	2.7	Coefficient of variation
416	436	364	511	670	196	Log index

268	269	270A	270B	271A	271B	Serial number
82141	78341	81962		84150		Hospital number
39	24	34		19		Age
8+2	1+0	2+2		0+1		Parity
24.9.70	9.2.70	9.11.70		1.11.70		Expected date of delivery
40	42	38	39	39	40	Gestation at FECG (weeks)
3	0	0		0		Medical condition
0	0	8		1		Obstetrical condition
1	0	1		0		Induction
16.25	3.25	2.5		8.5		Duration of 1st. stage (hrs)
0.25	0.25	0.25		0.5		Duration of 2nd. stage (hrs)
1	1	1		1		Delivery
0	0	0		0		Dysmaturity
11	19	20		13		Error in dates
4.10.70	28.2.70	29.11.70		14.11.70		Date of delivery
3.28	3.6	3.79		3.11		Weight at delivery (Kgs)
2	2	2		1		Sex
9	9	8		8		Apgar at 1 min.
10	10	10		10		Apgar at 5 min.
11	11	11		11		Apgar at 10 min.
0	0	0		0		Complications
433.45	475.71	417.9	415.92	400.7	438.35	Mean of int. hist.(millisecs)
12.2	24.45	8.7	5.9	10.71	10.41	Standard deviation (")
1	1	1		1		Disposal
2.8	5.14	2.1	1.41	2.7	2.4	Coefficient of variation
201	397	144	98	179	171	Log index

272	273A	273B	273C	274	275	Serial number
84150	82246			81985	81145	Hospital number
33	23			20	24	Age
1+4	3+1			0+0	1+0	Parity
2.11.70	13.11.70			20.8.70	99999	Expected date of delivery
38	38	39	40	39	38	Gestation at FECG (weeks)
4	1			0	0	Medical condition
3	8			0	3	Obstetrical condition
1	1			0	0	Induction
14	3.5			11.25	0.25	Duration of 1st. stage (hrs)
0.75	0.75			0.5	0.25	Duration of 2nd. stage (hrs)
1	1			1	1	Delivery
0	0			0	0	Dysmaturity
5	-2			1	99999	Error in dates
7.11.70	11.11.70			21.8.70	6.5.70	Date of delivery
3.14	3.96			2.89	3.4	Weight at delivery (Kgs)
2	1			1	1	Sex
9	9			8	8	Apgar at 1 min.
10	10			10	10	Apgar at 5 min.
11	11			11	11	Apgar at 10 min.
3	0			0	0	Complications
416.4	457.4	360.2	405.71	434.32	452.24	Mean of int. nist.(millisecs)
15.44	10.63	8.62	10.31	23.93	7.51	Standard deviation (")
1	1			1	1	Disposal
3.7	2.32	2.4	2.54	5.51	1.66	Coefficient of variation
256	174	146	172	394	123	Log index

276	277	278	279	280	281	Serial number
77006	78976	76432	40565	82162	79958	Hospital number
23	24	25	20	27	32	Age
I+I	4+0	0+0	0+0	0+I	2+0	Parity
27.6.69	2.4.70	4.10.69	I6.4.70	23.5.70	I7.4.70	Expected date of delivery
36	39	38	42	4I	37	Gestation at FECG (weeks)
9	0	0	0	0	0	Medical condition
5	I	I	2	2	3	Obstetrical condition
0	I	0	I	I	0	Induction
0	3	4.5	4.25	6	4.5	Duration of Ist. stage (hrs)
0	0.25	I.25	0.5	I.5	99999	Duration of 2nd. stage (hrs)
4	I	3	I	3	I	Delivery
0	0	0	0	0	0	Dysmaturity
-I5	9	5	II	I7	5	Error in dates
I2.6.69	II.4.70	9.I0.69	27.4.70	I0.6.70	22.4.70	Date of delivery
3	3.7	3.I	3.4	4.5	2.5	Weight at delivery (Kgs)
I	I	I	I	I	2	Sex
9	9	9	9	I0	8	Apgar at I min.
I0	I0	I0	I0	I0	I0	Apgar at 5 min.
II	II	II	II	I0	II	Apgar at I0 min.
0	0	0	0	0	0	Complications
446.9	448.4	4I4.8	435.24	4I5.4	4I7.3	Mean of int. nist.(millisecs)
II.9	I3.45	I2.8	I4.7	I3.7	9.8	Standard deviation (")
I	I	I	I	I	I	Disposal
2.66	3	3.I	3.4	3.3	2.35	Coefficient of variation
I95	220	2I2	242	224	I62	Log index

282	283	284A	284B	285	285A	Serial number
80556	80354	79645		76266	78426	Hospital number
30	I9	25		3I	23	Age
0+I	0+0	0+0		3+0	I+0	Parity
6.8.70	24.2.70	I7.5.70		27.7.69	I5.2.70	Expected date of delivery
42	4I	39	40	40	38	Gestation at FECG (weeks)
6	0	0		0	0	Medical condition
0	I	I		9	5	Obstetrical condition
I	0	I		0	I	Induction
99999	3.75	I7.25		I8	3.5	Duration of Ist. stage (hrs)
99999	I.35	I		0.5	0.25	Duration of 2nd. stage (hrs)
4	3	3		I	I	Delivery
0	0	0		0	0	Dysmaturity
I6	I7	2		II	I2	Error in dates
22.8.70	I0.3.70	I9.5.70		7.8.69	27.2.70	Date of delivery
3.77	3.6	99999		3.45	3.9	Weight at delivery (Kgs)
I	I	I		I	2	Sex
9	9	8		9	9	Apgar at I min.
I0	I0	5		I0	I0	Apgar at 5 min.
II	II	I0		II	II	Apgar at I0 min.
0	0	0		0	0	Complications
4I7.7	422.55	45I.I4	452.3I	462.5I	426.4	Mean of int. nist.(millisecs)
I9.7I	7.33	II.5	8.6	I8.32	25.62	Standard deviation (")
I	I	I	I	I	I	Disposal
4.7	I.73	2.54	I.9	3.96	6	Coefficient of variation
327	I2I	I88	I4I	299	423	Log index

286B	287	288	289	290	291	Serial number
78426	82316	79717	79416	80515	40804	Hospital number
23	19	21	20	23	24	Age
1+0	0+0	0+0	0+0	0+0	0+0	Parity
15.2.70	23.10.70	5.4.70	27.4.70	8.4.70	25.5.70	Expected date of delivery
40	39	39	39	42	40	Gestation at FECG (weeks)
0	0	0	10	9	0	Medical condition
5	1	2	0	0	2	Obstetrical condition
1	1	1	1	0	3	Induction
3.5	10.75	9.5	9.75	9.5	17	Duration of 1st. stage (hrs)
0.25	0.5	1.5	0.75	0.5	1.25	Duration of 2nd. stage (hrs)
1	1	3	1	1	1	Delivery
0	0	0	0	0	0	Dysmaturity
12	1	5	-6	17	14	Error in dates
27.2.70	24.10.70	10.4.70	21.4.70	25.4.70	9.6.70	Date of delivery
3.9	3.23	3.8	3.79	3.9	3.7	Weight at delivery (Kgs)
2	2	2	1	2	2	Sex
9	9	9	9	9	8	Apgar at 1 min.
10	10	10	10	10	10	Apgar at 5 min.
11	11	10	11	11	11	Apgar at 10 min.
0	0	0	0	0	0	Complications
391.32	387.5	448.55	435.6	447.1	347.56	Mean of int. nist.(millisecs)
14.52	5.33	17.8	25.7	13.9	8.44	Standard deviation (")
1	1	1	1	1	1	Disposal
3.7	1.4	3.96	5.9	3.11	2.43	Coefficient of variation
243	89	292	423	228	144	Log index

292A	292B	293	294	295	296	Serial number
77263		79065	40768	82337	79790	Hospital number
26		32	2I	I9	36	Age
2+2		0+I	0+0	0+0	0+0	Parity
I5.9.69		I6.9.69	I0.5.70	8.10.70	I6.6.70	Expected date of delivery
37	38	39	4I	4I	40	Gestation at FECG (weeks)
0		0	0	0	3	Medical condition
0		0	I	I	2	Obstetrical condition
I		0	I	I	0	Induction
9.25		3.25	I6	6.25	4	Duration of Ist. stage (hrs)
0.25		0.5	I.25	0.5	0.5	Duration of 2nd. stage (hrs)
I		I	3	I	3	Delivery
0		I	0	0	0	Dysmaturity
-I2		-4	39	II	8	Error in dates
3.9.69		I2.9.69	I8.6.70	I9.I0.70	24.6.70	Date of delivery
2.9		2.2	3.6	99999	3.94	Weight at delivery (Kgs)
I		I	2	2	2	Sex
9		9	9	9	8	Apgar at I min.
I0		I0	I0	I0	I0	Apgar at 5 min.
II		II	II	II	II	Apgar at I0 min.
0		0	0	0	0	Complications
380.2	433.93	459.9I	450.3	406.9	436.22	Mean of int. nist.(millisecs)
8.52	3.56	I6.I2	I2.3	7.84	9.32	Standard deviation (")
I	I	I	I	I	I	Disposal
2.24	0.8I	3.5	2.72	I.93	2.I4	Coefficient of variation
I43	59	263	20I	I30	I53	Log index

297A	297B	297C	298	299	300	Serial number
79887			80884	7968I	7937I	Hospital number
25			I9	28	39	Age
2+0			0+0	3+0	0+0	Parity
27.3.70			I3.6.70	30.4.70	24.4.70	Expected date of delivery
39	40	4I	40	4I	38	Gestation at FECG (weeks)
9			I0	3	0	Medical condition
2			0	0	I	Obstetrical condition
0			0	0	I	Induction
3.5			5.5	0.75	I2	Duration of Ist. stage (hrs)
0.25			0.5	0.25	99999	Duration of 2nd. stage (hrs)
3			I	I	4	Delivery
0			0	0	0	Dysmaturity
II			6	I4	4	Error in dates
8.4.70			I9.6.70	I4.5.70	28.4.70	Date of delivery
4.5			2.94	3.3	3.4	Weight at delivery (Kgs)
I			I	2	2	Sex
8			9	9	9	Apgar at I min.
I0			I0	I0	I0	Apgar at 5 min.
II			II	II	II	Apgar at I0 min.
0			0	0	0	Complications
393.9	444.8	4I9.24	46I.4	4I9.04	405.3	Mean of int. hist.(millisecs)
I0.54	9.7	II.7	I5.3	20.9	I2.13	Standard deviation (")
I			I	I	I	Disposal
2.7	2.2	2.8	3.3I	5	3	Coefficient of variation
I76	I59	I94	249	346	202	Log index

301	302	303	304	305	306	Serial number
77833	80369	75968	77601	80397	81389	Hospital number
19	34	30	34	22	28	Age
0+0	5+0	0+0	6+1	0+0	0+0	Parity
30.9.69	25.5.70	25.9.70	8.11.70	13.8.70	21.9.70	Expected date of delivery
38	42	40	37	40	42	Gestation at FECG (weeks)
0	0	9	0	6	0	Medical condition
1	2	1	5	0	2	Obstetrical condition
0	0	1	1	0	1	Induction
2	0	18	2	0	45	Duration of 1st. stage (hrs)
2	0	2	0.25	0	1	Duration of 2nd. stage (hrs)
3	4	3	1	4	3	Delivery
0	0	0	0	0	1	Dysmaturity
11	19	7	11	12	16	Error in dates
10.10.69	13.6.70	1.10.70	28.10.70	25.8.70	7.10.70	Date of delivery
3.1	4.33	3.48	2.89	4.56	2.38	Weight at delivery (Kgs)
1	1	1	2	1	1	Sex
9	9	9	9	8	9	Apgar at 1 min.
10	10	10	10	10	10	Apgar at 5 min.
11	11	11	11	11	11	Apgar at 10 min.
0	0	0	0	0	2	Complications
411.84	427.7	397.3	400	440.2	396.9	Mean of int. nist.(millisecs)
11.47	16.7	20.11	10.12	22.2	9.31	Standard deviation (")
1	1	1	1	1	1	Disposal
2.81	3.9	5.1	2.52	5.03	2.34	Coefficient of variation
191	276	336	169	365	156	Log index

307	308A	308B	309	310A	310B	Serial number
80782	81677		82500	79696		Hospital number
24	22		36	30		Age
0+0	1+0		0+2	4+0		Parity
23.8.70	14.8.70		27.7.70	9.5.70		Expected date of delivery
41	42	43	39	40	41	Gestation at FECG (weeks)
0	0		0	0		Medical condition
0	2		1	2		Obstetrical condition
1	1		1	0		Induction
16	1.5		4.75	4.5		Duration of 1st. stage (hrs)
0	0.25		0.75	99999		Duration of 2nd. stage (hrs)
4	1		1	1		Delivery
0	0		0	0		Dysmaturity
12	24		4	17		Error in dates
4.9.70	7.9.70		23.7.70	26.5.70		Date of delivery
3.79	3.79		3.05	3.6		Weight at delivery (kgs)
1	2		1	2		Sex
8	9		8	9		Apgar at 1 min.
10	10		10	10		Apgar at 5 min.
11	11		11	11		Apgar at 10 min.
0	0		0	0		Complications
418.8	457.45	432.22	379.53	438.8	421.2	Mean of int. nist.(millisecs)
11.6	12.41	17.4	12.99	14.4	12.45	Standard deviation (")
1	1		1	1		Disposal
2.8	2.71	4.02	3.42	3.3	2.96	Coefficient of variation
192	203	287	219	237	206	Log index

3I1	3I2	3I3	3I4	3I5	3I6	Serial number
83618	83218	82617	83615	81012	79112	Hospital number
40	29	24	32	39	26	Age
4+0	2+0	2+0	5+0	6+1	0+1	Parity
1.10.70	2.9.70	15.9.70	28.9.70	23.7.70	20.8.70	Expected date of delivery
41	40	34	40	40	40	Gestation at FECG (weeks)
0	0	0	0	3	0	Medical condition
1	2	12	1	1	1	Obstetrical condition
1	0	1	1	1	0	Induction
1	2.75	8.75	6.5	4.75	12.25	Duration of 1st. stage (hrs)
0.25	0.25	0.25	0.25	0.25	0.5	Duration of 2nd. stage (hrs)
1	1	1	1	1	1	Delivery
0	0	1	0	0	0	Dysmaturity
9	2	-2	2	5	2	Error in dates
10.10.70	4.9.70	13.9.70	30.9.70	28.7.70	22.8.70	Date of delivery
2.77	3.8	2.52	3.85	3.96	3.34	Weight at delivery (Kgs)
1	1	1	2	2	1	Sex
9	8	9	9	8	9	Apgar at 1 min.
10	9	10	10	10	10	Apgar at 5 min.
11	10	11	11	11	11	Apgar at 10 min.
0	0	0	0	4	0	Complications
508.2	367.2	445.11	417.05	454.6	439.33	Mean of int. nist.(millisecs)
11.8	11.67	22.7	9:41	21.83	15.12	Standard deviation („)
1	1	1	1	1	1	Disposal
2.31	3.2	5.1	2.25	4.8	3.44	Coefficient of variation
189	198	372	156	357	248	Log index

3I7	3I8A	3I8B	3I9	320	32I	Serial number
83II2	83III		8I608	83603	8I960	Hospital number
37	46		23	24	I9	Age
3+0	5+2		0+0	I+0	0+0	Parity
I3.I0.70	25.9.70		I0.9.70	3.II.70	26.I0.70	Expected date of delivery
38	40	4I	37	39	39	Gestation at FECG (weeks)
3	2		0	0	0	Medical condition
5	2		2	5	0	Obstetrical condition
0	I		0	0	0	Induction
I4	6.5		I0.25	0.75	9	Duration of Ist. stage (hrs)
0.5	I		2	0.25	0.5	Duration of 2nd. stage (hrs)
I	I		3	I	I	Delivery
0	0		0	0	0	Dysmaturity
2	I4		I2	-5	3	Error in dates
I5.I0.70	9.I0.70		22.9.70	29.I0.70	23.I0.70	Date of delivery
3.3I	2.89		3.37	2.92	2.58	Weight at delivery (Kgs)
I	2		I	2	I	Sex
8	9		9	9	9	Apgar at I min.
5	I0		I0	I0	I0	Apgar at 5 min.
I0	II		II	II	II	Apgar at I0 min.
2	0		4	0	0	Complications
498.97	443.5I	458.3	450.02	473.64	45I.3	Mean of int. hist.(millisecs)
20.4	22.3I	9.2I	II	I2.7I	I8	Standard deviation (")
I	I	I	I	I	I	Disposal
4.I	5.02	2	2.44	2.7	4	Coefficient of variation
328	366	I50	I80	206	294	Log index

322A	322B	323A	323B	324A	324B	Serial number
80953		8125I		82950		Hospital number
29		24		24		Age
I+0		0+0		0+0		Parity
I0.8.70		4.9.70		28.8.70		Expected date of delivery
37	38	39	40	40	4I	Gestation at FECG (weeks)
0	0	0		0		Medical condition
2		2		I		Obstetrical condition
0		0		I		Induction
7.3		3		I0.5		Duration of Ist. stage (hrs)
0.5		0.25		0.5		Duration of 2nd. stage (hrs)
I		I		2		Delivery
0		0		0		Dysmaturity
-4		2		9		Error in dates
6.8.70		6.9.70		6.9.70		Date of delivery
3.34		3.28		3		Weight at delivery (Kgs)
2		I		I		Sex
9		8		9		Apgar at I min.
I0		I0		I0		Apgar at 5 min.
II		II		II		Apgar at I0 min.
0		3		0		Complications
384.5	377.52	403.2	394.8	397	446.8	Mean of int. nist.(millisecs)
25	I7.2	I9.44	I2.72	I9.3	I3.62	Standard deviation (")
I		I		I		Disposal
6.5	4.55	4.82	3.22	4.9	3.0I	Coefficient of variation
430	290	324	213	323	223	Log index

325	326A	326B	327	328	329	Serial number
8I937	82535		8I429	83026	82323	Hospital number
37	32		27	2I	27	Age
2+0	6+0		I+0	0+0	0+0	Parity
24.I0.70	I3.7.70		2.I0.70	7.I0.70	9.I0.70	Expected date of delivery
4I	40	4I	40	4I	39	Gestation at FECG (weeks)
0	0		0	0	0	Medical condition
I	8		I	2	I	Obstetrical condition
I	0		0	I	I	Induction
5	2.75		2	6.5	20	Duration of Ist. stage (hrs)
0.I2	0.5		0.25	I	0.5	Duration of 2nd. stage (hrs)
I	I		I	I	3	Delivery
0	0		0	0	0	Dysmaturity
I3	I3		8	I3	5	Error in dates
6.II.70	26.7.70		I0.I0.70	20.I0.70	I4.I0.70.	Date of delivery
3.23	4.I4		3.57	3.5I	3.43	Weight at delivery (Kgs)
2	I		I	2	I	Sex
9	8		8	9	8	Apgar at I min.
I0	I0		I0	I0	I0	Apgar at 5 min.
II	II		II	II	II	Apgar at I0 min.
0	0		0	0	0	Complications
404.9	442.5	394.74	376.5	397.74	444.54	Mean of int. nist.(millisecs)
I3.2	I8.I	I6.5	I2	7.23	9.8	Standard deviation (")
I	I		I	I	I	Disposal
3.25	4.I	4.2	3.2	I.32	2.2	Coefficient of variation
220	297	237	327	I2I	I6I	Log index

330A	330B	331	332	333	334	Serial number
81791		81098	76500	81976	83137	Hospital number
23		31	35	24	19	Age
0+1		1+0	2+1	0+0	0+0	Parity
8.10.70		20.9.70	23.10.70	15.7.70	7.10.70	Expected date of delivery
38	39	37	40	40	41	Gestation at FECG (weeks)
0		0	0	0	0	Medical condition
1		3	0	1	2	Obstetrical condition
1		0	1	1	1	Induction
6		13	4.25	2	3.5	Duration of 1st. stage (hrs)
0.5		0.5	0.33	0.66	0.66	Duration of 2nd. stage (hrs)
1		1	1	1	1	Delivery
0		0	0	0	0	Dysmaturity
0		-17	4	3	13	Error in dates
8.10.70		3.9.70	27.10.70	18.7.70	20.10.70	Date of delivery
3.48		3.11	3.23	3.9	3.26	Weight at delivery (Kgs)
2		2	2	1	2	Sex
9		9	8	9	9	Apgar at 1 min.
10		10	10	10	10	Apgar at 5 min.
11		11	11	11	11	Apgar at 10 min.
0		0	0	0	0	Complications
449.12	446.8	389.4	460.24	456.9	415.45	Mean of int. nist.(millisecs)
9.1	7.53	12.43	15.24	12.9	9.22	Standard deviation (")
1	1	1	1	1	1	Disposal
2.02	1.7	3.2	3.3	2.8	2.21	Coefficient of variation
149	123	203	250	211	153	Log index

335	336					Serial number
77260	81885					Hospital number
22	36					Age
I+0	2+0					Parity
9.11.69	10.6.70					Expected date of delivery
38	38					Gestation at FECG (weeks)
I0	0					Medical condition
0	8					Obstetrical condition
0	0					Induction
8.5	9.25					Duration of Ist. stage (hrs)
I	1					Duration of 2nd. stage (hrs)
I	I					Delivery
0	0					Dysmaturity
7	8					Error in dates
I6.II.69	I8.6.70					Date of delivery
3.26	4.56					Weight at delivery (Kgs)
I	I					Sex
8	8					Apgar at I min.
I0	I0					Apgar at 5 min.
II	II					Apgar at 10 min.
2	0					Complications
439.02	445.2I					Mean of int. nist.(millisecs)
I2.34	22.7I					Standard deviation (")
I	I					Disposal
2.3I	5.I					Coefficient of variation
203	372					Log index

APPENDIX B

CASE SUMMARIES.

The cases are loosely grouped by Apgar score -

Apgar 0 - 4 Nos. 200 - 220

Apgar 5 - 7 Nos. 221 - 260

Apgar 8 - 10 Nos. 261 - 336

The following are of particular interest -

201, 203, 206, 207, 210, 215,

218, 225, 228, 232, 240, 243,

248, 259, 260, 269, 273, 275,

280, 292, 313, 317, 318, 322,

329, 331.

Case No.200 - This 25 year old para 0 + 2 was admitted for rest because of her bad obstetric history. In this pregnancy she threatened to abort at 19 weeks and was anaemic.

She was induced at term and had a short and quite easy labour. The baby was born spontaneously but with a much lower Apgar than expected (4).

In labour the foetal heart stayed very steady (132 - 136 per minute) and no meconium was passed.

The explanation for the poor result seems to be mechanical in that the umbilical cord was tightly round the baby's neck. This would be difficult to predict.

Mean cardiac interval	-	443.7
Standard deviation	-	7.74
Coefficient of variation	-	1.74
Log. index	-	127
Apgar	-	4

Case No. 201 - A 32 year old para 1 + 0 who was admitted in false labour. She was also found to have a urinary infection.

Two days after admission she spontaneously commenced to labour and after 9 hours delivered a very limp, ill baby.

None of the FECG indices gave any warning of this though late in the second stage the foetal heart suddenly dropped to 88 per minute and meconium staining appeared. This was undoubtedly due to a mechanical strangling of the baby by its umbilical cord.

This could not have been predicted by ante-natal FECG though it could have been diagnosed by in-labour monitoring.

Mean cardiac interval	- 417.3
Standard deviation	- 8.4
Coefficient of variation	- 2.0
Log. index	- 139
Apgar	- 1

Case No. 202 - This 19 year old primigravida was reputedly at 44 weeks gestation. The foetal heart had been thought to be irregular on auscultation. This irregularity did not show on the FECG. All the FECG indices predicted a good foetal condition.

After surgical induction the patient laboured very poorly for 2 days and came to Caesarean section. The baby's condition at birth was not good though it responded rapidly to resuscitation.

The mothers pelvimetry measurements after delivery showed a minor degree of contracted pelvis.

This case shows the necessity for some method of predicting maternal performance in addition to foetal status.

Mean cardiac interval	-	420.96
Standard deviation	-	8.6
Coefficient of variation	-	2.03
Log. index	-	142
Apgar	-	3

Case No.203 - A 25 year old para 1+ 0 admitted past dates for induction. Labour followed medical induction with a first stage of 11 hours and a second stage of 25 minutes. Before the onset of the second stage the foetal heart which had been steady at 144 per minute suddenly fell to 116 then 84, 64 and 0 over 15 minutes.
Caesarean section was not performed and a fresh stillbirth delivered vaginally.
All the FECG indices except perhaps the mean put this baby at very high risk.
The mother has since had a successful vaginal delivery of a girl, Apgar 9.

Mean cardiac interval	-	414.1
Standard deviation	-	30.25
Coefficient of variation	-	7.3
Log. index	-	502
Apgar	-	0 Foetal death.

Case No. 204 - This 25 year old primigravida was admitted past term with a frank breech presentation. Attempts at external version under anaesthesia had failed. After a weeks bed rest she was induced and had a 13 hour labour with an assisted breech delivery.

During her stay in hospital the FECG indices all improved changing from a poor prognosis to a good one.

It is difficult to draw conclusions from this case as the method of delivery almost invariably causes a low Apgar score.

Mean cardiac interval	-	415.12	407.0
Standard deviation	-	18.8	9.11
Coefficient of variation	-	4.52	2.24
Log. index	-	312	152
Apgar	-	2	

Case No. 205 - A 42 year old para 1 + 1 admitted at term with ruptured membranes but not in labour.

On the face of it this patient should have done well but in the event she developed foetal distress and came to Caesarean section.

A limp baby with an Apgar of 2 was delivered.

In this case both the CV and Log. index were high and put the baby correctly in the at risk category. The CV was the more convincing index.

Mean cardiac interval	-	429.7
Standard deviation	-	18.9
Coefficient of variation	-	4.4
Log. index	-	312
Apgar	-	2

Case No. 206 - This 17 year old primigravida was admitted at 42 weeks of gestation for induction. Induction was delayed for a week during which the FECG indices clearly changed for the worse.

After an 18 hour first stage the mother was clearly making little progress.

The foetal heart in this case shows clearly the initial rise in foetal heart rate which proceeds the classical slow rate of foetal distress. The rate rose from a steady 130 per minute to 172 per minute.

Caesarean section was performed and a limp baby with an Apgar of 2 was delivered.

Most authorities seem to agree that delay past 42 weeks in a primigravid patient puts the baby at risk of placental insufficiency which seems to have occurred here.

Mean cardiac interval	-	450.6	455.7
Standard deviation	-	9.82	19.54
Coefficient of variation	-	2.2	4.31
Log. index	-	161	319
Apgar	-	2	

Case No. 207 - This 36 year old para 2 + 0 was admitted at term with mild hydramnios.

X-ray unfortunately showed a marked hydrocephalous presenting as a breech. Induction was followed by a short first stage of 4 hours and the aftercoming head was perforated.

Clearly the baby was dead on delivery.

The FECG indices put this baby at high risk but the conditions were so unusual that no conclusions could safely be drawn.

Mean cardiac interval	-	402.6
Standard deviation	-	18.12
Coefficient of variation	-	4.5
Log. index	-	302
Apgar	-	0

Case No. 208 - This 20 year old primigravid patient was admitted at term for induction because of a minor degree of contraction at the pelvic brim.

After 36 hours of labour the cervix was fully dilated and forceps were applied under epidural anaesthesia.

The baby was not delivered and LUSCS was necessary.

Not surprisingly the baby was delivered with a low Apgar of 3.

The patient collapsed after the operation and required an 11 pint blood transfusion.

Both the mean cardiac cycle interval and the CV put this baby at risk before this traumatic entry into the world though it is hardly fair to claim an accurate prediction in the circumstances.

Mean cardiac interval	-	360.11
Standard deviation	-	11.51
Coefficient of variation	-	3.2
Log. index	-	196
Apgar	-	3

Case No. 209 - This was a case of pre-eclampsia in a 22 year old primigravida with a minor contracted pelvis. She was admitted at 39 weeks with a slightly raised BP. After a weeks rest with minimal fall in BP to $\frac{130}{90}$ she was induced.

After 9½ hours of labour the foetal heart which had been steady between 140 and 158 per minute rose to 184 per minute. Foetal distress was diagnosed and LUSCS performed. The baby's Apgar was 2.

Over the week in hospital the mean cardiac cycle showed no change. The decrease in CV and Log. index was due entirely to a drop in the SD.

Both readings for the CV put this child at risk.

The Log. index did not.

Mean cardiac interval	-	441.98	442.43
Standard deviation	-	16.95	14.51
Coefficient of variation	-	3.83	3.3
Log. index	-	278	238
Apgar	-	2	

Case No. 210 - A para 1 + 0, admitted at term because of a previous LUSCS for foetal distress.

Shortly after the FECG examination the patient spontaneously commenced in labour. After three hours minimal contractions the membranes ruptured and the liquor was found to be very heavily meconium stained. Caesarean section was again performed and the infant's Apgar score was 4.

This case illustrates several practical points. The foetal heart was reported between 110 and 140 beats per minute yet was considered regular. The very high SD certainly belies this and emphasises that at the fast rate of the foetal heart, irregularity is difficult to detect subjectively.

Both the CV and the Log index put this child at risk. The CV more positively so.

Mean cardiac interval	-	435.42
Standard deviation	-	20.56
Coefficient of variation	-	4.72
Log. index	-	338
Apgar	-	4

Case No. 211 - A 26 year old primigravida known to have a minor contracted pelvis. She was admitted at 41 weeks for induction and a trial of labour. After 26 hours in the first stage this was considered to have failed and Caesarean section performed. The foetal heart rate throughout was "clear and regular" between 136 and 148 beats per minute. There was no meconium staining.

All the FECG indices put this child at risk, in the event correctly.

Mean cardiac interval	- 391.4
Standard deviation	- 18.82
Coefficient of variation	- 4.8
Log. index	- 315
Apgar	- 4

Case No. 212 - This 15 year old girl was supposedly at 44 weeks on admission. She had a contracted pelvis and was allowed a trial of labour after rupture of the membrane. She never really commenced to labour and came to LUSCS. The baby's Apgar was 4.

The FECG indices certainly predicted a better result than that obtained.

Mean cardiac interval	- 415.1
Standard deviation	- 10.4
Coefficient of variation	- 2.5
Log. index	- 173
Apgar	- 4

Case No. 213 - A primigravid patient, age 34, admitted at term for induction.

A relatively short first stage of 4½ hours ensued. In the second stage however the foetal heart varied enormously between 96 and 160 beats per minute and forceps were applied. The baby's Apgar was 3.

Both the CV and Log. index put this infant at risk.

Mean cardiac interval	- 403.22
Standard deviation	- 19.44
Coefficient of variation	- 4.82
Log. index	- 324
Apgar	- 3

Case No. 214 - This was a case of a breech presentation in a 24 year old primigravida at term. The patient also had moderate pre-eclampsia (BP $\frac{170}{100}$). At surgical induction heavily meconium stained liquor was obtained and LUSCS performed without awaiting the onset of labour. The baby's Apgar was 2.

The low mean cardiac cycle (ie fast rate) and raised CV put this baby, correctly, at risk. The Log. index did not.

Mean cardiac interval	- 376.9
Standard deviation	- 12.6
Coefficient of variation	- 3.33
Log. index	- 212
Apgar	- 2

Case No. 215 - This 38 year old para 1 + 0 had suffered iron deficiency anaemia throughout the pregnancy. She was admitted because of this and suspected dysmaturity.

The baby suddenly and unexpectedly died. After a medical induction she delivered a macerated stillbirth.

The only post mortem finding was of a twisted, necrosed umbilical cord.

Though the FECG indices gave some indication of the poor outcome they could not be expected to cope with this degree of mechanical abnormality.

Mean cardiac interval	- 447.99
Standard deviation	- 17.41
Coefficient of variation	- 3.9
Log. index	- 285
Apgar	- 0

Case No. 216 - This 27 year old, para 2 + 1, was admitted for elective section because of two previous sections for disproportion.

The baby's Apgar was surprisingly low at 2.

All the FECG indices prognosed a much better result and clearly failed in prediction.

Mean cardiac interval	- 407.4
Standard deviation	- 4.8
Coefficient of variation	- 1.2
Log. index	- 80
Apgar	- 2

Case No. 217 - A 28 year old para 2 + 0 admitted for elective section because of two previous sections for disproportion. Mild anaemia was present.

The baby's Apgar was 4.

The FECG indices, mainly because of the high SD, suggested a much worse prognosis than this but as the patient was not allowed to labour the baby was not stressed.

Mean cardiac interval	-	429.9
Standard deviation	-	34.9
Coefficient of variation	-	8.14
Log. index	-	577
Apgar	-	4

Case No. 218 - This 30 year old primigravida was induced at 42 weeks gestation.

During 24 hours desultory labour the foetal heart rose slowly to 160 per minute and then dropped to 120 and became irregular. The liquor became meconium stained. LUSCS was performed for foetal distress and the baby born with an Apgar of 2.

This poor result was predicted by the FECG indices.

Mean cardiac interval	-	392.41
Standard deviation	-	24.14
Coefficient of variation	-	6.2
Log. index	-	404
Apgar	-	2

Case No. 219 - Although this 31 year old woman was technically a para 1 + 1 her full term pregnancy had ended in a stillbirth. She was admitted with pre-eclampsia and was induced. After 12 hours in labour the foetal heart rate rose from 120 to 160 per minute and all things considered a Caesarean section seems fully justified. The baby's Apgar was only 3.
This state of affairs was partially predicted by the CV but not the Log. index.

Mean cardiac interval	-	441.6
Standard deviation	-	17.1
Coefficient of variation	-	3.9
Log. index	-	281
Apgar	-	3

Case No. 220 - A 16 year old primigravida admitted at 33 weeks with premature rupture of the membranes.
The day following admission (and FECG) she had a very brisk ante-partum haemorrhage and had a 3 pint transfusion. Despite this she had a spontaneous vertex delivery of a baby boy, Apgar 3.
Unfortunately the FECG was done before the APH occurred so the indices must be inaccurate.

Mean cardiac interval	-	394.4
Standard deviation	-	11.75
Coefficient of variation	-	3.0
Log. index	-	197
Apgar	-	3

Case No. 221 - A 31 year old para 2 + 0. This patient was anaemic and had a small ante-partum haemorrhage at 37 weeks.

She was induced and had a normal vaginal delivery after a very short labour. The foetal heart did not vary greatly (128 - 140 per minute).

The CV put this baby at greater risk than did the Log. index which was more accurate.

Mean cardiac interval	- 417.82
Standard deviation	- 17.25
Coefficient of variation	- 4.12
Log. index	- 290
Apgar	- 5

Case No. 222 - A very straightforward case of 35 year old para 4 + 0. She was admitted at term with a slight elevation of BP but promptly commenced to labour and delivered normally.

The child's Apgar was 7 and the FECG indices all satisfactory.

Mean cardiac interval	- 398.2
Standard deviation	- 9.19
Coefficient of variation	- 2.31
Log. index	- 154
Apgar	- 7

Case No. 223 - A 19 year old primigravida admitted 10 days past term for induction. Mild hydramnios was present.

Buccal pitocin administration provoked labour and after 6 hours the foetal heart, which had been steady at 136 - 140, dropped to 96 per minute. However by then the second stage was nearly complete and a low forceps delivery carried out. The baby's Apgar was 6. The CV indicated a slightly worse prognosis than this but the Log. index was accurate enough.

Mean cardiac interval	-	430.02
Standard deviation	-	17.2
Coefficient of variation	-	4
Log. index	-	284
Apgar	-	6

Case No. 224 - A 28 year old para 3 + 0 admitted because of failed external cephalic version and anaemia.
The FECG indices put this baby into the risk category but despite an assisted breech delivery the baby was fit when delivered. Two weeks elapsed between the FECG and delivery, which is longer than desirable for accurate prognosis.
The FECG trace showed the breech presentation.

Mean cardiac interval	-	427.23
Standard deviation	-	24.33
Coefficient of variation	-	5.7
Log. index	-	402
Apgar	-	7

Case No. 225 - This was a case of a failed external cephalic version in a 27 year old para 1 + 0.
She went into labour spontaneously and after 5 hours delivered by the breech with minimal assistance.
The FECG trace showed the breech presentation.
Both the CV and LI put this baby correctly at some risk though the SD did not. In labour the foetal heart was steady between 140 and 156/min. There was no meconium staining.

Mean cardiac interval	-	410.01
Standard deviation	-	19.0
Coefficient of variation	-	4.63
Log. index	-	316
Apgar	-	5

Case No. 226 - A 22 year old primigravid patient admitted with ruptured membranes. Not established in labour.

The CV and the LI put this patient into the risk category. After 15 hours of labour the foetal heart rate dropped to 80/min. and a forceps delivery undertaken. The baby did well but without the forceps no doubt might well have been poor.

Mean cardiac interval	- 477.45
Standard deviation	- 20.02
Coefficient of variation	- 4.2
Log. index	- 325
Apgar	- 7

Case No. 227 - A 17 year old primigravid patient admitted at term with minimal blood pressure rise. Following induction she had a straightforward vertex delivery in 12 hours. The foetal heart was steady between 132 and 152 in labour and the baby did well. All the FECG indices correctly predicted this as a good risk case.

Mean cardiac interval	- 434.1
Standard deviation	- 12.61
Coefficient of variation	- 2.9
Log. index	- 208
Apgar	- 7

Case No. 228 - A 20 year old para 1 + 0 with anaemia and a variable lie at 41 weeks gestation.

After induction the first stage of labour was adequate at 9 hours. The second stage was reputed to last ¾ hrs before a forceps delivery was conducted for uterine inertia. Considering this length of second stage the baby's Apgar of 7 is remarkably good. The FECG indices put this baby in the good risk group.

This case demonstrates that assessment of the foetus is only part of the equation, maternal assessment is desirable to avoid this kind of problem.

Mean cardiac interval	- 452.33
Standard deviation	- 9.63
Coefficient of variation	- 2.13
Log. index	- 157
Apgar	- 7

Case No. 229 - A 35 year old para 0 + 1 admitted past dates for induction.

Following induction she had a spontaneous vertex delivery during which the foetal heart fell to 88/min. The CV and LI put this baby at risk though the SD did not. In the event the baby was in fair condition.

Mean cardiac interval	- 429.45
Standard deviation	- 18.6
Coefficient of variation	- 4.33
Log. index	- 307
Apgar	- 7

Case No. 230 - A small APH in a 29 year old para 1 + 0. The patient went into spontaneous labour but after only 7 hours the foetal heart dropped to 74/min.

The baby was delivered by Venteuse extraction under general anaesthesia.

All the FECG indices failed to put this baby at risk.

Mean cardiac interval	- 434.85
Standard deviation	- 6.8
Coefficient of variation	- 1.55
Log. index	- 112
Apgar	- 6

Case No. 231 - A 16 year old primigravid patient with pre-eclampsia. Labour was induced and after a 15 hour first stage and 45 minutes of second stage a forceps delivery was conducted because of a rising maternal BP. At no stage did the baby show any signs of foetal distress.

None of the FECG indices put the baby at risk.

Mean cardiac interval	- 451.4
Standard deviation	- 10.65
Coefficient of variation	- 2.4
Log. index	- 147
Apgar	- 7

Case No. 232 - A case of twins in a primigravid patient. The FECG correctly showed the twins and it was possible to construct an interval histogram for one of them. Unfortunately it is impossible to tell which one so no attempt at prognosis could be made.

Mean cardiac interval	- 451.8
Standard deviation	- 7.78
Coefficient of variation	- 1.72
Log. index	- 127

Case No. 233 - A 27 year old para 1 + 1 admitted for induction because of pre-eclampsia.

The CV and SD both put the baby at risk though the LI, as it seems correctly, was on the border-line.

Mean cardiac interval	-	434.1
Standard deviation	-	23.7
Coefficient of variation	-	5.45
Log. index	-	290
Apgar	-	7

Case No. 234 - A 22 year old para 0 + 0 induced at term because of pre-eclampsia.

After 8 hours in first stage and 1 hour in second stage the foetal head was fixed in a deep transverse arrest and a forceps delivery required.

The FECG indices put this baby at better risk than transpired though no doubt the result was influenced by mechanical factors.

Mean cardiac interval	-	455.14
Standard deviation	-	10.5
Coefficient of variation	-	2.3
Log. index	-	172
Apgar	-	6

Case No. 235 - A 22 year old para 2 + 0 admitted at term. As this patient had had a previous Caesarean section for foetal distress she was induced after 1 week. She failed to progress in the second stage and was delivered by forceps.

Two FECG examinations were done here which both showed a good foetal prognosis which was modified by the type of delivery.

Mean cardiac interval	-	419.12	455.73
Standard deviation	-	11.4	7.3
Coefficient of variation	-	2.71	1.6
Log. index	-	189	119
Apgar	-	6	

Case No. 236 - The classical Rottenrow patient, a 20 year old primigravida presenting for the first time. She was immediately admitted because of pre-eclampsia and induced. The foetal heart rose to 178/min. and meconium stained liquor was noted. She was delivered by forceps.

Of the FECG indices only the CV put this baby at some risk.

Mean cardiac interval	-	402.24
Standard deviation	-	13.75
Coefficient of variation	-	3.42
Log. index	-	229
Apgar	-	6

Case No. 237 - A 19 year old primigravid patient admitted for induction as postmature.

Following induction she had a quick spontaneous vertex delivery.

The CV put this baby at some slight risk.

Mean cardiac interval	- 411.8
Standard deviation	- 13.91
Coefficient of variation	- 3.41
Log. index	- 231
Apgar	- 7

Case No. 238 - This 29 year old para 2 + 0 had a previous child die of congenital heart desease. She was admitted past term for induction and had a spontaneous vertex delivery.

All the FECG indices correctly put the baby at some slight risk.

Mean cardiac interval	- 402.2
Standard deviation	- 19.56
Coefficient of variation	- 4.9
Log. index	- 326
Apgar	- 7

Case No. 239 - This 18 year old para 1 + 1 was admitted at term because of a previous Caesarean section for disproportion.

After the FECG examination she had a brisk APH and was again sectioned. She was later found to have infective hepatitis as well.

Not surprisingly the FECG indices bear little relevance to the result.

Mean cardiac interval	- 444.5
Standard deviation	- 11.65
Coefficient of variation	- 2.62
Log. index	- 191
Apgar	- 6

Case No. 240 - This 19 year old primigravid patient was 3 weeks past her dates on admission.

After induction she had a long labour with unco-ordinate uterine action. Nevertheless after 55 hours she delivered spontaneously.

The baby's Apgar was 6 but it was very slow to respond and the Apgar was only 7 after 5 minutes.

The FECG indices all put this baby at risk.

Mean cardiac interval	- 375.2
Standard deviation	- 22.41
Coefficient of variation	- 6.00
Log. index	- 378
Apgar	- 6

Case No. 241 - A 38 year old para 1 + 1 who had had a previous Caesarean section. In this pregnancy she was considered to have essential hypertension. Her BP remained about $\frac{140}{100}$ all through the last trimester.
Two FECG examinations were conducted.
With the exception of the means the FECG indices all showed deterioration. There was quite a large change for the good in the means.
Elective Caesarean section was performed so the baby did not have to suffer the stresses of labour.

Mean cardiac interval	-	386.3	462.5
Standard deviation	-	13.3	19.6
Coefficient of variation	-	3.44	4.2
Log. index	-	223	319
Apgar	-	6	

Case No. 242 - This was a case of pre-eclampsia in a 31 year old para 0 + 1. On admission her BP was $\frac{135}{80}$ and a week later it was $\frac{140}{90}$ despite rest and sedation.
The FECG indices all followed this worsening situation.
After induction she had a small accidental haemorrhage and was delivered by forceps. The foetal heart fell as low as 80/minute.
None of the indices put this baby at severe risk which despite the haemorrhage was correct.

Mean cardiac interval	-	450.43	418.50
Standard deviation	-	9.12	10.6
Coefficient of variation	-	2.02	2.53
Log. index	-	149	176
Apgar	-	6	

Case No. 243 - This 21 year old para 2 + 0 was admitted for treatment of anaemia.

Her Hb was 8g. on admission and rose to 10g. after a total dose imferon infusion.

She was induced at term and had a spontaneous vertex delivery after a short labour.

The FECG indices reflected the clinical course here but the Apgar score was probably lowered artificially by the cord being tight round the baby's neck.

Mean cardiac interval	-	373.6	424.39
Standard deviation	-	17.85	11.0
Coefficient of variation	-	4.8	2.6
Log. index	-	301	182
Apgar	-	6	

Case No. 245 - This 17 year old primigravida was admitted at 39 weeks with pre-eclampsia. With a week's bed rest her BP fell from $\frac{160}{100}$ to $\frac{130}{90}$. She was induced at term and after a short labour of 9 hours the mother's BP rose to $\frac{150}{95}$ and the baby was delivered by forceps. There were no foetal indications for instrumental delivery. The foetal heart rate was remarkably steady at 148 - 152/min and there was no meconium staining. None of the FECG indices put this baby at risk and they reflected the clinical improvement over the week.

Mean cardiac interval	-	408.45	388.34
Standard deviation	-	12.42	7.5
Coefficient of variation	-	3.04	1.95
Log. index	-	207	127
Apgar	-	7	

Case No. 246 - This 20 year old primigravid patient had been admitted four times during this pregnancy because of a raised BP. This always settled immediately after admission. She was again admitted at term for induction.

After a fairly short labour the mother's BP rose to $\frac{170}{95}$ and the baby was delivered by forceps. There were no foetal indications for delivery. The foetal heart remained within the range 136 - 156/min. and there was no meconium staining.

The FECG indices all put the baby in the good risk group which was borne out by the result.

Mean cardiac interval	-	436.6
Standard deviation	-	11.56
Coefficient of variation	-	2.64
Log. index	-	190
Apgar	-	7

Case No. 247 - This was a case of pre-eclampsia in a 24 year old para 0 + 1. She was admitted at 39 weeks with a BP of $\frac{130}{90}$. This fell to $\frac{110}{70}$ and she was induced at term.

After a good first stage the mother made heavy weather of the second stage. After an hour the foetal heart was found to be irregular between 104 and 124 /min. There was no meconium staining. The baby was delivered by forceps.

The CV followed the mother's improvement but in this case the LI did not. Initially the baby had a very small mean interval (i.e. fast rate) which became more normal but the variability did not improove.

The first CV put the baby at risk but none of the other indices did. Considering the delivery difficulties the baby did well.

Mean cardiac interval	-	352.7	393.04
Standard deviation	-	14.81	15.32
Coefficient of variation	-	4.2	3.9
Log. index	-	252	256
Apgar	-	7	

Case No. 248 - This 23 year old para 1 + 0 patient demonstrates an interesting point.

She was admitted at 41 weeks gestation as the foetal heart was found to be irregular by the stethoscope.

The FECG showed no such irregularity until a stethoscope was applied. In the event the umbilical cord was found to be round the baby's neck and the irregularity was caused by mechanical pressure on the cord.

As the patient had a previous failed trial of labour she came to Caesarean section.

The FECG indices correctly did not place this baby at high risk.

Mean cardiac interval	-	415.9
Standard deviation	-	12.41
Coefficient of variation	-	3.00
Log. index	-	206
Apgar	-	6

Case No. 249 - This 19 year old primigravida was admitted at term as she was a grade I cardiac. She went into labour spontaneously. The first stage was short, 7 hours, but the second stage lasted 2½ hours. She was delivered by forceps.

During labour the foetal heart varied between 126 and 164 yet was always reported as "regular".

There was some meconium staining in the liquor.

None of the FECG indices put this baby at risk.

Mean cardiac interval	-	451.4
Standard deviation	-	7.0
Coefficient of variation	-	1.54
Log. index	-	115
Apgar	-	5

Case No. 250 - Essentially this was a case of a failed trial of labour in a 23 year old primigravida. Post partum pelvimetry confirmed a contracted pelvis.
The FECG indices did not put this baby at risk.

Mean cardiac interval	-	430.35
Standard deviation	-	11.74
Coefficient of variation	-	2.72
Log. index	-	194
Apgar	-	7

Case No. 251 - A 28 year old primigravida admitted at 42 weeks for induction.
Induction was followed by a first stage of 26 hours and after 1½ hours in the second stage foetal distress was diagnosed because of meconium staining and a drop in foetal heart rate to 80/min. The baby was delivered by forceps.
The SD, CV and LI all put this patient in the poor risk category which was probably justified by the Apgar score of 5.

Mean cardiac interval	-	457.75
Standard deviation	-	26.8
Coefficient of variation	-	5.84
Log. index	-	437
Apgar	-	5

Case No. 252 - This 34 year old para 3 + 0 was admitted for induction because of pre-eclampsia. A very short labour followed with 3 hours in first stage but after 30 minutes in second stage forceps delivery was performed. There is no adequate reason given for this. The foetal heart remained within the range 136 - 156/min. and there was no meconium staining.
Of the FECG indices only the CV put this baby slightly at risk.

Mean cardiac interval	-	388.9
Standard deviation	-	13.62
Coefficient of variation	-	3.5
Log. index	-	228
Apgar	-	7

Case No. 253 - This 25 year old woman had had 3 abortions and no live children.
In pregnancy she had threatened to abort at 16 weeks. She was admitted past term for induction. A short labour of 6½ hours followed. In the second stage very heavy meconium staining was noted and despite a normal foetal heart rate forceps were applied and the baby delivered.
None of the FECG indices put the baby at risk.

Mean cardiac interval	-	366.9
Standard deviation	-	9.52
Coefficient of variation	-	2.6
Log. index	-	161
Apgar	-	7

Case No. 254 - This 29 year old primigravid patient was admitted past term with mild pre-eclampsia. Induction was followed by very inco-ordinate labour and after 22 hours a rim of cervix was still present. The baby was delivered by Venteuse extraction. There were no foetal indications for delivery.
None of the FECG indices put this baby at risk.

Mean cardiac interval	-	367.33
Standard deviation	-	11.14
Coefficient of variation	-	3.03
Log. index	-	189
Apgar	-	6

Case No. 255 - This 25 year old para 3 + 1 was admitted supposedly 2 weeks past term.
She went into labour spontaneously and delivered in only 2 hours.
None of the FECG indices put the baby at risk.

Mean cardiac interval	-	455.45
Standard deviation	-	10.85
Coefficient of variation	-	2.4
Log. index	-	177
Apgar	-	7

Case No. 256 - This was a case of mild pre-eclampsia in a 23 year old primigravid patient. She was admitted for induction. After 1 hour in the second stage foetal distress was diagnosed and delivery was by forceps. All the FECG indices, except the mean, forecast a poor risk baby. In the event the baby's Apgar was 5 and had only risen to 8 with 5 minutes active resuscitation.

Mean cardiac interval	-	435.5
Standard deviation	-	30.0
Coefficient of variation	-	6.9
Log. index	-	494
Apgar	-	5

Case No. 257 - This 20 year old primigravida was admitted because of extensive oedema.
Her BP was $\frac{130}{90}$. After a week the oedema had gone and and the BP remained at $\frac{130}{90}$. As she was reputedly at 42 weeks gestation she was induced. The first stage of labour was short, 5 hours, but after an hour in second stage the mother's BP had risen to $\frac{160}{100}$. Meconium staining was noted and the foetal heart rose to 160/min. Forceps were applied and the umbilical cord was found to be round the infant's neck.
Over the week the FECG indices followed the improving oedema and did not place the baby at risk.

Mean cardiac interval	-	372.5	384.1
Standard deviation	-	9.1	5.81
Coefficient of variation	-	2.4	1.51
Log. index	-	153	98
Apgar	-	6	

Case No. 258 - This 26 year old primigravida was admitted 2 weeks past term for induction. She had a short labour and a spontaneous vertex delivery.
The SD, CV and LI all put this baby, incorrectly, at risk. It may be that the unusually smooth delivery caused the child very little stress.

Mean cardiac interval	-	445.9
Standard deviation	-	24.74
Coefficient of variation	-	5.54
Log. index	-	406
Apgar	-	7

Case No. 259 - A 19 year old para 0 + 1 admitted for delivery as a breech. External version had failed. She laboured well and after 3 hours delivered the breech. At this point I.V. ergometrine was given in error and the head had to be delivered under general anaesthetic.
The baby's condition in the circumstances was surprisingly good.
The FECG indices had indicated a good prognosis, which under normal circumstances would have been accurate.

Mean cardiac interval	- 428.55
Standard deviation	- 12.32
Coefficient of variation	- 2.9
Log. index	- 203
Apgar	- 5

Case No. 260 - This 15 year old primigravida demonstrated the phenomenon of foetal heart irregularity being caused by the pressure of the stethoscope. The FECG only showed the irregularity while the stethoscope was applied firmly.
The mother laboured poorly and after 20 hours in first stage and 1½ hours in second stage the baby was delivered by forceps.
The FECG indices put this baby at risk.

Mean cardiac interval	- 399.55
Standard deviation	- 21.7
Coefficient of variation	- 5.4
Log. index	- 362
Apgar	- 6

Case No. 261 - This 37 year old woman had a sad case history. Now in her ninth pregnancy she had only three living children. Two children had died of fibrocystic disease.

She laboured spontaneously and delivered in the very short time of 45 minutes. The baby did well despite a dubious FECG prediction.

Mean cardiac interval	- 444.74
Standard deviation	- 18.81
Coefficient of variation	- 4.22
Log. index	- 308
Apgar	- 8

Case No. 262 - This 23 year old primigravida was admitted 2 weeks past term for induction.

Early in labour the foetal heart dropped to 96/min. and was obviously irregular.

Caesarean section was done for foetal distress.

The FECG indices put this baby very much at risk and no doubt would have been correct had labour continued.

Mean cardiac interval	- 429.5
Standard deviation	- 25.2
Coefficient of variation	- 5.9
Log. index	- 416
Apgar	- 8

Case No. 263 - This 18 year old primigravida was suspected of having a contracted pelvis.
In the event she laboured spontaneously and effectively and had a normal delivery.
The FECG indices, wrongly, put this baby at risk.

Mean cardiac interval	-	398.5
Standard deviation	-	26.1
Coefficient of variation	-	6.5
Log. index	-	436
Apgar	-	9

Case No. 264 - This was a case of pre-eclampsia in a 21 year old primigravida. Her blood pressure fell from $\frac{150}{90}$ to $\frac{110}{80}$ after admission.
Unfortunately the FECG examination was only carried out on admission and gave a falsely poor prediction.

Mean cardiac interval	-	400.7
Standard deviation	-	21.8
Coefficient of variation	-	5.4
Log. index	-	364
Apgar	-	8

Case No. 265 - This was a 20 year old primigravida admitted at 42 weeks gestation for induction. Signs of foetal distress appeared in the first stage. The foetal heart varied widely between 100 and 136 /minute. There was no meconium staining. She was delivered by forceps immediately full dilatation occurred.
The FECG indices had put this baby at risk. This was presumably correct as labour was not allowed to proceed.

Mean cardiac interval	-	500.24
Standard deviation	-	31.73
Coefficient of variation	-	6.34
Log. index	-	511
Apgar	-	8

Case No. 266 - This 19 year old primigravida was admitted with pneumonia at 38 weeks gestation.
After two weeks she laboured spontaneously but poorly. She was delivered by forceps.
The FECG examination here was 2 weeks before delivery, and while she still had the pneumonia. It yielded a falsely high prognosis.

Mean cardiac interval	-	456.97
Standard deviation	-	41.02
Coefficient of variation	-	8.97
Log. index	-	670
Apgar	-	9

Case No. 267 - This 26 year old primigravida had a very straightforward delivery.

The FECG indices all predicted the good outcome.

Mean cardiac interval	- 442.74
Standard deviation	- 11.97
Coefficient of variation	- 2.7
Log. index	- 196
Apgar	- 8

Case No. 268 - This 39 year old para 8 + 2 had a surprisingly long labour of 17 hours. Nevertheless the outcome was as predicted by the FECG indices.

Mean cardiac interval	- 433.45
Standard deviation	- 12.2
Coefficient of variation	- 2.8
Log. index	- 201
Apgar	- 9

Case No. 269 - This 24 year old para 1 + 0 was admitted 2 weeks past term.

She went into labour spontaneously and delivered easily in 4 hours.

During labour the foetal heart varied from 116 to 168/min. yet was reported as regular.

The FECG indices gave a false poor prognosis.

Mean cardiac interval	- 475.71
Standard deviation	- 24.45
Coefficient of variation	- 5.14
Log. index	- 397
Apgar	- 9

Case No. 270 - This 34 year old para 2 + 2 was admitted with an unstable lie.

Once the lie stabilised she was induced and delivered in under 3 hours.

There was a slight improvement in the FECG indices over the week but in any case they all gave a good prognosis.

Mean cardiac interval	-	417.9	415.92
Standard deviation	-	8.7	5.9
Coefficient of variation	-	2.1	1.41
Log. index	-	144	98
Apgar	-	8	

Case No. 271 - This was a case of pre-eclampsia in a 19 year old para 0 + 1. On admission her BP was $\frac{145}{90}$.

This settled over the week to $\frac{110}{65}$.

She was induced at term and delivered easily.

The FECG indices all followed the clinical course over the week and gave a good prognosis.

Mean cardiac interval	-	400.7	438.35
Standard deviation	-	10.71	10.41
Coefficient of variation	-	2.7	2.4
Log. index	-	179	171
Apgar	-	8	

Case No. 272 - This 33 year old woman had a bad obstetric history.

She had had four abortions and one live child.

She was admitted in false labour. She was induced and had an uncomplicated labour and delivery.

The CV put this baby at risk though the SD and LI did not.

Mean cardiac interval	-	416.4
Standard deviation	-	15.44
Coefficient of variation	-	3.7
Log. index	-	256
Apgar	-	9

Case No. 273 - This was a case of an unstable lie in a 23 year old para 3 + 1.

The lie stabilised at 41 weeks gestation and she was medically induced. She delivered spontaneously after 4 hours labour.

Three FECG examinations were carried out all with essentially similar results.

They all gave a good prognosis.

Mean cardiac interval	-	457.4	360.2	405.71
Standard deviation	-	10.63	8.62	10.31
Coefficient of variation	-	2.32	2.4	2.54
Log. index	-	174	146	172
Apgar	-	9		

Case No. 274 - This 20 year old primigravida was admitted at 39 weeks gestation because of vomiting which had led to mild dehydration. She laboured spontaneously and delivered easily.
Unfortunately a second FECG was not done after correction of the dehydration so the first gave a falsely poor prognosis.

Mean cardiac interval	- 434.32
Standard deviation	- 23.93
Coefficient of variation	- 5.51
Log. index	- 394
Apgar	- 8

Case No. 275 - This grossly obese, 19 stone, 24 year old, para 1 + 0 demonstrates a practical point. Palpation of the foetus was not possible yet the FECG was easily obtained. Fat never seems to affect the amplitude of the FECG.
She laboured unnoticed and delivered in the ward.
The FECG indices correctly prognosed the good result.

Mean cardiac interval	- 452.24
Standard deviation	- 7.51
Coefficient of variation	- 1.66
Log. index	- 123
Apgar	- 8

Case No. 276 - This 23 year old para 1 + 1 was admitted by the Flying Squad as an AxH. Examination in theatre revealed a posterior placenta praevia and the baby was delivered by Caesarean section.
It is probably not fair to claim that the FECG indices correctly prognosed a healthy baby.

Mean cardiac interval	- 446.9
Standard deviation	- 11.9
Coefficient of variation	- 2.66
Log. index	- 195
Apgar	- 9

Case No. 277 - This 24 year old primigravida was induced at term because of mild pre-eclampsia. She delivered spontaneously in 4 hours.
The FECG indices did not place the baby at risk.

Mean cardiac interval	- 448.4
Standard deviation	- 13.45
Coefficient of variation	- 3.0
Log. index	- 220
Apgar	- 9

Case No. 278 - This was one of the few outpatients in whom a really satisfactory FECG was obtained. She was a 25 year old primigravida.
She laboured spontaneously but after 1 hour in the second stage was delivered by forceps. There were no foetal indications for this.
The FECG indices correctly predicted the good outcome.

Mean cardiac interval	-	414.8
Standard deviation	-	12.8
Coefficient of variation	-	3.1
Log. index	-	212
Apgar	-	9

Case No. 279 - This 20 year old primigravida was reputedly at 42 weeks gestation when she was induced. She delivered unaided in 5 hours.
The FECG indices predicted the good outcome except perhaps for the CV which was borderline.

Mean cardiac interval	-	435.24
Standard deviation	-	14.7
Coefficient of variation	-	3.4
Log. index	-	242
Apgar	-	9

Case No. 280 - This 27 year old para 0 + 1 was induced at 41 weeks gestation. She had a short first stage of 6 hours but after 1½ hours in second stage the baby was delivered by forceps.

This was the only baby in the series to be awarded an Apgar score of 10 so clearly there were no foetal indications for interferance.

The FECG indices predicted a good outcome.

Mean cardiac interval	-	415.4
Standard deviation	-	13.7
Coefficient of variation	-	3.3
Log. index	-	224
Apgar	-	10

Case No. 281 - This was a very straightforward case of a 32 year old para 2 + 0.

She laboured spontaneously and delivered easily.

The FECG indices correctly predicted the good result.

Mean cardiac interval	-	417.3
Standard deviation	-	9.8
Coefficient of variation	-	2.35
Log. index	-	162
Apgar	-	8

Case No.282 - This 30 year old para 0 + 1 had a minor degree of contracted pelvis.

Following induction she was never really established in labour and came to Caesarean section.

The FECG indices predicted a poor result which, happily, did not occur. However the baby was never really stressed by labour so the accuracy cannot be assessed.

Mean cardiac interval	- 417.7
Standard deviation	- 19.71
Coefficient of variation	- 4.7
Log. index	- 327
Apgar	- 9

Case No. 283 - This 19 year old primigravida was induced at 42 weeks gestation.

She had a short first stage of labour (4 hours) but was delivered by forceps after 1½ hours in the second stage. There was no slowing of the foetal heart and no meconium staining.

The FECG indices correctly predicted the good outcome.

Mean cardiac interval	- 422.55
Standard deviation	- 7.33
Coefficient of variation	- 1.73
Log. index	- 121
Apgar	- 9

Case No. 284 - This 25 year old primigravida was admitted at 39 weeks gestation with mild pre-eclampsia. Over a week her BP fell from $\frac{140}{100}$ to $\frac{120}{80}$.
She was induced at term. After 17 hours in first stage and 1 hour in second stage the mother's BP rose to $\frac{170}{110}$.
She was delivered by forceps. There were no foetal indications for delivery.
The FECG indices followed the improvement in BP and correctly prognosed the good outcome. Most of the change was in the SD - i.e. the irregularity of the foetal heart - as the mean stayed remarkably constant.

Mean cardiac interval	-	451.14	452.31
Standard deviation	-	11.5	8.6
Coefficient of variation	-	2.54	1.9
Log. index	-	188	141
Apgar	-	8	

Case No. 285 - Despite a previous Caesarean section this 31 year old para 3 + 0 laboured spontaneously and delivered easily.
The CV put this baby at risk and the LI just missed a poor prognosis. Both were clearly wrong.

Mean cardiac interval	-	462.51
Standard deviation	-	18.32
Coefficient of variation	-	3.96
Log. index	-	299
Apgar	-	9

Case No. 286 - This was a case of a 23 year old para 1 + 0 admitted at 38 weeks gestation with an APH. She was induced at term and laboured well, delivering spontaneously in 4 hours.

Over two weeks the FECG indices improved markedly and the last examination predicted a fair outcome.

Mean cardiac interval	-	426.4	391.32
Standard deviation	-	25.62	14.52
Coefficient of variation	-	6	3.7
Log. index	-	423	243
Apgar	-	9	

Case No. 287 - This was an uncomplicated case of a 19 year old primigravida. She was induced at term and delivered spontaneously in 11 hours.

The FECG indices correctly prognosed the good result.

Mean cardiac interval	-	387.5
Standard deviation	-	5.33
Coefficient of variation	-	1.4
Log. index	-	89
Apgar	-	9

Case No. 288 - This 21 year old primigravida was induced at term.

After a good first stage of 9½ hours she tired in the second stage and after 1½ hours was making no progress. The baby was delivered by forceps.

There were no foetal indications for delivery. The CV suggested a poor prognosis but the other FECG indices did not.

Mean cardiac interval	- 448.55
Standard deviation	- 17.8
Coefficient of variation	- 3.96
Log. index	- 292
Apgar	- 9

Case No. 289 - This 20 year old primigravida was admitted at 39 weeks gestation with a BP of $\frac{160}{100}$. She was induced and delivered spontaneously in 10 hours. There was no indications of foetal distress and the FECG indices gave a falsely poor prognosis.

Mean cardiac interval	- 435.6
Standard deviation	- 27.7
Coefficient of variation	- 5.9
Log. index	- 423
Apgar	- 9

Case No. 290 - This 23 year old primigravida was admitted because of a persistant urinary infection. She was also Rhesus negative.
At 42 weeks she laboured spontaneously and delivered in 10 hours.
The FECG indices prognosed the good outcome.

Mean cardiac interval	-	447.1
Standard deviation	-	13.9
Coefficient of variation	-	3.11
Log. index	-	228
Apgar	-	9

Case No. 291 - This 24 year old primigravida was thought to be at 42 weeks gestation. She was induced and delivered normally in 18 hours. There were no foetal complications.
The FECG indices agreed on a good prognosis.

Mean cardiac interval	-	347.56
Standard deviation	-	8.44
Coefficient of variation	-	2.43
Log. index	-	144
Apgar	-	8

Case No. 292 - This is an interesting case of a 26 year old para 2 + 2 thought to be "small for dates".
She was admitted at 38 weeks by dates and the FECG indices showed a very good prognosis. The clinicians were unaware of this.
The urinary oestriol level fell to 9mgs. and she was induced at 38 weeks. At this point the FECG indices showed an even better prognosis which in the event was correct. The baby weighed 2.9kgs. (6lbs. 8oz.) which is hardly dysmature.

Mean cardiac interval	-	380.2	433.93
Standard deviation	-	8.52	3.56
Coefficient of variation	-	2.24	0.81
Log. index	-	143	59
Apgar	-	9	

Case No. 293 - This 32 year old para 0 + 1 was admitted with mild pre-eclampsia. She went into labour spontaneously and delivered easily in 3½ hours.
The CV put this baby just into the poor risk category but the SD and LI did not.
In the event the baby was diagnosed as dysmature and perhaps the unusually easy labour saved the day.

Mean cardiac interval	-	459.91
Standard deviation	-	16.12
Coefficient of variation	-	3.5
Log. index	-	263
Apgar	-	9

Case No. 294 - This 21 year old primigravida was admitted in false labour at term.

She was induced but after 16 hours in the first stage and 1 hour in second stage she failed to progress. The baby was delivered by forceps but at no stage were there any signs of foetal distress.

The good condition of the baby was correctly prognosed by the FECG indices.

Mean cardiac interval	- 450.3
Standard deviation	- 12.3
Coefficient of variation	- 2.72
Log. index	- 201
Apgar	- 9

Case No. 295 - A 19 year old primigravida who was admitted at 41 weeks gestation for induction. She laboured well and delivered in 7 hours with no sign of foetal distress.

The FECG indices indicated a good prognosis.

Mean cardiac interval	- 406.9
Standard deviation	- 7.84
Coefficient of variation	- 1.93
Log. index	- 130
Apgar	- 9

Case No. 296 - This 36 year old primigravida was admitted for induction but went into labour spontaneously. The first stage lasted 4 hours and after 30 minutes in second stage she was delivered by forceps. There seems no adequate reason for this. There were no signs of foetal distress and it was hardly a long labour.
The FECG indices prognosed the good outcome.

Mean cardiac interval	-	436.22
Standard deviation	-	9.32
Coefficient of variation	-	2.14
Log. index	-	153
Apgar	-	8

Case No. 297 - This 25 year old para 2 + 0 was Rhesus negative but had no antibodies. She was admitted with a urinary infection.
She laboured spontaneously but was delivered by forceps after 4 hours. The reason given is foetal distress but there are no signs of this on the labour record.
The FECG indices varied a little over the two weeks but all predicted the good result.

Mean cardiac interval	-	393.9	444.8	419.24
Standard deviation	-	10.54	9.7	11.7
Coefficient of variation	-	2.7	2.2	2.8
Log. index	-	176	159	194
Apgar	-	8		

Case No. 298 - This 19 year old primigravida laboured and delivered spontaneously in 6½ hours.

There was no foetal distress.

The FECG indices agreed with the good result.

Mean cardiac interval	-	461.4
Standard deviation	-	15.3
Coefficient of variation	-	3.31
Log. index	-	249
Apgar	-	9

Case No. 299 - This 28 year old para 5 + 0 had an atrial septal defect. She laboured spontaneously and delivered in less than 1 hour.

The FECG indices falsely indicated a poor prognosis.

Mean cardiac interval	-	419.04
Standard deviation	-	20.9
Coefficient of variation	-	5.0
Log. index	-	346
Apgar	-	9

Case No. 300 - This 39 year old primigravida failed to labour after induction and was delivered by Caesarean section.

The FECG indices indicated a good result.

Mean cardiac interval	-	405.3
Standard deviation	-	12.13
Coefficient of variation	-	3.0
Log. index	-	202
Apgar	-	9

Case No. 301 - This 19 year old primigravida laboured spontaneously but after a good first stage of 2 hours failed to progress in second stage. She was delivered by forceps. There were no foetal indications for delivery. The FECG indices gave a good prognosis.

Mean cardiac interval	- 411.84
Standard deviation	- 11.47
Coefficient of variation	- 2.81
Log. index	- 191
Apgar	- 9

Case No. 302 - This 34 year old para 5 + 0 had previously delivered by Caesarean section. In this pregnancy she was induced but failed to labour. Caesarean section was again performed.

The CV indicated a poor risk but the other FECG indices disagreed. As the baby was not subjected to the stress of labour it is difficult to assess this case.

Mean cardiac interval	- 427.7
Standard deviation	- 16.7
Coefficient of variation	- 3.9
Log. index	- 276
Apgar	- 9

Case No.303 - This 30 year old primigravida had psychiatric problems. She was induced at 42 weeks gestation but had a very poor labour. She was delivered by forceps after 18 hours in first stage and 2 hours in second stage.

The FECG indices gave a falsely poor prognosis.

Mean cardiac interval	-	397.3
Standard deviation	-	20.11
Coefficient of variation	-	5.1
Log. index	-	336
Apgar	-	9

Case No. 304 - This 34 year old para 6 + 1 was induced at 38 weeks gestation following a very small APH. She delivered spontaneously in 2 hours with no complications. The FECG indices prognosed the good result.

Mean cardiac interval	-	400.0
Standard deviation	-	10.12
Coefficient of variation	-	2.52
Log. index	-	169
Apgar	-	9

Case No. 305 - This 22 year old primigravida was admitted for elective section because of known contracted pelvis.

The FECG indices predicted a poor outcome but as the baby was not subjected to the stress of labour their value cannot be judged.

Mean cardiac interval	- 440.2
Standard deviation	- 22.2
Coefficient of variation	- 5.03
Log. index	- 365
Apgar	- 8

Case No. 306 - This 28 year old primigravid patient was admitted at 42 weeks gestation for induction. She laboured poorly, 45 hours in first stage and 1hour in second stage before being delivered by forceps.

There were no foetal indications for delivery - in fact the foetal heart remained remarkably steady about 140 /min. throughout.

The FECG indices predicted the good foetal outcome.

Mean cardiac interval	- 396.9
Standard deviation	- 9.31
Coefficient of variation	- 2.34
Log. index	- 156
Apgar	- 9

Case No. 307 - This 24 year old primigravida was induced at 41 weeks gestation. She laboured poorly for 16 hours and was delivered by Caesarean section. The reason given for this was foetal distress. The labour record does not substantiate this. The foetal heart stayed within the range 144 - 160 /min. and there was no meconium staining.

The FECG indices predicted a good result.

Mean cardiac interval	-	418.8
Standard deviation	-	11.6
Coefficient of variation	-	2.8
Log. index	-	192
Apgar	-	8

Case No. 308 - This 22 year old para 1 + 0 was reputedly at 43 weeks gestation when she was induced. She laboured well and delivered in 2 hours.

The FECG indices showed deterioration over the last week and the last CV gave a falsely poor prognosis. The other indices remained within the good prognosis group.

Mean cardiac interval	-	457.45	432.22
Standard deviation	-	12.41	17.4
Coefficient of variation	-	2.71	4.02
Log. index	-	203	287
Apgar	-	9	

Case No. 309 - This was a case of pre-eclampsia in a 36 year old para 0 + 2. She was induced at term and delivered spontaneously.

The FECG examination was done one week before delivery and the pre-induction examination was unfortunately missed.

Both the CV and mean were slightly in the poor prognosis group but the SD and LI were good. A more recent examination may well have shown improvement.

Mean cardiac interval	-	379.53
Standard deviation	-	12.99
Coefficient of variation	-	3.42
Log. index	-	219
Apgar	-	8

Case No. 310 - This was a case of mild pre-eclampsia in a 30 year old para 1 + 0.

On admission her BP was $\frac{140}{90}$ and it settled to $\frac{106}{70}$ over a week.

She was induced at term and delivered spontaneously.

The FECG indices followed her clinical improvement and predicted the good outcome.

Mean cardiac interval	-	438.8	421.2
Standard deviation	-	14.4	12.45
Coefficient of variation	-	3.3	2.96
Log. index	-	237	206
Apgar	-	9	

Case No. 311 - This 40 year old para 4 + 0 was induced at 41 weeks gestation because of raised blood pressure. She delivered easily in 2 hours with no signs of foetal distress.

The FECG prediction was good.

Mean cardiac interval	- 508.2
Standard deviation	- 11.8
Coefficient of variation	- 2.31
Log. index	- 189
Apgar	- 9

Case No. 312 - This 29 year old para 2 + 0 laboured spontaneously and delivered in 3 hours with no complications. The FECG indices predicted the good result.

Mean cardiac interval	- 367.2
Standard deviation	- 11.67
Coefficient of variation	- 3.2
Log. index	- 198
Apgar	- 8

Case No.313 - This 24 year old para 2 + 0 seemed to have everything against her. She had pre-eclampsia, was thought to be "small for dates" and had low urinary oestriol levels. The FECG indices agreed with this poor state of affairs yet although the child was born dysmature it was in very good condition.

Mean cardiac interval	- 445.11
Standard deviation	- 22.7
Coefficient of variation	- 5.1
Log. index	- 372
Apgar	- 9

Case No. 314 - This 32 year old para 5 + 0 laboured and delivered spontaneously with no complications. The FECG indices predicted the good outcome.

Mean cardiac interval	-	417. 05
Standard deviation	-	9.41
Coefficient of variation	-	2.26
Log. index	-	156
Apgar	-	9

Case No. 315 - This 39 year old para 6 + 1 was medically induced at term. She delivered spontaneously in 5 hours. The foetal heart rate remained within the range 144 - 152 /min. but there was considerable meconium staining. The FECG indices had not predicted a good outcome and it may be that, had labour not been so simple, they could well have been correct.

Mean cardiac interval	-	454.6
Standard deviation	-	21.83
Coefficient of variation	-	4.8
Log. index	-	357
Apgar	-	8

Case No. 316 - This 26 year old para 0 + 1 had a Shirodka suture during this pregnancy. After its removal she laboured spontaneously and delivered in 13 hours with no complications.

The CV put this baby slightly at risk but the other FECG indices did not.

Mean cardiac interval	-	439.33
Standard deviation	-	15.12
Coefficient of variation	-	3.44
Log. index	-	248
Apgar	-	9

Case No. 317 - This 37 year old para 3 + 0 was admitted with a small APH at 38 weeks gestation. She laboured spontaneously at term and delivered normally.

The FECG examination was done on admission and the next two were missed.

The baby had a true knot in the umbilical cord and although delivered with an Apgar of 8 collapsed soon after and required very active resuscitation.

Mean cardiac interval	-	498.97
Standard deviation	-	20.40
Coefficient of variation	-	4.10
Log. index	-	328
Apgar	-	8

Case No. 318 - This very careless 46 year old para 5 + 2 was a grade IV cardiac failure due to mitral stenosis. She first presented at the clinic at term and was immediately admitted.

Her condition improved with care and following induction she delivered easily.

The FECG indices quite dramatically followed her improvement and predicted the eventual good outcome.

Mean cardiac interval	-	443.51	458.3
Standard deviation	-	22.31	9.21
Coefficient of variation	-	5.02	2.0
Log. index	-	366	150
Apgar	-	9	

Case No. 319 - This 23 year old primigravida laboured spontaneously at 38 weeks gestation.

After 10½ hours in first stage and 2 hours in second stage she was de livered by forceps. The foetal heart showed no signs of distress but meconium was passed.

The FECG indices predicted the good result.

Mean cardiac interval	-	450.02
Standard deviation	-	11.0
Coefficient of variation	-	2.44
Log. index	-	180
Apgar	-	9

Case No. 320 - This 24 year old para 2 + 0 had a small APH at 38 weeks gestation. She laboured spontaneously at term and delivered very quickly (1 hour).
The FECG indices predicted the good outcome.

Mean cardiac interval	-	473.64
Standard deviation	-	12.71
Coefficient of variation	-	2.7
Log. index	-	206
Apgar	-	9

Case No. 321 - This was a 19 year old primigravida admitted in false labour at term. She recommenced after induction and delivered spontaneously after 10 hours with no complications.
The CV falsely predicted a poor outcome but the other FECG indices did not.

Mean cardiac interval	-	451.3
Standard deviation	-	18.0
Coefficient of variation	-	4.0
Log. index	-	294
Apgar	-	9

Case No. 322 - This 29 year old para 1 + 0 lost her first baby as a result of placental insufficiency.
In this pregnancy she was admitted at 38 weeks gestation with pre-eclampsia. Her blood pressure settled from $\frac{150}{95}$ to $\frac{140}{80}$. She laboured and delivered spontaneously with no signs of foetal distress.
The FECG indices certainly followed the clinical improvement but did not predict the final outcome very accurately.

Mean cardiac interval	-	384.5	377.52
Standard deviation	-	25	17.2
Coefficient of variation	-	6.5	14.55
Log. index	-	430	290
Apgar	-	9	

Case No. 323 - This 24 year old primigravida was admitted because of moderate pre-eclampsia. Her BP settled from $\frac{170}{90}$ to $\frac{110}{90}$ and she laboured and delivered spontaneously.
The FECG indices followed her improvement accurately and predicted the good result.

Mean cardiac interval	-	403.2	394.8
Standard deviation	-	19.44	12.72
Coefficient of variation	-	4.82	3.22
Log. index	-	324	213
Apgar	-	8	

Case No. 324 - This was a 24 year old primigravida. She was admitted with pre-eclampsia and her BP settled from $\frac{150}{95}$ to $\frac{110}{75}$.

She laboured and delivered spontaneously with no signs of foetal distress.

The FECG indices followed her clinical improvement and correctly predicted the outcome.

Mean cardiac interval	-	397.0	446.8
Standard deviation	-	19.3	13.62
Coefficient of variation	-	4.9	3.05
Log. index	-	323	223
Apgar	-	9	

Case No. 325 - This 37 year old para 2 + 0 was induced at 42 weeks gestation and delivered in 5 hours with no complications.

The FECG indices correctly prognosed the outcome.

Mean cardiac interval	-	404.9
Standard deviation	-	13.2
Coefficient of variation	-	3.25
Log. index	-	220
Apgar	-	9

Case No. 326 - This 32 year old para 6 + 0 was admitted for social reasons. There was no change in her condition over a week.

She laboured spontaneously and delivered in 3 hours. Although there was no concern over the foetal heart rate copious meconium was passed.

The CV predicted a poor outcome though the SD and LI did not.

Mean cardiac interval	-	442.5	394.74
Standard deviation	-	18.1	16.5
Coefficient of variation	-	4.1	4.2
Log. index	-	297	287
Apgar	-	8	

Case No. 327 - This 27 year old para 1 + 0 was blind as was her previous child.

She laboured spontaneously and delivered in 2½ hours with no complications.

The LI was falsely predictive of a poor outcome but the other indices were within the good range.

Mean cardiac interval	-	376.5
Standard deviation	-	12
Coefficient of variation	-	3.2
Log. index	-	327
Apgar	-	8

Case No. 328 - This 21 year old primigravida was induced at 42 weeks gestation. She laboured well and delivered normally.

The FECG indices predicted a good outcome.

Mean cardiac interval	-	397.74
Standard deviation	-	7.23
Coefficient of variation	-	1.82
Log. index	-	121
Apgar	-	9

Case No. 329 - This 27 year old primigravida was admitted with mild pre-eclampsia.

She was induced but laboured poorly. She had a difficult forceps delivery despite which the baby was in excellent condition. There were no signs of foetal distress.

The FECG indices predicted a good result.

Mean cardiac interval	-	444.54
Standard deviation	-	9.8
Coefficient of variation	-	2.2
Log. index	-	161
Apgar	-	8

Case No. 330 - This 23 year old para 0 + 1 was admitted because of pre-eclampsia. Her BP settled from $\frac{150}{100}$ to $\frac{110}{80}$ and she was induced at term.

She delivered spontaneously in 6½ hours with no signs of foetal distress.

The FECG indices all followed the clinical improvement and predicted the good outcome.

Mean cardiac interval	-	446.8
Standard deviation	-	7.53
Coefficient of variation	-	1.7
Log. index	-	123
Apgar	-	9

Case No. 331 - This 31 year old para 1 + 0 was admitted following a very small APH.

In the ward the foetal heart rate was reported as 180 /min. - the mean calculated from the FECG made it only 153 /min.

She laboured spontaneously and delivered in 13 hours.

The FECG indices correctly predicted this good result.

Mean cardiac interval	-	389.4
Standard deviation	-	12.43
Coefficient of variation	-	3.2
Log. index	-	208
Apgar	-	9

Case No. 332 - This 35 year old para 2 + 0 laboured spontaneously and delivered after 5 hours with no complications.

The FECG indices correctly predicted a good result.

Mean cardiac interval	- 460.24
Standard deviation	- 15.34
Coefficient of variation	- 3.3
Log. index	- 250
Apgar	- 8

Case No. 333 - This 24 year old primigravida was induced at term. She delivered in only 3 hours with no complications.

The FECG predicted the good result.

Mean cardiac interval	- 456.9
Standard deviation	- 12.9
Coefficient of variation	- 2.8
Log. index	- 211
Apgar	- 9

Case No. 334 - This 19 year old primigravida was induced at 41 weeks gestation. She delivered in 5 hours with no signs of foetal distress.

The FECG indices agreed on a good prognosis.

Mean cardiac interval	- 415.45
Standard deviation	- 9.22
Coefficient of variation	- 2.21
Log. index	- 153
Apgar	- 9

Case No. 335 - This 22 year old para 1 + 0 laboured spontaneously and delivered in 10 hours with no complications.

The FECG indices predicted the good outcome.

Mean cardiac interval	-	439.02
Standard deviation	-	12.34
Coefficient of variation	-	2.81
Log. index	-	203
Apgar	-	8

Case No. 336 - This 36 year old para 2 + 0 laboured spontaneously and delivered in 11 hours. There were no signs of foetal distress.

The FECG indices wrongly placed this baby in the at risk group.

Mean cardiac interval	-	445.21
Standard deviation	-	22.71
Coefficient of variation	-	5.10
Log. index	-	372
Apgar	-	8

APPENDIX C.

I. Ballistocardiograph analysis.

2. Second form of analysis

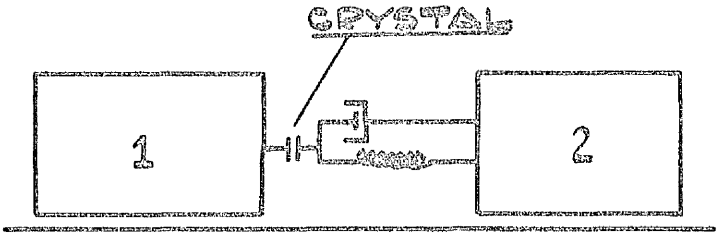
3. Impedance plethysmogram analysis.

APPENDIX C.

1 BALLISTOCARDIOGRAPH ANALYSIS

Theory

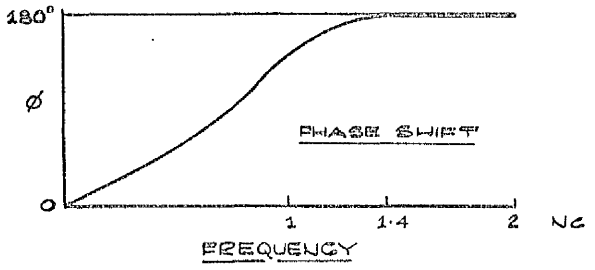
Consider two large masses, on a friction free plane surface, connected by a coupling which includes a force transducer (crystal). The coupling can be represented by a spring and dashpot system.



If mass 2 is fixed in position then the natural frequency of mass 1 with respect to it will be very low if mass 1 is large enough. The converse is also true. If both masses are free the natural frequency of the system is virtually totally dependent upon the coupling.

When a disturbing force is applied to mass 1, in the axis of the coupling, the force is transferred to mass 2 (and therefore measured by the transducer) with an efficiency dependent on the frequency of the disturbing force and the natural frequency of the system, i.e. the coupling.

For practical purposes, if the frequency of the disturbing force is 1.4 or more of the natural frequency, a linear response is obtained.



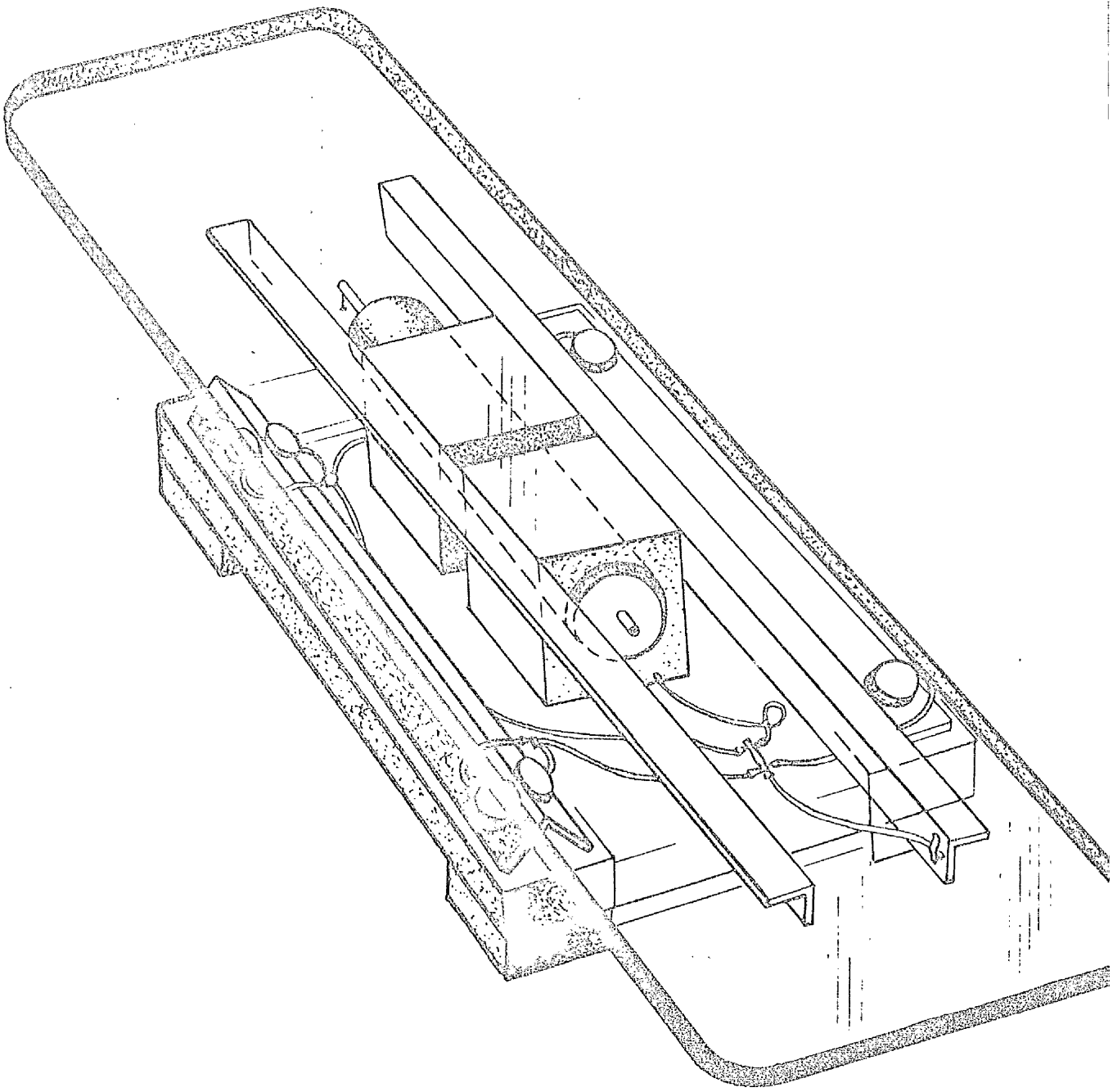
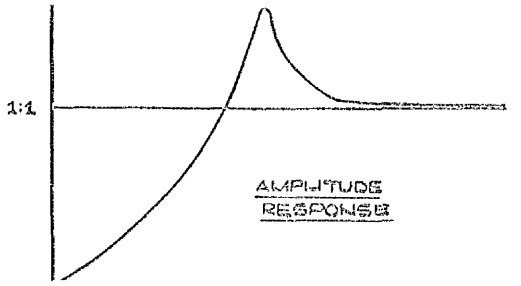


Fig. C.I. Air-bearing ballistocardiograph.

Similarly, phase shift with respect to frequency will reach and remain at 180° about 1.4 x Nc.



If the calibration of the transducer is accurately known, then direct force measurements of any disturbing force (or its components in the line of the coupling) can be measured directly and provided the natural frequency of the coupling is below the frequencies to be measured, phase shift should remain at a constant 180° irrespective of the masses involved (provided they are large).

Practice

The idealised situation is closely approached by the air-bearing bed developed by N.E.L. (Fig. 1.)

The table (mass 1), made of plywood, is suspended over rails by 6 pressure fed, orifice controlled air-bearing.

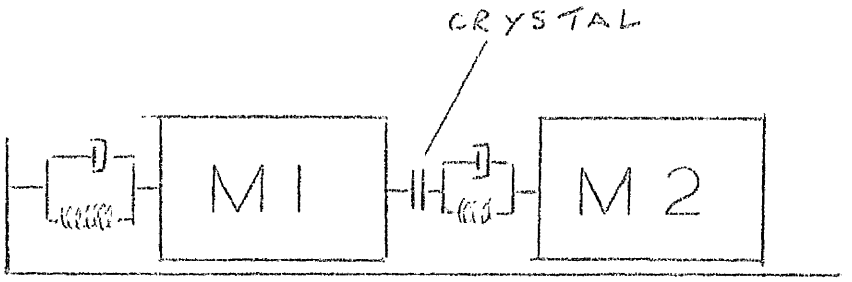
The bearings and rails are arranged to allow only one degree of freedom. That is longitudinal movement. The opposing surfaces are machined plane to a tolerance of 29 μ.

The inertia mass (mass 2) is a steel cylinder suspended beneath the table by two annular air bearings and coupled to the table via a stiff rubber coupling and Xtal transducer (Kistler Instruments Type 922).

The output of the Xtal transducer is amplified by a Kistler Instrument Model 568 charge amplifier and provided the coupling is arranged to satisfy the theorectical requirements, direct measurement of the disturbing forces acting on the table can be obtained.

2. Second form of analysis.

If the coupling between the two masses is made less rigid and another coupling to mechanical "earth" is made (this prevents drift of the whole system) the model then becomes that of a double mass, spring and dashpot.



In this case the applied force F causes a displacement Y_1 of M_1 and Y_2 of M_2 and this relative displacement is measured by the crystal. F is calculated from the formula

$$F = K \times (Y_1 - Y_2)$$

K is the spring constant.

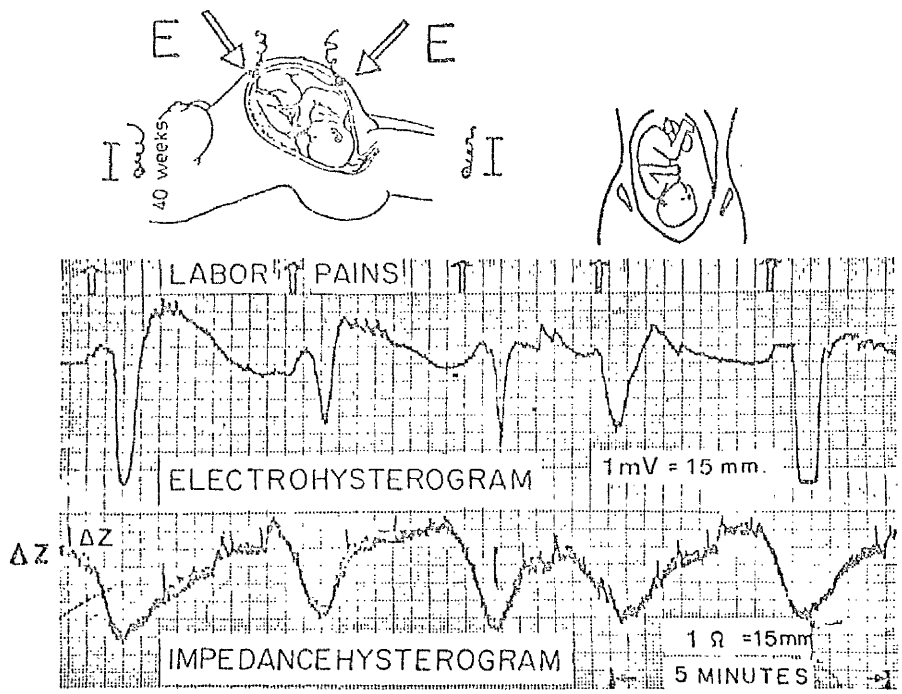


Fig. 1. Typical electrohysterograms and impedance hysterograms during evident labor. Current is applied to ECG type of electrodes on neck and one leg. Low constant current of about 1 mA at 5 kHz or higher is applied to current electrodes at the neck or arm level and one leg. Potential drop is measured from the smaller silvered discs or other electrodes in the Y-axis at about 15 cm apart over the bulging uterus. Control maternal ECG is usually recorded from lead I and fetal electrocardiograms are usually recorded in the Y-axis in line, but beyond the impedance electrodes. The micro-changes in impedance are super-imposed on this fundamental impedance pattern

APPENDIX C.

3. IMPEDANCE PLETHYSMOGRAM ANALYSIS

This analysis is presented by kind permission of Prof. Nyboer and his colleagues.

Fig. 1 shows the methods used for recording and the transient averages on which the calculations are made are shown in Fig. 5.10.

Mutual base impedance was 4.25 Ω for the 15 cm abdominal section. Slower records easily identify maternal respiration. Ultra-slow records identify uterine contraction according to figure 1. Maternal plus foetal impedance pulse waves are recorded as ΔZ. The impedance rapidly decreases at about 0.3 sec following the maternal R-wave. This decrease represents an electrical shunt of blood resulting from an increase in volume of the uterus and abdomen occurring with each maternal pulse systole. The peak change of maternal volume systole occurs 0.15 sec later. The end-systolic phase and diastolic phase lasts 0.6 sec. This receding slope shows irregularities of volume or impedance. Using the method outlined previously, all foetal R-waves were easily identified and averaging of the impedance data produced a consistent foetal pulse wave.

The volume change as the arteriovenous volume (A - V) pulse within the field of the potential or impedance electrodes, measures about 0.002 Ω peak to peak for the foetus and 0.015 Ω peak to peak for the uterus and abdomen. The correction slope for venous return is about 40%. Calculations of blood volume pulsed on the basis of parallel law which we could ascribe to the foetus on the A - V difference alone , is 3.5 ml/beat. As the pulse rate was

140 min (SD = 3.5), the pulsatile index equalled 590 ml/beat before correction. The run-off correction approximated 142 ml. Thus, the total pulsatile volume index in the foetal torso region as measured approached 732 ml/min. With correction for venous return during systole, the pulsatile volume index of the uterine segment as measured with the foetus approximated 3,139 ml/min.

APPENDIX D.

1 Digicorder program.

2 MEDLARS search program.

'Digicorder' program to calculate mean, standard deviation and coefficient of variation.

PRESS FIND - CLEAR STORES - ENTER INITIAL x IN I - PRESS START
AND INPUT VALUES OF f. f=0 MUST BE PUNCHED ON KEYBOARD

```
BEGIN
STOP (enter f)
D2
ENTER II
RECALL A
X
RECALL I
STORE III
X
RECALL I
STORE IN IV
12.5
ADD TO I
END
RECALL IV
÷
RECALL II
=
CLEAR IV
RECALL I
STORE IN IV
RECALL III
÷
RECALL II
=
STOP (mean)
CLEAR II
RECALL T
STORE IN II
RECALL II
X
RECALL A
=
NEGATE
ADD TO IV
RECALL IV
√
STOP (S.D.)
X
100
=
÷
RECALL II
=
STOP (C.V.)
END
```

MEDLARS Search Program.

Search subject		Neonatal physiology and prognosis.
MeSH terms	List A	FETUS
		FETAL HEART
	List B	HUMAN
	List C	ELECTRODIAGNOSIS
		ELECTROCARDIOGRAPHY
		ELECTROENCEPHALOGRAPHY
		ELECTROKYMOGRAPHY
		GALVANIC SKIN RESPONSE
		TELEMETRY
		PROGNOSIS
		ULTRASONICS
		BALLISTOCARDIOGRAPHY
		ECHOCARDIOGRAPHY
Output		Search for A and B and C
Sorting output		Printout by author

APPENDIX E

I MEDICAL TERMS

II ENGINEERING TERMS

MEDICAL TERMS.

ACIDOSIS — A fall in blood pH - usually to less than 7.2.

AMNIOSCOPY — A technique for visually examining the membranes and liquor by the vaginal route.

ANOXIA — Complete lack of oxygen.

ANTEPARTUM — Before delivery.

BRADYCARDIA — A slowing of the heart. In the context pf foetal distress usually to a below 120 beats/min.

CAESAREAN SECTION — Delivery of a child through an incision (Latin caesere - to cut) in the mother's abdomen.

CONGENITAL — Present at birth.

EMBRYO — The developing baby in its first 3 months of intrauterine life.

ECG — Electrocardiograph - a recording of the electrical potentials developed by the heart.

FOETUS(fetus) — The unborn baby.

FUNDUS — The upper pole of the uterus.

HEART BLOCK — A failure of electrical conduction between the atria and venticles of the heart so that each beat at their own separate rate.

HYDATIDIFORM MOLE — A growth which fills the uterus. It is derived from the placental tissue of a fertilised ovum . It gives all the early signs and symptons of a pregnancy.

HYPOXIA — A partial lack of oxygen.

HYSTEROTOMY — The operation of opening the uterus. Usually performed to remove a small foetus - a caesarean section in miniature.

INDUCTION — The proceedure for encouraging labour to begin. Medical induction - this includes the time honoured oil, bath and enema, and the use of pitocin preparations either buccally or intravenously. Surgical induction - this involves dilation of the uterine cervix and rupture of the amniotic membranes.

LIQUOR AMNII — The 'waters' in which the foetus lies within the uterus.

MECONIUM — The contents of the foetal bowel.

NEONATE — The newborn infant in his first week of independent life.

PARACENTESIS — A technique for obtaining a sample of liquor by inserting a needle through the mother's abdomen.

PARTURITION — The process of birth.

PERINATAL — The perinatal period extends from the 28th week of a pregnancy to the end of the baby's first week of independent life.

POSITION — In obstetrics this term is used to describe the relationship of the presenting part of the foetus to its mothers pelvis. e.g. left-occipito - anterior or right - sacro - transverse.

POSTMATURE There is no general agreement on the definition of this term. For present purposes it will be considered as a pregnancy which has passed the expected date of delivery.

POSTPARTUM After delivery.

PREMATURE Although this term would seem to refer to the duration of intra - uterine life the definition is by birth weight. A weight of $5\frac{1}{2}$lbs or less is considered premature.

PUBIS The anterior join of the pelvic bones.

SUPRAVENTRICULAR TACHYCARDIA

A speeding up of the heart rate due to factors acting on the cardiac conduction system before it reaches the ventricles.

TACHYCARDIA An acceleration of the heart rate. In the context of foetal distress to over 160 beats/min.

VERNIX A combination of old skin, sebaceous material and liquor which covers the foetus in the later week of pregnancy.

VAGUS A nerve. A part of the parasympathetic system.

ENGINEERING TERMS.

The majority of the engineering terms used in this thesis are defined as they occur in the text. For more complete definitions the reader is referred to an elementary text-book of electrical engineering such as -

An Introduction to Electronics - by D. Hunter.
(Pub. Holt, Rinehart & Winston)

AMPERE(amp) Unit of electrical current.
The definition of the ampere is complex but for practical purposes it is defined against a standard available at the National Standard Bureau. 1 milliamp = amps x 10^{-3}

BANDWITH The range of frequencies over which an amplifier or other electronic circuit will operate efficiently.

BIO-ELECTRICITY Electrical signals produced by biological sources.

COMMOM MODE REJECTION
A measure of the ability of a differential amplifier to reject a signal present at both its inputs.

DIFFERENTIATION The conversion of a function of change to a function of rate of change.

DISCRIMINATION In this context the process of distinguishing one element of a complex electrical signal either by amplitude or frequency.

GAIN The gain of an amplifier is the ratio of the output signal (Vo) to the input signal (Vi). For convenience this is usually expressed in decibels (dB)

$$\text{gain} = \underline{(\log_{10} \frac{Vo}{Vi})}$$

GALVANOMETER — A device for measuring electrical current flow.

IMPEDANCE — The resistance offered to an alternating current by an electronic component or circuit, measured in ohms.

INTEGRATED CIRCUIT

A method for producing a complete electronic circuit on a single silicon chip. Transisters, diodes amd resistamces are most commonly used. Capacitors are difficult to manufacture in these circuits.

NOISE — In this context this is the unwanted components of the final electrical signal. The commomest sources of noise are the mains frequency (50 Hz) and the thermal noise generated in transisters.

OHM — Unit of resistance to current flow (R). Defined from the absolute ampere by OHM'S Law $\frac{E}{I} = R$

VOLT — Unit of electrical potential (E) defined from the absolute ampere by Ohm's Law E = IR.

$E = IR$

1 millivolt = volts x 10^{-3}

1 microvolt = volts x 10^{-6}