STATEMENT OF THE EXTENT OF MY PERSONAL CONTRIBUTION TO THE ORIGINAL WORK DESCRIBED IN THIS THESIS.

I was the sole worker in the following investigations:-

1. The studies concerning the effects of epidural analgesia on pulmonary ventilation before, during and after operation.
2. The measurements of blood loss in gynaecological surgery.
3. The measurement of the effect of epidural analgesia on central and peripheral venous pressure.
4. The recordings of uterine action in inco-ordinate labours by guard-ring tocograph.

I originated and was the principal worker in the following investigations:-

1. The studies of acid-base balance during epidural analgesia. Dr. J.G. Mone assisted with this work.
2. The measurement of blood loss at forceps delivery. Dr. G. Wallace assisted with this work.
3. The graphic analyses of labour for the assessment of the effect of epidural analgesia on inco-ordinate uterine action. Dr. J. Willocks was a joint worker.
4. The observations concerning the effect of epidural analgesia on hypertension during labour. Dr. J. Willocks worked with me on this investigation.

In the investigation into the effects of epidural analgesia on skin and muscle blood flow I used a heat clearance apparatus which

SUMMARY OF A THESIS ON EPIDURAL ANALGESIA

SUBMITTED FOR THE DEGREE OF DOCTOR OF MEDICINE

BY

DONALD D. MOIR, M.B., Ch.B., F.F.A.R.C.S., D.A., D.Obst.R.C.O.G..

There are two distinct sections in this thesis. The first concerns original investigations into the effects of epidural analgesia on pulmonary ventilation and acid-base balance. The second section comprises original investigations into various aspects of epidural analgesia in gynaecology and obstetrics. There are also descriptions of the techniques used, the complications encountered and a short history of epidural analgesia.

The effects of epidural analgesia on pulmonary ventilation and acid-base balance

Resting and maximal ventilation were assessed by measuring tidal volume, minute volume, vital capacity and peak expiratory flow rate. Measurements were made before and during high epidural block in unpremedicated subjects, some of whom were free of respiratory disease and some of whom had chronic broncho-pulmonary disease. Tidal and minute volumes were unaffected by epidural analgesia and vital capacity and peak expiratory flow rate were only slightly reduced, indicating that paralysis of the respiratory muscles was minimal. The results are analysed statistically.

During lower abdominal surgery under epidural analgesia, tidal and minute volumes varied widely in conscious patients, but were

always adequate for resting requirements. In the post-operative period resting ventilation was normal and maximal ventilation was about 80 per cent of the pre-operative level during epidural analgesia This finding demonstrates the superiority of epidural analgesia over other types of post-operative pain relief. Opiate drugs reduce maximal ventilation to about 30 per cent of normal.

Acid-base studies by the micro-method of Astrup confirmed the adequacy of resting alveolar ventilation during high epidural analgesi and may be regarded as complimentary to the studies of pulmonary ventilation.

The clinical applications of epidural analgesia in patients with severe respiratory disease are discussed and are illustrated by examples from the writer's experience.

The mode of action of epidural analgesia is discussed and the method is contrasted favourably with subarachnoid analgesia and general anaesthesia with particular reference to pulmonary function and blood gas values.

Epidural analgesia in gynaecology and obstetrics

The influence of epidural analgesia on blood loss in gynaecological and obstetric operations was studied. A haemoglobin extraction-dilution technique was used for the accurate measurement of total external blood loss.

At 117 Manchester operations and 94 vaginal hysterectomies, when epidural analgesia was administered the blood loss averaged 87 ml. and 166 ml. respectively and was approximately one third of the loss recorded under general anaesthesia with nitrous oxide and halothane or with nitrous oxide, a muscle relaxant and intermittent positive pressure ventilation. A statistical analysis shows that profound hypotension is not necessary for the effective reduction of bleeding when epidural analgesia is employed.

At forceps delivery, epidural analgesia was associated with a mean blood loss of 274 ml. while pudendal nerve block and general anaesthesia were associated with losses of 412 ml. and 518 ml. respectively. Statistical analysis of 214 forceps deliveries showed that the anaesthetic technique was the only factor which significantly influenced blood loss after normal labour.

In attempt to elucidate the mechanisms by which epidural block reduces operative bleeding, even in the absence of significant arterial hypotension, some studies of the peripheral circulation were performed. It was demonstrated that the central and peripheral venous pressure are reduced by epidural block and it is postulated that the fall in venous pressure contributes substantially to the reduction in blood loss at operation by reducing venous oozing.

A heat clearance technique was used to measure peripheral blood flow in the skin and muscle of the lower limb. Epidural analgesia caused a substantial increase in cutaneous blood flow and a small reduction in muscle blood flow. The vascular resistance was reduced in skin and increased in muscle. Allowances were made for reductions in mean arterial blood pressure.

Continuous lumbar epidural analgesia was used in the management of 224 patients who had prolonged and painful labours due to inco-ordinate uterine action. The factors associated with inco-ordinate labour are analysed in detail and the high incidence of relative cephalo-pelvic disproportion is stressed. Graphic analysis of 150 labours demonstrated that the cervix usually dilates more rapidly after the induction of epidural analgesia. It appears that epidural block has a therapeutic action on the dysfunctional uterus, as well as providing complete relief of pain and distress. A guard-ring tocodynamometer was used to demonstrate the inco-ordinate nature of the uterine action. It is probable that the use of epidural analgesia can often safely avoid delivery by Caesarean section in inco-ordinate labour. The perinatal mortality was 1.3 per cent in this series and is low for cases of this type.

Continuous epidural analgesia had a beneficial effect on severe hypertension during labour. The technique is excellent for forceps delivery and, in experienced hands, can be safer than general anaesthesia. The principal hazard of epidural analgesia in obstetrics is an excessive fall in maternal blood pressure which may cause inadequacy of the utero-placental blood flow and foetal hypoxia.

PREFACE

This thesis is based on personal investigations into diverse aspects of epidural analgesia carried out over the last five years and on practical experience with the method in some 1200 cases over seven years. The subject matter ranges from the effects of epidural analgesia on pulmonary ventilation and acid-base balance to assessments of the value of the technique in obstetrics and gynaecology.

The original investigations were stimulated by clinical problems which arose during anaesthetic appointments held in Glasgow and in the United States of America. The studies of pulmonary function and acid-base balance arose from the search for an anaesthetic technique which had negligible effects on respiratory function and would therefore be particularly suitable for patients with severe respiratory disease who had to have abdominal surgery. Such patients are frequently encountered in an industrial city such as Glasgow and present serious problems to the anaesthetist. It is shown that epidural analgesia, unlike many general anaesthetic techniques, has insignificant effects on pulmonary ventilation and carbon dioxide homeostasis. Continuous epidural analgesia provides excellent post-operative pain relief with only a slight reduction in the ability to breathe deeply and cough effectively.

For the last four years the author's clinical work has been principally concerned with anaesthesia for obstetrics and gynaecology. Favourable personal experiences with epidural analgesia in these fields in the United States of America encouraged the introduction of the

EPIDURAL ANALGESIA

OBSERVATIONS ON PHYSIOLOGICAL AND THERAPEUTIC ASPECTS OF LUMBAR EPIDURAL ANALGESIA IN SURGERY, GYNAECOLOGY AND OBSTETRICS.

A THESIS SUBMITTED FOR THE DEGREE OF DOCTOR OF MEDICINE

OF THE UNIVERSITY OF GLASGOW.

BY

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method into British obstetrics, where it had hitherto been little used. In the Queen Mother's Hospital, Glasgow epidural analgesia has been in regular use for four years. It is believed that this hospital was the first in Great Britain to establish a 24 hour service by resident anaesthetists for the provision of epidural analgesia in labour. At present, 6 per cent of patients delivered in the Queen Mother's Hospital receive continuous epidural analgesia in the first stage of labour and 11 per cent of forceps deliveries are conducted under epidural block.

As experience grew, it became apparent that epidural analgesia offered more than complete relief of pain in labour. Graphic analysis of labour showed that the rate of cervical dilatation increased substantially in 72 per cent of patients with inco-ordinate uterine action, following the administration of continuous epidural analgesia. Labour was shortened and Caesarean section was probably avoided in many patients with prolonged and inco-ordinate labours. There were beneficial effects on severe hypertension associated with pre-eclampsia. Substantial reductions in blood loss at delivery were confirmed by accurate measurements of blood loss by a haemoglobin extraction-dilution technique. The use of epidural analgesia as an alternative to general anaesthesia for operative delivery avoids the serious hazards of vomiting or regurgitation of stomach contents and the foetus is not exposed to respiratory depressant drugs.

In gynaecological surgery substantial reductions in operative blood loss were demonstrated when operations were performed under epidural analgesia. It is shown that profound arterial hypotension is not necessary for the satisfactory reduction of bleeding. To assess the mechanisms which may be concerned in the reduction of bleeding at operation under epidural block, observations were made of central and peripheral venous pressure and peripheral blood flow was measured by a heat clearance technique. It is suggested that the reduced venous pressure which exists during epidural block is an important factor in reducing blood loss.

It is believed that, in a number of special circumstances, epidural analgesia has attributes which make it the technique of choice. The successful conduct of epidural analgesia brings satisfaction to the anaesthetist who uses the method, as well as benefit to his patients. The increasing interest which British anaesthetists have shown in epidural analgesia over the last few years perhaps indicates a growing awareness of the hazards of general anaesthesia in certain circumstances, particularly in obstetric anaesthesia and in anaesthesia for the respiratory cripple. There is a widespread interest in methods of reducing operative blood loss, if these can be used with safety. The safety and effectiveness of any anaesthetic technique are proportional to the skill and experience of the anaesthetist and it is noted with satisfaction that more and more anaesthetists are gaining experience with epidural analgesia. The risks of epidural analgesia, although different from the risks of general anaesthesia, may be just as serious.

A factor which impedes the wider use of epidural analgesia by British anaesthetists is the pressure of work in many operating theatres.

Anaesthetists may be heavily burdened with routine and emergency anaesthesia and the extra few minutes required to carry out epidural block may seem to be unavailable. Such difficulties can be overcome and when epidural analgesia has become an established part of an anaesthetist's practice, then surgeons, obstetricians and the anaesthetist himself would not willingly forego the advantages of epidural analgesia.

January, 1968.

CONTENTS

THE HISTORY OF EPIDURAL ANALGESIA.

Two important events preceded the introduction of epidural analgesia. The first was the invention of a functional glass syringe with a hollow needle attached, by Alexander Wood of Edinburgh in 1853. Syringes and needles of a primitive pattern had been used by others before this date. Christopher Wren, the architect and astronomer, had used a quill and a small bladder to give intravenous injections about 1657 (Dundee, 1956). The first device with any real resemblance to a modern syringe was that of Pravas of Lyons. This was designed about 1853 and had a piston which was screwed down on a spiral thread. The hollow needle seems to have been first used by Francis Rynd, a Dublin surgeon, about 1845 (Mogey, 1953). Alexander Wood combined the hypodermic needle and glass syringe and abandoned the spiral action of Pravaz's piston. Wood's objective was the injection of morphine directly into painful areas because it was believed at the time that morphine would be locally effective if this was done. Wood did note that the general effects of morphine, occurred regardless of the site of injection.

The second precursor of epidural analgesia was the discovery of cocaine, the first local anaesthetic. In 1859, Nieman and Lossen isolated pure cocaine from the plant erythroxylon coca. Gaedicke had, in 1855, separated the alkaloid in an impure form from the South American coca plant who's leaves were chewed by the natives for their stimulant effects. Von Anrep, in 1879, observed that cocaine had a local analgesic action. The first clinical use of cocaine was in 1884 when Koller used it for topical anaesthesia of the cornea. This was done on the suggestion of Sigmund Freud, at that time an opthalmologist, and had Freud not gone on holiday shortly after making the suggestion, he might have added to his fame by being the first to use a local anaesthetic. Halstead, the American surgeon, first used conduction analgesia in 1885 when he injected cocaine into the mandibular nerve. Halstead became a cocaine addict as the result of his experiments on himself with the drug. Regional analgesia became safer after the introduction of procaine by Einhorn in 1904 and Stovaine by Fourneau (fourneau, a stove) in the same year. The earliest epidural blocks were done with cocaine. Today, lignocaine (Gordh, 1949) and prilocaine (Wieдling 1960) have replaced procaine in its turn.

In 1885, Corning an American neurologist, injected cocaine in the region of the spinal canal and produced analgesia of the legs and perineum. His technique was a poor one and it was by good luck that he injected the cocaine into the epidural or more probably the subarachnoid space (Macintosh, 1957). Corning like Alexander Wood, was trying to deposit a drug as near as possible to a painful or diseased site and he injected cocaine between the eleventh and twelfth thoracic spinous processes of a man suffering from "spinal weakness and seminal incontinence." It was the German, Quincke who, in 1891, described the technique of lumbar puncture which is essentially that used today. It was not until 1899 that Bier of Germany and Tuffier of France used Quincke's method to produce the first deliberate subarachnoid blocks. Macintosh (1957) vividly describes the experiments of Bier and his assistant Hildebrand, on each other. One evening, Bier had a lumbar puncture performed on himself by Hildebrand and much cerebrospinal fluid was lost. Bier then performed a lumbar puncture on Hildebrand and injected 5mg. cocaine crystals dissolved in unsterile tap water. Analgesia ensued and was confirmed by the pulling of pubic hair, squeezing of the testes and hitting the skin with a hammer. To celebrate this success, the participants then sat down to dinner, wine and cigars. After this display of Teutonic fortitude, both suffered from headaches and vomiting for a few days; these effects being attributed to the lumbar puncture and the unsterile injection rather than to the other events of the evening. When associated with such complications, subarachnoid analgesia was unlikely to be an acceptable substitute for all but the worst of general anaesthetics. Nevertheless, the idea of Vertebral conduction analgesia was attractive and standards of general anaesthesia were often low. Epidural block does not cause headache, an important advantage over subarachnoid block even today.

The search for an effective and safe method of conduction analgesia continued and in 1901 two reports of successful epidural (caudal) blocks were presented to the Société Biologique of Paris. On 20th April, 1901, Sicard reported on "Les injections médicamenteuses extra-durales par voie sacro-coccygienne." Seven days later, Cathélin described "Une nouvelle voie d'injection rachidienne. Méthode d'injections épidurales par

le procédé du canal sacré. Applications a l'homme."
Sicard and Cathélin seem to have worked independantly. Each used the caudal approach to the epidural space. Cathelin did try the lumbar approach. His technique was a poor one, involving subarachnoid puncture and then withdrawal into the epidural space and he abandoned the lumbar approach for lack of success. Later in the same year, Tuffier also used the caudal approach successfully, but had poor results with the lumbar route.

For some twenty years after 1901, caudal epidural analgesia was used mainly in continental Europe and the lumbar approach was hardly used at all. From France, the method spread to Germany. In 1909 von Stoeckel of Marburg used caudal analgesia in obstetrics and the technique was quite extensively used thereafter at the Freiberg Frauenklinik by Von Gaza and Schlimpert. Lawen (1912) and Heile (1913) tried the lumbar approach but had little success due to lack of an accurate method of identifying the epidural space. Caudal analgesia was first used in the U.S.A. in 1917 by Thompson of Texas (Hingson and Hellman, 1956).

The development of lumbar epidural analgesia followed the description by the Spaniard, Fidel Pagés, in 1921 of a successful method of identifying the lumbar epidural space. Pagés' method was purely tactile, depending on the sensitivity of the operator's fingers in detecting the sensation of a needle passing through the ligamentum flavum to enter the epidural space. This method requires considerable dexterity. In the same year (1921), the

French workers Sicard and Forestier introduced the loss of resistance method for indentifying the epidural space. This method is still probably the most popular and successful one available and is the method used by the author. A loaded syringe is attached to the needle which is then advanced through the spinal ligaments, while a constant pressure is applied to the plunger of the syringe. As the needle pierces the ligamentum flavum, injection which has hitherto been almost impossible, becomes very easy. Sicard and Forestier were concerned with the injection of radiopaque substances into the lumbar epidural space for diagnostic purposes and it remained for the Italian Dogliotti to use the loss of resistance method on a large scale for lumbar epidural analgesia. Dogliotti reported his experiences in 1933, the year in which Guttierez, the Argentinian, described his hanging-drop technique for identifying the epidural space. Various mechanical aids were later introduced. These included the Odom's indicator (1936), the spring loaded syringe (Brunner and Ilké, 1949), the distended balloon (Macintosh, 1950) and the spring loaded needle (Macintosh 1953). All of these methods depend for their success on the existance of a negative pressure in the epidural space, a phenomenon present in only about 81 per cent of subjects in the lumbar region (Dawkins, 1963). Success is not assured with any of the mechanical methods, although the 19 per cent failure rate can be reduced to 5 per cent by various devices which introduce a slight positive pressure at the tip of the needle

(Dawkins, 1963). The loss of resistance method of Sicard and Forestier and of Dogliotti is successful in nearly 100 per cent of cases in skilled hands.

An important development in the application of epidural analgesia has been its use in obstetrics, both as a method of pain relief in the first stage of labour and as a technique of anaesthetis for operative delivery. The German workers such as Von Stoecke, Von Gaza and Schlimpert who used caudal analgesia in obstetrics, in the years after 1909, were restricted by the absence of any method of affecting prolonged analgesia for the relief of pain throughout labour. Cleland, the Oragon obstetrician, attempted to overcome this problem in 1932 by the not really satisfactory method of performing repeated caudal blocks in labour. Cleland's other contribution to obstetric conduction analgesia was the definition of the anatomical pathways of uterine pain. An importance advance was the introduction of continuous caudal epidural analgesia into obstetrics by Hingson and Edwards in 1943. These American workers at first used uretic catheters to maintain analgesia for pain relief in the first stage of labour, for forceps delivery and for the control of the hypertension of pre-eclampsia and eclampsia. They claimed, with justification, that "pain is no longer a necessary concomitant of labour and delivery."

Single shot lumbar epidural analgesia was used in obstetries by Graffagnino and Sayler in New Orleans in 1932. The continuous lumbar technique was first used in labour in 1949 by Flowers, Hellman and Hingson. Cleland, in the same year, described his combination block which entailed the introduction of two catheters, one into the lumbar epidural space for first stage analgesia and one into the caudal epidural space for analgesia for delivery. This technique was unnecessarily complicated and has been abandoned. Curbello of Havana, also in 1949 used continuous lumbar epidural analgesia with ureteric catheters.

Epidural analgesia, by both caudal and lumbar techniques, is today extensively used in North America for normal and abnormal obstetrics and there is no more effective method of analgesia at present available. American obstetric practice differs in some respects from that of the United Kingdom. Forceps delivery is often preferred to spontaneous delivery, deliveries are conducted by doctors rather than midwives and almost all confinements take place in hospital. Anaesthetists are more familiar with epidural analgesia and more often provide a 24 hour resident obstetric anaesthetic service. The writer knows of only three British maternity hospitals in which the anaesthetic staff provides a regular service for epidural analgesia and it has been the writer's aim, over the last four years to establish a place for epidural analgesia in British obstetric practice.

Epidural analgesia has never achieved the popularity in Great Britain which it now enjoys in the U.S.A. and Canada. Galley used caudal analgesia in 1944 and a visit by Hingson to the United Kingdom in 1949 aroused a transient interest in the use of continuous caudal analgesia in obstetrics.(Brit. med.J., Leading

Article, 1949; Hingson, 1949). Isolated reports of the use of caudal and lumbar epidural analgesia have appeared (Dawkins, 1945; Galley, 1949; Arthur and Johnson, 1952; Johnson, 1954; Bryce-Smith and Williams, 1955; Ball and Chambers, 1956; Scott and Kyles, 1961). Until recently, epidural analgesia was mainly used by a few enthusiasts. There has however, been a steadily increasing use of lumbar epidural analgesia for selected indications in the last few years.

The former resistance of most British anaesthetists has perhaps inevitably been bound up with the unfavourable position of subarachnoid analgesia following the reports of serious neurological sequelae from the latter technique. Also there was a general satisfaction with the muscle relaxant techniques of general anaesthesia in the years after the introduction of curare into anaesthesia. This satisfaction, although still in general justified, is perhaps less applicable to certain patients and to certain surgical procedures. In particular, the patient with severe chronic bronchitis and emphysema may fare badly when given muscle relaxants; general anaesthesia is often associated with troublesome bleeding in pelvic surgery, and in the field of obstetric analgesia and anaesthesia; the general anaesthetics and systemic analgesics carry their own hazards. Epidural analgesia is being used by some anaesthetists for the relief of post operative pain because it provides excellent analgesia without respiratory depression. Other therapeutic indications include acute pacreatitis, dissecting aneurysm of the aorta, miscellaneous vasospastic conditions and prolapsed intervertebral disc.

The statement made by Cathélin in 1901 has been more than fulfilled. He said that epidural analgesia was "une méthode nouvelle qui mérite d'etre étudié par les chirurgiens et par les médecins, comme procédé d'analgesie opératoire pour calmer les douleurs (accouchements douloureux, douleurs des cancers inopérables du rectum, fissures, hemorroidaires)." Cathélin's list of therapeutic indications has been extended considerably and this thesis is concerned with some aspects of epidural analgesia which seemed worthy of study.

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TECHNIQUES OF LUMBAR EPIDURAL ANALGESIA

A Description of the Techniques Employed in The Investigations Which are Recorded in This Thesis

To avoid frequent repetition, the details of the techniques of lumbar epidural analgesia used in the various investigations and and clinical studies which comprise the bulk of this thesis are here described in detail. The local anaesthetics used are listed and the reasons for chosing these particular drugs are indicated.

Single shot lumbar epidural analgesia for surgery

The method now described was used for the investigations concerning acid-base balance, pulmonary ventilation and blood loss at gynaecological operations.

An open vein is first ensured by inserting an intravenous needle or setting up an intravenous infusion.

All equipment, including drugs, is autoclaved. The anaesthetist scrubs up and dons a sterile gown and gloves.

The patient is placed in a lateral position and the spine is flexed. The skin over a wide area of the back and buttocks is cleansed with 0.5 per cent chlorhexidene (Hibitane) solution in an alcoholic base. Care is taken to avoid contamination of the anaesthetist's fingers and equipment with antiseptic. A "spinal" towel is draped over the lumbar region.

The level of the line joining the iliac crests is determined.

This line crosses the L.4-5 interspace. Puncture is usually performed at the L.3-4 or L.2-3 interspace. An intradermal wheal of local anaesthetic solution is raised at the mid-point of the chosen interspace and a further one or two mls. of this solution are injected subcutaneously. The skin is now pierced with a Sise introducer which is inserted precisely in the mid-line and at the mid-point between the adjacent spinous processes. This forms a track for Tuohy needle. A 16 S.W.G. (Standard Wire Gauge) Tuohy needle with Huber point is passed along the ready made track until the ridge of the supraspinous ligament is felt. The Tuohy needle is advanced through the supraspinous ligament, exactly in the mid-line, until the point lies within the interspinous ligament. The stilette is withdrawn from the Tuohy needle and a 20 ml. glass syringe containing about 10 ml. of local anaesthetic solution is attached.

The epidural space is identified by the loss of resistance technique (Sicard and Forestier, 1921; Dogliotti, 1933). The hub of the Tuohy needle is gripped with the thumb and the first two fingers of the left hand, while the hand is steadied against the patient's back. The thumb of the right hand exerts an even pressure on the plunger of the syringe. The left hand now advances the needle steadily through the spinal ligaments in the mid-line. A very slight inclination of the needle towards the patient's head is employed. The left hand usually senses an increased resistance to advance of the needle when the tough ligamentum flavum is reached at a depth of some 4 cm. on average. The steady advance continues. As the epidural space is entered, the left hand appreciates a sudden "give" while at the same time a small quantity of solution is discharged from the syringe.

Tests for inadvertent subarachnoid puncture are now performed. Aspiration of cerebrospinal fluid (C.S.F.) is attempted and for this a 2 ml. syringe is preferred. The syringe is then detached and if any liquid drips from the needle it is allowed to fall onto the bared hand. Local anaesthetic solution feels cold and C.S.F. feels warm. In case of real doubt a positive "Dextrostix" test for glucose will confirm that the liquid is C.S.F. In the event of a subarachnoid puncture, the epidural block is abandoned. The writer has seen two cases of accidental total subarachnoid block follow successful epidural puncture after an initial subarachnoid tap.

A test dose for the exclusion of subarachnoid injection is no longer used and this is the practice of many experienced workers. There is seldom real doubt when the needle is in the subarachnoid space, a test dose is sometimes itself inconclusive and there is the risk of displacement of the needle while waiting for the test dose to act. In a personal series of over 900 epidural blocks, subarachnoid injection has not occurred. Subarachnoid puncture occurred on eight occasions, was clearly detected and no injection was made. This experience is substantiated by reported series of many thousands of cases, where the incidence of subarachnoid puncture is between one and two per cent but the incidence of subarachnoid injection (total spinal block) is only about 0.04 per cent (Chaplin and Renwick, 1958; Carr and Hehre, 1962; Lund et al. 1961; Hellman, 1965).

The local anaesthetic solution is now slowly injected. A rate of about 0.5 ml. per second is appropriate. The Tuohy needle is withdrawn, the puncture site is sprayed with "Nobecutane" and a sterile dry dressing is applied. The patient is turned on to his back and is ready for operation in about ten minutes. Blood pressure readings are taken approximately every five minutes.

A light general anaesthetic is sometimes given, especially if the patient is more than usually apprehensive. Gynaecological patients who receive epidural analgesia for operations for repair of uterine prolapse are often middle-aged women who prefer to be unconscious. The general anaesthetic usually given is a thiopentone, suxamethonium, nitrous oxide, oxygen, halothane sequence. An endotracheal tube is inserted and a very light plane of anaesthesia is maintained. It is believed that a properly given light general anaesthetic with a clear airway and adequate spontaneous ventilation is likely to be associated with less respiratory depression, hypercarbia and hypoxaemia than is heavy sedation with narcotics and tranquillisers.

Continuous Epi-Operative Analgesia urgery
and Post-Operative Analgesia

This was the technique used in the investigations into post-operative ventilatory function. It is used when a prolonged operation is to be performed or when it is planned to maintain post-operative epidural analgesia in the hope of preventing post-operative pulmonary atelectasis.

The epidural space is identified by the method which has just been described for single-shot epidural analgesia. A Lee catheter (Lee, 1962) with a blunt tip (Moir and Hesson, 1965) is used to enable top-up injections to be given. The modified catheter tip was introduced by the manufacturers following accidental perforation of the dura by one of the original sharp-pointed catheters. The catheter passes easily through a 16 S.W.G. Tuohy needle and is advanced in a cephalad direction until the third mark has passed through the hub of the needle. About two inches of catheter now lie in the epidural space. It is possible to introduce a greater length of catheter into the epidural space. If this is done the catheter may curl up in the epidural space, instead of passing upwards, and the likelihood of the catheter passing out of the epidural space through an intevertebral foramen is increased. (Sanchez et al., 1967). If the catheter tip leaves the epidural space, analgesia will be absent or localised to a narrow area on one side only. A lumbar insertion of about two inches of catheter will provide effective analgesia for upper and lower abdominal surgery and for the relief of post-operative pain. This has also been the experience of Bromage (1954 and 1967a). The technically more difficult thoracic epidural block has been used by Simpson and his colleagues (1961) for post-operative analgesia and has the advantage of being less likely to cause hypotension.

The epidural catheter having been inserted, the Tuohy needle is withdrawn over the catheter. The catheter is now connected to a sterile, plastic 50 ml. syringe which has been charged with local anaesthetic. This syringe is now sealed inside a sterile transparent bag so that top-up injections can be given without the need to scrub-up. (Cole, 1964). A dry sterile dressing is applied to the back and the catheter is securely fixed to the spine at the point of emergence. The catheter is then led up to the shoulder or to the flank, where the syringe is taped to the skin. Bacterial cultures from epidural catheters which had been in place for up to 10 days were sterile (Barrets, 1962). The syringe-in-bag system ensures sterility, avoids the need to scrub-up, permits patient mobility and self-injection by the patient is almost impossible.

There are a number of other ways of maintaining epidural analgesia. Hingson and Edwards (1943) used a multidose bottle, a 3-way tap and a syringe. The Oxford Chuck may be used (Simpson and Salt, 1961). Others have used an autoclaved mechanical dispenser (Atherley, 1961) and a motor driven syringe with a timing device (Cox and Spoerel, 1964). Intermittent injections from a sealed sterile drip apparatus are currently popular. (Scott and Walker, 1963; Burn, 1963) and a continuous infusion may be used (Green and Dawkins, 1966). These methods all have one or more disadvantages. It may be necessary to scrup-up before the injection, the patient's movement may be restricted by the apparatus and in the case of at least one type of drip apparatus a near fatality occurred when a patient accidentally received over 1700 mg. lignocaine (Edmonds-Seal, 1964) The writer has heard of a patient who himself speeded up his lignocaine drip and was later discovered in a collapsed and unconscious state. Luckily he survived. Green and Dawkins (1966) report two cases of accidental overdosage with their continuous drip technique.

During long surgical operations, top-up injections are given at regular intervals and before analgesia wears off. When used for post-operative analgesia, injections are usually given as soon as pain returns and the epidural block is normally maintained for the first 24 hours after operation. This makes considerable demands on the anaesthetic and nursing staff and ideally the patient should be in a recovery ward. The patients are confined to bed, but are encouraged to move about in bed. Breathing exercises are given and coughing is encouraged. Hypotension is rarely a problem in the awake, active patient who does not stand erect.

Continuous Lumbar Epidural Analgesia in Obstetrics

The basic technique is that just described for surgery and for post-operative analgesia. Because it is difficult to obtain good flexion of the lumbar spine in late pregnancy, the epidural puncture is performed with the patient in a sitting position.

In the pregnant patient, there is a more extensive spread of local anaesthetic in the epidural space (Bromage, 1962; Hehre et al, 1965) and doses must be reduced by about one third. The greater spread is probably due to the engorgement of the epidural veins which occurs in pregnancy and this reduces the volume of the epidural space available for the spread of solution (Bromage, 1962). During a painful uterine contraction the C.S.F. pressure rises substantially (Marx et al, 1961; Vasicka et al, 1962) so that the dura may bulge and further reduce the effective volume of the epidural space. The rise in C.S.F. pressure only occurs if the uterine contraction is painful and is attributable to generalised maternal muscular activity and straining which may be associated with the Valsalva manoeuvre. The epidural venous pressure is likely to rise during muscular activity. For these reasons, injection is avoided during a painful uterine contraction.

Top-up injections are given as soon as pain returns and analgesia is always maintained until delivery. If epidural block is being used for the management of severe hypertension during labour, then top-up injections are given when the blood pressure rises. The rise in blood pressure often occurs before pain returns.

For operative vaginal delivery, a larger dose of local anaesthetic is injected with the patient in a sitting position. To ensure anaesthesia of the lower birth canal it is necessary to block the second, third and fourth sacral nerve roots. Caesarean section can be performed under epidural analgesia, but it has been found that the majority of patients prefer general anaesthesia for this procedure, although most patients who have a forceps delivery under epidural block are delighted with the experience.

During labour, the patients are encouraged to lie in the lateral position because this prevents the supine hypotensive syndrome of pregnancy by avoiding pressure on the inferior vena cava by the gravid uterus. Blood pressure, pulse rate, foetal heart rate and uterine contractions are monitored regularly during labour. Retention of urine is not uncommon and may be due to obstetric causes or to anaesthesia of the bladder. Catheterisation of the bladder may be required.

Vasopressor drugs are to be avoided during pregnancy. Alpha receptor activators such as methoxamine produce spasm of the uterine arteries, foetal bradycardia and tetanic uterine contractions (Greiss and Van Wilkes, 1964; Vasicka et al, 1964). If a vasopressor drug must be given, then a drug such as ephedrine or metaraminol, which acts mainly on the myocardium is preferred (Schnider, 1966).

These, and other aspects of epidural analgesia in labour are later discussed more fully.

Local Anaesthetic Drugs and Doses

Single-shot lumbar epidural analgesia for surgery

A 1.5 per cent solution of lignocaine is normally used. A 1.5 per cent prilocaine (Citanest) solution has also been used and is equally effective and probably safer. Toxicity of local anaesthetic drugs is rarely a problem with single-shot epidural blocks because the doses used are less than the maximum safe doses. Adrenaline 1:200,000 is usually added to the local anaesthetic solution. The addition of adrenaline significantly lowers the blood levels of local anaesthetic drug attained during epidural analgesia (Bromage and Robson, 1961; Scott, 1965) and increases the safe dose of lignocaine from 200 mg. to 500 mg. and the safe dose of prilocaine is raised from 400 mg. to 600 mg. (Anaesthesia Editorial, 1964). Adrenaline also prolongs the action of the local anaesthetic drug.

The dose of local anaesthetic drug is reduced for three principal reasons; increasing age, degenerative vascular disease and pregnancy. Sex, height and weight are of relatively minor importance in determining the appropriate dose (Bromage, 1962). A suitable dose of 1.5 per cent lignocaine solution for a healthy young man about to have an elective abdominal operation would be from 25 ml. to 30 ml. (375 mg. to 450 mg.). An elderly woman with arteriosclerosis might only require 10 ml. of 1.5 per cent lignocaine (150 mg.) for the same procedure.

The percentage strength of the local anaesthetic solution is of little importance in determining the extent of analgesia. The same weight of drug produces about the same extent of analgesia, regardless of the percentage strength of the solution (Bromage et al 1964).

For the studies of pulmonary function and acid-base balance a 1.5 per cent solution of lignocaine with 1:200,000 adrenaline was used. This solution was, at the time when the studies were carried out, the most popular one for epidural analgesia. This statement is probably still true in 1967. The same solution was also used for the blood loss studies in gynaecological surgery.

Continuous Lumbar Epidural Analgesia for Surgery and Post-operative Analgesia.

Again a 1.5 per cent solution of lignocaine with 1:200,000 has been the local anaesthetic normally used. Prilocaine is less suitable for repeated injection than is lignocaine, because methaemoglobinaemia develops as the total dose of prilocaine increases. Visible cyanosis is likely after 1,000 mg. of prilocaine and has been recorded after only 600 mg. (Daly et al, 1964; Scott et al, 1964; Adamson and Spoerel, 1966). Methaemoglobinaemia impairs the oxygen carrying capacity of the blood. The condition can be reversed by the intravenous injection of some 4 mls. of methylene blue.

For surgery, the doses of 1.5 per cent lignocaine with adrenaline are modified according to age and arteriosclerosis, as described in the previous section. For post-operative analgesia the writer normally uses 1.5 per cent lignocaine with 1:200,000 adrenaline, often mainly because this solution was used for the recent abdominal operation and is therefore already in the 50 ml. top-up syringe. Other workers use weaker lignocaine solutions for post-operative analgesia and these also appear to be satisfactory (Simpson et al, 1961, Bunn, 1963). When using the safe top-up method of a 50 ml. syringe enclosed in a sterile transparent bag, the use of stronger solution in smaller volume enables more doses to be obtained from the syringe with equal effect.

Continuous Lumbar Epidural Analgesia in Obstetrics.

For pain relief in labour and for all types of vaginal delivery a 2 per cent solution of lignocaine with 1:200,000 adrenaline has been the routine local anaesthetic. The 2 per cent solution was chosen mainly because of the practical advantage of obtaining more individual doses from a single syringe when analgesia is provided for a prolonged labour. Quite small volumes of 2 per cent lignocaine suffice for first stage analgesia. From 6 ml. (120 mg.) to 9 ml. (180 mg.) will relieve the pains of labour completely in most cases. Occasionally, in order to relieve severe backache in the first stage of an abnormal labour, a larger dose is required. This is because the backache which may be so distressing in an occipito-posterior position of the foetal head or in hypertonic inco-ordinate uterine action, seems to be transmitted by the sacral nerve roots, so that a more extensive epidural block is required for its relief. For operative vaginal delivery 10 ml. (200 mg.) to 14 ml. (280 mg.) of 2 per cent lignocaine are injected, to ensure analgesia of the lower birth canal.

Prilocaine is considered to be quite unsuitable for continuous local anaesthetic techniques in obstetrics because both mother and foetus will develop methaemoglobinaemia, thus impairing the foetal oxygen supply by two mechanisms.

Tachyphyllaxis, which in this context implies a progressive reduction in the duration of analgesia after repeated injections of local anaesthetic drug, has been a problem in very long labours. Some 60 per cent of patients who received epidural analgesia for more than 10 hours developed tachyphyllaxis to such a degree that analgesia then lasted for less than half of the original time. (Moir and Willocks, 1966).

The cause of this condition is unknown and changing the local anaesthetic agent does not affect tachyphyllaxis when it has once developed. (Bromage, 1967, b).

In view of the claims made for bupivacaine (Marcaine) that analgesia lasted for 5 or 6 hours, this drug has now been used in a small series of 28 continuous epidural blocks in labour. The results have been rather disappointing. The average duration of analgesia was 2 hours and 47 minutes. The drug was used in a 0.5 per cent solution combined with 1:200,200 adrenaline.

Single-shot Lumbar Epidural Analgesia in Obstetrics.

This is sometimes administered for forceps delivery, when 10 ml. (200 mg.) to 14 ml. (280 mg.) of 2 per cent lignocaine with 1:200,000 adrenaline are injected while the patient sits up.

For Caesarean Section a single lumbar epidural injection of 10 ml. to 14 ml. of 2 per cent lignocaine with adrenaline 1:200,000 adrenaline provides satisfactory operating conditions in most cases. Occasionally traction reflexes are troublesome and a covering general anaesthetic would be required to block these reflexes. The occurrence of these reflexes may be related to the gentleness, or otherwise, of the operator.

PULMONARY FUNCTION AND ACID BASE BALANCE

PULMONARY FUNCTION AND ACID BASE BALANCE

Introduction

In 1954 Scurr first described a patient with coma and inadequate ventilation after an anaesthetic in which a muscle relaxant drug and intermittent positive pressure ventilation (I.P.P.V.) had been used. In 1956 Hunter described six similar patients, all of whom died. Hunter wrongly attributed the condition to "neostigmine resistant curarisation." In 1960 the writer described such a patient who was successfully treated by tracheostomy and prolonged I.P.P.V. (Moir, 1960). Others have recorded similar cases (Young and Mendel, 1959; Brooks and Feldman, 1962; Moir and Reid, 1963). The condition is now well recognised and is indeed quite common. Campbell and his colleagues (1967) treated 202 cases in four years in a respiratory intensive care unit and postoperative respiratory inadequacy was the commonest reason for admission to their unit.

The causes of postoperative respiratory failure include metabolic acidosis associated with hypovolaemia and hypotension (Brooks and Feldman, 1962), fluid and electrolyte imbalance and pre-existing broncho-pulmonary disease. Often all of these aetiological factors are present and invariably anaesthesia has involved the use of muscle relaxants and I.P.P.V. usually for abdominal surgery. True suxamethonium apnoea was uncommon in one large series (Campbell et al, 1967) but this may simply be a reflection of the anaesthetic practice of one particular hospital.

Treatment may involve the correction of metabolic acidosis and electrolyte deficiencies and the restoration of normal blood volume by appropriate intravenous fluid therapy. In all but the mildest cases, assisted or controlled ventilation will be required by endotracheal tube or even tracheostomy.

In Campbell's (1967) series the mortality in patients who developed respiratory failure after elective upper abdominal surgery was 32 per cent and the mortality rose to 47 per cent after upper abdominal surgery. In a smaller personal series (Moir and Reid, 1963) there were 3 deaths in 10 cases of respiratory failure after abdominal surgery despite treatment which in each case included prolonged I.P.P.V. Even if treatment is successful, the management of these patients involves much time and skill and can tax the resources of the average hospital. It was experience with these cases which stimulated the writer to carry out certain investigations into pulmonary function and acid base balance during epidural analgesia. If epidural analgesia could provide relief of pain and muscular relaxation for abdominal surgery while not affecting the level of spontaneous ventilation then it would enable high risk patients to be anaesthetised without the use of muscle relaxants and I.P.P.V.

Respiratory failure is always accompanied by carbon dioxide retention (Comroe et al, 1962). That carbon dioxide is a narcotic was recognised by Henry Hill Hickman in 1824 when he used the gas to anaesthetise small animals (Keys, 1941). Some 30 years later, John Snow again described the narcotic and toxic properties of carbon dioxide (Foregger, 1960). In their classic experiments, Haldane and Smith (1892) showed that the inhalations of 10 per cent carbon dioxide produced stupefaction in the absence of hypoxia and in 1924 Haldane demonstrated that high concentration of carbon dioxide depressed respiration. Waters (1937) recorded a fatality due to misguided postoperative therapy with carbon dioxide and oxygen. Barach, in 1944 suggested that carbon dioxide retention might cause coma in emphysematous patients although such an occurrence seems to have been first recognised by Westlake and his colleagues in 1955. It is perhaps surprising that it is only quite recently that anaesthetists have become truly aware of the narcotic and respiratory depressant effects of endogenous hypercarbia.

Table I shows the values for arterial blood pH and carbon dioxide tension (Pco_2) which three groups of workers have found to be associated with coma.

TABLE I

Arterial blood pH and Pco_2 values associated with coma

pH	Pco2 (m.m.Hg.)	Source
Below 7.1	Above 122	Westlake et al, 1955.
Below 7.25	Above 90	Sieker and Kickham, 1965.
Below 7.09	Above 129	O'Reilly, 1960

The values reported by Westlake et al (1955) are close to those recorded by O'Reilly (1960), but Sieker and Hickham (1956) noted coma at a lesser degree of respiratory acidosis. The discrepancy may be explained on several counts, such as the difficulty in defining and assessing levels of consciousness, the influence of narcotic and sedative drugs, the effect of hypoxia and the effects of pH and Pco2 changes acting together. In the postoperative period, the persistent effects of premedicant and anaesthetic drugs may reduce the degree of respiratory acidosis required to cause coma. The pH and pco2 of the cerebrospinal fluid probably influence the state of consciousness and there is often a difference between blood and cerospinal fluid acid base values (Leading Article, Lancet, 1967).

Whatever the aetiological factors in the individual patient, postoperative respiratory failure is extremely uncommon unless muscle relaxant drugs and I.P.P.V. have been used. Following such an anesthetic adequate spontaneous ventilation cannot be established or maintained and coma or semi-coma is associated. It would seem logical to seek an otherwise acceptable anaesthetic technique for abdominal surgery, which avoids the use of musle relaxants, the abolition of spontaneous ventilation and the use of I.P.P.V. Such a technique would have to provide good muscular relaxation and yet permit adequate spontaneous ventilation. The second criterion excludes the use of inhalational anaesthesia of a depth sufficient for abdominal muscular relaxation. If really effective, postoperative analgesia could be provided without the use of respiratory depressant drugs, then a valuable additional asset would be present.

Epidural analgesia is associated with excellent muscular relaxation for abdominal surgery, spontaneous ventilation is present and if a continuous technique is used, then almost perfect post-operative anaglesia can be maintained. If spontaneous ventilation were adequate during even high epidural block, then epidural analgesia would satisfy the criteria proposed. In 1962, no studies of the effect of epidural analgesia on respiratory function before or during surgery had been published. It was therefore decided to assess the effects of epidural analgesia on respiratory function by measuring resting and maximal ventilatory capacity and by acid-base studies. The investigations now to be described have been reported on elsewhere (Moir, 1963; Moir and Mone, 1964).

PULMONARY VENTILATION DURING EPIDURAL ANALGESIA

In the years before 1962 several writers had expressed the opinion that epidural analgesia could provide pain relief and muscular relaxation for abdominal surgery without impairing the activity of the respiratory muscles. These opinions were not based on objective measurements and there was disagreement on the maximum concentration of lignocaine which would produce this differential block. Southworth and Hingson (1953) stated that two per cent lignocaine did not cause intercostal paralysis and Dawkins (1954) believed that the block produced by 1.5 per cent lignocaine was almost entirely sensory. Bromage (1954) thought that the degree of motor block increased as the concentration of lignocaine increased above 1.25 per cent. Lee (1959) said that during high epidural block with 1.5 per cent lignocaine the respiratory minute volume might be low and Morris (1960) thought that 2 per cent lignocaine might well cause intercostal paralysis.

Two reports had been published demonstrating a substantial improvement in ventilation after epidural analgesia in patients who had severely impaired ventilation in association with post-operative abdominal wound pain (Bromage, 1955; Simpson et al, 1961). No studies had been done on patients who were free of pain. Since abdominal wound pain very substantially depresses ventilation (Anscombe and Buxton, 1958), it was decided to study patients before surgery and before administration of any premedicant or anaesthetic drugs. Any alterations in ventilatory function would then be attributable solely to the epidural block. Since epidural analgesia might be particularly useful in patients with bronchopulmonary disease, the study was designed to include patients with normal and diseased respiratory systems.

METHOD

Observations were made on 42 patients, 10 of whom were females. All were about to undergo abdominal surgery and non e had received any premedicant drugs. Their ages ranged from 34 to 74 years (mean 53.2 years), their weights ranged from 52.2kg. to 89Kg. (mean 68.6Kg) and their heights ranged from 157 cm. to 185 cm. (mean 168 cm.)

Significant chronic bronchopulmonary disease was present in 12 patients. In three of these the disease was far advanced in that two had a recent history of cor pulmonale and one had extensive bilateral pulmonary tuberculosis with cavitation. The other nine patients in this group had a history of chronic productive cough, moderate exertional dyspnoea and sometimes wheezing due to obstructive bronchopulmonary disease of moderate severity. The diagnosis was based on the history, physical examination, radiological findings and pulmonary function studies. All patients in this group had a low peak expiratory flow rate.

The other 30 patients had no discernable respiratory disease.

Measurements were made of tidal volume, minute volume, vital capacity and peak expiratory flow rate. The first three observations were made with a Wright's respirometer (Wright, 1955). This instrument has an absolute accuracy of ± 7 per cent to ± 10 per cent (Byles, 1960; Nunn and Ezi-Ashi, 1962). The same respirometer was used for all observations so that it is likely that any error in absolute values is a constant one throughout the investigations and that any percentage changes are sufficiently accurate for the purpose of this investigation. Nunn and Ezi-Ashi (1962) agree that the Wright's respirometer is sufficiently accurate for a comparable purpose, the testing of the effects of drugs or ventilation. Peak expiratory flow rates were measured with a Wright's peak flow meter (Wright and McKerrow 1959). These instruments were used because they are readily available and are suitable for use in a busy operating theatre by a single-handed anaesthetist. Vital capacity and peak expiratory flow rate were recorded as the mean of three readings, taken after preliminary practice. All measurements were made with the patient in a sitting position.

Patients were visited on the day before operation and the proposed procedure explained to them and their consent obtained. On arrival in the anaesthetic room, the assessments of ventilation were made.

Epidural analgesia was then induced. A single-shot technique was used in 33 cases and a continuous technique in 9 cases. Epidural puncture was performed at the L2-3 or L1-2 interspace using the loss of resistance technique. In order to obtain analgesia extending into the upper thoracic region, a rather large volume of 1.5 per cent lignocaine with added 1:200,000 adrenaline was injected. The volume varied with age, height and general health of the patient. The average volume injected was 29.8 ml. (457mg.) and the doses ranged from 20 ml. (300mg.) to 38 ml. (570mg.). A 1.5 per cent solution of lignocaine is probably the most widely used local anaesthetic solution for epidural analgesia, at least in Great Britain and experience has shown that it gives excellent conditions for abdominal surgery.

From 20 to 35 minutes after this injection, the upper level of cutaneous analgesia to pinprick was assessed. In all cases, this lay between the fifth and the second thoracic dermatones. The tests of ventilatory function were then repeated.

The systolic blood pressure was maintained above 90mm.Hg. in all cases and a vasopressor drug (Methoxamine) was given to 13 patients to maintain the blood pressure. This was done, at least in part, because hypotension may decrease the vital capacity, especially in patients with obstructive lung disease (Bromage, 1956.). Oxygen was not given before the completion of all observations.

RESULTS

Patients with no respiratory disease. The alterations in tidal volume, minute volume, vital capacity and peak expiratory flow rate associated with high epidural block in 30 patients with normal pulmonary function are summarised in Table 2. The individual results are listed in the Appendix, Table A.

TABLE 2

Mean and percentage changes in ventilation during epidural analgesia in 30 patients with normal lung function.

	Before block Mean ± Stand. Devn.	During block Mean ± Stand. Devn.	Mean Alterations	Mean percentage alteration
Resting tidal volume (ml.)	570.7±76.5	564.6±74.9	-6.1	-1.1
Resting minute volume (ml.)	7898.3±1143	7820.3±1171	-78	- 1.0
Vital capacity(ml)	3763.7±996.1	3501.7±753	-262	-7.1
Peak exp. flow(L/min)	496.3±92.2	471.7±90.2	-24.6	-5.0

A statistical analysis was performed using the Student t test for the assessment of the significance of the difference between each pair of mean values. Only the peak expiratory flow rate values are significantly different from each other ($P < 0.05$). The difference between the other pairs of means are not significant at the generally accepted 5 per cent level.

The changes in tidal volume and minute volume are small and are probably well within the normal range for the conscious subject. Emotional stresses in these unpremedicated patients who were in unfamiliar surroundings, may have influenced the resting level of ventilation. A mean reduction of 1 per cent in tidal volume and minute volume is of no practical importance.

The reduction in vital capacity of 262 ml. (7.1 per cent) is just outwith the range of normal variation of ± 200ml. to 250ml. of Mills (1949) and Comroe and his colleagues (1955), but is of little clinical significance to the normal subject. The mean reduction in peak expiratory flow rate of 24.6 litres (5 per cent), although statistically significant, is also of small clinical significance to patients with previously normal peak expiratory flow rates.

Patients with chronic respiratory disease. Table 3 shows the mean alterations in ventilation observed in 12 patients with pre-existing chronic broncho-pulmonary disease. The individual results are presented in the Appendix, Table B.

Statistical analysis by the Student t test reveals a significant reduction in vital capacity and peak expiratory flow rate after epidural block ($P < 0.01$ in both instances). The increases in minute and tidal volumes are not significant ($P < 0.1$ in both instances).

TABLE 3

Mean and percentage changes in ventilation during epidural analgesia in 12 patients with chronic broncho-pulmonary disease.

	Before block Mean ± Stand Devn.	During block Mean ± Stand Devn.	Mean Alterations	Mean percentage Alteration
Resting tidal volume (ml.)	521.7 ± 58.2	540 ± 70.8	+18.3	+3.5
Resting minute volume (ml.)	7297±856.6	7533±1094	+23.6	+3.2
Vital capacity(ml.)	2712±597.7	2481±551.4	-231	-8.5
Peak exp. flow(L/min.)	237.8±74.1	214±70	-23.8	-9.7

The mean reduction in vital capacity (231ml. or 8.5 per cent) is just within the range of normal variation. The absolute reductions in vital capacity and peak expiratory flow rate in this group of patients with poor respiratory function are not very different from the absolute reductions in the normal group of patient (Tables 2 and 3). The percentage reductions are of course, somewhat greater in the group with chronic lung disease. It is nevertheless evident that the alterations in resting ventilation are negligible in both groups and that reduction in maximal ventilatory capacity is negligible in the normal group and small in the abnormal group.

DISCUSSION.

It has been shown that resting pulmonary ventilation is unaltered by high epidural block and that there is a reduction of only

7 per cent in vital capacity and 5 per cent in peak expiratory flow rate in healthy subjects. Before concluding that these small reductions in maximal ventilatory performance are indications of a corresponding percentage reduction in the power of the respiratory muscles, it is first necessary to examine the contribution of the various muscles of respiration to inspiration and expiration.

Electromyography has demonstrated that the principal muscles of inspiration are the fifth to the ninth external intercostal muscles and that at resting levels of ventilation, expiration is largely a passive process (Campbell, 1955; Green and Howell, 1955). The abdominal muscles have no inspiratory function and are usually only involved in expiration when the minute volume exceeds 40 litres (Campbell and Green, 1953). When the expiratory flow rate is very high, the abdominal muscles become the most important muscles of expiration. Consequently, the abdominal muscles are the principal muscles used in coughing and in performing a measurement of peak expiratory flow rate. The abdominal muscles are also used during a test of vital capacity. Although Wade (1954) thought, on radiological evidence, that about 75 per cent of the ventilation involved in the performance of a test of vital capacity was due to movement of the diaphragm, Campbell (1958a) believes that not all of this diaphragmatic movement is due to active contraction of the diaphragm. Some of the ascent of the diaphragm is probably due to its being thrust upwards by the intra-abdominal pressure developed by contraction of the abdominal muscles during forced expiration.

From the preceding observations, it might be predicted that if epidural block to about the 5th thoracic dermatome were accompanied by muscular paralysis, then the vital capacity would be reduced by at least 25 per cent and the peak expiratory flow rate would be reduced by a still greater amount. The observed decreases were of much lesser degree.

In the presence of intercostal and abdominal muscular paralysis, the diaphragm would be the principal functioning muscle of respiration. Precise information is not available on the reduction in ventilatory capacity which follows paralysis of individual respiratory muscles or groups of muscles. It appears that the reduction is often slight and that the body has considerable reserves of muscle power available for ventilation. In the normal subject, the ability to perform tests such as vital capacity and maximum voluntary ventilation is not limited by muscle power because the contraction of the respiratory muscles is less than maximal during the performance of these tests (Campbell, 1958b). Minor degrees of weakness of the respiratory muscles or paralysis of only a few muscles may simply use up the reserves of muscle power and cause little or no reduction in the ability to perform tests such as vital capacity and peak expiratory flow rate. This may be the situation which existed during the high epidural blocks performed in this investigation.

Detectable paralysis of the intercostal and abdominal muscles is minimal during epidural block with 1.5 per cent lignocaine, yet when this solution is injected into a mixed peripheral nerve, profound muscular weakness or total paralysis commonly ensues. A differential nerve block is usually explained on a general basis of easier penetration of the smaller pain fibres of 0.5 m. microus in diameter, in comparison with the larger motor fibres of about 16 microus diameter (Swerdlow and Brown, 1961; Gassel and Diamantopolous, 1964; Bromage and Burfoot, 1966). Weak solutiom of local anaesthetic drugs do not affect the large motor fibres. It is therefore postulated that, at its site of action, the 1.5 per cent lignocaine solution has become diluted to a concentration insufficient to cause motor block but still adequate for analgesia. Local anaesthetic solution injected into the lumbar epidural space spread widely and their sites of action are probably equally widespread. From the lumbar epidural space solutions spread to the paravertebral spaces, penetrate the dura and pass centrally along the nerve roots and thence into the cerebrospinal fluid and into the spinal cord itself (Dogliotti, 1933; Rudin et al, 1951; Frumin et al 1953; Moore et al 1958; Usubiaga et al, 1964). It is noteworthy that 2 per cent, 3 per cent, 4 per cent and 5 per cent lignocaine solutions containing the same number of milligrams of drug all produce an epeidural block of the same extent and quality (Bromage et al 1964). This phenomenon can also be explained on a basis of finally equivalent dilution at the site of action. Dawkins (1954) suggested that easier penetration of the thinner dural covering of this posterior nerve root ganglia may explain the predominantly sensory block, but this, in view of the findings just received, cannot be the whole explanation for the differential block.

The pH of the local anaesthetic solution and the pH at its cellular site of action affect the intensity of the block. A solution of high pH acting at a site of low pH produces the most intense block (Krahl et al 1940; Lofgren 1948; Bonica et al, 1957). The addition of adrenaline to the lignocaine solution, as in the present investigation, somewhat intensifies the slight weakness of the lower limbs which sometimes occurs during lumbar epidural block (Bromage et al 1964). From personal observation of over 400 lumbar epidural blocks in obstetrics in which 2 per cent lignocaine with 1:200,000 adrenaline was used, weakening of the lower limbs is rarely pronounced.

The results of a similar investigation into the effects of epidural analgesia on ventilation have been published by Freund and his colleagues (1967), four years after the initial publication of the writer's work. Freund and his co-authors found a 3 per cent reduction in inspiratory capacity and a 21 per cent reduction in expiratory reserve volume during high epidural block with 15.625 mls. of 2 per cent lignocaine with 1:200,000 adrenaline. This work confirms the writer's observation of a minimal reduction in vital capacity, but the reduction in expiratory reserve volume appears to indicate a rather greater degree of abdominal muscular weakness although paralysis must have been far from complete. The difference may have been due to the use of a stronger solution of lignocaine and a larger total dose of this drug, or to the use of a different method of assessing the power of the muscles of expiration. Freund measured the maximum volume of air which can be exhaled from the resting expiratory level, whereas the author measured the maximum rate of air flow during expiration.

Bromage (1954) has observed clinically improved ventilation in patients with severe emphysema and bronchospasm after the onset of epidural analgesia. Bromage attributed the improvement to the release of bronchospasm, although a high sympathetic block by leaving the parasympathetic nerves intact, might be expected to increase rather than aleviate bronchospasm. The beneficial effect in this group of patients, which the writer has also detected clinically, may be due to the interruption of some unknown reflex arc (Bromage, 1967). Despite these impressions, there was no measureable improvement in ventilation in the 12 patients with chronic obstructive bronchopulmonary disease in the present series, except that one of the patients had an increase in peak expiratory flow rate from 217.5L/min. to 222.5L/min., an increase of doubtful significance. It is recognised, however, that clinical and subjective improvement in ventilation may not be associated with an improvement derectable by pulmonary function tests.

By no means all aspects of ventilation were investigated. There is, however, a good correlation between peak expiratory flow rate and forced expiratory volume (Higgins, 1957; Lockhart et al, 1960; Tinker, 1961) and maximum voluntary ventilation

(Prime 1960). Forced expiratory volume, functional residual capacity and compliance were measured by Simpson and his colleagues (1961) during continuous epidural analgesia in the immediate postoperative period. The reduction in these aspects of ventilation was always small when compared with the pre-operative values.

Finally, a comparison with the known effects of spinal subarachnoid analgesia on ventilation is useful. The results of the only three published studies (including the author's) are listed in Table 4. All these results were obtained from healthy patients before surgery and the effects of premedication have been excluded.

TABLE 4.

The Effects of Subarachnoid and Epidural Block on Ventilation.

	Epidural block	Subarachnoid block
Reduction in inspiration	7% (Author) 3% (Freund et al,1967)	9% (Egbert et al,1961) 8% (Freund et al,1967)
Reduction in expiration	5% (Author) 21%(Freund et al,1967)	50% (Egbert et al,1961) 48% (Freund et al,1967)

It is evident that maximal inspiratory function is only slightly impaired by both subarachnoid and epidural analgesia. There is an important difference in the effects of the two techniques on maximal expiratory function. Subarachnoid analgesia is associated with a 50 per cent loss of expiratory capacity which is indicative of considerable weakness of the abdominal muscles. Epidural analgesia causes a much smaller reduction in maximal expiratory function. The discrepancy between the author's finding of a 5 per cent reduction in peak expiratory flow rate and the 21 per cent reduction in expiratory reserve volume observed by Freund and his colleagues (1967) has already been discussed and may be due to the use of a different test of lung function and a different strength and dose of local anaesthetic.

PULMONARY VENTILATION DURING ABDOMINAL SURGERY AND EPIDURAL ANALGESIA.

The preceding investigation was concerned only with patients about to be operated on and who had not received any premedication. During abdominal operations, the effects of depressant drugs, hypotension, hypovolaemia, operating positions other than the supine and diaphragmatic splinting by packs and retractors might be expected to reduce effective ventilation. In order to assess ventilation during lower abdominal surgery performed under epidural analgesia, the following (unpublished) study was carried out.

METHOD.

Ventilation was assessed in 20 women during abdominal hysterectomy. The age of the patients ranged from 40 years to 62 years (mean age 48.8 years) and the weight ranged from 51.5Kg. to 77.3Kg. (mean weight 61.3kg.) All were free of serious respiratory or cardiovascular disease. Each received Morphine sulphate 10mg. and Atropine sulphate 0.6mg. by intramuscular injection one hour before anaesthesia.

A single-shot epidural block was administered at the L.2-3 interspace, using a 1.5 per cent solution of lignocaine with 1:200,000 adrenaline. The dose of lignocaine was from 20ml. (300mg.) to 28 ml. (420 mg.) and the mean dose was 24.4ml. (366mg.). When cutaneous analgesia had extended upwards to at least the 5th thoracic dermatome, the operation was begun. Intravenous methoxamine was given to 3 patients and no other drugs were administered.

The patients were in the supine position during opening of the abdomen. On opening the peritoneal cavity, the operating table was put into a 10 degree head-down tilt. In all cases packs were inserted into the abdominal cavity and a self-retaining abdominal retractor was used.

An anaesthetic face-mask was applied to the patient's face throughout the operation and oxygen was supplied at a flow rate of 10 litres per minute by a Magill anaesthetic circuit (system A, Mapleson, 1954). In these circumstances rebreathing should not occur if the minute volume does not exceed 10 litres as was the case during this investigation (Mapleson, 1954, Woolmer and Lind, 1954, Kain and Nunn, 1967). A Wright's respirometer was placed between the mask and the expiratory valve to measure expiration and tidal and minute volumes were observed continuously.

RESULTS.

The observed ranges of tidal and minute volume during abdominal hysterectomy performed under high epidural analgesia are listed in TableO in the Appendix.

Tidal volumes ranged from 380ml. to 1450 ml. in the whole series. The tidal volume of each patient varied from time to time. These variations were often substantial and sometimes appeared to be related to various surgical, auditory or visual stimuli. Every patient had, at some time during the operation, a tidal volume in excess of basal requirements. The mean value for the highest recorded tidal volume in 20 patients was 977 ml. (range 680ml. to 1450ml.)

The range of minute volumes was from 6110ml. to 9840ml. for the series. Again every patient at some time during the procedure had a minute volume at least adequate for basal requirements. The mean value for the 20 highest recorded minute volumes was 8413 ml. (range 7330ml. to 9840ml.)

It is concluded that, even a fter premedication with Morphine and in a 10 degree head-down position, healthy patients can maintain adequate resting ventilation during the performance of lower abdominal surgery under high epidural block.

POSTOPERATIVE VENTILATION DURING EPIDURAL ANALGESIA.

The preceding studies have confirmed the adequacy of resting spontaneous ventilation during epidural analgesia both before and during surgery. It has also been shown that maximal ventilatory function is only slightly reduced by epidural analgesia before operation. Because an important application of epidural analgesia is in the treatment of post-operative pain, when it is used in the hope of providing pain relief without depression of ventilation and coughing, it was decided to assess the effects of epidural block on vital capacity and peak expiratory flow rate in patients recovering from abdominal surgery.

This work was done in 1962 and has not been published.

METHOD.

Twelve patients were studied. All were elderly males who were having retropubic prostatectomy. Their ages ranged from 59 years to 78 years (mean age 67.3 years). All had pre-existing bronchopulmonary disease of the obstructive type, associated with a productive cough, dyspnoea and sometimes wheezing. An indication of the severity of this respiratory disease can be obtained from the pre-operative lung function tests in Table 5. Epidural analgesia was chosen as the anaesthetic technique primarily because of the respiratory disease.

No premedication was given. On arrival in the anaesthetic room, vital capacity and peak expiratory flow rate were measured on a Wright's respirometer and a Wright's peak flow rate. Results were recorded as the average of the three highest readings.

Epidural puncture was performed at the L3-4 or L2-3 interspace and an epidural catheter (Lee, 1962) passed into the epidural space. A dose of from 12 ml. (180mg.) to 17ml. (255mg.) of 1.5 per cent lignocaine solution with 1:200,000 adrenaline was injected through the catheter. The average dose was 15ml. (225mg.). Cutaneous analgesia to pin-prick reached upwards to between the 8th and the 5th thoracic dermatomes.

Analgesia was maintained throughout the operation and for the first 24 hours after operation by top-up injections through the catheter. The patients were kept in a recovery room under constant observation for at least 24 hours. Methoxamine was given to three patients to maintain the systolic blood pressure above 90mm.Hg.

Retropubic prostatectomy was performed through a Pfannensteil transverse lower abdominal incision. Between one hour and three hours after the operation, the tests of vital capacity and peak expiratory flow rate were repeated. Throughout the recovery period, the patients were encouraged to breathe deeply and to cough up secretions and a physiotherapist co-operated in this regime. No systemic analgesic drugs were given.

RESULTS.

The mean values for vital capacity and peak expiratory flow rate before and after prostatectomy in twelve patients with significant respiratory disease are shown in Table 5. The individual values are listed in Table F in the Appendix.

There was a mean reduction of 217.1ml. (9.8 per cent) in vital capacity between the pre-anaesthetic period and the early postoperative period when the patients were now under continuous epidural analgesia. The mean reduction in peak expiratory flow rate between these two periods was 48.7L/min. (28.6 per cent).

TABLE 5

Mean and percentage change in vital capacity and peak expiratory flow rate before and after prostatectomy under continuous epidural analgesia.

	Before Operation Mean ± Stand Devn.	After Operation Mean ± Stand Devn.	Mean Percentage Reduction.
Vital capacity (ml.)	2218.3±438	2001.2±401	-9.8%
Peak exp. flow rate(L./min)	205.2±62	156.5±53	-28.6%

DISCUSSION.

The series is small but the patients in the series are of comparable age, all of the same sex, all had the same operation and all had fairly severe respiratory disease. The standard deviations from the mean values for vital capacity and peak expiratory flow rate (Table 1) are small and the conclusions are probably valid.

The precentage reduction in vital capacity after operation, and during epidural analgesia (9.8 per cent) is almost identical to the 9.7 per cent reduction in vital capacity produced by epidural block in patients with respiratory disease prior to operation (Table 3, page 34). It is evident that, during epidural analgesia, vital capacity is only slightly reduced even after abdominal surgery. Other workers have demonstrated a substantial improvement in vital capacity in the postoperative period when epidural analgesia was then induced for the first time. The vital capacity is reduced to between 25 per cent and 50 per cent of normal by abdominal surgery (Churchill and McNee, 1927; Beecher, 1933; Bromage, 1955; Anscombe and Buxton, 1958). The vital capacity can be restored to between 70 per cent and 100 per cent of its pre-operative value by instituting epidural analgesia (Bromage, 1955; Simpson et al, 1961). Simpson and his colleagues found that the vital capacity could be restored on average to 85 per cent of its pre-operative value by epidural block after lower abdominal surgery. This figure is not very dissimilar to the author's finding of a mean postoperative vital capacity of 90 per cent of the pre-operative value. The difference may be a chance finding or may be associated with the fact that in Simpson's series, epidural analgesia was not instituted until after the vital capacity had already fallen due to pain, while in the present series epidural analgesia was maintianed continuously.

The beneficial effects of epidural analgesia may be contrasted with the effect of morphine, which improves the reduced postoperative vital capacity by only 10 per cent to 30 per cent (Bromage, 1955; Parbrook et al, 1964). The disappointing results with morphine are due to the fact that increasing the analgesic effect of the drug also increases the respiraptory and cough depressant action of morphine. Slightly better results can be obtained from the inhalation of low concentrations of nitrous oxide, but the restoration of vital capacity is still much less than is achieved with epidural block (Parbrook et al, 1964; Parbrook, 1966.)

The 28.6 per cent average reduction in peak expiratory flow rate after operation in the present series is substantially greater than the 9.8 per cent reduction in vital capacity. Bromage (1967) also found that peak expiratory flow rate was reduced to a greater degree than was vital capacity. The explanation may be that bronchial secretions had already accumulated during and after surgery. A vital capacity measurement takes no account of the rate of movement of air so that a normal value may be recorded if sufficient time is available for the slower exchange of the same amount of air. Narrowing of the airways by accumulated secretions would, however, reduce the peak expiratory flow rate. Patients are, understandably, unlikely to expectorate during a surgical operation and it may be then that secretions accumulated. The reduction in peak expiratoryflow rate is probably not due solely to paralysis of the expiratory muscles, because epidural block itself has been shown to reduce peak expiratory flow rate by only 5 per cent to 10 per cent (see page 32).

Parbrook and his colleagues (1964) found that the peak expiratory flow rate was reduced to between 20 per cent and 50 per cent of its pre-operative level after abdominal surgery and that opiates improved the peak flow rate by less than 20 per cent. Bromage (1967) observed a 40 per cent to 70 per cent restoration in peak flow rate after epidural analgesia in the post-operative period.

Functional residual capacity and total compliance are almost unchanged during epidural analgesia after abdominal surgery (Simpson et al, 1961).

There is impressive evidence that epidural analgesia is associated with much more effective pulmonary ventilation after abdominal surgery than are systemic and inhalational analgesics.

ACID-BASE BALANCE DURING EPIDURAL ANALGESIA.

As a sequel to the preceding investigations into the mechanical aspects of pulmonary ventilation during epidural analgesia, it was decided to assess the effects of high epidural block on the pH, carbon dioxide tension (Pco2) and standard bicarbonate level of the blood. Because inadequate alveolar ventilation will always produce retention of carbon dioxide in the blood (Comroe et al, 1962), then failure to detect a respiratory acidosis (a rise in Pco2, with or without a fall in pH) would demonstrate the adequacy of pulmonary ventilation.

METHOD

Twenty patients (fifteen males and five females) were studied. Their ages ranged from 28 years to 74 years (mean age 49 years). Their weights ranged from 62Kg. to 85Kg. (mean weight 71Kg.) and their heights ranged from 152 cm. to 190 cm. (mean height 171cm.).

Eight patients had chronic obstructive broncho-pulmonary disease (chronic bronchitis and emphysema) which was far advanced in one patient because it was associated with cor pulmonale. The respiratory disease was moderately severe in the other seven patients, being associated with a persistent productive cough, dyspnoea and sometimes wheezing. The assessment was based on the history, physical examination, chest X-ray and sometimes on lung function tests. The other twelve patients had no detectable respiratory or cardiovascular disease.

All patients were visited before operation and the proposed procedure was explained. No premedication was given.

On arrival in the anaesthetic room capillary blood samples were obtained by stab puncture of the thumb. Care was taken to ensure a free flow of blood without compression of the thumb. Whole blood pH, Pco2 and standard bicarbonate were determined by the micro-method of Astrup and his colleagues (1960) and the monogram of Sigaard Andersen and Engel (1960).

Epidural analgesia was then induced by a single injection of 1.5 per cent lignocaine with 1:200,000 adrenaline at the L.2-3 interspace. As in the investigation into ventilatory function, a deliberately large volume of local anaesthetic solution was injected in order to obtain a high level of analgesia. The average volume injected was 33.7ml. (505mg. lignocaine) and the range was 28 ml. to 40ml. (420mg. to 600mg. lignocaine).

Between 25 and 30 minutes after the injection of the lignocaine solution the upper level of cutaneous analgesia to pinprick was assessed. The spread of solution was assumed to be complete when the level of analgesia had not altered after a further five minutes. The upper level of analgesia lay above the fifth thoracic dermatome in all patients, the range being from the fourth to the second thoracic dermatome. A second capillary blood sample was then taken for acid-base estimations.

The systolic blood pressure was maintained above 90mm. Hg. and methoxamine was given to five patients to counteract hypotension. A free flow of capillary blood was obtained from all patients, even after the use of methoxamine.

Oxygen was not given until the second blood sample had been obtained, nor was any drug, other than methoxamine, given before this time.

RESULTS.

The mean values for pH, Pco2 and a standard bicarbonate of capillary blood taken before and during epidural block from twelve patients who had no respiratory disease are shown in Table 6. In Table 7, the mean values obtained from the eight patients with significant chronic broncho-pulmonary disease are given. The individual values for each of the twenty patients are listed in Tables D and E in the Appendix.

TABLE 6.

pH, Pco2 and standard bicarbonate in twelve patients without respiratory disease, before and during high epidural block.

	Before Block		During Block	
	Mean ± Stand. Devn.	Range	Mean ± Stand. Devn	Range
pH	7.40 ± 0.026	7.37 to 7.46	7.40 ± 0.021	7.37 to 7.44
Pco2(mm.Hg.)	40.8 ± 4.4	32 to 48	39.2 ± 3.3	32 to 44
Stand.Bicarb. (m.Equiv./L.)	24.0 ± 1.80	22 to 26	23.5 ± 0.68	22 to 24.5

TABLE 7

pH, Pco2 and standard bicarbonate in eight patients with chronic bronchopulmonary disease, before and during high epidural block.

	Before Block		During Block	
	Mean ± Stand. Devn.	Range	Mean ± Stand. Devn.	Range
pH	7.41 ± 0.035	7.37 to 7.47	7.39 ± 0.035	7.36 to 7.46
Pco2(mm.Hg.)	36.5 ± 4.2	29 to 41	38.9 ± 3.9	28.5 to 47
Stand.Bicarb (m.Equiv./L)	23.4 ± 2.1	19 to 26.5	22.9 ± 1.16	21 to 25

DISCUSSION

Before interpreting the results of this investigation, it is necessary to consider the range of normality for capillary blood pH, Pco2 and standard bicarbonate and to assess the validity of using capillary rather than arterial blood samples.

The following ranges of normal values have been proposed (Table 8).

TABLE 8

Normal Values for Blood pH, Pco2 and standard Bicarbonate.

pH	Pco2 (mm.Hg.)	Stand.Bicarb (m.Equiv./L)	Source
7.36 to 7.44	36 to 44	22 to 26	Nunn (1962)
7.38 to 7.45	34 to 46	23.6 to 27.2	Whitehead (1963)
7.36 to 7.42	33 to 47	-	Siggaard Andersen (1963)
7.35 to 7.45	35 to 49	23 to 29	Bradley, Spencer and Semple(1964)

The values for pH (7.36 to 7.44) and Pco2 (36 to 44mm.Hg.) quoted by Nunn (1962) are perhaps the most widely accepted normal values, but it is noticeable that the more recent workers accept a somewhat higher Pco2 as being within normal limits.

There is usually a close relationship between the pH, Pco2 and standard bicarbonate of capillary and arterial blood (Cooper and Smith, 1961; Doorat and Kennedy, 1965; Langlands and Wallace, 1965). Doorat and Kennedy found that capillary blood Pco2 was within ± 2.0mm.Hg. of the arterial blood Pco2 a nd that the capillary blood pH and standard bicarbonate were respectively within ± 0.025 pH units and ± 0.5m.Equiv./L of arterial blood levels. Capillary blood sampling is thus normally an acceptable alternative to the use of arterial blood samples and avoids the risks of arterial puncture. Although the risks of arterial puncture are acceptable where the procedure is performed as an adjunct to treatment, there would have been no direct therapeutic value to the patients involved in this investigation and so arterial puncture was not done. For valid results, the capillary blood should flow freely without compression of the thumb or ear lobe. Cooper and Smith (1961) found that the normally good correlation between arterial and capillary blood acid-base values could be affected by upsets of the autonomic nervous system such as sweating and marked alterations in heart rate and blood pressure. Epidural analgesia is associated with cutaneous vasodilatation although it is unlikely that the epidural block was high enough to affect the blood flow to the thumb.

The systolic blood pressure was kept above 90mm.Hg. in all the patients studied and although a vasoconstrictor drug, methoxamine, was used occasionally to prevent hypotension, the flow of blood from the thumb was always free.

The observed mean values for capillary blood pH, Pco2 and standard bicarbonate in the subjects with healthy respiratory systems and in those with chronic broncho-pulmonary disease are all within any of the ranges of normality listed in Table 8. The over-all effect of high epidural analgesia on acid-base balance has been insignificant and there has been no retention of carbon dioxide (Tables 6 and 7).

When the values for each patient are considered (Tables D and E, Appendix) almost all of these values are within any of the ranges of normality proposed in Table 8.

Among the twelve subjects who were free of respiratory disease (Appendix Table D) there are three Pco2 values which may be regarded as normal or as slightly abnormal. Patient number six had a pco2 of 35mm.Hg. before anaesthesia and the Pco2 fell to 32 mm.Hh. during epidural block. Patient number twelve had Pco2 values of 32mm.Hg. and 37mm.Hg. before and during epidural analgesia. These results are explicable on a basis of mild hyperventilation due to anxiety in unpremedicated patients and far from indicating respiratory depression, they confirm the adequacy of ventilation. Patient number one had a pre-anaesthetic Pco2 of 48mm.Hg. which fell to a normal value of 44mm.Hg. during epidural block.

Among the eight patients with bronchopulmonary disease (Appendix Table E) there are two instances of a low Pco2 (patients numbers one and two) also explicable by hyperventilation due to anxiety. Patient number three had a pre-anaesthetic Pco2 of 41mm.Hg. which rose to 47mm.Hg. during epidural analgesia. This value may not be abnormal (Siggard Andersen, 1963; Bradley et al, 1964) and was observed in a patient who had very severe bronchopulmonary disease and a history of cor pulmonale.

With one doubtful exception, all Pco2 and pH values observed during high epidural analgesia are indicative of normal ventilation or mild hyperventilation.

In a steady state, isolated readings of Pco2 should reflect respiratory function (Nunn, 1964). The patients were at rest during the investigation so that the rate of metabolic production of carbon dioxide would be low and fairly constant. The anaesthetic state was also reasonably steady in that the level of cutaneous analgesia had been constant for at least five minutes when the second blood sample was taken and major alterations in blood pressure and heart rate were avoided. The capillary blood Pco2 is therefore a reasonably accurate reflection of alveolor ventilation in the circumstances of the investigation.

Alveolor hypoventilation always causes carbon dioxide retention (Comroe et al, 1962) and it is therefore concluded that resting alveolor ventilation is normally adequate during high epidural block. This conclusion is in agreement with the observation made in the preceding study, that resting tidal and minute volume are normal during epidural analgesia.

Epidural analgesia is often compared with spinal subarachnoid analgesia. The available information about the effect of these two techniques on blood gas values may be usefully reviewed here. Older work has associated high subarachnoid analgesia with normal blood oxygen saturation (Latteral and Lundy, 1949; Sancetta et al, 1953; Greene et al, 1956) and with low blood oxygen saturation (Johnson, 1951). In a careful investigation, published after the first report of the present writer's work, Ward and his colleagues (1965) observed normal pH, Pco2 and Po2 levels in arterial blood during both epidural and subarachnoid blocks in healthy volunteers who were not undergoing surgery. Modern techniques of blood gas analysis confirm that resting alveolar ventilation is adequate during subarachnoid and epidural analgesia in patients not undergoing surgical operations.

During general anaesthesia the blood gas values may vary widely according to the technique in use, unless frequent monitoring of blood gases is performed. Spontaneous ventilation with the more potent anaesthetic agents is likely to be associated with a raised arterial Pco2 (Black and McKane, 1965; Marshall, 1966) unless the inspired.

oxygen percentage is high, the arterial Po2 may be below normal. Conversely, when muscle relaxants and intermittent positive pressure ventilation are in use, hyperventilation is often deliberately or accidentally employed with a consequent substantial reduction in the arterial blood Pco2 and elevation of the pH. These effects, some of them potentially harmfull, are in marked contrast to the absence of change in blood gases during epidural analgesia.

APPLICATIONS OF EPIDURAL ANALGESIA IN RESPIRATORY DISEASE

There are two principal applications of epidural analgesia in connection with respiratory disease. The first is the use of epidural analgesia as an anaesthetic technique when surgery, particularly abdominal surgery, is required in patients with severe bronchopulmonary disease. The second application is the use of continuous epidural analgesia in the management of post-operative pain in the hope of preventing pulmonary atelectasis.

Epidural Analgesia for Abdominal Surgery In Patients with Respiratory Disease.

In 1954 Bromage wrote "Epidural analgesia is a simple, safe and effective method, having certain definite advantages over current relaxant techniques in a limited field of surgery, as well as possessing a number of therapeutic applications." Bromage went on to summerise the operative indications as "surgery below the diaphragm ---- where the complete relaxation of the abdominal wall is associated with spontaneous ventilation, reduced blood loss and post-operative analgesia." These statements are true today, although few anaesthetists would use epidural analgesia routinely for abdominal surgery. Leaving aside the not unimportant question of reduced blood loss, the muscular relaxation, (adequate) spontaneous ventilation and post-operative analgesia make epidural analgesia particularly suitable for abdominal surgery in patients with respiratory disease. The adequacy of spontaneous ventilation during epidural analgesia has been demonstrated (pages 32 to 34), as has the minor degree of impairment of maximal ventilation.

For the great majority of patients, the muscle relaxant techniques of anaesthesia provide excellent operating conditions with safety. They lend themselves well to the busy operating theatre and are familiar to all modern anaesthetists. Epidural analgesia requires time and a certain expertise. Both techniques have their inherent risks which diminish as experience and knowledge increase. For the following reasons it is considered that epidural analgesia is specially indicated in patients with severe respiratory disease.

There are three principal times when respiratory complications may develop in patients with existing bronchopulmonary disease who are given a general anaesthetic which involves the use of muscle relaxants and intermittent positive pressure ventilation (I.P.P.V.). The first is in the course of the anaesthetic, when there may be difficulty in achieving adequate pulmonary ventilation due to bronchial secretions and "air-trapping" in the emphysematous lung (Reid, 1958). If air-trapping occurs during I.P.P.V., the intra-thoracic pressure may rise sufficiently to impair venous return to the heart. The second danger period occurs when the anaesthetic is withdrawn. It may be difficult or impossible to restore adequate spontaneous ventilation. This condition of post-operative respiratory failure with depressed consciousness (carbon dioxide narcosis, acidotic coma) has been discussed on pages 24 to 27 and carries a high mortality, even with skilled treatment (Campbell et al, 1967). The third danger period is in the first 24 or 48 hours after operation, when pulmonary atelectasis may develop.

The use of epidural analgesia for abdominal operations in appropriate cases should eliminate the problems of maintaining and restoring ventilation during and immediately after anaesthesia. If spontaneous ventilation was adequate for resting requirements before surgery, it is likely to remain adequate during epidural analgesia and there can also be no problem of re-establishing spontaneous ventilation in the post-anaesthetic period. Dinnick (1960) with the considerations just outlined in mind, has gone so far as to state that "patients with severe emphysema are the only patients in whom regional analgesia is absolutely indicated on medical grounds" and Nunn (1958) is also inclined towards this view.

The prevention of atelectasis is discussed in the following section.

Epidural Analgesia for Post-operative Pain Relief

The relief of post-operative abdominal wound pain is complete when epidural analgesia is administered, and this relief is obtained without clouding of consciousness and with only slight depression of ventilation. Pulmonary function is usually severely impaired after abdominal surgery and the improvement after the administration of morphine is slight (Bromage, 1955, Parbrook et al, 1964). The improvement after epidural analgesia is much greater (Bromage, 1955; Simpson et al, 1961; Bromage, 1967) and if epidural analgesia is maintained throughout operation and the early post-operative phase then substantial falls in ventilation do not occur (Author, pages 41 to 46).

A relationship between post-operative pain and the development of pulmonary atelectasis after abdominal surgery is widely accepted, and is based on the observed effects of abdominal wound pain on respiratory function and the restoration of respiratory function to near normal levels after effective analgesia. The patient with untreated post-operative abdominal wound pain has a 50 to 75 per cent reduction in vital capacity (Churchill and McNeil, 1927, Beecher, 1933; Bromage, 1955, Parbrook et al, 1964), a 50 to 80 per cent reduction in peak expiratory flow rate (Parbrook et al, 1964), a 20 per cent reduction in total compliance (Okinaka, 1965; Lewis and Welch, 1965) and a 20 per cent reduction in functional residual capacity (Anscombe, 1957, Lewis & Welch, 1965). Clinical observation of patients with severe untreated abdominal pain corroborates many of these observations. Such patients hold the abdominal and thoracic wall rigid to act as a splint and minimise respiratory movement. The shallow respirations are often grunting and the sufferer will neither breathe deeply nor cough effectively. Because of the fixed body wall, ventilation tends to occur within the normal functional residual capacity.

Many other factors predispose to atelectasis. Pre-existing respiratory disease and heavy smoking (Palmer, 1961), old age (Dripps and Van Deming, 1964), male sex (Bunker et al, 1959), prolonged surgery (Rovenstein and Taylor, 1936) and the inhalation of dry gases (Burton, 1962) are all associated with an increased incidence of post-operative atelectasis. A common, but probably erroneous impression is that the incidence of atelectasis varies with different anaesthetic techniques.

When due allowance is made for important variables such as age, sex existing respiratory disease and the site of operation the incidence is almost the same with various inhalational agents (Rovenstein and Taylor, 1936; Schmidt and Waters, 1939; Dripps and Van Deming, 1946), muscle relaxants (Bunker et al, 1959) and subarachnoid analgesia (Dripps and Van Deming, 1946). The results of Dripps and Van Deming (1946) are interesting. There was, in their first series, a higher incidence of atelectasis after general anaesthesia than after subarachnoid analgesia. The difference was however, due to the active post-operative care, given only to the group who received subarachnoid analgesia. The difference disappeared in a second series in which both groups received an active "stir-up" regime. This second study was well conducted and illustrates some of the difficulties in assessing any prophylactic or therapeutic measures. against post-operative atelectasis.

Although many factors set the stage for atelectasis, the ultimate causes may be only two. These are bronchial obstruction with plugs of mucus or other foreign matter, with distal absorption of gases and alveolar collapse (Baker et al, 1951; Palmer and Sellick, 1953) and underventilation of the whole lung, or parts of it (Hamilton, 1961). It has been suggested that there may, in some cases, be a loss of chemical surfactants from the alveolar lining with consequent increase in its surface tension and a tendency for the adjacent alveolar surfaces to adhere (Mead et al, 1957; Pattle, 1958). This is believed to occur in the respiratory distress syndrome of the newborn or hyaline membrane disease (Avery and Mead, 1959), but has not been demonstrated in atelectasis after abdominal surgery.

In practice, post-operative atelectasis is usually due either to a failure to cough up bronchial secretions or a failure to ventilate adequately. A steady level of ventilation, whether spontaneous or controlled and at the resting level of tidal volume, if maintained for as little as twenty minutes produces a progressive fall in lung compliance, a decrease in total lung volume, a fall in functional residual capacity and an increasing venous admixture effect. (Bernstein, 1957; Mead and Collier, 1959; Finley et al, 1960; Ferris and Pollard, 1960; Valasquez and Farhi, 1961). These effects are the results of widespread collapse of alveoli and can be reversed or prevented by a few deep breaths. This fixed, low-volume type of ventilation, without the occasional deep breath, is commonly seen in association with severe abdominal pain and may also exist during general anaesthesia with either spontaneous or controlled ventilation. Narcotic drugs depress the mechanism of the occasional deep breath or sigh which seems to prevent the development of atelectasis in the normal resting or sleeping subject (Pierce and Garofalo, 1965; Egbert and Bendixen, 1964) and the use of morphine in large doses post-operatively can increase the incidence of atelectasis (Egbert and Bendixen, 1964).

The only method of analgesia which is likely to be free of significant depressant effects on coughing and deep breathing is some form of nerve block. After abdominal surgery multiple bilateral intercostal or paravertebral nerve block would be needed at regular intervals and such techniques are not practical in the absence of a truly long-acting local anaesthetic agent. Continuous epidural analgesia is the only really effective and practical technique and the analgesia can easily be maintained for 24 hours or longer. The technically more difficult thoracic epidural block has been used very successfully by Simpson and his colleagues (1961) and if limited to the nerve distribution supplying the upper abdomen, is associated with very little hypotension, so that patients can be ambulant. However, even with the easier lumbar approach the patient can move freely in bed and this has been the approach used by the writer.

There has been no published evidence to date, that epidural analgesia really does prevent post-operative atelectasis in a large controlled series, although all writers on the subject assume that it does so and often quote impressive individual case histories. The theoretical basis for the use of continuous epidural analgesia is sound and the writer can but add his quota of illustrative case histories.

CASE HISTORIES

Case Number 1. A small, thin man aged 43 years had suffered from pulmonary tuberculosis for 22 years and now had diffuse bilateral pulmonary fibrosis and areas of emphysema. His vital capacity was 1360 ml. and his FEV_1 (one second forced expiratory volume) was 58 per cent of his actual vital capacity. While in hospital for medical treatment of a peptic ulcer he had a massive haematemesis for which emergency partial gastrectomy was performed. He was anaesthetised with thiopentone, nitrous oxide and d-tubocurarine. I.P.P.V. was given by a Blease ventilator. The operation lasted for over 2 hours and 2,500 ml. of blood were transfused. At the completion of the operation he became semi-conscious for a few minutes, but spontaneous ventilation was obviously inadequate and a tracheal   was present. Twenty minutes after the completion of the operation the patient had lost consciousness, was cyanosed when not breathing oxygen and was in respiratory failure. A capillary blood sample at this time showed a pH of 7.08 and a Pco_2 of 95 mm.Hg. A regime of I.P.P.V. was instituted and maintained for 22 hours. Convalescence was slow and complicated by respiratory infection and atelectasis.

Four months later the patient had to be reanaesthetised because he had developed a sub-acute intestinal obstruction due to a carcinoma of the colon. He was given a continuous lumbar epidural block with 1.5 per cent lignocaine and 1:200,000 adrenaline and a bowel resection was performed. There was no respiratory difficulty and recovery was uneventful. Continuous epidural analgesia was maintained for almost 24 hours after operation and no post-operative pulmonary complications occurred.

Comment:

The first anaesthetic, which entailed the use of a muscle relaxant and I.P.P.V., was followed by post-operative respiratory failure with severe respiratory acidosis. Typically this occurred after emergency upper abdominal surgery in a patient with severe chronic respiratory disease and probably hypovolaemia. The patient might well have died on this occasion. When reanaesthetised with a continuous epidural block there was no respiratory difficulty during or after operation. The uncomplicated second anaesthetic was given for a lower abdominal operation when the patient was in reasonably normal fluid and electrolyte balance, so that the circumstances were different in these respects from those existing on the first occasion and credit may not go entirely to the epidural block.

Case Number 2. A 72 year old man had advanced obstructive broncho-pulmonary disease of the emphysema and chronic bronchitis type. He had cor pulmonale and was orthopnoeic with the "fish-like" breathing of advanced emphysema with air-trapping. His vital capacity was 1140 ml. and his $F.E.V_1$ was 36 per cent of his actual vital capacity. He was a very poor anaesthetic risk, but himself insisted on operation. He was anaesthetised by a colleague for a retropubic prostatectomy. Thiopentone 200 mg. was followed by nitrous oxide and d-tubocurarine and I.P.P.V. was commenced. Before the skin could be incised, cardiac arrest had occurred. Resuscitation was successful and the operation was abandoned. The anaesthetist noted difficulty in performing I.P.P.V.

Despite these events, the patient still insisted on operation and ten days later he was given a continuous epidural block by the writer. The operation and the recovery were uneventful. Epidural analgesia was maintained for 30 hours after operation and breathing exercises carried out.

Comment:

The cardiac arrest under general anaesthesia was thought by the anaesthetist concerned to have been due to air-trapping in association with I.P.P.V. with a consequent steep rise in intrathoracic pressure and severe impairment of venous return to the heart in a patient who already had right heart failure (cor pulmonale). The pre-operative respirations were of the type associated with loss of pulmonary elasticity, collapse of airways and distal air-trapping. Epidural analgesia did not further impair ventilation nor aggrevate air-trapping. In particular it did not impair the power of expiration in this patient.

Case Number 3. A 35 year old woman had long-standing bilateral pulmonary tuberculosis with cavitation for which an extensive thoracoplasty had been performed six years before. She was now 38 weeks pregnant and was admitted in respiratory failure to a maternity hospital. When first seen she was very drowsy and appeared to have a superimposed acute respiratory infection. Her capillary blood pH was 7.16 and the Pco_2 was 105 mm.Hg. Her condition improved with tracheal suction, controlled 27 per cent oxygen therapy and analeptics and an antibiotic. She had regained consciousness (pH now 7.28, Pco_2 60 mm.Hg.) when labour began. Lumbar epidural block was impossible because of the spinal deformity due to the thoracoplasty and so a continuous caudal block was performed when labour became painful. No systemic analgesic drugs were required and labour progressed painlessly, culminating in a forceps delivery of an active baby. In the puerperium, her vital capacity was 900 ml. and her

$F.E.V_1$ was 61 per cent.

The patient went home with her baby ten days later. She died four months after this, in another hospital, of respiratory failure precipitated by an acute respiratory infection.

Comment:

This patient had very little functioning lung tissue (Vital capacity 900 ml.) as the result of tuberculous cavitation and thoracoplasty. She also had an element of airway obstruction ($F.E.V_1$ 61 per cent). A respiratory infection sufficed to reduce her vital capacity to below the normal resting tidal volume and caused respiratory failure which, on the second occasion, proved fatal. When labour began, it was decided that narcotic analgesics might well further depress the already inadequate respirations and that the muscular effort of a spontaneous delivery should be avoided by the use of the obstetric forceps. A continuous epidural (caudal) block provided complete analgesia for labour and delivery.

BLOOD LOSS IN GYNAECOLOGY AND OBSTETRICS

BLOOD LOSS IN GYNAECOLOGY AND OBSTETRICS

The Influence of Epidural Analgesia, General Anaesthesia and Pudendal Nerve Block on Operative Blood loss

Methods of Blood Loss Estimations.

There are several methods of estimating blood loss at operation or delivery. The ideal method should be safe, accurate to within ± 2 per cent, simple enough for routine use, rapid and be able to estimate the total external blood loss and not merely the blood on drapes or in suction bottles. The result should not be affected by the presence of liquids other than blood. In some situations, it may be desirable to estimate concealed blood loss in the tissues as well as the external blood loss.

The following are the methods of blood loss estimation which have been used:-

Visual assessment

Serial haematocrit estimations

Gravimetric methods (patient weighing and swab weighing)

Extraction-dilution techniques (electrolyte conductivity and colorimetric methods)

Blood volume measurements.

Visual Assessment

This is doubtless the most widely used method and can be extremely unreliable. Although perhaps acceptable for clinical purposes in fit adult patients where the blood loss is not great, (Thornton, 1963) visual estimates may be wildly inaccurate when large blood losses are involved. The surgeon's estimate is usually an underestimate (Bruce and Lyter, 1951). The average error of visual estimates in a series of surgical operations was 40 per cent, but some individual errors were much greater (Cullen, 1961). At forceps deliveries, the writer found that visual estimate by experienced obstetricians were, on average, 28 per cent below the true blood loss and that the estimates made by nurses were still more inaccurate (Moir and Wallace, 1967). It is difficult to allow for contamination with liquids other than blood when making a visual assessment of blood loss. No estimate can be made of concealed blood loss in the tissue.

Serial Haematocrit Estimations

These given an inaccurate estimate of blood loss and are of little value for clinical or research purposes. The haemotocrit reading will be lowered by the compensatory increase in plasma volume which follows acute blood loss (Stanton et al, 1949).

Gravimetric Methods

(a) Patient weighing. This is a clumsy method which entails the use of a large weighing table to weigh the patient before and after the operation. Allowances have to be made for the weight of dressings, drains, drip apparatus, insensible water loss, infused fluids and tissue excised surgically and the error is likely to be considerable (Thornton, 1963.)

(b) Swab weighing. Provided that all the blood shed at operation is collected on swabs and weighing is done before drying occurs then swab weighing is acceptably accurate (Moore et al, 1965.) No account is taken of blood lost onto drapes and gowns or onto the floor. If there is contamination with liquids, such as urine, liquor amnii or irrigating fluids, then swab weighing will be grossly inaccurate. It is usually assumed that 1 ml. of blood weighs 1 Gramme. In fact, the specific gravity of plasma is 1.0270 and that of red cells is 1.0293. A correction factor could be applied.

Swab weighing would give acceptable results in for example, gynaecological surgery, but would be quite unsuitable for the assessment of blood loss at delivery when blood is often widely distributed and there is usually gross contamination with liquor amnii.

Gravimetric methods cannot assess concealed blood loss within the tissues.

Blood Volume Measurement

The plasma volume is measured by injecting intravenously a carefully measured quantity of a dye such as Evans Blue or of radio-isotope tagged albumin. I^{131} or I^{135} are the isotopes used. These methods assume that the dye or isotope is evenly distributed throughout the whole plasma volume within about ten minutes after injection and that in this period of time, there is neither loss of the substance from the circulation nor metabolism of the substance. The plasma concentration of dye or isotope is then assayed and the plasma volume calculated. There is a slight tendency for radio-iodine tagged albumin to leak from the circulation, but these methods are reasonably accurate if the state of the circulation is normal. In haemorrhagic shock the injected substance may not be evenly distributed throughout the plasma, so that in the very situation where knowledge of the blood volume would be of greatest clinical value, the inaccuracy is greatest (Thornton, 1963; Moore et al, 1965).

The red cell mass can be measured by injecting a known quantity of isotope-tagged red cells. Either Cr^{51} or P^{32} may be used to tag the cells.

The whole blood volume may be calculated from the haemotocrit and either the measured plasma volume or red cell mass. This calculation may be inaccurate because the haematocrit may vary in different parts of the circulation, especially in shock (Albert et al, 1965).

Blood volume measurements are the only means of measuring concealed blood loss into the tissues. This type of blood loss is high in some surgical procedures. In a series of radical mastectomies the concealed loss amounted to an extra 25 per cent over the external loss (Caceres and Whittemburg, 1959) and in thoracic surgical procedures, the concealed blood loss averaged 45 per cent in one series (Forgee and Smith, 1952). In other procedures, for example, at forceps delivery and at vaginal hysterectomy, there is no measurable concealed loss into the tissues (Pritchard et al, 1960) so that it becomes unnecessary to use blood volume estimations in order to assess total blood loss at operation of this type.

Extraction-Dilution Techniques

(a) Electrolyte Conductivity Methods. Leveen and Rubricus (1958) described a method of blood loss estimations based on the extraction of blood from swabs and linen by placing them in a washing machine. When the blood had been washed out into the water in the washing machine tub, the quantity of blood extracted was assessed by measuring the electrical conductivity of the solution in the tub. The electrical conductivity was measured by the Wheatstone bridge principal and was dependent on the electrolyte content of the blood. This method gives an accurate assessment of total external blood loss, but the accuracy will be severely impaired if there is any contamination by electrolyte - containing body fluids or irrigating fluids. The method is therefore unsuitable for most urological operations and for obstetric procedures.

(b) Colorimetric Methods. These methods also employ a washing machine to extract blood from swabs and linen. The haemoglobin content of the wash-tub water is then measured, either directly or after conversion to acid haematin. Gotch and Little (1924), Pilcher and Sheard (1937) and White and Burton (1942) used techniques involving conversion to acid haematin and recovery is incomplete with these methods (Thornton, 1963). Currently used techniques involve the estimation of haemoglobin itself, usually by optical densitometry (Rose et al, 1962; Thornton et al, 1963; Rustad, 1963) and the recovery rate is very close to 100 per cent (Moore et al, 1965; Newton, 1966; Moir and Wallace, 1967).

The technique used by the writer for investigating blood loss at gynaecological and obstetric operations was a haemoglobin extraction-dilution technique and used the principle of optical densitometry for measurement of haemoglobin. The details of the technique are now described.

Technique of Blood Loss Estimation with the Rustad-Ohlin Perdometer.

At the end of the operation or after completion of the third stage of labour and suture of the episiotomy, all swabs, packs, drapes, gowns and gloves were collected. Blood spilled onto the floor was mopped up and in obstetric cases, the blood in the placenta bowl was retained.

A Rustad-Ohlin Perdometer apparatus was used fro the measurement of total external blood loss (Rustad, 1963). The a pparatus consists of a standard Hoover washing machine to which has been added a source of light, a photo-electric cell and a galvanometer. By an arrangement of plastic tubes, there is a continuous circulation of blood-stained water from the wash-tub past the light source. As the haemoglobin content of the wash water rises, the transmission of light diminishes. The amount of light transmitted is measured by the photo-electric cell, which therefore functions as a haemoglobinometer for the assessment of the haemoglobin

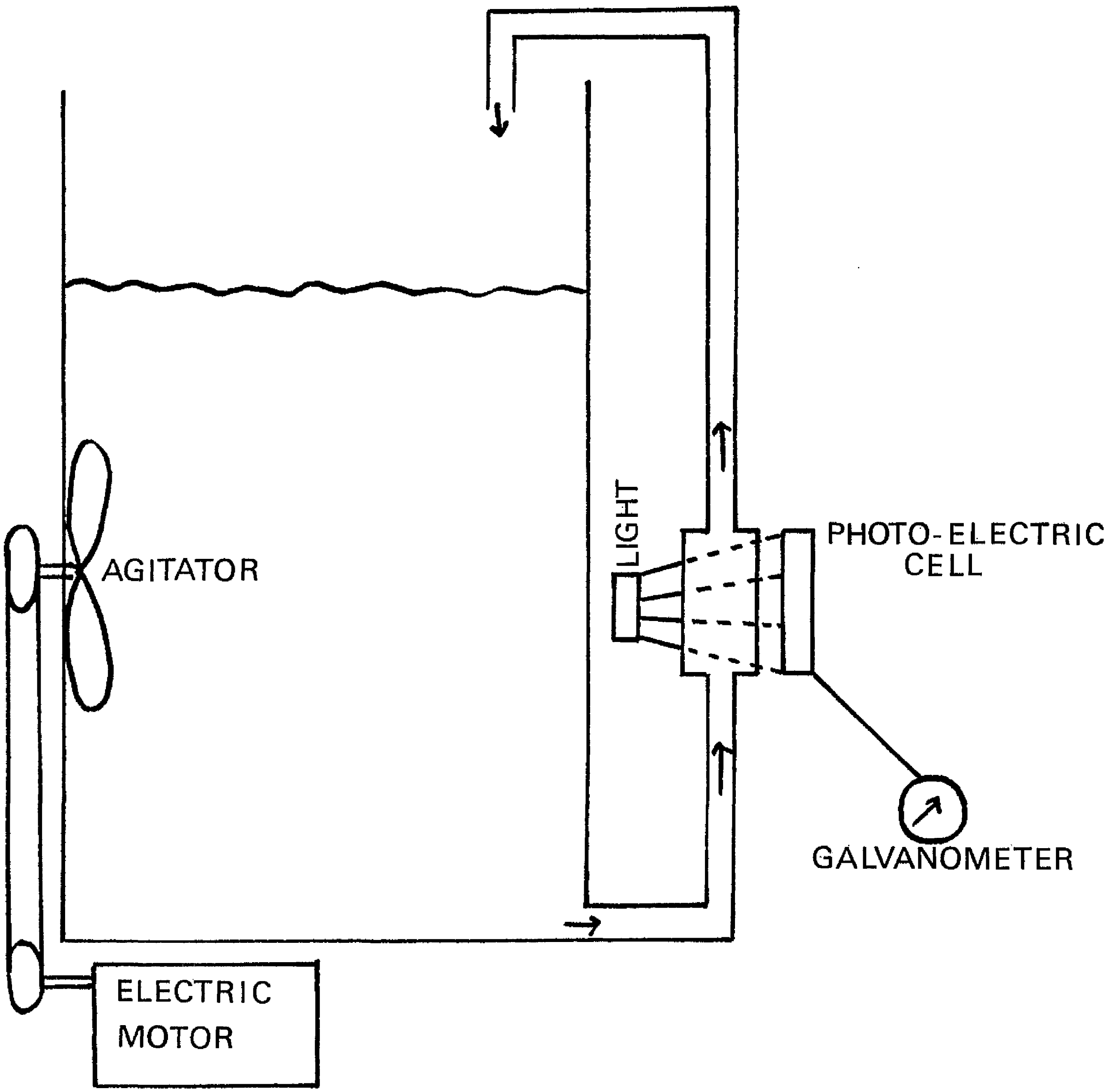


DIAGRAM 1.   PRINCIPLE OF THE PERDOMETER.

content of the water in the tub. Diagram I illustrates in schematic form, the principle of the Perdometer.

Before performing an estimation, the tube of the washing machine is filled with tap water, up to a mark on the side of the tub. There is thus always a constant volume(40 litres) of water in the tub. To this water is now added 100 ml. of a detergent solution. The detergent ('Perdosol') acts as a haemolytic agent and assists in the washing-out of blood from the linen. The washing machine is now switched on for a few minutes while the water detergent mixture circulates past the light source and photo-electric cell. When the galvanometer, connected to the photo-electric cell has registered a steady reading, for at least three minutes, this reading is regarded as the zero point for future readings. The galvanometer is, in practice, adjusted to a zero reading on the scale.

All the blood-stained linen is now put into the washing machine tub and any blood clots are added after first breaking them down. The washing process is now carried out for at least 20 minutes. Washing is complete when a steady galvonometer reading has been obtained for at least five minutes. This reading is an assessment of the total amount of haemoglobin present in 40 litres of water. Knowing the haemoglobin value for the whole blood put into the washing machine (that is, the patient's pre-operative haemoglobin value) the blood loss can be calculated from the following formula (Thornton, 1963).

$$\text{Blood loss in ml.} = \frac{\text{Hb.(G/100ml.) of wash water} \times \text{volume of wash water}}{\text{Hb.(G/100ml.) patient's Hb.} \times \text{dilution factor for patient's Hb.}}$$

When using the Rustad-Ohlin Perdometer this calculation is made semi-automatically by the apparatus itself.

The Perdometer has been used by the writer for the assessment of blood loss at over 200 gynaecological operations and jointly with one of his obstetric colleagues for the assessment of blood loss at over 700 normal and operative deliveries (Wallace, 1967; Moir and Wallace, 1967; Moir, 1968). Throughout the period of use, the accuracy of the apparatus has been regularly checked by assaying a carefully measured volume of expired blood bank blood. The recovery rate was always between 97 per cent and 100 per cent. Because contamination of linen with antiseptic, urine, liquor amnii and meconium was common in obstetric cases, all these substances were separately assessed and none gave any positive reading when put into the Perdometer.

Haemoglobin-dilution techniques such as this, are ideally suited to the measurement of blood loss in obstetrics where blood is widely distributed on swabs, pads, linen, sheets and on the floor. Contamination with other liquids is common. Swab-weighing could be grossly inaccurate in the circumstances, although it could have been used for the gynaecological operations. In obstetrics, the commonly used method of weighing the blood in the placenta bowl must give a substantial underestimate of the true blood loss (Moir and Wallace, 1967).

The Perdometer gives a very accurate assessment of total external blood loss, even in difficult circumstances, such as obstetrics and urological surgery where other methods may be very inaccurate. No estimate of concealed blood loss within the tissues can be made. It is known, however, that such losses are almost non-existent at vaginal deliveries, both spontaneous and operative and at vaginal hysterectomies (Pritchard et al, 1960).

BLOOD LOSS AT FORCEPS DELIVERY

A Statistical Analysis of The Influence of Epidural Analgesia, General Anaesthesia, Pudendal Nerve Block and Obstetric Factors on Blood Loss at 214 Forceps Deliveries.

This investigation was designed to assess the influence of three standard methods of anaesthesia for forceps delivery on the total external blood loss during the second and third stages of labour and repair of episiotomy. Because obstetric, as well as anaesthetic factors might influence blood loss at forceps delivery, it was necessary to assess certain obstetric variables. In particular, oxytocic drugs, inco-ordinate uterine action in the first stage of labour, rotation of the foetal occiput at delivery, pre-eclampsia and parity were assessed for their influence on blood loss.

The investigation was performed in 1966. At that time there were only two reports of accurate measurements of blood loss at forceps deliveries. Pritchard and his colleagues (1960) found an average blood loss of 455ml. at 65 forceps deliveries with episiotomy. They measured external blood loss and blood volume changes. They found no evidence of concealed blood loss (sequestration) in the tissues. Newton (1966) measured external blood loss at 105 deliveries, most of which were spontaneous, but "a few" were forceps deliveries. The 28 primigravidae in Newton's series lost, on average, 625ml. of blood and the 77 multiparae lost 314 ml. on average. In 1967, Brant measured blood loss by a haemoglobin dilution technique at 57 vaginal deliveries of which 42 were spontaneous vertex deliveries, 9 were forceps deliveries, 3 were breech deliveries and 3 were twin deliveries. Brant gave no results for mean blood loss. Neither Newton nor Brant differentiated between the various types of delivery in their series, yet as Wallace (1967) has shown, there is a very substantial difference in blood loss between the various types of operative vaginal delivery and spontaneous delivery.

None of these workers assessed the influence of anaesthesia on blood loss, and they made incomplete allowances, or sometimes no allowance at all for the numerous obstetric variables. These reports do serve to emphasise that the overall true blood loss at vaginal deliveries is much higher than is commonly believed and they illustrate the sometimes gross underestimates which are associated with simply weighing such blood as may be collected in the placenta bowl. Newton (1966) found that 22 per cent of his heterogeneous group of patients lost over 500ml. of blood and 21 per cent of Brant's (1967) uncontrolled group lost more than 500ml. of blood. These studies do little to elucidate the causes of bleeding at delivery.

Several authors have recorded their impression that bleeding is less when delivery takes place under regional rather than general anaesthesia. Goldman (1959) thought that bleeding at forceps delivery was reduced when pudendal nerve block was used. Rodriguez (1959) and Hingson and his colleagues (1961) commented on the very low blood loss sometimes associated with forceps delivery under epidural analgesia. None of these workers used an accurate method of measurement but relied on visual assessments.

There seemed to be a real need for an accurate assessment of anaesthetic and obstetric factors which might affect bleeding at forceps delivery and so the following investigation was carried out jointly with an obstetric colleague. The findings have been published elsewhere (Moir and Wallace, 1967).

METHOD

The technique and principles of blood loss measurement with the Rustad-Ohlin Perdometer are described on pages 75 to 78. Each patient's haemoglobin concentration was measured, not more than 24 hours before delivery, by a spectrophotometer.

Blood loss was estimated at 214 consecutive and unselected mid cavity forceps deliveries. Medio-lateral episiotomy was performed in every case. Each patient received an oxytocic drug at delivery of the anterior shoulder of the foetus. Ergometrine 0.5mg. was injected intravenously on 120 occasions and 94 patients received 1ml. of Syntometrine (Synthetic oxytocin, 5 units with Ergometrine 0.5mg.) by intramuscular injection. A continuous intravenous infusion of synthetic oxytocin

(Syntocinon) was given during labour and delivery to 11 patients.

Anaesthetic Techniques.

One of three standardised methods of pain relief was employed. The choice of technique was influenced solely by anaesthetic and obstetric considerations.

Lumbar Epidural Analgesia.

This was used for 52 forceps deliveries. In 46 instances, delivery was performed under a continuous epidural block which had been instituted during the first stage of labour. The remaining six patients received a single-shot epidural block for forceps delivery. In each case, the local anaesthetic drug was a 2 per cent lignocaine solution with 1:200,000 adrenaline. The dose of Lignocaine solution was 12ml. (240mg.) to 14 ml. (280mg.) This dose was injected while the patient was in a sitting position and perineal anaesthesia was present in every case.

Of the 46 continuous epidural blocks, 28 were administered for inco-ordinate uterine action in the first stage of labour. Uterine action was normal in the other cases.

General Anaesthesia.

Forceps delivery was performed under general anaesthesia in 71 patients. Anesthesia was induced with 150mg. to 250mg. of thiopentone, followed by 100mg. suxamethonium. A cuffed endotrachael tube was passed. Anaesthesia was maintained with nitrous oxide and 30 to 35 per cent of oxygen. Muscular relaxation was maintained by intermittent injections of suxamethonium in 21 cases and with d-tubocuratine in 50 cases. Intermittent positive pressure ventilation (I.P.P.V.) was performed by a mechanical ventilator and each patient's minute volume was between 8 litres and 10 litres.

Pudendal Nerve Block.

Bilateral pudendal nerve block and local infiltration of the perineum was used for 91 forceps deliveries. A 1 per cent solution of prilocaine (Citanest) was used. The total dose injected varied between 25ml. (250mg.) and 40ml. (400mg.) There was no adrenaline in the solution. The pudendal nerve was blocked in Alcock's canal by the transvaginal approach.

Statistical Analysis.

The Student t test is used for assessment of the significance of the difference between the various pairs of mean values. A probability factor (P) of less than 0.05 is regarded as significant and a P value of less than 0.01 is regarded as highly significant.

RESULTS.

Anaesthetic Technique.

There were 186 forceps deliveries which terminated labours in which uterine action had been clinically normal during the first stage. The blood loss and incidence of postpartum haemorrhage (blood loss over 500ml.) in these 186 deliveries are shown, according to the anaesthetic used, in Table 9.

TABLE 9

The Influence of anaesthesia on blood loss at 186 mid-cavity forceps deliveries terminating normal labour.

Anaesthetic Technique	No. of cases	Blood loss (ml.) Mean ± Stand Devn.	Range	Percentage of patients losing over 500 ml.
General anaesthesia	71	518 ± 302	50 - 1410	40
Pudendal block	91	412 ± 246	45 - 1430	29
Epidural analgesia	24	274 ± 58	110 - 390	0

There is a highly significant difference (P always < 0.01) between the mean blood loss associated with any one anaesthetic technique and each of the other techniques.

It is worthy of note that no patient delivered under epidural analgesia lost more than 400ml. of blood, yet under general anaesthesia and pudendal block analgesia, the incidence of postpartum haemorrhage was respectively 40 per cent and 29 per cent. The mean blood loss at delivery under epidural analgesia is about half the mean loss when general anaesthesia is used.

Because it has now been shown that the anaesthetic technique has a highly significant influence on blood loss at forceps delivery, all the subsequent analysis of various obstetric factors are performed for groups of patients who all received the same anaesthetic.

Uterine Action.

All the patients who received general anaesthesia and pudendal block analgesia had reasonably normal uterine action in the first stage of labour and so no comparisons can be made.

Continuous epidural analgesia was administered to 28 patients who had a prolonged first stage of labour due to inco-ordinate uterine action. Comparison with the 24 patients who received epidural analgesia and had normal uterine action shows that an inco-ordinate first stage of labour is associated with an increased blood loss at delivery ($P < 0.02$). The results are summarised in Table 2. No patient who had normal uterine action and an epidural block had a postpartum haemorrhage, while six patients (21 per cent) who had inco-ordinate uterine action and an epidural block had a blood loss in excess of 500 ml.

TABLE 10

The Influence of uterine action on blood loss at 52 mid-cavity forceps deliveries under epidural analgesia.

Uterine action in first stage of labour	No. of cases	Blood Loss (ml.) Mean ± Stand Devn.	Range	Percentage of patients losing over 500ml.
Normal	24	274 ± 58	110-390	0
Inco-ordinate	28	408 ± 144	100-720	21

Because it has now been shown that anaesthesia and inco-ordinate uterine action significantly affect blood loss at forceps delivery, both these factors are allowed for in the following analysis.

Oxytocic Drugs.

All patients delivered under general anaesthesia received intravenous ergometrine, so that no comparison is possible within this group.

There were 91 patients who received pudendal block analgesia and had normal uterine action in the first stage of labour. An intramuscular injection of Syntometrine 1 ml. was given to 68 of these patients and 23 patients received 0.5 mg. ergometrine by intravenous injection. All injections were given at delivery of the anterior shoulder of the foetus. The blood losses associated with these two oxytocic drugs are shown in Table 11. There is no statistically significant difference in the blood loss associated with the two drugs. ($P < 0.4$).

TABLE 11

The influence of two oxytocic drugs on blood loss at 91 mid-cavity forceps deliveries under pudendal block

Oxytocic drug.	No. of Cases	Blood loss (ml.) Mean ± Stand Devn	Range	Percentage of patients losing over 500ml.
I.V. ergometrine 0.5mg.	23	425 ± 262	100-910	31
I.M. syntometrine 1ml.	68	385 ± 214	45-1430	22

The 52 patients delivered under epidural analgesia must be classified according to the presence or absence of incoordinate uterine action in the first stage of labour as well as accoding to the oxytocic drug administered at delivery. Table 12 shows that when this is done, blood loss is not significantly influenced by whether intravenous ergometrine or intramuscular syntometrine is used ($P < 0.5$ in normal labour and $P < 0.4$ in inco-ordinate labour).

TABLE 12.

The influence of two oxytocic drugs on blood loss at 52 mid-cavity forceps deliveries under epidural analgesia.

Type of labour in first stage	Oxytocic drug	No. of cases	Blood loss (ml.) Mean ± Stand Devn.	Range	Percentage of patients losing over 500ml.
Normal	IV ergometrine 0.5 mg.	10	292 ± 64	110-390	0
Normal	IM syntometrine 1 ml.	14	264 ± 72	150-370	0
Inco-ordinate	IV ergometrine 0.5 mg.	16	383 ± 180	100-720	19
Inco-ordinate	IM syntometrine 1 ml.	12	442 ± 69	310-550	25

It may have been that ergometrine was administered intravenously when a predisposition to third stage haemorrhage existed, because it was hospital policy to give ergometrime to patients with a history of previous postpartum haemorrhage and to those who had received an oxytocic drug during labour or for the induction of labour.

Continuous Oxytocin Infusion.

Syntocinon drips were only used with a frequency sufficient to permit statistical analysis in one group of patients; the group who received continuous epidural analgesia for inco-ordinate uterine action in the first stage of labour. Abnormal uterine action is difficult to classify on clinical grounds but syntocinon infusions were probably used mainly in cases of hypotonic inco-ordinate uterine action. However, not all patients may have had the same type of uterine dysfunction. The oxytocin infusions were maintained until after completion of the third stage of labour.

Table 13 shows the blood loss at delivery in 11 patients who received syntocinon infusions and 17 patients also with inco-ordinate uterine action, who received no infusion. The use of a syntocinon infusion did not significantly effect blood loss at delivery ($P < 0.4$).

TABLE 13

The influence of syntocinon infusions on blood loss at mid-cavity forceps delivery under epidural analgesia in 28 cases of inco-ordinate uterine action.

	No. of cases	Blood loss (ml.) Mean ± Stand Devn.	Range	Percentage of patients losing over 500 ml.
Syntocinon infusion	11	444 ± 180	100-720	55
No infusion	17	397 ± 117	130-640	13

Position of the foetal occiput at delivery

Rotation of the foetal occiput, either manually or by forceps is likely to prolong delivery and may entail a more extensive episiotomy, so that increased blood loss might be anticipated. The foetal head was rotated from the occipito-posterior or occipito-transverse position in 94 deliveries and the occiput was in an anterior position at 120 deliveries.

In Table 14, patients are grouped according to whether the occiput was rotated or not at delivery and according to the type of anaesthesia administered and the character of the uterine action in the first stage of labour. Although the average losses were always higher when rotation of the occiput was performed, the differences are seldom large and are never quite statistically significant ($P < 0.1$ to < 0.7).

TABLE 14

The influence of rotation of the foetal occiput on blood loss at 214 mid-cavity forceps deliveries.

Anaesthetic Technique.	Rotation of occiput	No. of cases	Blood loss (ml.) Mean ± Stand Devn.	Range	Percentage of patients losing over 500ml.
General Anaesthesia	Yes No	43 28	560 ± 345 468 ± 235	130-1410 50-1060	42 39
Pudendal Block	Yes No	21 70	421 ± 259 395 ± 225	45-1080 110-1430	28 30
Epidural analgesia (normal labour)	Yes No	10 14	298 ± 81 260 ± 58	110-370 160-390	0 0
Epidural analgesia (Inco-ordinate labour)	Yes No	20 8	417 ± 141 397 ± 164	100-720 130-640	22 25

Pre-eclampsia

Patients who had a blood pressure of 140/90 mm.Hg. or higher and either oedema or albuminuria at the time of delivery were considered to have pre-eclampsia. Table 15 shows the blood losses at delivery according to the presence or absence of pre-eclampsia, the method of anaesthesia and the type of uterine action in the first stage of labour. Pre-eclampsia did not significantly affect blood loss at delivery (P < 0.5 to < 0.8).

TABLE 15

The influence of pre-eclampsia on blood loss at 214 mid-cavity forceps deliveries.

Anaesthetic Technique.	Pre-eclampsia	No. of cases	Blood loss (ml.) Mean ± Stand Devn.	Range	Percentage of patients losing over 500ml.
General Anaesthesia	Yes	40	509 ± 324	50-1410	40
	No	31	526 ± 275	145-1195	42
Pudendal Block	Yes	43	423 ± 246	130-1430	30
	No	48	386 ± 237	45-990	29
Epidural analgesia (Normal labour)	Yes	9	258 ± 79	110-390	0
	No	15	294 ± 94	160-370	0
Epidural analgesia (Inco-ordinate Labour)	Yes	13	382 ± 158	100-640	25
	No	15	424 ± 167	210-720	21

Parity

There were 183 primigravidae and 31 multigravidae in the series. These figures are explained by the high incidence of conditions such as second stage delay and pre-eclampsia in primigravidae. All but four of the 52 patients delivered under epidural analgesia were primigravidae and so a statistical analysis is not justified for this group. The blood losses in primigravidae and multigravidae delivered under general anaesthesia and pudendal block analgesia are shown in Table 16.

Although primigravidae lost more blood than multigravidae, the differences are not statistically significant ($P < 0.5$ to 0.7).

TABLE 16

The influence of parity on blood loss at 162 mid-cavity forceps deliveries.

Anaesthetic technique	Parity	No. of cases	Blood loss (ml.) Mean ± Stand Devn.	Range	Percentage of patients losing over 500ml.
General anaesthesia	Primigravidae	60	564 ± 257	50-1410	40
	Multigravidae	11	509 ± 308	300-1120	36
Pudendal block	Primigravidae	75	424 ± 252	45-1430	28
	Multigravidae	16	370 ± 286	90-850	37

Haemoglobin values after delivery

Haemoglobin values were measured by spectrophotometer, within the 24 hours preceding delivery and again on the third day after forceps delivery in 98 patients. No patient received a blood transfusion. The mean blood loss in the whole group was 401.6ml. The mean reduction in haemoglobin value on the third day after delivery, in relation to the pre-delivery value, was 1.2G/100 ml. This respresents a mean reduction in the patient's haemoglobin values of 0.3G/100ml. for each 100ml. of blood lost at delivery.

DISCUSSION

The suitability of haemoglobin extraction-dilution techniques for the measurement of obstetric blood loss and their high degree of accuracy have already been discussed (pages 74 to 78). The accuracy of the Rustad-Ohlin Perdometer was repeatedly assessed during this study and the recovery rate was always over 97 per cent. This is probably the most accurate method available for the assessment of external blood loss.

Visual estimates of blood loss at delivery may be substantially lower than the true loss. Cullen (1961) recorded an average observer underestimate of 40 per cent and Newton (1966) noted a 46 per cent average underestimate. These errors are doubtless due to the difficulty which even the experienced observer has in assessing the volume of blood widely dispersed on linen, on the floor and in the placenta bowl and in estimating the extent of dilution of this blood by liquor amnii.

At 113 forceps deliveries in the present series, the obstetrician was asked to make a careful visual estimate of blood loss. The average error was an underestimate of 28 per cent, but in individual cases the error was much greater. In general, the greater the true loss, the greater was the error. The obstetricians were well aware of the difficulties of visual estimation and tried to allow for these difficulties. Estimates by nurses, who usually measured only the blood in the placenta bowl, were even more inaccurate. These observations indicate that reports concerning blood loss at delivery are of little value unless an accurate method of blood loss estimation is used.

The blood losses in this series may seem surprisingly large. Under general anaesthesia, 40 per cent of patients lost over 500ml. of blood (average loss 518 ml.) and under pudendal block analgesia, 29 per cent lost over 500ml. of blood (average loss 412 ml.) The much lower blood loss (average 274 ml.) and absence of postpartum haemorrhage under epidural analgesia are striking.

The results of this series take no account of maternal blood lost in the placenta. Newton and Moody (1961) have estimated that an average volume of 60ml. of maternal blood is lost in this way.

All the patients in this investigation had a medio-lateral episiotomy and this in itself is an important source of bleeding. Wallace (1967) found that a medio-lateral episiotomy at spontaneous vertex deliveries was associated with an average blood loss of 130ml. The timing of the episiotomy at forceps delivery in relation to traction and rotation of the foetal head may influence blood loss. In the present series, timing of the episiotomy varied with the practice of each obstetrician and there is an impression that early episiotomy increases blood loss.

Despite the high mean blood losses and the high incidence of postpartum haemorrhage associated with forceps delivery under general anaesthesia and under pudendal block analgesia, only seven out of 214 patients

(3.3 per cent) were given a blood transfusion. The physical signs of shock were rarely recorded. It should be remembered that at forceps delivery, there was sometimes only one doctor present and that he was conducting the delivery and was not in a position to record pulse rates and blood pressures. Nevertheless it appears that a previously healthy pregnant woman can often lose up to 1,000 ml. or even 1,500 ml. of blood and show none of the classical signs of acute blood loss. Such a patient must be on the brink of a drastic sudden circulatory collapse. Brandt (1967) also stressed that hypotension and tachycardia were late signs of blood loss in healthy pregnant women and advocated blood transfusion after a loss of 500 ml. and before hypotension developed.

Despite the demonstra tion that average blood losses are higher than most have believed and despite the high incidence of blood losses of more than 500ml., it would be ill-considered to suggest any alteration in the traditional definition of postpartum haemorrhage as a blood loss of more than 20 ounces (or currently, 500ml.) In the absence of an immediate and accurate assessment, a visual estimate of a blood lossof 500 ml. calls for action and a realisation that the true loss is likely to be substantially greater.

Although absolute indication for blood transfusion are uncommon at forceps delivery, blood losses of the magnitude recorded under general anaesthesia and pudendal block analgesia contribute substantially to the development of postpartum anaemia. The average reduction in haemoglobin value in 98 patients was 1.2G/100ml. or 0.3G/100ml. for each 100ml. of blood loss. On this basis, a patient whose pre-delivery haemoglobin value was 12.0G/100ml. and who lost 1,000 ml. of blood at delivery, would have a post-delivery haemoglobin value of approximately 9G/100ml.

An appreciation of the true extent of the blood loss at forceps delivery when certain types of anaesthesia are used, may result in a wider use of blood transfusion in an effort to prevent or treat shock and postpartum anaemia (Brandt, 1967). Blood transfusion is expensive, may not always be available and is not without its own risks. Of every 200 patients who receive two or more bottles of blood, one patient will develop post-transfusion hepatitis (Brit.Med.J., 1967, Leading Article). It has been said that there is a yearly minimum of 1,500 deaths due to blood transfusion in the U.S.A. alone (Jenkins and Graves, 1961), but according to Joseph (1960) this estimate is too high.

Obstetric haemorrhage remains a major cause of maternal deaths and many of these deaths are avoidable.

The use of a technique of anaesthesia, such as epidural analgesia, which substantially reduces blood loss at delivery, offers at least three advantages in the reduction of postpartum anaemia, the avoidance of blood transfusion and perhaps even in the avoidance of the occasional maternal death from haemorrhage or the effects of blood transfusion. It is essential that epidural analgesia be used with skill and care so that the complications of haemorrhage are not merely replaced by the complications of epidural analgesia. Although epidural analgesia may prevent excessive bleeding, it should not be administered to a patient who has already lost a large amount of blood.

Several variables have been assessed, but only two factors significantly influenced blood loss when statistical analysis had been performed. These factors were the anaesthetic technique and the type of uterine action in the first stage of labour.

Anaesthetic technique

If pudendal block analgesia is regarded as a control technique, unlikely to influence myometrial activity in the third stage of labour, then general anaesthesia was associated with increased bleeding and epidural analgesia was associated with reduced bleeding.

All the patients who received a general anaesthetic had the same type of anaesthesia and in all cases only a very light level of narcosis was maintained. There was no exposure to any of the potent anaesthetic agents such as halothane, chloroform, ether or cyclopropane which are clinically well recognised as relaxants of the uterine muscles.

Only four drugs were administered in the course of the anaesthetic; thiopentone, nitrous oxide, suxamethonium and sometimes d-tubocurarine. There appear to have been no objective studies of the effect of thiopentone and nitrous oxide on the uterus. It is widely believed that thiopentone, at least in doses up to 250mg., does not relax the myometrium and it seems unlikely that nitrous oxide, when given with at least 30 per cent of oxygen would reduce uterine contractibility.

Suxamethonium was used for intubation of the trachea in all cases and in 21 cases intermittent injections of suxamethonium were given for the maintenance of muscular relaxation. The other 50 patients received d-tubocurarine for this purpose. Felton and Goddard (1966), using intra-amniotic pressure recordings, showed that suxamethonium actually increases uterine contractibility, and so it is very unlikely that this drug would cause uterine postpartum haemorrhage. There appears to be no evidence concerning the effect of d-tubocurarine on the myometrium. In the present series, the 21 patients who received intermittent suxamethonium injections had an average blood loss of 596ml. and the 50 patients who received d-tubocurarine lost 512ml. of blood on average. This difference is not statistically significant ($P < 0.4$) and it is therefore probable that neither of these muscle relaxant drugs causes postpartum haemorrhage.

It might be that general anaesthesia was chosen for the more difficult and prolonged forceps deliveries and that therein lies the explanation for the higher blood loss. The converse that epidural analgesia was chosen for the easiest forceps deliveries, would then have to be accepted, because epidural analgesia was associated with the lowest blood losses. In practice, general anaesthesia was usually given for one or more of the following indications: an occipito posterior or occipito-transverse position of the foetal head, hypertension in the second stage of labour, foetal distress requiring immediate anaesthesia and psychological unsuitability for forceps delivery under regional analgesia. Some of the easiest forceps deliveries were performed under general anaesthesia when the indication was hypotension in the second stage of labour and no mechanical difficulty was present. Some of the forceps deliveries performed under epidural block were obstetrically difficult deliveries. Table 17 shows the number of forceps deliveries performed, under each type of anaesthesia, when pre-eclampsia and an occipito-posterior or occipito-transverse position were present.

TABLE 17

Incidence of pre-eclampsia and occipito-posterior (or transverse) position in 186 mid-cavity forceps deliveries.

Anaesthetic	Total Number	Cases of pre-eclampsia	O.P. or O.T. position.
General anaesthesia	71	40 (56%)	43 (60%)
Pudendal block	91	43 (47%)	21 (23%)
Epidural analgesia (Normal labour)	24	9 (38%)	10 (42%)

It is apparent that a somewhat higher percentage of the patients who received a general anaesthetic had either pre-eclampsia or an occipito-posterior position and sometimes both of these abnormalities. Yet it has already been shown in the course of this study, that neither pre-eclampsia nor rotation of the foetal head at delivery has a statistically significant influence on blood loss.

It can only be concluded that the explanation for the higher blood loss under general anaesthesia is not readily apparent and may lie in an unsuspected effect of one of the anaesthetic drugs, in a tendency to use general anaesthesia for certain obstetric abnormalities, or in some unknown third factor.

The reduced bleeding at delivery under epidural analgesia, in comparison with both general anaesthesia and the "control" technique of pudendal block, is almost certainly the result of the sympathetic denervation of the uterus associated with lumbar epidural analgesia. There is consequently a powerful, sustained retraction of the uterus in the third stage of labour which is easily recogniseable on palpation. This phenomenon has long been known to occur at delivery under subarachnoid analgesia and indeed, before effective intravenous oxytocic drugs became available, subarachnoid block was sometimes used in the treatment of persistent atonic postpartum haemorrhage.

Inco-ordinate uterine action.

It has been shown that, at forceps delivery under epidural analgesia after a prolonged first stage of labour due to inco-ordinate uterine action, blood loss is significantly higher than after a normal first stage and forceps delivery under the same type of analgesia. It would appear that when there is uterine dysfunction in the first stage of labour, there is likely to be poor uterine retraction in the third stage.

The explanation for this observation may be in some unknown inherent defect in the myometrium or in the regulation of uterine activity by hormonal or nervous mechanisms. When there is prolonged inco-ordinate labour, generalised and local uterine biochemical upset may develop. Acidosis, dehydration and electrolyte imbalance may further impair uterine activity in all stages of labour. Mark (1961) showed, in vitro, that the uterus contacts less effectively and responds poorly to oxytocin in an acid medium and water and electolyte studies of Hawkins and Nixon (1958) show that dehydration, sodium retention and chloride and potassium depletions develop in prolonged labour and may cause secondary uterine inertia.

Opinions in the obstetric literature are divided on whether there is a relationship between prolonged first stage labour and third stage haemorrhage. Some of the now classic obstetric texts, asserted that prolonged labour was a major cause of postpartum haemorrhage (Munro kerr et al, 1933; Cameron et al, 1939). From a selection of more recent obstetric opinions, De Boer (1955), Keettell and Pretis (1956) and Rodesch and his colleagues (1965) are of the belief that inco-ordinate uterine action in the first stage of labour predisposes to postpartum haemorrhage, while Morris(1963) and Donald (1964) have not observed this relationship. The explanation for these conflicting views may be that most obstetricians do not now permit labour to continue for as long as was common 30 years ago. There is also a growing awareness of the need for intravenous therapy during prolonged labour so that water, electrolytes and calories are now more often supplied in adequate amounts.

BLOOD LOSS DURING MAJOR VAGINAL SURGERY.

A statistical analysis of the influence of epidural analgesia, general anaesthesia, hypotension and age on bleeding at Manchester operation and vaginal hysterectomies.

In 1966, McLaughlin wrote that "the capacity to ply his scalpel boldly (but often invisibly) at the bottom of a bloodsodden operative field is no longer the hallmark of the competent surgeon." Bleeding during major vaginal surgery is too often troublesome, is occasionally dangerous and seems at times to be influenced by factors which are outwith the knowledge and control of surgeon and anaesthetist.

Several American workers have estimated blood loss during vaginal operations and their results are summarised in Table 17.

TABLE 17.

Mean blood losses during major vaginal surgery.

Operation	Mean blood loss (ml.)	
Manchester operation	849 703	Buchman, 1953 Wexler, 1959
Vaginal hysterectomy with vaginal repair	716 772 775	Buchman, 1953 Wexler, 1959 Lazor and Krieger, 1959
Vaginal hysterectomy only	289 *	Copenhaver, 1964.

The high average values recorded by these American workers may be attributed at least in part, to the prolonged operating times which are common in the U.S.A. These authors give no details of the anaesthetics used. Their series were numerically quite small (range 5 to 33 patients), the range of individual blood losses was always wide and their methods of blood loss estimation were not always accurate. All these workers used swab-weighing to assess blood loss. Buchman (1953) and Wexler (1959) avoided contamination of drapes and gowns by collecting blood in a plastic bag and weighing this blood and their results are probably accurate. The other workers did not estimate blood shed onto linen.

There appears to have been only one British report of blood loss measurement in gynaecological surgery. Loudon and Scott (1960) assessed blood losses at 96 vaginal repair operations by swab-weighing and visual estimation of blood on linen and gowns. Under thiopentone, nitrous oxide anaesthesia with a muscle relaxant and intermittent positive pressure ventilation (I.P.P.V.) the mean blood loss was 260 ml. Under lumbar epidural analgesia with a light covering general anaesthetic the mean blood loss was only 98 ml.

Another British worker, Linacre in 1961 reported on one thousand gynaecological operations performed under induced hypotension with a ganglion blocking drug and anaesthesia with thiopentone, nitrous oxide, a muscle relaxant and I.P.P.V. Unfortunately, Linacre did not measure blood losses, but merely stated that in 87.9 per cent of cases the operating field was "dry," in 10.5 per cent it was "fair" and in 1.6 per cent it was "wet." Linacre stressed the safety of hypotensive anaesthesia when the patient was in a head-down position.

Eckenhoff and Rich (1966) commented on the scarcity of reports comparing the advantages and safety of hypotensive with normotensive anaesthetic techniques. With this fact in mind, and in the belief that excessive bleeding often hinders the performance of delicate vaginal surgery and occasionally endangers life, an accurate assessment of blood loss was made at 211 gynaecological operations and a statistical analysis was performed to assess the influence of anaesthesia and age on bleeding. This work was performed in 1965 and 1966 and has been accepted for publication (Moir, 1968.)

METHOD.

Blood loss estimations were performed by a haemoglobin extraction-dilution technique using the Rustad-Ohlin Perdometer. The details of the technique are described on pages 75 to 78 . The accuracy of the Perdometer was assessed on eight occasions during this investigation and the recovery rate for known quantities of blood was always between 97 per cent and 100 per cent.

There were 211 patients in the series. Ages ranged from 37 years to 85 years. The operations performed were 117 Manchester operations (anterior colporrhaphy and posterior colpoperineorrhaphy with amputation of the cervix) and 94 vaginal hysterectomies with anterior and posterior vaginal repair. Standardised surgical procedures were used by the surgeons who performed the operations and these surgeons were all on the staff of a single gynaecological department.

Each patient's haemolgobin value was estimated spectrophotometrically within the 36 hours before operation.

Anaesthetic techniques

Premedication was papaveretum (Omnopon) 20mg. with hyoscine (Scopolamine) 0.45mg. except that patients over 65 years of age received atropine 0.6mg. with morphine 10mg. or 7.5mg.

One of two standardised general anaesthetics was administered to 109 patients and lumbar epidural analgesia with a light covering general anaesthetic was given to 102 patients. The epidural blocks are subdivided into a normotensive and a hypotensive group so that the effects of four anaesthetic techniques on blood loss at two types of operation could be assessed.

General anaesthesia with spontaneous ventilation.

Anaesthesia with thiopentone suxamethonium, nitrous oxide, oxygen and halothane was used on 56 occasions. The dose of thiopentone did not exceed 350mg., the inspired halthane concentration was 1 per cent or less, and the inspired oxygen concentration was always at least 30 per cent. Spontaneous ventilation was permitted through an endotracheal tube connected to a Magill circuit (system A, Mapleson, 1954) with a fresh gas flow of at least 8 litres per minute. Rebreathing in these circumstances is most unlikely (Mapleson, 1954, Woolmer and Lind, 1954, Kain and Nunn, 1967).

General anaesthesia with I.P.P.V.

Anaesthesia with thiopentone (not more than 350 mg.), nitrous oxide, oxygen and d-tubocurarine was administered to 53 patients. I.P.P.V. was performed by a volume-cycled mechanical ventilator with a non-rebreathing circuit and a negative pressure was not employed during expiration. The trachea was intubated with a cuffed tube. The expired minute volume was from 9 to 11 litres and the inspired oxygen concentration was at least 30 per cent.
Hypoxaemia was therefore unlikely (Slater et al, 1965).

Lumbar Epidural analgesia.

Single-shot epidural analgesia was given to 102 patients. From 10 ml. (150mg.) to 24 ml. (360mg.) of 1.5 per cent lignocaine solution with added 1:200,000 adrenaline was injected at the L3-4 or L2-3 interspace. The lower doses were given to elderly patients and to patients with degenerative arterial disease because as age increases and arteriosclerosis develops, the spread of solutions in the epidural space increases (Bromage, 1962). A light general anaesthetic was also given using thiopentone, nitrous oxide, oxygen and, if necessary, 0.5 per cent halothane vapour was added to the gas mixture inspired from a Magill circuit. The trachea was intubated. This very light general anaesthetic was given because of the reluctance of female patients to undergo major surgery in the lithotomy position while conscious.

The patients who received epidural analgesia were classified, for the present purpose, as normotensive when the stable systolic blood pressure during operation remained above 80mm.Hg. and as hypotensive when the stable systolic blood pressure lay between 60mm.Hg. and 80mm.Hg. In fact, some fall in blood pressure occurred during all the epidural blocks and in all but two of the cases classed as normotensive, the systolic blood pressure fell to under 110 mm.Hg.

54 patients were classed as normotensive and 48 were hypotensive. Hypertension was always associated with a warm, vasodilated skin and palpable radial and carotid pulses. No vasopressor drugs were administered during surgery.

Blood pressure was monitored at ten minute intervals throughout operation in all 211 patients. A mercury sphygmomanometer was used for the patients who received general anaesthesia alone. An oscillometer was used to measure the lower blood pressures which occurred under epidural analgesia.

Three patients with advanced arterial disease and a history of coronary insufficiency or cerebrovascular accident were not given epidural analgesia. There was no other exclusion of patients from a particular anaesthetic technique.

RESULTS.

The results are analysed statistically by the Student t test for the estimation of the significance of the difference between pairs of mean values. As is conventional, a difference is regarded as significant if the probability of the difference being due to chance is less than 5 per cent ($P < 0.05$) and as highly significant if the probability is less than 1 per cent ($P < 0.01$).

Manchester Operations

The influence of anaesthesia on mean blood loss at Manchester Operations.

Table 18 shows the mean blood losses associated with four anaesthetic techniques at 117 Manchester operations.

TABLE 18

The influence of anaesthesia on mean blood loss at 117 Manchester Operations.

Anaesthetic	No. of cases	Mean Blood loss ± Stand Devn. (ml.)
Hypotensive epidural	24	81 ± 64
Normotensive epidural	30	92 ± 53
N_2O, halothane	35	212 ± 127
N_2O, relaxant, I.P.P.V.	28	289 ± 155

Statistical analysis by the Student t test shows that, with either type of epidural analgesia, the blood loss is highly significantly less than the loss associated with either type of general anaesthesia (P always < 0.01). The difference between the mean blood losses associated with hypotensive and normotensive epidural analgesia is not significant ($P < 0.5$) When the two general anaesthetics are compared, the mean loss associated with technique employing I.P.P.V. is significantly greater than the loss occurring with nitrous oxide, halothane and spontaneous ventilation ($P < 0.05$).

Of the 54 patients who received epidural analgesia, 70 per cent lost under 100ml. of blood, while only 14 per cent of the 63 patients who received general anaesthesia lost as little as this. A total loss of less than 100ml. of blood over a period of perhaps 45 minutes produces a dry operating field.

If the smallest mean loss in Table 18 is regarded as 100 per cent, then the following are the relationships between the four anaesthetic techniques:-

Hypotensive epidural analgesia	100 per cent
Normotensive epidural analgesia	114 per cent
N_2O, halothane	262 per cent
N_2O, relaxant, I.P.P.V.	353 per cent

The mean blood loss associated with epidural analgesia is approximately one third of the loss associated with general anaesthesia.

<u>Anaesthesia and the rate of blood loss at Manchester Operations</u>

Mean blood loss values take no account of variations in operating time, a factor which might influence total blood loss in the individual case. Calculation of the rate of blood loss (ml. per minute) eliminates the effect of different operating times. The mean rates of blood loss associated with the four anaesthetics are shown in Table 19.

TABLE 19

The influence of anaesthesia on mean rate of bleeding at 117 Manchester Operations.

Anaesthetic	No. of cases	Mean rate of bleeding ± Stand Devn. (m./minute)
Hypotensive epidural	24	1.5 ± 0.9
Normotensive epidural	30	2.1 ± 1.2
N_2O, halothane	35	5.0 ± 2.7
N_2O, relaxant, I.P.P.V.	28	6.3 ± 2.5

Statistical analysis reveals that the relationships between the anaesthetic techniques are now altered in some aspects. Both types of epidural analgesia remain superior to both general anaesthetics ($P < 0.01$), but hypotensive epidural analgesia is now seen to be associated with a significantly lower rate of bleeding than normotensive epidural analgesia ($P < 0.05$) and the difference between the mean rates of bleeding associated with the two general anaesthetics is not statistically significant ($P < 0.1$).

If the smallest rate of blood loss in Table 19 is taken as 100 per cent, then the relationships between the rates of bleeding with the four anaesthetics are :-

Hypotensive epidural analgesia 100 per cent

Normotensive epidural analgesia 140 per cent

N_2O, halothane	333 per cent
N_2O, relaxant, I.P.P.V.	420 per cent

The average rate of bleeding under epidural analgesia is between approximately one quarter and one third of that associated with general anaesthesia.

The influence of age on blood loss at Manchester Operation.

The ages of the patients in this series of 117 Manchester operations ranged from 37 years to 85 years and it seemed possible that age might influence blood loss. In Table 20, the patients receiving each anaesthetic are arbitrarily subdivided into those over 65 years of age and those under 65 years of age.

TABLE 20

The influence of anaesthesia and age on mean blood loss at 117 Manchester Operations.

Anaesthetic	Patients under 65years		Patients over 65years	
	No.Of cases	Mean blood loss ±Stand Devn(ml)	No.of Cases	Mean blood loss ±Stand Devn(ml)
Hypotensive epidural	14	94 ±56	9	50 ± 14
Normotensive epidural	18	106 ± 83	12	70 ± 29
N_2O, halothane	23	255 ±126	12	131 ± 105
N_2O, relaxant I.P.P.V.	18	306 ±125	10	257 ± 207

The mean blood losses in patients over 65 years of age are always lower than the losses in patients under 65 years old. The mean blood loss in the older age group is almost half that observed in the younger age group in association with two anaesthetics, hypotensive epidural analgesia and nitrous oxide, halothane anaesthesia. In these two groups only, the reduction in mean blood loss with old age is statistically significant ($P < 0.05$ and $P < 0.01$ respectively).

Since age can influence mean blood loss, it is desireable to assess the significance of the differences between the mean blood losses associated with each anaesthetic when administered to patients of the same age group. When this is done, the differences already demonstrated for patients of all ages (Table 18) are confirmed, except that the difference between the mean losses associated with the two general anaesthetics ceases to be significant ($P < 0.2$ for those over 65 years and P. 0.1 for those under 65 years).

It has been shown that anaesthesia and sometimes operating time and age influence bleeding at Manchester operations. One final analysis, taking all three factors into account is required.

In Table 21 the mean rates of bleeding (ml. per minute) are shown for all anaesthetics and for each age group.

Both types of epidural analgesia are still superior to both types of general anaesthesia (P always < 0.01). Hypotensive epidural analgesia is associated with a significantly lower rate of bleeding than normotensive epidural analgesia in the group of patients under 65 years of age ($P < 0.05$) but not in the older age group ($P < 0.3$). Neither technique of general anaesthesia is significantly better than the other ($P < 0.2$) and so the apparent superiority of nitrous oxide, halothane anaesthesia over the technique involving I.P.P.V. is not substantiated when the variables of age and operating time are allowed for.

TABLE 21

The influence of anaesthesia and age on mean rate of bleeding at 117 Manchester operations

Anaesthetic	Patients under 65years		Patients over 65years	
	No. of cases	Mean blood loss ± Stand Devn(ml)	No. of cases	Mean blood loss ± Stand Devn(ml)
Hypotensive epidural	14	1.6 ± 1.1	9	1.3 ± 0.4
Normotensive epidural	18	2.5 ± 1.3	12	1.6 ± 0.7
N_2O, halothane	23	5.3 ± 3.0	12	4.3 ± 2.0
N_2O, relaxant I.P.P.V.	18	6.5 ± 2.2	10	6.0 ± 3.0

Vaginal Hysterectomies.

The influence of anaesthesia on mean blood loss at vaginal hysterectomy.

The mean blood losses at 94 vaginal hysterectomies with colpoperineorrhaphy, performed under four anaesthetic techniques, are shown in Table 22.

TABLE 22

The influence of anaesthesia on mean blood loss at 94 vaginal hysterectomies.

Anaesthetic	No. of cases	Mean blood loss ± Stand Devn. (ml.)
Hypotensive epidural	24	144 ± 112
Normotensive epidural	24	188 ± 184
N_2O, halothane	21	441 ± 181
N_2O, relaxant, I.P.P.V.	25	460 ± 184

The mean values are all approximately twice those recorded at Manchester operations, due to the more extensive and prolonged surgery, but the relationships between the mean blood losses are almost the same as those observed at Manchester operations.

Epidural analgesia is again associated with a highly significantly lower mean blood loss than either technique of general anaesthesia ($P < 0.01$). The difference between the mean losses observed with the two general anaesthetic techniques is not significant ($P < 0.8$); nor is the difference between the mean losses under hypotensive and normotensive epidural analgesia of significance ($P < 0.4$).

None of the 46 patients who received general anaesthesia lost less than 100ml. of blood, yet 22 (46 per cent) of the 48 patients operated on under epidural block lost under 100ml. of blood.

The mean blood loss at vaginal hysterectomy under epidural analgesia is approximately one third of the mean blood loss under general anaesthesia.

Anaesthesia and rate of blood lost at vaginal hysterectomy.

To allow for variations in operating time, the rate of bleeding (ml. per minute) was calculated for each case. The mean rates of blood loss for each anaesthetic technique are shown in Table 23.

TABLE 23.

The influence of anaesthesia on mean rate of bleeding at 94 vaginal hysterectomies.

Anaesthetic	No. of cases	Mean rate of bleeding ± (ml./minute).
Hypotensive epidural	24	2.0 ± 1.4
Normotensive epidural	24	2.9 ± 2.6
N_2O, halothane	21	5.5 ± 1.4.
N_2O, relaxant, I.P.P.V.	25	5.6 ± 2.1

The statistical relationships remain the same as those demonstrated between the mean blood losses at vaginal hysterectomy. That is, the only significant difference between the various mean rates of bleeding is that existing between either type of epidural analgesia and either type of general anaesthesia.

The influence of age on blood loss at vaginal hysterectomy.

There were 49 patients under 65 years of age and 45 patients over 65 years old. Table 24 shows that the mean blood loss associated with every anaesthetic technique was lower in patients over 65 years of age. This reduction in the elderly is statistically significant in three of the four anaesthetic groups ($P < 0.01$ for both general anaesthetics and P 0.05 for hypotensive epidural analgesia).

TABLE 24.

The influence of anaesthesia and age on mean blood loss at 94 vaginal hysterectomies.

Anaesthetic	Patients under 65 years		Patients over 65 years	
	No. of cases	Mean blood loss ± Stand Devn (ml.)	No. of cases	Mean blood loss ± Stand Devn (ml.)
Hypotensive epidural	12	164 ± 121	12	121 ± 101
Normotensive epidural	13	267 ± 226	11	101 ± 59
N_2O, halothane	11	580 ± 185	10	330 ± 68
N_2O, relaxant I.P.P.V.	13	541 ± 182	12	356 ± 118

When the rate of blood loss is calculated for each type of anaesthetic within each age group, the relationships between the four anaesthetic techniques remain the same as those already demonstrated by calculation of mean losses and mean rates of bleeding for the whole group (see Table 25.)

TABLE 25.

The influence of anaesthesia and age on mean rate of bleeding at 94 vaginal hysterectomies.

Anaesthetic	Patients under 65 years		Patients over 65 years	
	No. of cases	Mean rate of bleeding ± Stand. Devn. (ml./minute).	No. of cases	Mean rate of bleeding ± Stand. Devn. (ml./minute).
Hypotensive epidural	12	2.2 ± 1.5	12	1.8 ± 1.2
Normotensive epidural	13	3.7 ± 3.2	11	1.9 ± 1.2
N_2O, halothane	11	6.4 ± 1.2	10	4.8 ± 1.3
N_2O, relaxant, I.P.P.V.	13	6.6 ± 2.3	12	4.3 ± 1.1

DISCUSSION

The accuracy of the method of blood loss measurement used in this study has already been discussed at some length on pages 74 to 78 .

Statistical analysis of blood losses at 211 major vaginal operations has shown that bleeding is reduced by two factors, namely the use of epidural analgesia rather than general anaesthesia and increasing age of the patient. It has also been shown that, after making allowance for age and variations in operating time, a technique of general anaesthesia employing nitrous oxide, halothane and spontaneous ventilation is associated with statistically the same amount of bleeding as a technique employing nitrous oxide, a muscle relaxant and I.P.P.V.

During epidural analgesia, a stable systolic blood pressure below 80 mm.Hg. usually produced a slight further decrease in bleeding when compared with epidural analgesia associated with a stable systolic blood pressure between 80mm.Hg. and 110mm.Hg. This reduction in bleeding with hypotension was usually small and, after making allowances for the effects of age and operating times, was statistically significant in one group only, namely patients under 65 years of age, who had Manchester operations. It is concluded that whatever the blood pressure, epidural analgesia produced operating conditions which were much superior to those associated with general anaesthesia and that, in practice the gain from the production of hypotension to below 80mm.Hg. is likely to be small or even non-existent. It is thus possible to reduce bleeding at gynaecological surgery effectively by using epidural analgesia, a very light covering general anaesthetic and a safe degree of hypotension with vasodilatation. The safety of the technique may be enhanced by the fact that patients are in the lithotomy position during surgery.

When blood loss is under 50ml. at an operation lasting some 50 minutes, the operating field is almost dry and the surgeon's task is greatly eased. Such operating conditions may fairly be described as excellent. When the blood loss is between 50ml. and 100ml., conditions may be described as very good and if the loss is between 100ml. and 200ml. operating conditions are usually satisfactory. The following are the percentages of patients falling into these categories in the whole series of 211 operations.

Blood loss	102 epidural blocks	109 general anaesthetics
0- 50 ml.	24%	3%
51-100 ml.	35%	6%
101-200ml.	23%	17%

Thus, in 82 per cent of epidural blocks and 26 per cent of general anaesthetics, operating conditions were satisfactory, very good or excellent.

Reducing the operative blood loss benefits the surgeon and therefore the patient. The need for blood transfusion is reduced. Blood transfusion is associated with a definite morbidity and on occasion, fatality, either from the immediate or delayed effects of transfusion (Editorial, Brit. Med. J., 1967).

There will always be a number of patients in whom bleeding is troublesome, no matter what anaesthetic is chosen. In the present series of 211 operations, haemorrhage in excess of 500 ml. occurred in 22 (20 per cent) of 109 general anaesthetics and in 2 (2 per cent) of 102 epidural blocks. Some of this bleeding may be due to factors such as obesity, hypertension, an unusually severe gynaecological lesion and poor surgical or anaesthetic technique. Nevertheless, blood loss of more than 500 ml. was ten times commoner under general anaesthesia than epidural analgesia.

There were no deaths in the series and no serious complications attributable to any of the anaesthetic techniques. There was no instance of secondary haemorrhage and the surgeons were aware of the need for meticulous haemostasis when operating under epidural analgesia.

Among the many factors which may influence operative bleeding are the arterial blood pressure, the venous pressure, the arterial blood PCO_2 and PO_2, variations in regional blood flow due to the anaesthetic technique, the level of the operation site relative to the right atrium, obesity, age, the severity of the disease and the skill of the anaesthetist and surgeon.

In vaginal surgery,bleeding commonly takes the form of a venous or capillary ooze and obvious arterial bleeding is unusual. Raising the peripheral venous pressure is likely to increase venous bleeding at operation. The central and peripheral venous pressures are raised by coughing and straining (Hamilton et al, 1944) and by I.P.P.V. (Hubay et al, 1954, Pierce and Van Dam, 1962), so that a poorly administered anaesthetic or the use of I.P.P.V. may increase venous bleeding. I.P.P.V. slows the peripheral venous blood flow rate. Hodgson (1964) found that I.P.P.V. trebled the venous emptying time of the deep veins of the leg, a finding which Hodgson thought might be relevant to the development of deep venous thrombosis.

In the present series I.P.P.V. with a patient minute volume of from 9 to 11 litres was employed. Such a minute volume is likely to be associated with a respiratory alkalosis. The oxygen content of the inspired gas mixture was at least 30 per cent, so that arterial hypoxaemia was unlikely (Slater et al, 1965). This technique of anaesthesia was associated with a blood loss which was not significantly different from the loss which occurred with an anaesthetic technique employing nitrous oxide, halothane and spontaneous ventilation. The latter technique is usually associated with a moderate respiratory acidosis (Black and McKane, 1965; Marshall, 1966; Ivanov et al, 1967) and a minimal effect on venous pressure (Caffrey et al, 1965). It is therefore suggested that any beneficial effect of the presumed respiratory alkalosis of I.P.P.V. was offset by the rise in venous pressure, also due to I.P.P.V. Conversely, any adverse effect on bleeding due to respiratory acidosis during spontaneous ventilation may have been offset by the lower venous pressure pertaining with this type of ventilation. It is stressed that only moderate hyper-ventilation was used with I.P.P.V. and that spontaneous ventilation was unassisted. Loudon and Scott (1960) also believe that a raised venous pressure is an important cause of bleeding in vaginal surgery.

The substantial reduction in bleeding which was observed under epidural analgesia although probably in part due to arterial hypotension may also be attributable in important degree to a reduction in venous pressure at the operation site. It has been shown that even with only moderate arterial hypotension (systolic blood pressure between 80mm.Hg. and 110mm.Hg.), the blood loss under epidural analgesia was much less than that associated with general anaesthesia. It was also demonstrated that profound arterial hypotension under epidural analgesia (systolic blood pressure below 80mm.Hg.) produced only a slight and not usually statistically further reduction in bleeding relative to epidural analgesia with moderate hypotension.

It is suggested that some of these observations may be explained by the effects of the sympathetic nerve block of epidural analgesia on venous tone and venous pressure. Sympathetic nerve block dilates the veins (Beaconsfield, 1954). These hypotonic venins are easily distensible and the pressure within them is low. Small gravitational forces can now empty these veins (Lurie, 1963). Under epidural block, even slight elevation of the operation site will empty the hypotonic veins and minimise venous oozing. The writer has found that epidural analgesia reduced central venous pressure and peripheral venous pressure. These observations are described on pages 126 to 133.

Capillary bleeding is related to the arteriolar blood pressure at a point just distal to the precapillary sphincters. If the pressure at this point falls below the critical closing pressure of the precapillary sphincter, then the capillaries will be emptied of blood (Burton, 1954). In general, and provided that the anaesthetic technique is associated with vasodilatation, the critical closing pressure falls synchronously with the arterial blood pressure (Jennings, 1964). Russell and his colleagues (1962) showed by venous occlusion plethysmography that epidural block is associated with a greatly increased cutaneous blood flow and a slightly increased muscle blood flow in the leg. The writer has confirmed these findings using a heat-clearance technique (see pages 138 to 145).

Eckenhoff and Rich (1966) have adapted the sound and well-established pharmacological principle that the optimum dose of a drug is the minimum effective dose. These writers state that the aim of hypotensive anaesthesia is the least degree of hypotension which will minimise bleeding. Eckenhoff and Rich speak from a substantial experience of hypotensive anaesthesia and they stress that the avoidance of hypoxia and respiratory acidosis is essential to the safe conduct of hypotensive anaesthesia.

Epidural analgesia is associated with spontaneous ventilation which is more than adequate for resting purposes, as has been demonstrated in the earlier part of this thesis and profound hypotension is not necessary for an effective reduction in bleeding.

It has been shown, from analysis of this series of cases, that patients over 65 years of age usually bleed significantly less than younger patients. The diminished bleeding in the elderly patients is probably due to the low oestrogen levels of these women and an associated reduction in the vascularity of the genital tract. Oestrogens are vasodilators and Nickerson and Lee (1965) showed that their administration to pre-menopausal women increased operative bleeding. According to Johnson and Roddick (1956) and Copenhaver (1964), but contrary to a widely held belief, there is no correlation between the day of the menstrual cycle and operative blood loss.

Finally, the effect of locally injected vasoconstrictor solutions on bleeding at vaginal surgery should be mentioned. Lazar and Krieger (1959) and Copenhaver (1964) found that adrenaline was effective when used in this way. Despite the failure of these workers to estimate blood loss which was not absorbed onto swabs, the effect of adrenaline was sufficiently great to make their results credible. Local injections of adrenaline solutions may have dangerous and even fatal consequences. Lazar and Krieger (1959) observed an incidence of cardiac arrhythmias and hypertension high enough to make them suggest that adrenaline should not be used in older patients. Cardiac arrest has followed the local infiltration of adrenaline during halothane anaesthesia (Varejes, 1963; DeLange, 1963; Rosen and Roe, 1963). Posterior pituitary extracts are as effective as adrenaline (Pratt et al, 1960; Dillon, 1962). Octapressin is also as effective as adrenaline and probably safer (Lazar and Snider, 1966.)

THE EFFECTS OF EPIDURAL ANALGESIA ON CENTRAL AND PERIPHERAL VENOUS PRESSURE.

Partly in order to test the hypothesis that one of the causes of the reduction in bleeding observed during surgery under epidural analgesia is a reduction in venous tone, it was decided to measure peripheral and central venous pressures before and during epidural blocks. The results of this study have not been published.

METHOD.

Ten patients were studied. These patients were all women who were about to have elective operations under lumbar epidural analgesia. Their ages ranged from 42 years to 59 years (mean age 50 years). The patients did not have varicose veins or any other detectable abnormality of the cardiovascular system. No premedication was given. The proposed procedure had been explained and consent obtained.

On arrival in the anaesthetic room, lumbar epidural puncture was performed at the L3-4 interspace with a 16 S.W.G. Tuohy needle. Normal saline was used for the loss of resistance test so that no local anaesthetic was injected into the epidural space at this stage. When the epidural space had been identified, a Lee catheter (Lee, 1962) was introduced into the space. The Tuohy needle was withdrawn and the epidural catheter was connected to a syringe containing 1.5 per cent lignocaine solution. Adrenaline was not added to this solution. No local anaesthetic was injected.

The patient was now turned into the supine position and peripheral and central venous pressures were recorded. A short 16 S.W.G. plastic intravenous canula (Angiocath) was inserted into a vein on the dorsum of the foot by percutaneous puncture. This canula was joined to a 3-way tap, one arm of which wasconnected to a slow normal saline infusion. The other arm was connected to a length of manometer tubing, graduated in centimetres. The zero mark on the manometer scale was placed level with the vein from which measurements were to be made.

For the recording of central venous pressures, a 14,S.W.G. needle was inserted into a prominent vein at the elbow and a plastic canula with a wire stilette was passed through this needle until the tip of the canula was judged to lie in the subclavian vein, the superior vena cava or the right atrium. The stilette was withdrawn and the canula was connected by a 3-way tap to a manometer and to a slow normal saline infusion. When the tip of the canula lay in the right atrium or in a vessel which is in continuity with the right atrium without intervening valves, a true central venous pressure could be recorded (Borow et al, 1965). Correct placement was confirmed by observing a clear venous pulse and fluctuations in pressure with inspiration and expiration. The zero mark of the manometer scale was placed on a level with the manubrio-sternal junction. This reference point was chosen because it is clearly identifiable in contrast to the mid-axillary line which is sometimes used. The pressures recorded will therefore be some 5cm. water higher than the true right atrial pressures.

After a few minutes at rest, the peripheral and central venous pressures were recorded. Three successive readings were made at two minute intervals. The mean of these three readings was recorded and is the figure which appears in Table 26.

Without moving the patient in any way, a dose of 1.5 per cent plain lignocaine solution was now injected through the epidural catheter. The dose of lignocaine solution ranged from 17 ml. (255mg.) to 22 ml. (330 mg.) and the average dose was 20.1ml. (302mg.) The dose of lignocaine for these healthy women was varied over this quite narrow range according to age and height. After an interval of at least twenty minutes, the upper level of cutaneous analgesia to pin-prick was assessed. This level ranged from the ninth to the fifth thoracic dermatome (mean T.6.5).

Three further readings of peripheral and central venous pressure were now made at two minute intervals and the result recorded as the mean of the three readings.

Arterial blood pressures were recorded by a mercury sphygmomanometer at intervals of five minutes during the procedure. The systolic blood pressure lay between 85 mm.Hg. and 100mm.Hg. at the time of the second readings. No vasoconstrictor drug was injected and oxygen was not administered.

RESULTS.

The effect of epidural block on central venous pressure and the venous pressure in a vein on the dorsum of the foot in ten subjects is shown in Table 26. The venous pressures are recorded as the mean of three readings.

TABLE 26.

The effect of lumbar epidural block on central and peripheral venous pressure in 10 patients.

Patient	Age (years)	Sensory level	Peripheral venous pressure(cm.H_2O).		Central venous pressure(cm.H_2O)	
			Before block	During block	Before block	During block
1	48	T.7	16.3	14.2	3.2	2.0
2	54	T.6	11.2	9.0	4.5	3.2
3	42	T.9	14.5	10.8	5.5	4.8
4	47	T.7	17.2	13.3	6.2	4.0
5	56	T.7	23.5	20.2	2.3	1.5
6	53	T.5	13.0	7.2	4.0	2.5
7	59	T.8	21.3	16.0	3.8	1.8
8	45	T.6	15.8	14.5	6.5	5.0
9	46	T.6	14.3	10.0	7.0	5.0
10	50	T.5	19.0	15.5	4.3	1.5

These results are summarised in Table 27, which shows the mean values, standard deviations and mean percentage changes for the ten patients.

TABLE 27

The mean and percentage changes in central and peripheral venous pressure under epidural analgesia in 10 patients

	Before block Mean ± Stand Devn.	During block (Mean ± Stand) Devn.	Mean percentage reduction
Peripheral venous pressure (cm. H_2O)	16.6 ± 3.7	13.1 ± 4.1	21.1
Central venous pressure (cm. H_2O)	4.73 ± 1.5	3.13 ± 1.4	33.9

Statistical analysis by the Student t test shows that the reductions in peripheral and central venous pressure are significant ($P < 0.05$ in both instances).

DISCUSSION

This small study has demonstrated a fall in peripheral venous pressure in the veins of the foot, and in central venous pressure in every patient.

The peripheral venous pressure on the dorsum of the foot fell by an average of 3.5 cm. water (21 per cent). The peripheral venous pressure is an imprecise way of assessing the peripheral venous circulation. The pressure within a given peripheral vein may be much influenced by local factors such as posture, the competence of venous valves, local obstruction to blood flow and muscle tone. The pressure must also be effected by the amount of arterial pressure transmitted across the capillaries, the vascular tone and the circulatory blood volume. Some of these factors may have been fairly constant in the conditions of the study and others may have altered as epidural block developed. The arterial blood pressure fell, muscle tone and movement in the legs may have diminished and venous tone may have decreased. Any or all of these three factors may have produced the observed reduction in venous pressure in the foot.

Central venous pressure is determined by the interrelated effects of the pump action of the heart the circulating blood volume and the vascular tone (Borow et al, 1965). To this list should be added the effects of changes in intrathoracic pressure.

In careful investigations, Ward and his colleagues (1965) and Bonica and his colleagues (1966) found that cardiac output was unchanged during epidural block to the level of T.5 performed with 2 per cent lignocaine to which adrenaline had not been added. The addition of adrenaline 1:200,000 to the local anaesthetic solution produced a 30 per cent increase in cardiac output, attributed to the systemic absorbtion of adrenaline. Because of these observations, adrenaline was not used in the present series and it is assumed that cardiac output was unaltered. It is unlikely that circulating blood volume altered between the first and second sets of observations although there appears to be no information available about the effects of epidural analgesia on blood volume. There were probably no important changes in intrathoracic pressures during this study. Ventilation was spontaneous and should have been unaffected by epidural block (Moir, 1963; Moir and Mone, 1964).

The reduction in central venous pressure by a mean value of 1.6 cm. in water (34 per cent) was probably due to a reduction in vascular tone due to the widespread sympathetic blockade produced by epidural block. Ward and his colleagues (1965) found a slight decrease in total peripheral resistance during epidural block with plain lignocaine which indicated a reduction in vascular tone, which may have been partially counteracted by an increased vascular tone in the parts of the body unaffected by the epidural block. The writer has observed, by a heat-clearance technique of blood flow measurement, a substantial decrease in resistance to blood flow in the lower limbs during epidural block (see pages 138 to 145) as have Russell and his colleagues (1962). The veins are the capacitance vessels of the vascular system and in the normal subject can hold up to 60 per cent of the circulating blood volume (Landis and Hortenstine, 1950).

The possible significance of venous pressure in relation to bleeding at gynaecological surgery has been discussed on pages to , where it is suggested that, when the veins are dilated and the venous pressure is low, small gravitational forces, may empty these veins of blood. In this context, it should be remembered that the quite high pressures recorded in the veins of the foot may well be considerably higher than the pressures in the veins which may be cut during vaginal surgery. It is likely however, that pressure within the veins of the genital tract also falls during epidural block.

PERIPHERAL BLOOD FLOW DURING LUMBAR EPIDURAL BLOCK.

As a further consequence of an interest in the mechanism of the reduction in bleeding which occurs at operations performed under epidural analgesia, it was decided to study the effect of lumbar epidural block on skin and muscle blood flow in the lower limbs.

There appears to have been only one published investigation into the effects of epidural block on peripheral blood flow. In 1962, Russell and his colleagues used the venous occlusion plethysmography technique evolved by Barcroft and Edholm (1943) to measure the effects of lumbar epidural block on the blood flow in the calf and foot of normal subjects and patients with peripheral vascular disease. They assumed that blood flow changes in the calf represented changes in muscle blood flow and that changes in the blood flow in the foot were due to cutaneous blood flow alteration. Russell and his colleagues observed a four-fold increase in skin blood flow during epidural block in normal subjects. There was no statistically significant alteration in muscle blood flow. In the patients with peripheral vascular disease, there were no significant changes in skin or muscle blood flow. These results are in general agreement with the previously observed effects of chemical block of the lumbar sympathetic chain (Lewis and Grant, 1925; Rapport et al, 1952).

The following investigation was carried out jointly with Doctor William Thomson, who had already developed and tested the technique used and who provided the apparatus and much technical knowledge and skill. The results of this investigation, which was performed in 1966, have not been published.

The principle of heat clearance was applied to the measurement of peripheral blood flow.

<u>Theory and method of the heat clearance technique of blood flow measurements.</u>

According to Gibbs (1933) the rate of heat loss from a constantly heated body in a tissue depends on (a) the amount of heat lost by conduction through static tissue and (b) the amount of heat lost by convection by blood flowing through the tisse in close proximity to the heated body. Heat loss by conduction through static tissue occurs at a constant rate, so that variations in the temeprature of the constantly heated body dpend solely on variations in blood flow.

The constantly heated body may be the tip of a needle which has a built-in electric heater of minute size (Grayson, 1952; Hensel and Ruef, 1954; Mowbray, 1959) or a flat metal disc, also containing a heater, and suitable for surface applications (Hensel and Bender, 1956). In the present study a heated needle was used to measure muscle blood flows and a small metal disc was used to measure skin blood flows.

The needle and the disc also house thermojunctions for the accurate reading of temperatures at two points. Temperature is recorded at the area of the heater and at a reference point a short distance away and beyond the range of the heater. A temperature gradient exists between the heated and unheated parts of the needle or disc. It is this temperature gradient which is recorded when a "blood flow" reading is made. The magnitude of this gradient is related to the rate of blood flow past the heated area of the needle or disc. A large gradient signifies a low rate of heat loss from the heated area and therefore a low blood flow rate.

Kety (1960) states that all clearance methods of blood flow measurement depend on the following equation:

$$Q_A = Q_J + Q_V + Q_E + Q_M$$

where Q_A is the amount of indicator entering the tissue in a given time, Q_j is the amount retained in the tissue, Q_V is the amount lost in the venous blood, Q_E is the amount excreted by other routes and Q_M is the amount metabolisied in the tissues.

Where the indicator is heat, rather than say an isotope, Q_M is zero. The equation now becomes:

$$Q_A = Q_j + Q_V = Q_E$$

Q_j and Q_E depend on the thermal conductivity of the tissue, which is constant for that tissue (Gibbs, 1933) so that the equation may now be written

$$Q_A = K + Q_V$$

This is a restatment of Gibbs' (1933) principle that, since tissue conductivity is constant, heat loss from a heated body within that tissue varies only with the rate of blood flow.

The apparatus used in this study was the Fluvograph. This apparatus contains circuits which supply heating currents of from 0 to 30 mA and uses a heated needle and surface disc electrode as described by Hensel and Rouf (1954) and Hensel and Bender (1956). The heating currents are adjusted to produce a temperature gradient of about 3°C. between the heated and reference areas of the needle and disc electrode. Compensating voltages of from 0 to 500 uV are available for backing off the thermocouple outputs. Thermocouples are built into the needle for the recording of the temperature at the heated tip and at a reference point on the shaft of the needle which is out of the range of the heater. Similarly the disc electrode has a thermocouple at the heated area and in this case two other thermocouples in unheated areas of the disc. The needle is about 4 inches long and of fine gauze (about 20 S.W.G.) and the disc is about as large as a sixpence. Heater currants and compensating voltages are read on a light spot galvanometer.

The Fluvograph apparatus used in this study has been assessed by Thomson (1966) against widely varied and known flow rates in laboratory conditions and found to be an accurate and convenient method of estimating rapid changes in peripheral blood flow and a method which avoids the use of radio-isotopes.

The apparatus has not been calibrated in absolute terms and results are read as temperature gradients and are best expressed as percentage changes from resting blood flow. Where it is possible to occlude all blood flow suddenly and completely to an organ or a limb by the application of a clamp or toutniquet, readings at zero blood flow can be made. The difference between the temperature gradient at zero flow and at resting flow represents a range of blood flow of from 0 per cent to 100 per cent. In the present investigations, the sudden inflation of a pneumatic tourniquet was used to produce zero blood flow in the lower leg.

METHOD.

Blood flow studies were performed on six female patients between the ages of 34 years and 56 years (mean age 44.5 years).

All were free of significant disease of the cardiovascular system and were about to have elective major gynaecological surgery. All had received Papaveretum (Omnopon) 20 mg. and hyoscine (Scopolamine) 0.45 mg. one hour before the experiment began. The proposed procedure had been explained to the patient and her consent obtained.

On arrival in the anaesthetic room a lumbar epidural puncture was performed at the L3-4 interspace with a 16 S.W.G. Tuohy needle. Normal saline was used for the loss of resistance test, so that no local anaesthetic was injected at this stage. A Lee catheter was passed into the epidural space, the Tuohy needle was withdrawn and the catheter was connected to a syringe containing 1.5 per cent plain lignocaine solution. No injection was made.

The patient was now placed in the supine position. The disc electrode was securely strapped to the right great toe and the needle electrode was inserted deeply into the muscle mass of the calf. The insertion of the needle is almost painless, as the writer knows from personal experience. At least 15 minutes were now allowed to elapse until the patient felt calm and any twitching of the calf muscles had ceased.

Readings of resting skin and muscle blood flow were now taken. Immediately thereafter, a pneumatic tourniquet, which had earlier been positioned round the thigh, was suddenly inflated to a pressure well above the systolic blood pressure.

Readings were again taken from both electrodes at zero blood flow. As has been explained in the preceding section, the readings which were recorded were of the temperature gradient between the heated and reference parts of the electrodes.

The tourniquet was released and from 18ml. (270mg.) to 20ml. (300mg.) of 1.5 per cent lignocaine solution, without adrenaline, was injected through the epidural catheter and without moving the patient in any way.

Readings at resting and zero blood flows were made 10 minutes, 25 minutes and 40 minutes after the epidural injection of lignocaine.

Systolic and diastolic blood pressures were recorded by a mercury sphygmomanometer at five minute intervals during the whole investigation. From these readings mean arterial blood pressures were calculated. The mean arterial blood pressure is the diastolic blood pressure plus one third of the pulse pressure (Wood, 1956).

RESULTS.

The temperature gradients obtained from the paired thermocouples in the skin and muscle electrodes before and during epidural block are listed in Tables G and H in the appendix. Also listed are the percentage changes in blood flow calculated from these temperature gradients and the mean arterial blood pressure at the time of each reading.

Peripheral blood flow depends on the cardiac output the peripheral resistance and the mean arterial blood

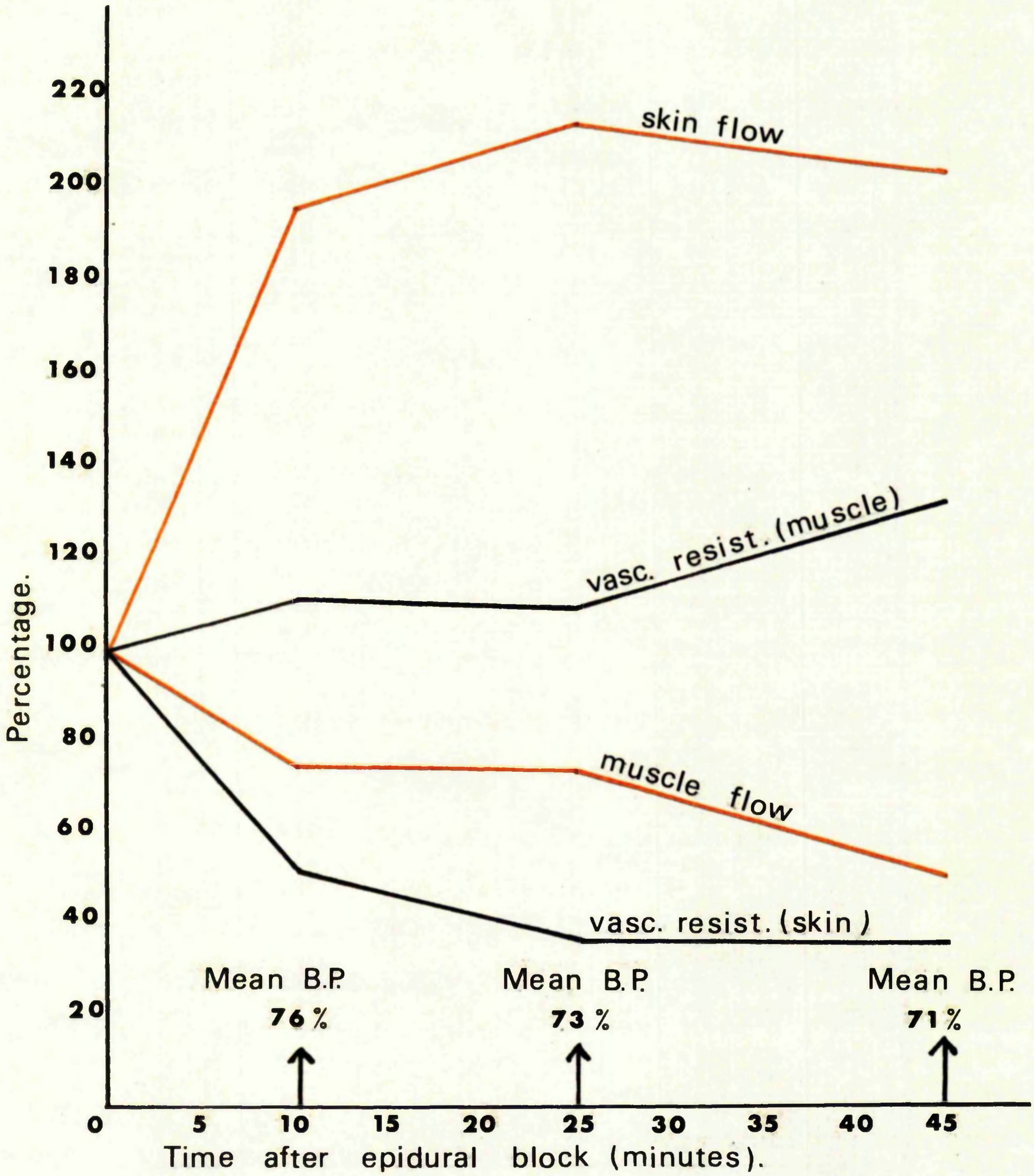


Figure 1.

Mean percentage changes in skin and muscle blood flow, vascular resistance and mean arterial blood pressure during 6 epidural blocks.

pressure. Cardiac output was not measured in this study, but has been found to be unaltered during even high epidural block with plain lignocaine solutions (Ward et al, 1965; Bonica et al, 1966). The mean arterial blood pressure at the time of each recording is known and the final average fall in mean arterial pressure was a reduction to 71 per cent of pre-anaesthetic level. It is assumed that cardiac output was unchanged.

A proper interpretation of the observed changes in peripheral blood flow must take account of the fall in mean arterial blood pressure and any alterations in vascular resistance in the skin and muscle of the lower leg. For this reason an Index of Vascular Resistance has been calculated from each set of readings of blood flow (temperature gradient) and mean arterial blood pressure. The method of calculation of the Index of the Vascular Resistance is given in Appendix I, page 271 . Comparisons between the indices of resistance enable the degree of vasodilatation or vasoconstriction to be assessed, when due allowance has been made for alterations in blood flow and blood pressure.

Figure I illustrates graphically the average percentage alterations in blood flow, vascular resistance and mean arterial blood pressure in skin and muscle during the first 40 minutes of lumbar epidural analgesia in six patients. The percentage changes in vascular resistance are the indices of vascular resistance expressed as percentages.

Table 28 presents the same results in tabular form.

TABLE 28

Mean changes in blood flow, vascular resistance and mean arterial blood pressure in 6 patients during epidural block.

Time	Blood flow		Vascular Resistance		Mean arterial blood pressure	
	Skin	Muscle	Skin	Muscle		
Before block	100%	100%	100%	100%	100%	78mm.Hg.
10 minutes	196%	77%	51%	107%	76%	59mm.Hg.
25 minutes	216%	77%	36%	106%	73%	57mm.Hg.
40 minutes	207%	56%	36%	133%	71%	55mm.Hg.

DISCUSSION

The Fluvograph apparatus has been shown to be accurate when tested against widely varying, known flow rates. There is a tendency to slow baseline drift in the needle electrode. Any inaccuracies due to this can be eleiminated by taking a fresh reading at zero blood flow after each flow reading (Thomson, 1966). This was done after each reading during the present investigation, and indeed a baseline drift was observed during some of the studies. Due to the presence of banked thermocouples in the skin electrode the tendency to drift is less and in any case, error is eliminated by taking fresh zero flow readings.

The increases in skin blood flow during epidural analgesia were substantial. Ten minutes after the injection of the local anaesthetic the cutaneous blood flow had approximately doubled and remained at this level until the last readings were taken, forty minutes after the injection. The increased skin blood flow was accompanied by a fall in vasculaor resistance to an average of 36 per cent of the pre-anaesthetic level. There was an average reduction in mean arterial blood pressure to 71 per cent of control level. These are, in general terms, the anticipated effects of lumbar sympathetic block on cutaneous blood flow in the foot (Lewis and Grant, 1925, Rapaport et al, 1952).

Russell and his colleages (1962) observed a fourfold increase in skin blood flow during lumbar epidural block. The potential maximum increase in cutaneous blood flow must depend on the degree of vasoconstriction present at the time of the epidural block. Vessels which are already almost maximally dilated cannot be greatly affected by an epidural block. The patients in the writer's series had received papaveretum 20mg. and hyoscine 0.45mg. and these drugs may have affected skin blood flow before the epidural blocks were instituted. Russell and his co-authors (1962) used a different technique of blood flow measurement (plethysmography) and give no information about the agents used for epidural block, the height of the blocks and the changes in blood pressure. Their patients had received no premedication. There are therefore several possible expalanations for the observation of a 400 per cent increase in skin flow in Russell's study and a 200 per cent increase in the present investigation.

The changes in muscle blood flow in the present investigation are not always consistent. In most cases there was a moderate reduction in muscle blood flow and by 25 minutes after epidural block, the muscle blood flow had fallen to an average of 77 per cent of the control level and by 40 minutes the flow had fallen further to 56 per cent of the control value. These reductions in muscle blood flow were accompanied by an increase in vascular resistance within the muscle. The vascular resistance had risen to 106 per cent by 25 minutes and 135 per cent by 40 minutes. While these changes were developing, the mean arterial blood pressure was falling to a final minimum of 71 per cent of control value. Because the mean blood pressure fell along with the muscle blood flow, the change in flow are actually quite small, when the synchronous changes in blood pressure are considered.

The present observations were made on patients who were in the supine position, not under general anaesthesia and not undergoing surgery. These patients had already received premedication and no adrenaline was added to the local anaesthetic solution because of the known effect of adrenaline on the cardiac output in these circumstances (Ward et al, 1965; Bonica et al, 1966). Altering any of these factors might have affected the results of this investigation. Operative trauma and blood loss might well affect peripheral blood flow.

In summary, and in the circumstances of this investigation, there was a twofold increase in cutaneous blood flow and a substantial fall in cutaneous vascular resistance during epidural analgesia. There was also a slight reduction in muscle blood flow and a small increase in vascular resistance within the muscle.

EPIDURAL ANALGESIA IN OBSTETRICS

Epidural Analgesia in Obstetrics

Since January, 1964, the writer's clinical work has been mainly concerned with obstetric anaesthesia and analgesia. From 1961 to 1962 the author had been privileged to work with Professor Hingson of Cleveland, Ohio, who first used continuous epidural (caudal) analgesia in labour (Hingson and Edwards, 1943). The pain relief afforded by continuous caudal and lumbar epidural analgesia was impressive and seemed to surpass all other types of analgesia.

In the last decade epidural analgesia by caudal and lumbar approaches has been extensively used in the U.S.A. and Canada and in some large centres over 80 per cent of deliveries take place under epidural analgesia (Hellman, 1965; Moore, 1966). In 1961, Hingson and his colleagues estimated that 200,000 continuous epidural blocks are administered annually to women in labour in the U.S.A. These epidural blocks are used mainly in normal labour and delivery is by forceps in from 50 per cent to 90 per cent of cases (Hingson et al, 1961, Moore, 1966, Thomson, 1967). In contrast, epidural analgesia has been very little used in British obstetrics. There are several reasons for this.

The frequent use of continuous epidural analgesia for labour and delivery makes heavy demands on the anaesthetic, obstetric and nursing staffs, entails hospital confinement for all patients, affects the practice of obstetrics and necessitates an obstetric service based on the obstetrician rather than the midwife. The routine use of epidural analgesia could not be contemplated in a British maternity hospital, nor in the opinion of British obstetricians would this be desirable. The aim of British obstetrics remains the spontaneous delivery of a healthy child by a healthy mother. Even with tuition and encouragement, delivery by forceps is required in at least 50 per cent of labours controlled under epidural analgesia (Moore, 1966). There is too, a belief held by some British obstetricians and anaesthetists, despite much contrary evidence, that epidural analgesia is too dangerous to be used. The following workers have reported a total of over 125,000 epidural blocks in labour without a maternal death (Chaplin and Renwick, 1958; Bush, 1959; Eisen et al., 1960; Norris et al, 1960; Hingson et al, 1961, Evans et al, 1962; Hellman, 1965; and Moore, 1966). The maternal mortality rate associated with the aspiration of stomach contents alone was estimated by Dinnick in 1957 to be 1 in every 3,380 general anaesthetics. Such figures say much for the skill of the American anaesthetists who administered these 125,000 epidural blocks and perhaps emphasise the low standards of general anaesthesia for obstetrics which often existed in Great Britain before 1957. Standards have doubtless improved today, but as Kinch (1959) said "Analysis of obstetric anaesthetic deaths reveals that it is not the agent that kills, but the incompetent use of the agent."

It was the writer's belief in 1964 that epidural analgesia could find a place within the framework of a British obstetric practice, not as a routine method of analgesia, but when specially indicated. That this concept has been fulfilled, at least in one maternity hospital, is due in large measure to the co-operation of the writer's obstetric, anaesthetic and nursing colleagues while the indications for epidural analgesia were being developed, sometimes by trial and error. It is thought that the Queen Mother's Hospital, Glasgow was the first British hospital to have a 24 hour service for the institution and maintenance of continuous epidural analgesia. The recording of detailed obstetric and anaesthetic information concerning, to date, 492 epidural blocks has enabled knowledge to be acquired concerning the effects of epidural analgesia in labour and delivery in patients with obstetric abnormalities.

Churchill-Davidson (1966) recognised the need for a wider availability of resident anaesthetic services in British maternity hospitals, both for the administration of general anaesthesia and the provision of really effective analgesia in labour. He said "The provision of an adequate service for pain relief in labour (organised by the anaesthetic department) is still very backward even in some of the wealthiest countries."

Anaesthesia was in its infancy when Sir James Young Simpson wrote, in 1848 "The distress and pain which women often endure while they are struggling through a difficult labour are beyond description and seem to be more than human nature would be able to bear under any other circumstances." Simpson believed that "it is our duty as well as our privilege to use all legitimate means to mitigate and remove the physical sufferings of the mother during parturition."
Simpson wrote these words as a consequence of his introduction of chloroform into obstetric practice and before this event he must have had to observe women in painful labour, sometimes for days at a time,

while almost powerless to aleviate their distress. Today's obstetricians do not expect their patients to endure such suffering for long. Caesarean section is often used to terminate prolonged and painful labour. This operation is sometimes done for humanitarian rather than for compelling obstetric reasons, because no really effective method of safe and sustained pain relief has been available.

Nevertheless, many women experience considerable pain in labour and do not always obtain satisfactory relief from conventional systemic and inhalational analgesics. A recent study in Sheffield recorded that 40 per cent of recently delivered women thought that pain relief in labour had been inadequate (Beazley et al, 1967). There can be no doubt that epidural analgesia is effective and the statement of Hingson and Edwards in 1943 that "pain is no longer a necessary concommitant of obstetric labour and delivery" is true when epidural analgesia is used. Authoritative American obstetric opinion is convinced of the value of epidural analgesia. Greenhill (1955) wrote "There is no more satisfactory and pleasant type of analgesia in obstetrics" and Eastman (1956) said that epidural block "cannot be bettered" as a method of analgesia. Although there are important basic differencies between American and British obstetric policies, the writer and the obstetricians with whom he works are convinced that epidural analgesia has a valuable contribution to make to the management of inco-ordinate labour and as a form of therapeutic anaesthesia in certain obstetric and medical diseases which may complicate labour. When used mainly in prolonged and abnormal labours or as an aid to the management of pre-eclampsia, cardiac and respiratory disease during labour, the frequent need for forceps delivery ceases to be a valid objection to the use of epidural analgesia. The great majority of patients who have received epidural analgesia in the Queen Mother's Hospital would in any case have required forceps delivery for obstetric reasons and it is probable that some of the patients delivered by forceps would have been delivered by Caesarean section earlier in an inco-ordinate labour (Moir and Willocks, 1966 and 1967).

A number of British anaesthetists and obstetricians have used continuous lumbar or caudal epidural analgesia in cases of inco-ordinate uterine action or in the management of severe pre-eclampsia and eclampsia (Galley, 1949; Johnson, 1952; Arthur and Johnson, 1952; Johnson, 1954; Bryce-Smith and Williams, 1955; Tunstall, 1960; Scott and Kyles, 1961). By 1954, Johnson had managed 74 cases of inco-ordinate uterine action under continuous caudal analgesia and he believed that cervical dilatation progressed more rapidly after epidural block and that the need for Caesarean section was reduced. The other reported British series consist of only a very few cases.

At present 6 per cent of all patients delivered in the Queen Mother's Hospital, Glasgow have an epidural block administered during labour or for operative delivery. The following observations were made on the 492 epidural blocks (408 continuous and 84 single-shot) administered between January 1964 and December 1967.

The method of lumbar epidural analgesia used in obstetrics has been described on pages

COMPLICATIONS

The following complications were observed during 492 consecutive lumbar epidural blocks administered during labour. Because 84 blocks were single injections without placement of an epidural catheter, the figures for complications which are associated only with continuous epidural analgesia are related only to the 408 continuous blocks. There were no maternal deaths in the series.

Hypotension

This was the commonest complication. The systolic blood pressure fell to below 90 mm.Hg. at least once in 36 of 492 blocks (7.3 per cent). In the course of the 408 continuous epidural blocks 2,360 injections were made and there were 45 episodes of hypotension so that the incidence of hypotension for all epidural injections was 1.9 per cent.

The incidence of hypotension reported by other workers who have used epidural analgesia in obstetrics varies from 1.3 per cent to 25 per cent (see Table 29).

Table 29

The reported incidence of hypotension during epidural analgesia in labour.

	Incidence of hypotension	No. of cases
Hellman, 1965	1.3%	26,000
Hehre et al, 1965	1.3%	291
Cowles, 1965	2.1%	235
Chaplin and Renwick, 1958	3.5%	1,000
Fleming and Campbell, 1959	11.0%	114
Nielsen et al, 1962	15.0%	213
Hehre and Sayig, 1960	25.0%	212

The widely varied incidence of hypotension in these series may be accounted for by different criteria of hypotension (the level of blood pressure constituting significant hypotension is not always stated), by the care with which blood pressure was monitored and by the doses of local anaesthetics used. It is noticeable that in the reports published before 1962 the incidence of hypotension is usually much higher than in the more recent reports. It was in 1962 that Bromage demonstrated that in pregnant women, local anaesthetics spread more extensively within the epidural space and that doses should be reduced by about one third during pregnancy.

In the writer's series hypotension was almost always immediately corrected by turning the patient into the left lateral position and hypotension was therefore usually due to the supine hypotensive syndrome of pregnancy. This syndrome is attributed to occlusion of the inferior vena cava by the gravid uterus, causing a diminished venous return to the heart and a reduction cardiac output.

Kerr and his colleagues (1964) in a small but carefully controlled series of patients found that over 80 per cent of women had complete occlusion of the inferior vena cava when in the supine position during the last trimester of pregnancy. Yet Holmes (1960,a) observed significant hypotension in the supine position in only 3.6 per cent of 500 pregnant women. Occlusion of the inferior vena cava is not usually associated with hypotension because venous return to the heart can usually be maintained by the vertebral venous system. It is suggested that during epidural analgesia, the increase in venous tone which is probably required for the forcing of blood along the narrower and more tortuous vertebral venous system may not always occur, because of the effects of the lumbar sympathetic block on the veins of the lower limbs.

Since the fact that hypotension during epidural analgesia in labour is nearly always due to the supine hypotensive syndrome was fully appreciated, patients have been encouraged to lie on one side during labour conducted under epidural block. As a result of this policy the incidence of hypotension has fallen from 19 in the first 100 cases in this series to 5 in the last 200 cases (2.5 per cent).

The supine hypotensive syndrome occurs in from 3 per cent to 4 per cent of normal conscious pregnant women, at least occasionally. (Howard et al, 1953; Holmes, 1960,a) is sometimes seen during general anaesthesia (Holmes, 1960b; Crawford, 1965) and has been recorded in 18 per cent of 600 subarachnoid blocks in obstetrics (Kennedy et al, 1959).

The use of vasopressor drugs to correct hypotension during epidural analgesia in labour is hardly ever necessary and is best avoided (Shnider, 1966). Methoxamine (Vasoxine) and allied alpha receptor activators produce spasm of the uterine arteries, foetal bradycardia and tetanic uterine contractions (Greiss and Van Wilkes, 1964; Vasicka et al, 1964). If a vasopressor drug must be used, agents such as ephedrine and metaraminol which raise blood pressure mainly by increasing myocardial contractility, may be safer (Shnider, 1966). The writer has not used a vasopressor drug during epidural analgesia in labour for 3 years. Hypotension usually responds to the use of the left lateral position, combined if necessary with elevation of the legs and the administration of oxygen.

The minimal level of maternal blood pressure which is compatible with adequate foetal oxygenation is unknown, but has been stated by experienced clinicians to be about 80 mm.Hg., systolic (Greene, 1958). The vascular tone of the utero-placental circulation is relevant. Haemorrhagic shock, with its associated vasoconstriction and hypovolaemia will be associated with a lower rate of uterine perfusion than hypotension of the same degree due to epidural analgesia (Greiss, 1967). Sympathetically mediated vascular tone is almost non-existant in the resting uterine vascular bed (Greiss and Gobble, 1967) so that the hypotension of epidural analgesia is unlikely to be associated with a compensatory vasodilatation in the utero-placental vessels in normal patients. It is, therefore, likely that when hypotension occurs under epidural block, there is a reduction in uterine blood flow which is roughly proportional to the fall in blood pressure (Greiss, 1967).

Accidental spinal anaesthesia

Inadvertent injection of local anaesthetic into the subarachnoid space occurred on two occasions (0.4 per cent). This is a high incidence of this complication. Both injections were made by registrar anaesthetists, inexperienced with epidural analgesia. In one of the cases, after a successful epidural puncture, the epidural catheter penetrated the dura. The catheters used at that time had a sharp tip (Lee, 1962) and these catheters are now made with a blunt tip (Moir and Hesson, 1965). Both mothers who received accidental spinal anaesthesia are well, as are their infants.

Experienced workers in series of many thousands of cases report accidental spinal anaesthesia in from 0.03 per cent to 0.1 per cent of lumbar epidural blocks (Chaplin and Renwick, 1958; Eisen et al, 1960; Norris et al, 1960; Lund et al, 1961; Hellman, 1965). Only Carr and Mehre (1962) report subarachnoid puncture by the catheter.

Prompt and efficient treatment of accidental subarachnoid block should prevent serious complications in mother and child. An open vein must be secured before performing any epidural block and facilities for artificial ventilation of the lungs must be immediately available.

Spinal Tap

While attempting epidural puncture, the subarachnoid space was recognised as having been entered on three occasions (0.6 per cent) and no injection was made. This is an acceptably low incidence of this complication. Others have recorded an incidence of spinal taps of from 0.4 per cent to 3.3 per cent in large series of lumbar epidural blocks (Bonica et al, 1957; Chaplin and Renwick, 1958; Mehre and Sayig, 1960; Lund et al, 1961; Carr and Mehre, 1962).

When a subarachnoid puncture had been made and recognised, the entire procedure was abandoned because there is a risk of spread of local anaesthetic to the subarachnoid space if epidural puncture is successful at another interspace (Eisen et al, 1960; Bodell et al, 1962; Hellman, 1965). Because epidural puncture was performed in the sitting position in this series of obstetric patients, the cerebrospinal fluid pressure in the lumbar region was probably high and cerebrospinal fluid flowed freely out of the wide-bore Tuohy needle in the three cases in which spinal tap was recognised.

Bloody Tap

Significant bleeding from an epidural vein was recognised on five occasions (1 per cent). Bleeding usually ceased quickly. On only one occasion did the tip of the catheter rest within a vein, and the catheter was successfully placed after re-puncture at another interspace. The engorged epidural veins of pregnancy may predispose to a bloody tap, a complication which is not mentioned by most writers on epidural analgesia in obstetrics. Chaplin and Renwick (1958) observed a bloody tap in 1.1 per cent of 1,000 cases and Bedell and his colleagues (1962) mention this complication but do not record its incidence rate.

Paravertebral Passage of the Catheter

Paravertebral Passage of the Catheter

The catheter passed out of the epidural space through an inter-vertebral foramen into a paravertebral space in 5 of 408 continuous epidural blocks (1.2 per cent). The condition was diagnosed when no analgesia resulted from undoubtedly successful epidural puncture. Withdrawing the catheter slightly and injecting more local anaesthetic produced effective analgesia in three cases. Re-puncture was performed at an adjacent interspace in the other two cases.

Hehre and Sayig (1960) noted paravertebral passage of the catheter in 1 per cent of their cases. The likelihood of an epidural catheter passing out of the epidural space is probably related to the introduction of too great a length of catheter. When several inches of catheter are introduced, paravertebral passage may occur in 7 per cent of cases (Sanchez et al, 1967).

Failure to pass the epidural catheter.

On four occasions in 408 continuous peidural blocks (1 per cent), after apparently successful epidural puncture, the catheter could not be passed into the epidural space. When difficulty was experienced, attempts were made to pass the catheter in both cephalad and caudal directions and a fresh, and therefore stiffer catheter tried before abandoning this part of the procedure or performing another epidural puncture at an adjacent interspace.

Failure to locate the epidural space

This occurred on two occasions in 492 epidural blocks (0.4 per cent), so that in conjunction with three spinal taps and two subarachnoid injections there were, in all seven instances of failure to locate the epidural space (1.4 per cent). This is a low failure rate. Most workers report failure to identify the lumbar epidural space in from 2 per cent to 3 per cent, a figure which does not include failure due to subarachnoid puncture. (Hehre et al, 1960; Lund et al, 1961; Bodell et al, 1962).

Neurological Sequelae

One patient developed a small area of cutaneous anaesthesia in a region of the thigh supplied by the femoral nerve. Sensation returned within ten days. This complication followed a difficult forceps delivery and may have been an obstetric palsy. Moore (1964) has observed six cases of damage to the nerves of the lumbo-sacral plexus by the foetal head or the obstetric forceps and Eison and his colleagues (1960) noted minor trauma to nerves in 0.3 per cent of 9,500 forceps deliveries under lumbar epidural block.

One patient had a headache for five days after an accidental spinal tap. The complete absence of headache after uncomplicated epidural block is a major advantage over subarachnoid block.

Drug Reactions

There were no toxic reactions in this series. The dose of lignocaine at each injection ranged from 120 mg. to 280 mg. and was always combined with 1:200,000 adrenaline. In the more prolonged epidural blocks the total dose of lignocaine was from 2,400 mg. to 3,700 mg., administered over a period of from 18 hours to 27 hours.

At this point it is pertinent to compare the complications of lumbar epidural analgesia in obstetrics with those of caudal epidural analgesia. Caudal analgesia is an alternative technique which has not been entirely replaced by the lumbar approach.

The incidence of significant hypotension (systolic blood pressure below 90 mm.Hg.) was from 4.4 per cent to 23 per cent in several series of over 1,000 continuous caudal blocks in obstetrics (Bush, 1959; Nellermoe et al, 1960; De Jong, 1961; Ellis and De vita, 1962; Evans et al, 1962). The incidence of hypotension is thus very comparable to that recorded for lumbar epidural blocks. It is sometimes stated (Moore, 1966) that accidental spinal anaesthesia is less likely with the caudal technique. This statement is not supported by the report of Bush (1959) in which there was a 0.3 per cent incidence of this complication in 15,000 caudal blocks and De Jong (1961) and Nellermoe and his colleagues (1962) recorded 0.1 per cent of accidental spinal anaesthetics in large series of caudal blocks.

Hingson and his colleagues (1961) reported a death from an epidural abscess following a continuous caudal block and Bush (1959) reported a non-fatal case of abacterial purulent chemical meningitis after a caudal block. Perhaps the most bizarre complication recorded is the occurrence of accidental injection of the foetus in utero with local anaesthetic on four separate occasions during attempted caudal blocks. Two of these four babies died (Finster et al, 1965).

The failure rate for caudal analgesia is much higher than for lumbar epidural analgesia and lies between 8 per cent (Bush 1959) and 20 per cent (Hingson et al, 1961). Caudal analgesia entails the administration of a dose of local anaesthetic approximately twice as large as is required for the lumbar technique (Moore, 1966).

There is therefore no proven advantage for caudal analgesia and the high failure rate and the larger dose of local anaesthetic required are important disadvantages. The writer reserves caudal analgesia for the occasional patient who has severe deformity of the lumbar spine.

Tachyphylaxis

This term is here used to mean a form of acute tolerance to the local anaesthetic drug and manifested by a substantially reduced duration of action. This troublesome phenomenon was observed in

59 per cent of continuous epidural blocks in which four or more top-up injections were required. In these cases the duration of analgesia, as assessed by the mothers' subjective response to uterine contractions, diminished progressively until in 73 per cent of this group of patients, analgesia eventually lasted less than half as long as it had with the first injections. Commonly the analgesia obtained from the first dose of 2 per cent lignocaine with adrenaline lasts for a little over 2 hours and the analgesia is perfect. After some 15 hours of labour, analgesia may only last for 45 minutes and is sometimes less than perfect.

Tachyphylaxis has seldom been reported by other workers, perhaps because they have used epidural analgesia only for the last few hours of normal labour, whereas the majority of blocks in the writer's series were administered for many hours during abnormal labours which were both prolonged and unusually painful. There appear to be only two references to tachyphylaxis in the literature on epidural analgesia in labour. Bush (1959) noted a need for more frequent injections when labour was unduly prolonged and Bromage and his colleagues (1964) mention that tachyphylaxis occurs occasionally. It is the writer's impression that tachyphylaxis will develop in almost every case, if labour is sufficiently prolonged.

The cause of tachyphylaxis is unknown. When the condition has developed after repeated injections of lignocaine, changing to mepivacaine (Carbocaine) or bupivacaine (Marcaine) has been ineffective. The analgesia produced by the second local anaesthetic was also of limited duration and intensity.

Inactivation of the lignocaine or the adrenaline by autoclaving can be excluded as the cause of tachyphylaxis because autoclaving affects neither lignocaine (Bridenbaugh and Moore, 1964) nor adrenaline to which the preservative sodium metabisulphite has been added (De Jong, 1964). This preservative was present in the solution used. Inactivation by autoclaving would be expected to diminish the analgesic effect of the lignocaine solution at all injections, but in fact, this only occurred after several injections. It would appear that tachyphylaxis must in some way be due to a more rapid removal of local anaesthetic from its site of action or to a more rapid detoxication.

Whatever its cause, tachyphylaxis is a major problem in the more prolonged obstetric epidural blocks. The total dose of local anaesthetic drug administered increases rapidly and the demands on anaesthetic staff who administer the top-up injections become heavy. Very occasionally it has been considered advisable to terminate epidural analgesia in such circumstances. Perhaps lignocaine is not the best local anaesthetic drug for prolonged epidural analgesia and the new longer acting agent bupivacaine (Marcaine) may be a more suitable drug. Duthie and his colleagues (1968) have used bupivacaine for thirty continuous epidural blocks in labour and found that analgesia lasted for three hours and that there was very little reduction in the duration of analgesia during blocks which lasted 13 hours on average. The writer has observed a comparable duration of action with bupivacaine in 26 epidural blocks in labour, but as already stated, has found that when tachyphylaxis has already developed with lignocaine, if bupivacaine is then administered the duration of analgesia is still abnormally short.

Maternal and Perinatal Mortality

There were no maternal deaths.

There were 494 babies born after 492 epidural blocks. There were two sets of twins. The perinatal mortality was 1.82 per cent. Four infants were stillborn and six died within one week of delivery. Two of the neonatal deaths were due to severe multiple congenital abnormalities which were incompatible with life. The corrected perinatal mortality is therefore 1.45 per cent.

One of the four stillbirths followed intra-uterine death during a prolonged labour associated with an extreme degree of inco-ordinate uterine action and maternal distress with gastro-intestinal distension, vomiting and ketonuria. Death was due to intra-uterine foetal hypoxia probably associated with a poor placental circulation and maternal biochemical upsets. There was no foetal bradycardia and no meconium staining of the liquor amnii to warn of impending death in utero and this case highlights the need for information about the condition of the foetus before birth. One infant died during forceps delivery. The mother had severe pre-eclampsia and the foetal heart had been heard immediately before delivery. There had been foetal tachycardia and meconium staining of the liquor amnii earlier in labour. Neither of these two stillbirths can be attributed to the use of epidural analgesia.

The remaining two stillbirths were the twin infants of a patient who had severe pre-eclampsia, maternal distress and a somewhat inco-ordinate labour. Epidural analgesia assuaged the extreme maternal distress and maintained the blood pressure at near normal levels. On one occasion, however, the blood pressure fell to 85 mm.Hg. systolic and thereafter, neither foetal heart was audible. Four hours later twin stillborn infants were delivered by forceps. It is likely that in a patient with previous hypertension due to pre-eclampsia, the transient hypotension reduced placental blood flow to a level incompatible with foetal survival. The hypotensive episode occurred while the patient was in the supine position for the purpose of auscultation of the foetal hearts and the weight of the large uterus and twin foetuses may have caused severe supine hypotension.

Of the five neonatal deaths, two were due to congenital abnormalities incompatible with life. Two deaths were caused by intracranial haemorrhage, probably due to trauma at difficult forceps delivery. Cephalo-pelvic disproportion was present on these two occasions and may have had a causal relationship not only with the difficult delivery but with the inco-ordinate uterine action for which epidural analgesia was administered. The fifth neonatal death occurred in a premature infant who weighed only 3 pounds 10 ounces when born at 34 weeks gestation to an unmarried mother with very severe pre-eclampsia. None of these neonatal deaths is attributed to epidural analgesia.

A corrected perinatal mortality of 1.43 per cent is satisfactory when related to the obstetric abnormalities present in nearly all of the 492 mothers.

The Safety of Epidural Analgesia in Obstetrics

The potentially fatal complications of lumbar epidural analgesia in obstetrics are total spinal anaesthesia, profound hypotension, gross overdose of local anaesthetic drug and epidural abscess or other serious neurological sequelae. The first three complications may kill the mother, the foetus or both if effective treatment is not immediately instituted. In practice, the incidence of most of these serious complications is very low or non-existent in recently published very large series of cases. Mention has already been made of 125,000 lumbar epidural blocks without a single maternal death.

The incidence of most complications, serious and trivial, in the writer's series is average or less than average in relation to other published series. The accidental injection of local anaesthetic into the subarachnoid space on two occasions and the high incidence of hypotension in the earlier blocks are the only complications which occurred with undue frequency. Toxic reactions and sepsis were entirely absent.

To off-set the risks of epidural analgesia, there are some important advantages over general anaesthesia for operative delivery and over systemic analgesic drugs for the relief of pain in labour. There is no risk of pulmonary aspiration of stomach contents. Analgesia is almost perfect and is achieved without the depression of respiration in the newborn. There may be an improved utero-placental blood flow in certain pathological states and blood loss at delivery is substantially reduced.

General anaesthesia until recently accounted directly for 4 per cent of maternal deaths in England and Wales (Ministry of Health Report, No. 108, 1963) and half of these anaesthetic deaths were due to the immediate or delayed effects of regurgitation or vomiting of stomach contents. There is no reason to believe that the situation has altered radically since 1963. In 1957 Dinnick estimated that of every 3,380 women who received a general anaesthetic for delivery, one died of the inhalation of vomitus. The inhalation of stomach contents may cause immediate death from asphyxia or delayed death from the acid-aspiration (Mendelson's) syndrome (Mendelson 1946). The situation in the U.S.A., at least until recently, was worse than that in Great Britain. Dumitru (1960) stated that 10 per cent of all maternal deaths were due to anaesthesia and that more than half of these deaths were due to the pulmonary aspiration of stomach contents under general anaesthesia. Philips and his colleagues (1961) reported that between the years 1945 and 1958, vomiting under general anaesthesia caused an average of one maternal death per year in Baltimore. Information is not available about the experience of the anaesthetists or the agents used for these fatal anaesthetics, but deaths still occur in skilled hands, with modern techniques. In the light of such figures, the actual safety of epidural analgesia for the mother is impressive.

Beckett and his colleagues (1965)and Parker (1965) have measured maternal and cord blood lignocaine levels at delivery under continuous lumbar epidural analgesia. Foetal levels were, on average, half of the maternal levels (range 45 per cent to 80 per cent). Maternal blood lignocaine levels were always below the toxic level even when the mothers had received over 1,000 mg. of lignocaine, so that foetal blood levels were always well within the safe range. There is therefore no possibility of drug-induced neonatal respiratory depression due to epidural analgesia when performed with lignocaine.

Using the Apgar score (Apgar 1953; Apgar et al, 1958) to assess the condition of the newborn infant, many workers have observed less neonatal depression at delivery under epidural analgesia than at delivery under general anaesthesia (Apgar et al, 1957; Bush, 1959; Friedman et al, 1960; Nielsen et al, 1962; Bodell et al, 1962). The difficulty of assessing the effects of anaesthetic techniques and agents on the newborn has been stressed by Crawford (1962) when he pointed out that obstetric factors often outweigh anaesthetic factors in the causation of asphyxia neonatorum. Moreover, the obstetric factors vary from case to case. James (1960) thinks that it is the percentage of depressed babies born under any given set of circumstances which is important. Because of the varied and often severe and multiple obstetric abnormalities which existed in most of the patients in the writer's series, attempts to assess the effect of epidural analgesia on the condition of the newborn infant would be unrewarding.

With the exception of total spinal anaesthesia and a severe toxic reaction to the local anaesthetic agent, which are rare complications of epidural analgesia, the only harmful effect for the foetus in utero is the reduction in utero-placental blood flow which may accompany excessive maternal hypotension (Greiss, 1967). Correction of this hypotension with vasopressor drugs may again impair utero-placental blood flow because of the associated spasm of the uterine arteries and tetanic contraction of the uterus (Vasicka et al, 1964; Greiss and Van Wilkes, 1964). Only two perinatal deaths in the present series of 492 epidural blocks were in any way attributed to epidural analgesia. These were the twin stillborn infants of a patient who had severe pre-eclampsia and whose blood pressure fell briefly to 85 mm.Hg. systolic. Thereafter the foetal hearts could not be heard.

There is evidence from radio-isotope clearance studies that utero-placental blood flow is much reduced in prolonged labour due to inco-ordinate uterine action and that when epidural analgesia is induced in these circumstances, the blood flow increases (Johnson and Clayton, 1955). Epidural analgesia may, in cases of inco-ordinate uterine action, not only bring about an improvement in uterine action (Johnson, 1954; Tunstall, 1960; Moir and Willocks 1966 and 1967) but may improve oxygenation of the foetus in utero.

A final advantage of epidural analgesia is the reduction in bleeding at delivery in comparison with delivery under general anaesthesia or pudendal block analgesia. The evidence for this statement is presented elsewhere in this thesis (pages 83 and 84).

INDICATIONS FOR EPIDURAL ANALGESIA

Almost all of the 408 continuous lumbar epidural blocks were performed on patients who not only required effective relief of pain, but who also had significant obstetric abnormality. Epidural analgesia was hardly ever used as a method of pain relief in normal labour, although this was occasionally done for patients who were psychologically ill-suited to childbirth and for unmarried mothers.

Sometimes more than one indication existed for continuous epidural analgesia. Pre-eclampsia and inco-ordinate uterine action were quite often present in the same patient. The primary indications for continuous epidural analgesia are listed in Table 30.

Table 30

The Primary Indications for
408 Continuous Lumbar Epidural Blocks in Labour.

Indication	Number of cases	Percentage of total
Inco-ordinate uterine action	224	55.0
Severe hypertension during labour	42	10.4
Inadequate analgesia from conventional methods	132	32.1
Cardiac disease	6	1.5
Respiratory disease	4	1.0

The 132 patients who received continuous epidural analgesia because they had obtained inadequate analgesia from conventional methods (Table 30) commonly had an unusually prolonged and painful labour, often associated with an occipito-posterior position of the foetal head. Most of these patients were primigravidae.

Of the 82 single-shot epidural blocks, 73 were performed for delivery by forceps or vacuum extractor (ventouse) and 11 blocks were administered for Caesarean section.

INCO-ORDINATE UTERINE ACTION

Continuous epidural analgesia was administered to 224 women who had a prolonged and painful first stage of labour due to inco-ordinate uterine action. The earlier cases in this group have been the subject of two previous reports (Moir and Willocks, 1966 and 1967). The present report confirms the value of epidural analgesia in dysfunctional labour in a much larger series of patients.

Description of Cases

All patients had definitely abnormal uterine action in the first stage of labour and conventional treatment with systemic analgesic drugs, often in large doses, had failed to relieve the severe pain of dysfunctional uterine contractions. Dilatation of the cervix was proceeding at a very slow rate and sometimes had ceased altogether. All patients had, in varying degree, the features which constitute the syndrome of maternal distress. In the severe cases Caesarean section was already being considered as a method of relieving maternal pain and distress which had become almost intolerable.

Inco-ordinate uterine action was essentially a clinical diagnosis based on the occurrence of uterine contractions of varying frequency and strength which prolonged labour, failed to dilate the cervix and failed to produce descent of the presenting part of the foetus. Abnormal uterine action in the first stage of labour may be classified as hypotonic or hypertonic inco-ordinate uterine action or as cervical dystocia. In hypertonic inco-ordinate uterine action the contractions are often very painful and the uterus may have a high tonus between contractions. These powerful contractions do not dilate the cervix effectively. It appears that the normal polarity of the uterus has been lost. Intra-amniotic pressures are high in all parts of the uterus and the synchronous contraction of the upper pole and relaxation of the lower segment and cervix uteri which characterise normal labour are absent (Alvarez and Caldeyro-Barcia 1954). Hypertonic inco-ordinate uterine action is very painful and often causes distressing backache. This backache appears to have its origin in the cervix uteri and blockade of the sacral nerve roots is necessary for its relief. The great majority of the 224 patients who received epidural analgesia for dysfunctional labour had hypertonic inco-ordinate uterine action.

Hypotonic inco-ordinate uterine action, or uterine inertia, is not usually associated with severe pain anduterine contractions are weak and infrequent. Oxytocin infusions are often used in this condition and the uterine contractions stimulated by oxytocic drugs are often painful. Epidural analgesia has sometimes been given in these circumstances. Sometimes periods of hypertonic and hypotonic uterine action alternated in the same patient during a long labour. This phenomenon was also noted by Jeffcoate (1961).

Cervical dystocia is a rarity and probably only occurs when there is a physical deformity of the cervix due perhaps to scarring and fibrosis. The term cervical dystocia has sometimes, in the past, been used to describe hypertonic inco-ordinate uterine action.

In all cases in this series the inco-ordinate nature of the action of the uterus was confirmed by a graphic analysis of labour, using the method of Friedman (1955) and in a few cases the pattern of uterine activity was recorded by a tocodynamometer (Smyth, 1957).

The systemic upsets associated with maternal distress were frequently seen and associated obstetric abnormalities were common. Table 31 shows the relevant obstetric findings in 224 patients and Table 32, lists the physical findings during labour, before the performance of epidural block.

Table 31

Obstetric Findings in 224 Patients
with Inco-ordinate Uterine Action.

	No. of patients	Percentage
Primigravidae	211	94
Age under 30 years	199	89
Height 61 inches (155cm) or less	86	38
Gestation more than 41 weeks (287 days)	97	43
Foetal weight more than 8lbs (3.63Kg.)	116	52
Occipito-posterior position	145	65
Membranes ruptured for 24hrs to 48hrs.	114	51
Membranes ruptured more than 48 hrs.	29	13

Table 32

Physical Findings at the Time of Epidural Block in 224 Patients with Inco-ordinate Uterine Action.

	Number of Cases	Percentage
Tachycardia (over 100/min.)	138	62
Pyrexia (over 99.4°F,37.5°C)	76	34
Ketonuria	177	79
Vomiting	82	37
Gastro-intestinal distension	20	9

Ninety-four per cent of patients were primigravidae. The thirteen patients who were not primigravidae were all in their second pregnancy and all had a history of inco-ordinate uterine action in their first pregnancy. Seven of these patients had previously been delivered by Caesarean section, and this operation had been performed before full dilatation of the cervix. These figures confirm that inco-ordinate uterine action is an abnormality almost confined to primigravidae or to multiparae who have not previously reached full cervical dilatation in labour. There is no evidence in this series to support the belief that advancing age is associated with an increasing incidence of inco-ordinate labour. Eight-nine per cent of the patients were under 30 years of age and only two patients (0.9 per cent) were over 35 years old. Friedman and Sachtleben (1965) also found that age had no influence on the duration of labour in a study of 3,300 primigravidae.

That 38 per cent of these women were less than 61 inches tall is probably a result of the poor nutritional standards in the City of

Glasgow. Small stature may be associated with a contracted pelvis or there may be relative cephalo-pelvic disproportion if the baby is large. Jeffcoate (1965) noted a relationship between small stature and inco-ordinate uterine action, which is confirmed in this series.

Jeffcoate (1965) also noted a relationship between post-maturity and inco-ordinate labour and suggested that poor relaxation of the lower uterine segment may cause delayed onset of labour and poor uterine action when labour does begin. Pregnancy had lasted for more than 41 weeks in 43 per cent of patients in the present series.

Large babies were common and 52 per cent of babies weighed over 8 pounds at birth. The occurrence of relative cephalo-pelvic disproportion when a small woman has a large baby has been stressed (Jeffcoate, 1961 and 1965). There were 86 patients under 61 inches in height and 41 of these women (48 per cent) had babies weighing more than 8 pounds.

The foetal occiput was in the posterior position in 65 per cent of patients during the first stage of labour. This in itself often causes a rather prolonged and painful labour, even when uterine action is normal. The 114 patients in this group who had an occipito-posterior position of the foetal head also had inco-ordinate uterine action. Epidural analgesia was also used in many painful labours associated with an occipito-posterior position and normal uterine action. These cases are considered later. When the foetal occiput lies posteriorly, a large diameter of the foetal head must pass through the narrowest diameter of the pelvis. This may produce relative cephalo-pelvic disproportion, which might not have existed had the occiput been in an anterior position.

The membranes were no longer intact at the time when epidural block was performed in 94 per cent of patients. The membranes had been ruptured for at least 24 hours in 64 per cent of patients. Amniotomy had been performed for the induction of labour in 55 per cent of patients. The usual indications for amniotomy were pre-eclampsia and postmaturity. When the membranes had been ruptured for more than 24 hours, an antibiotic was given. Ampicillin was given to the majority of patients in the hope of preventing infection in mother and child. (Blecher et al 1966). Recently, cephaloridine has been used in preference to ampicillin because this drug can produce higher blood levels in the foetus after administration to the mother (Barr and Graham, 1967).

The average duration of labour before the performance of epidural block was 20.4 hours and the average duration of epidural analgesia was 11.1 hours. As can be seen from Table 32, tachycardia and ketonuria were present in the majority of patients. About one third of all patients had vomited more than once and a similar number had pyrexia of over 37.5°C. (99.4°F.) Thirst and clinical signs of dehydration were common. Hawkins and Nixon (1957) found that after 24 hours of labour the plasma water concentration falls, the sodium level rises and the chloride and potassium levels fall. These writers think that dehydration and electrolyte imbalance may further impair uterine action. Gastro-intestinal dilatation occurred in 9 per cent of patients and this condition is likely to be associated with extensive loss of electrolytes and water into the lumen of the gut. The statistics in Table 32 are evidence of considerable maternal morbidity which is accompanied by a great deal of pain and mental distress.

The Effect of Epidural Analgesia on Progress in Labour

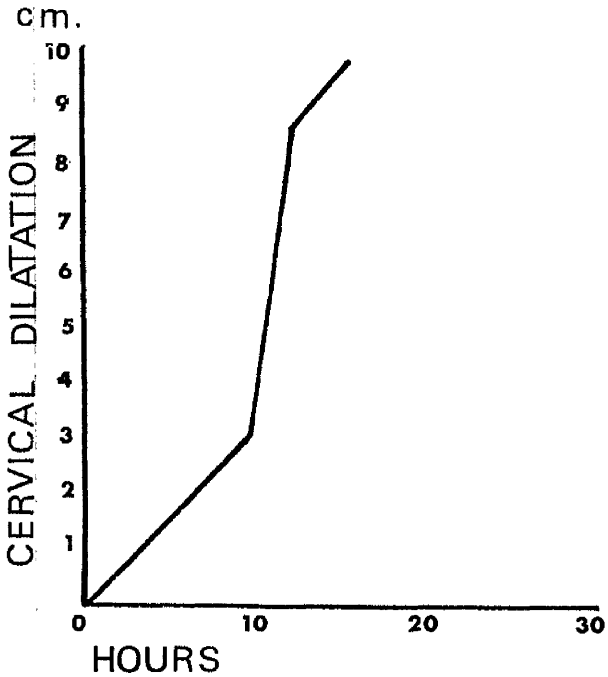
Progress in labour was assessed by graphical analysis of the rate of cervical dilatation in the first 150 cases in this series. The character of the uterine contractions was assessed in 14 cases by the use of a guard-ring tocodynamometer.

Graphic Analysis of Labour

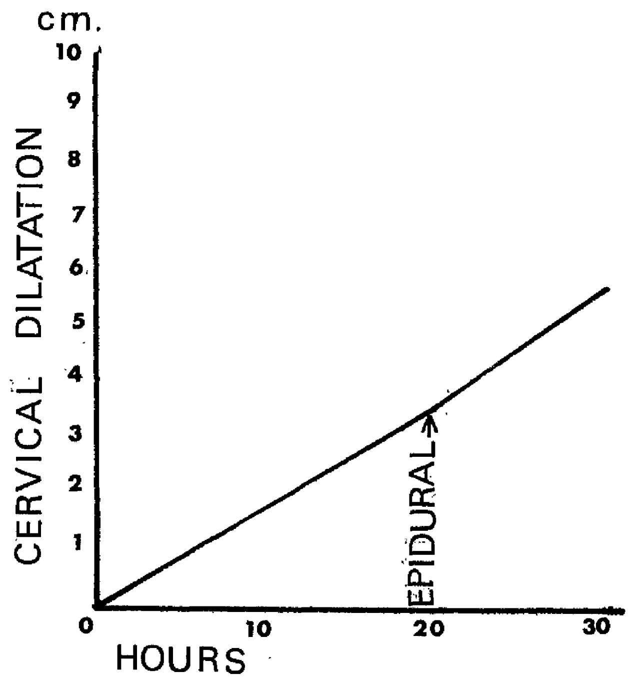
Epidural analgesia was not induced until the cervix was at least 4 cm. dilated and once induced, analgesia was maintained until delivery. Labour had lasted for an average of 20.4 hours before epidural block and the average duration of epidural analgesia was 11.1 hours. The frequency, duration and intensity of the uterine contractions were recorded by abdominal palpation throughout labour. Cervical dilatation was assessed by vaginal examinations. Rectal examinations were sometimes performed, but were not used in the assessment of cervical dilatation for the graphic analysis of labour.

To obtain an objective assessment of the rate of progress in labour before and after epidural block a graph or Partogram (Rodesch et al, 1965) was constructed in retrospect for each patient. Cervical dilatation was plotted against time. Friedman has used this method for the study of many thousands of labours in many types of patients (Friedman, 1954, 1955 and 1956; Friedman and Sachtleben, 1961a, 1961b, 1962a, 1962b, 1963a, 1963b, 1965). Friedman (1965) from his wide experience, believes that "because dilatation of the cervix is the result of all the driving force of uterine contractions acting upon the uterine contents and against the resistance of the maternal soft parts" the study of the rate of dilatation of the cervix is "the best index of progress in labour." Friedman (1955) from an analysis of 500 normal primigravid labours found that the normal curve of cervical dilatation in primigravidae is S-shaped. There is an initial latent phase of about 10 hours duration. This is followed by an active phase which begins when the cervix is 3 cm. dilated, on average, and is accompanied by rapid cervical dilatation to 8 cm. or 9 cm. over a period of some 4 hours. There is then a final deceleration phase during which the cervix reaches full dilatation at a slower rate. Friedman's curve of the average normal primigravid labour is reproduced in figure 2.

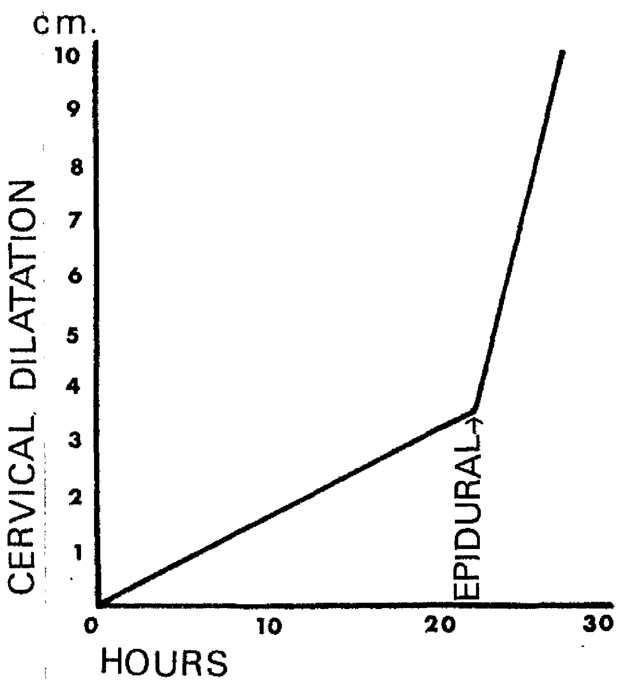
When the Partograms had been constructed for each patient, the rate of cervical dilatation from 3 cm. (when the active phase of labour usually begins) until epidural analgesia was induced was compared with the rate of cervical dilatation after epidural block. No account was taken of the rate of cervical dilatation before 3 cm. The latent phase of labour was thus excluded from the calculations. Had this not been done, a false impression of an increased rate of progress after epidural block might have arisen. These patients had a much prolonged "active phase" of labour in which, although uterine contractions were often vigorous, cervical dilatation proceeded very slowly. The results of the analysis of 150 Partograms are summarised in Table 33.



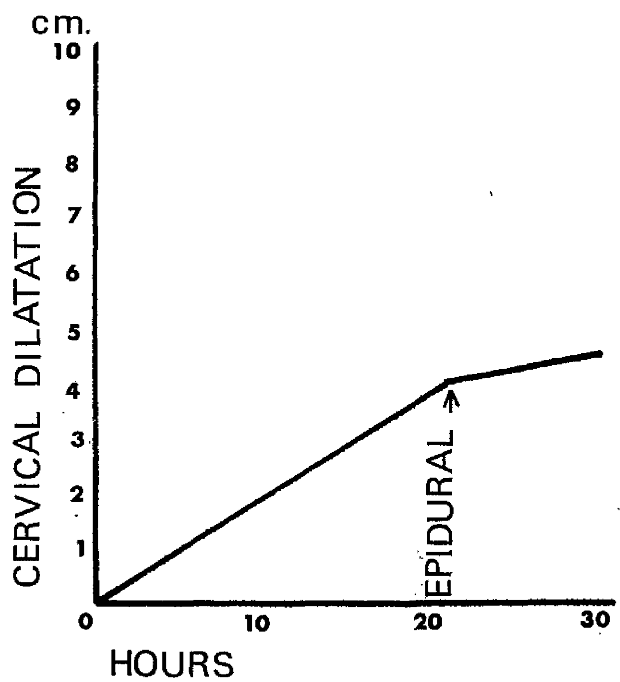
Normal Primigravid Labour
(After Friedman).



Inco-ordinate Labour
No Response to Epidural



Inco-ordinate Labour
Rapid Dilatation After Epidural



Inco-ordinate Labour
Slower Dilatation After Epidural

Figure 2.

Rates of cervical dilatation in normal primigravid labour and the three basic responses to epidural analgesia in inco-ordinate labour.

Table 33

The Rate of Cervical Dilatation after Epidural Block
in 150 Cases of Inco-ordinate Uterine Action.

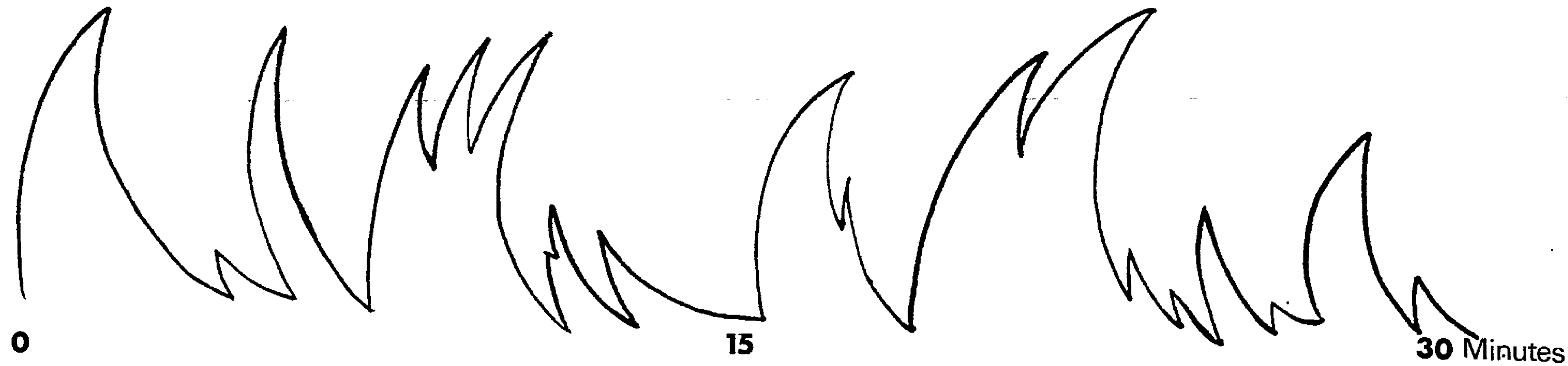
Rate of Cervical Dilatation	No. of Patients	Percentage
Increased by more than 3 times	64	43
Increased by $1\frac{1}{2}$ to 3 times	43	29
Unaltered	29	19
Slowed	14	9

It can be seen from Table 33 that in 72 per cent of cases the rate of cervical dilatation was increased by at least $1\frac{1}{2}$ times and was actually slowed in only 9 per cent of cases after epidural block.

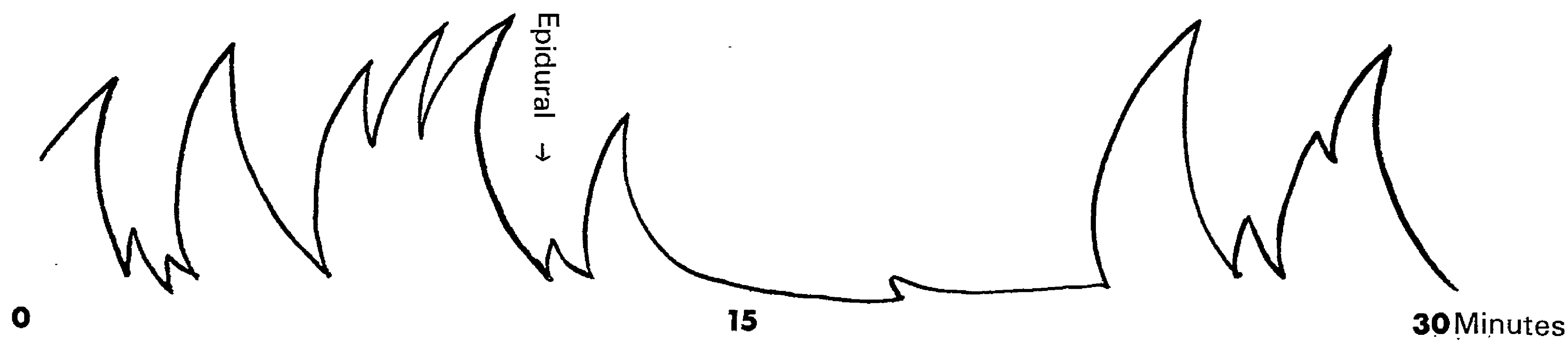
Figure 2 shows representative partograms illustrating the three basic types of response to epidural analgesia. The curve of normal labour in primigravidae is also depicted.

It appears that in the majority of cases of inco-ordinate uterine action, epidural analgesia speeds up a much prolonged active phase of labour.

An oxytocin (Syntocinon) infusion was used in 48 cases in the whole series of 224. There was no consistent policy on the use of oxytocic drugs in the first stage of labour and some of these infusions were given for a short period only. It may be that a more liberal use of this therapy would have improved uterine action, especially in those patients who did not respond to epidural analgesia by more rapid dilatation of the cervix (Moir and Willocks, 1967).



Reproduction of tocographic tracing showing inco-ordinate uterine action.



Reproduction of tocographic tracing showing temporary diminution of uterine activity associated with hypotension after epidural block.

Figure 3

Tocodynamometry

A guard-ring tocodynamometer (Smyth, 1957) was used for the external recording of uterine contractions in 14 patients. Smyth (1957) claimed that this instrument gives precise quantitative readings of intra-uterine pressures. Parker (1965) claimed that quantitative readings were obtained only if there was adequate liquor amnii present. Duggan and his colleagues (1966) compared the values obtained for intra-amniotic pressure with a tocodynamometer with those obtained by direct intra-amniotic manometry and found a poor correlation.

The tocodynamometer does give a useful visual indication of the frequency and duration of uterine contractions and a rough indication of their strength. No attempt was made to assess quantitatively the intra-uterine pressures. The totally disorganised pattern of the contractions in inco-ordinate uterine action is illustrated in figure 3. When tracings were taken before and after epidural block there was no marked alteration in the irregular pattern of uterine activity, even although the rate of cervical dilatation increased. Other workers, using the more sensitive and quantitative technique of intra-amniotic manometry by an intra-uterine cannula have observed a reversion from the abnormal patterns of inco-ordinate labour to those of normal labour following lumbar sympathetic block (Caldeyro-Barcia and Alvarez, 1952; Hunter, 1963).

One patient in the present series showed a 15 minute period of uterine inactivity following an episode of moderate hypotension (systolic blood pressure 95 mm.Hg.). From their studies of uterine activity during epidural analgesia in normal labours, Vasicka and his colleagues (1964) conclude that hypotension is the only feature associated with epidural analgesia which may impair uterine activity. These workers recorded intra-amniotic pressures directly.

Method of Delivery

The mode of delivery in 224 patients who had continuous epidural analgesia for inco-ordinate uterine action is shown in table 34.

The Method of Delivery in 224 Patients with Inco-ordinate Uterine Action who Received Epidural Block.

Method of Delivery	Number of cases	Percentage
Caesarean Section	54	24
Forceps	134	59
Vacuum extraction	29	13
Spontaneous vertex	7	3

Caesarean section was performed in 54 patients (24 per cent). The operation was performed in the second stage of labour on ten occasions. A trial of forceps delivery had been abandoned in seven cases and in three cases vaginal delivery was not attempted because of anticipated mechanical difficulty due to cephalo-pelvic disproportion. The indications for Caesarean section included cephalo-pelvic disproportion, foetal distress, maternal pyrexia and failure to progress in labour. Frequently more than one of these indications existed. One patient had a Caesarean section for impending rupture of a previous Caesarean section scar.

Further analysis shows that the presence of cephalo-pelvic disproportion exerted a great influence on the Caesarean section rate in this series of patients.

The Effect of Cephalo-Pelvic Disproportion

Antenatal examination had excluded major degrees of contracted pelvis in the present 224 patients. Despite this, in 64 cases

(29 per cent) the obstetrician who conducted the delivery considered that cephalo-pelvic disproportion, often in association with a malposition of the foetal head, caused appreciable mechanical difficulty. This difficulty was sometimes sufficient to make Caesarean section necessary. Sometimes the diagnosis of cephalo-pelvic disproportion was made for the first time during labour and in a few instances disproportion was not detected until delivery.

There were 86 women (38 per cent) who were less than 61 inches tall and this doubtless contributed to the high over-all incidence of disproportion. Cephalo-pelvic disproportion was considered to be present in 47 (55 per cent) of these 86 small patients. Babies weighing over 8 pounds (3.63 Kg.) were born to 32 (68 per cent) of the 47 women who had disproportion. Of the other 39 women of small stature who were not thought to have disproportion, 15 (38 per cent) had babies weighing more than 8 pounds at birth. There is, therefore, confirmation of the findings of Jeffcoate (1965) that small women who have large babies are liable to have inco-ordinate labours. This abnormally high incidence of cephalo-pelvic disproportion was often associated with mechanical difficulty at delivery.

Disproportion was present in 17 (12 per cent) of the 138 women who were over 61 inches in height. There were 69 (50 per cent) babies who weighed over 8 pounds at birth in this group of 138 patients. Ten (60 per cent) of the 17 patients who had disproportion had babies weighing more than 8 pounds.

There were thus 116 babies weighing over 8 pounds in the whole series of 224 patients, so that 52 per cent of patients with inco-ordinate labour had large babies.

There were 64 patients (29 per cent) in the whole series of 224 women who had cephalo-pelvic disproportion. The method of delivery is shown in table 35, according to the presence or absence of disproportion.

Table 35

Method of Delivery in 224 Cases of Inco-ordinate Uterine Action According to the Presence of Disproportion.

Method of delivery	64 pats. with dis/portion		160 pats. without dis/portion	
	No. of cases	Percentage	No. of cases	percentage
Caesarean section	34	53	20	12
Forceps	27	42	107	67
Vacuum extraction	3	5	26	16
Spontaneous vertex	Nil	Nil	7	4

Table 35 shows striking differences in the method of delivery according to whether disproportion was present or absent. Caesarean section was performed in 53 per cent of the group of 64 patients who had cephalo-pelvic disproportion and in only 12 per cent of the group of 160 women who did not have disproportion. The indications for Caesarean section were often different in the two groups. Actual or anticipated mechanical difficulty at delivery was the principal indication for Caesarean section in the group with disproportion. In the group in which disproportion was absent the relatively small number of Caesarean sections were performed for foetal distress, maternal pyrexia and failure to progress in labour.

To determine whether the presence or absence of cephalo-pelvic disproportion influenced the rate of cervical dilatation during epidural analgesia, the 150 labours which were analysed graphically were subdivided into a group of 47 labours associated with disproportion and a group of 103 labours in which disproportion was not a feature. The results of this analysis are shown in table 36.

Table 36

The rate of cervical dilatation during epidural analgesia in 150 inco-ordinate labours, according to the presence of disproportion.

Rate of Cervical Dilatation	47 cases with dis/portion		103 cases without dis/portin	
	No. of cases	Percentage	No. of cases	Percentage
Increased by more than 3 times	19	40	45	44
Increased by 1½ to 3 times	12	26	31	30
Unaltered	10	21	19	18
Slowed	6	13	8	8

It is evident from Table 36 that disproportion exerted little influence on the rate of cervical dilatation during epidural analgesia. The rate of cervical dilatation increased in 74 per cent of patients who did not have disproportion and in 66 per cent of those patients who had disproportion.

Having shown that cephalo-pelvic disproportion markedly increases the Caesarean section rate but has only a small, and perhaps insignificant, influence on the rate of cervical dilatation, it is now desirable to assess the influence of disproportion and the rate of cervical dilatation on the method of delivery. Consequently the 150 labours which were analysed graphically were subdivided according to the rates of cervical dilatation and the presence or absence of disproportion. The Caesarean section rates were then calculated for each group (see Table 37).

Table 37

Caesarean section rates in 150 inco-ordinate labours according to the presence of disproportion and the rate of cervical dilatation under epidural analgesia.

	47 patients with disproportion			103 patients without disproportion		
Rate of cervical dilatation	No. of pats.	No. of Caes. sections	Caes. section rate (percent)	No. of pats.	No. of Caes. sections	Caes. section rate (per cent)
Increased at least $1\frac{1}{2}$ times	31	14	45	76	3	4
Unaltered or slowed	16	11	69	27	10	37

It is seen from table 37 that in the absence of cephalo-pelvic disproportion the Caesarean section rate was only 4 per cent if the cervix dilated more rapidly during epidural analgesia and that the Caesarean section rate rose to 37 per cent in the minority of patients who did not have an increased rate of cervical dilatation.

When disproportion was present, the Caesarean section rate was 45 per cent even when cervical dilatation progressed more rapidly under epidural analgesia. The Caesarean section rate was yet higher (69 per cent) if there was both disproportion and no acceleration of cervical dilatation.

These figures confirm that if cephalo-pelvic disproportion is present then Caesarean section will be required in roughly half of all patients who have inco-ordinate uterine action and that the principal reason for performing Caesarean section will be mechanical difficulty and not failure of cervical dilatation, at least when epidural analgesia is used. In the absence of disproportion, the probability of a vaginal delivery is high, especially if cervical dilatation proceeds more rapidly under epidural analgesia. It may be anticipated that about 75 per cent of patients who do not have disproportion will have an improved rate of cervical dilatation under epidural analgesia and that unless some extraneous factor, such as foetal distress, intervenes then vaginal delivery should be achieved with safety.

Perinatal Mortality

There was one still-birth and two neonatal deaths in 224 deliveries after inco-ordinate labours managed with epidural analgesia. The perinatal mortality was 1.3 per cent. These perinatal deaths have been included in the total perinatal mortality for the whole series of 492 obstetric epidural blocks (see page 162).

The still-birth was the result of intra-uterine death during a first stage of labour which had already lasted for 30 hours. Epidural analgesia had been induced only two hours before the death of the foetus. Foetal death was attributed to intra-uterine hypoxia associated with poor placental circulation and maternal acidosis with electrolyte imbalance and dehydration. The biochemical upsets in the mother probably created an intra-uterine environment in which the foetus could not survive. There was no warning alteration of the foetal heart rate nor passage of meconium.

The two neonatal deaths were due to obstetric trauma at delivery in patients with cephalo-pelvic disproportion. One infant was delivered with some difficulty by forceps and died the next day of intra-cranial haemorrhage. The other infant died of intra-cranial haemorrhage when 5 hours old. An attempt had been made to deliver this infant both by forceps and by the vacuum extractor. When these attempts failed Caesarean section was performed. Cephalo-pelvic disproportion was diagnosed for the first time during the attempts at vaginal delivery.

Epidural analgesia played no direct part in any of these deaths, which are due to obstetric hazards associated with prolonged labour and difficult vaginal delivery. A perinatal mortality of 1.3 per cent is, nevertheless, not unsatisfactory for these abnormal cases. The three perinatal deaths occurred in the group pf 64 patients who had cephalo-pelvic disproportion and the perinatal mortality rate for this group is 4.7 per cent. The perinatal mortality for the 160 cases of inco-ordinate uterine action uncomplicated by disproportion was zero.

DISCUSSION

A survey of these 224 patients with inco-ordinate uterine action brings to light features which have previously been observed by others, notably Macrae (1949) and Jeffcoate (1961 and 1965). There was a high incidence of young primigravidae, short maternal stature, large foetal size, occipito-posterior position, postmaturity and prolonged rupture of the membranes. Almost all patients had at least some of the features of the syndrome of maternal distress. These patients suffered much pain which characteristically took the form of severe and almost unremitting backache.

Mechanical difficulty in labour and during delivery because of varying degrees of cephalo-pelvic disproportion occurred frequently in the sizeable group of patients of short stature who had a large baby and an occipito-posterior position. When disproportion was present the Caesarean section rate was increased by almost five times, although disproportion had little effect on the increased rate of cervical dilatation which usually followed epidural block. Caesarean section was performed on 53 per cent of the 64 patients who had disproportion and the operation was performed primarily because of the mechanical problem which these patients presented.

Nevertheless, in the presence of minor degrees of cephalo-pelvic disproportion, the action of the uterus may be the deciding factor in achieving cervical dilatation and descent of the presenting part of the foetus. This factor cannot be assessed in the primigravid patient until labour begins. It has been shown, by graphic analysis of 150 inco-ordinate labours, that uterine action improved, sometimes dramatically, in 72 per cent of patients after epidural block and that uterine action worsened in only 9 per cent of patients. The difficulty experienced in detecting minor degrees of cephalo-pelvic disproportion antenatally has been mentioned and occasionally the mechanical problem was not appreciated until operative vaginal delivery was attempted. This was the situation which contributed directly to both neonatal deaths in this series.

The perinatal mortality was 1.3 per cent and is low for a series of prolonged labours. Comparisons with other published data are difficult because various definitions of prolonged labour are used and cases of inco-ordinate uterine action are sometimes included with prolonged labours due to other causes. Table 38 lists perinatal mortality rates in prolonged labours obtained from British and Irish maternity hospital reports.

Table 38

Perinatal mortality rates in prolonged labours

	Duration of Labour	Perinatal Mortality(%)
Royal Maternity Hospital, Belfast, 1963.	over 24 hrs	2.5
Liverpool Maternity Hospital, 1963.	over 36 hrs.	3.3
Queen Charlotte's Maternity Hospital, 1963	over 36 hrs.	3.4
National Maternity Hospital, Dublin, 1964	over 36 hrs.	4.1
Rotunda Hospital, Dublin, 1964	Not stated	4.3
Royal Maternity Hospital, Belfast, 1965	over 24 hrs.	5.8
Royal Maternity Hospital, Glasgow, 1962	over 48 hrs.	7.6

Goodwin and Reid (1963) observed that perinatal mortality rose as labour lengthened. After 24 hours of labour the perinatal mortality rose to almost 5 per cent, at 36 hours the foetal death rate was almost 7 per cent and at 44 hours the perinatal mortality had risen sharply to over 20 per cent. Goodwin and Reid also recorded a sharp rise in the incidence of foetal distress after 36 hours of labour.

There are several possible explanations for the low perinatal mortality in the present series. Firstly, there were no premature infants and prematurity is normally associated with an increased foetal loss. Secondly, there was the avoidance of the large doses of opiate drugs which are usually administered to patients in prolonged labour. Inco-ordinate labour is believed to be associates with a reduced utero-placental blood flow and consequently with intra-uterine hypoxia (Bonica and Hunter, 1965). Johnson and Clayton (1965) measured utero-placental blood flow by a radio-active sodium clearance technique and observed a 60 per cent reduction in blood flow during prolonged inco-ordinate labours managed under conventional sedatives and analgesics. When epidural analgesia was used, the reduction in utero-placental blood flow averaged only 20 per cent. There was only one foetal death in 224 inco-ordinate labours managed under epidural analgesic and it is possible that the absence of any substantial reduction in placental blood flow contributed to this result. When epidural analgesia was induced, intravenous fluid therapy was also given to correct maternal dehydration, electrolyte depletion and keto-acidosis. This can only have improved the intra-uterine environment. Perhaps all these explanations are applicable and there is no evidence that the use of epidural analgesia in prolonged labour is harmful to the foetus. If foetal death occurs it is more likely to be due to obstetric causes. Excessive maternal hypotension is probably the only potentially harmful effect of epidural block.

It has been demonstrated that epidural analgesia is associated with an improved rate of cervical dilatation and therefore with a more efficient type of uterine action. The precise mechanism of this action is uncertain. Hypertonic inco-ordinate uterine action is thought to be associated with an imbalance between the sympathetic and parasympathetic nerves of the uterus resulting in sympathetic dominance (Willson and

Alesbury, 1951; Caldeyro-Barcia et al, 1960). Lumbar epidural analgesia involves a blockade of the lumbar and lower thoracic sympathetic nerves. Hunter (1963), by recording intra-amniotic pressures has demonstrated the development of a normal pattern of uterine activity after lumbar epidural block in cases of hypertonic inco-ordinate uterine action.

The improvement in uterine action observed in the present series could have more than one explanation. Uterine blood flow was probably improved by epidural block (Johnson and Clayton, 1955) and this might have improved myometrial function and relieved the myometrial hypoxia and metabolic acidosis which may be presumed to have existed in some cases. Mark (1961) demonstrated, in vitro, that the myometrium contracts poorly in an acid medium. Hawkins and Nixon (1957) observed water and electrolyte depletion in prolonged labours and suggested that this might further impair the function of the uterus. It is reiterated that intravenous therapy with electrolyte and sugar solutions was given when epidural analgesia was induced. It is likely that several factors, including the use of epidural analgesia, contributed to the improved uterine action.

Finally the psychological aspects cannot be ignored. The patient who has an inco-ordinate labour is often extremely anxious about herself and her baby and may be in a hysterical state. Weeping and screaming are not uncommon and indicate a loss of emotional control. The effective relief of pain by epidural block alters the whole mental state of these patients and it is conceivable that this too may reduce the level of sympathetic activity within the uterus with an improvement in uterine action.

The obstetric policy in this series of patients was, in general, conservative. Caesarean section was performed in 54 (24 per cent) of 224 patients. Clear and compelling obstetric indications existed for these Caesarean sections. Cephalo-pelvic disproportion was the principal indication for 34 (63 per cent) of Caesarean sections. The remaining 20 Caesarean sections were performed for foetal distress, maternal infection or failure to progress satisfactorily in labour.

Others have obtained acceptable results by a more radical approach to prolonged labour. Table 39 lists the Caesarean section rates and perinatal mortality rates taken from the annual reports of some well-known British maternity hospitals in which a radical policy has been pursued.

Table 39

Caesarean section and perinatal mortality rates for prolonged labour

	Caes. section rate (per cent)	Perinatal mortality rate (per cent)
Royal Maternity Hospital, Belfast, 1963	80	2.0
Royal Maternity Hospital, Belfast, 1965	72	3.1
Queen Charlotte's Maternity Hospital, 1963	45	3.4
Queen Charlotte's Maternity Hospital, 1962	40	2.6
Liverpool Maternity Hospital 1963	40	3.3

The Caesarean section rates of 80 per cent and 72 per cent reported from Belfast refer only to cases of inco-ordinate action without disproportion. In this type of case the Caesarean section rate was 12 per cent in the present series. The perinatal mortality rates of 2.0 per cent and 3.1 per cent in the Belfast series may be contrasted with the complete absence of foetal loss in case of inco-ordinate uterine action without disproportion in the present larger series. The perinatal mortality rates quoted in Tables 38 and 39 do not justify a policy of early and frequent Caesarean section in terms of foetal salvage.

Perhaps humanitarian considerations were involved in the decision to practice early Caesarean section. When epidural analgesia is used, such considerations need not arise because the relief of pain is almost complete and anxiety too is in large measure relieved. As a measure of the pain and distress which may be experienced in an inco-ordinate labour managed with conventional analgesics, the findings of Jeffcoate and his colleagues (1952) are of interest. In a follow-up of 147 patients who had been delivered by Caesarean section or by forceps after prolonged and inco-ordinate labour, it was found that more than one third of these patients had deliberately avoided further pregnancy. This decision was due to the experience of an inco-ordinate labour and was uninfluenced by the method of delivery.

When Caesarean section is performed for inco-ordinate uterine action in a primigravid patient, uterine dysfunction is likely to recur in a subsequent labour if the cervix has not reached half dilatation in the first labour (Jeffcoate et al, 1952, Jeffcoate, 1961). In these circumstances a repeat Caesarean section may well be required in the second labour. The avoidance of Caesarean section is thus worthwhile especially in the younger primigravida. Even the delaying of Caesarean section until the cervix is more than half dilated is likely to result in a more normal second labour and a vaginal delivery (Jeffcoate et al. 1952). In the absence of other indications for Caesarean section, labour may be allowed to continue painlessly and probably more efficiently if epidural analgesia is used.

The patient who has once been delivered by Caesarean section faces an increased risk in subsequent confinements, whatever the method of delivery on these occasions.

Caesarean section is not always an easy or atraumatic operation and blood loss may average over 900 ml. (Wallace, 1967). Post-operative complications occur and the risk of thromboembolism is six times greater than after vaginal delivery (Claye, 1961).

When the pain and distress of inco-ordinate labour have been relieved, the obstetrician can review the case in a calmer and less emotional atmosphere. He may then reflect on the maxim of William Smellie (1752) that "it takes more skill to prevent than to perform an operation." He will try "to maintain a balanced perspective towards the vaginal and abdominal routes of delivery in complicated cases" (Chassar Moir, 1964).

Inco-ordinate labour is a major problem in current obstetric practice. The problem arises in about 2 per cent of labours (Donald, 1964b). Caesarean section solves the immediate problem but the same sequence of events is likely to recur in a subsequent labour. As most patients who have inco-ordinate labours are young primigravidae, this is often an important reason for avoiding Caesarean section if this can be done with safety. The requirements are the relief of pain, the control of uterine action and the correction of biochemical upsets. It is not claimed that epidural analgesia controls uterine action but there is good evidence that it usually improves abnormal uterine action when combined with other measures such as the restoration of normal fluid and electrolyte balance and the correction of keto-acidosis.

As Nixon (1952) has said, "Great caution is required in assessing the value of treatment in cases of long labour. It is easy to laud a particular type of therapy when in fact vis medicatrix naturae played a major part in the termination of labour." Be this as it may, epidural analgesia, at the very least provides time for the healing power of nature to act in a pain-free environment.

SEVERE HYPERTENSION DURING LABOUR

Severe hypertension is defined, for the present purpose, as a systolic blood pressure of 160 mm. Hg. or higher and a diastolic blood pressure of 100 m..Hg. or higher.

In the present total series of 492 epidural blocks, 42 were carried out mainly because of severe hypertension during labour. Continuous epidural analgesia was given to 34 patients in the first stage of labour and 8 patients received a single-shot epidural block in the second stage of labour for forceps delivery. The cause of the hypertension was believed to be pre-eclampsia in all cases. The diagnosis of pre-eclampsia was based on the presence of severe hypertension and either oedema or albuminuria. Sometimes all three criteria were present. A few patients had visual disturbances or headaches. There were no cases of eclampsia. The level of hypertension was sometimes far in excess of the minimum value of 160/100 mm.Hg. (see table 40).

Conduction analgesia has been used by a number of North American workers to lower the blood pressure in severe pre-eclampsia. Lumbar epidural analgesia was used by Lund (1951), Ostlere (1952), Mylks (1960) and Bonica (1965) and caudal analgesia was used by Whitacre and his colleagues (1948). Continuous subarachnoid block was preferred by McElrath and others (1949), by Jones and his colleagues (1952) and by Tuohy (1952).

Only very limited use has been made of conduction analgesia for the control of hypertension in labour by British workers. Bryce-Smith and his colleagues (1949) reported a case of eclampsia treated in this way and six cases of severe pre-eclampsia were treated with subarachnoid or caudal block by Bryce-Smith and Williams (1955). Scott (1955) reported the satisfactory use of lumbar epidural analgesia, in two patients in whom bromethol had failed to control blood pressure. Since 1955, there appear to have been no reports by British workers of the use of conduction analgesia in pre-eclampsia.

Description of Cases and Results.

Epidural analgesia was administered to 42 patients in the first or second stage of labour principally because of hypertension of at least 160/100 mm.Hg. in the preceding two hours. All patients had received substantial doses of sedative and analgesic drugs such as morphine, pethidine and promazine without a reduction in blood pressure to below 160/100 mm.Hg. Bromethol had been given per rectum to 7 patients and this too had not satisfactorily reduced the blood pressure.

In addition to severe hypertension, 18 patients had albuminuria and 39 patients had oedema. No fits occurred, but in several cases, the risk of eclampsia must have been high. There were

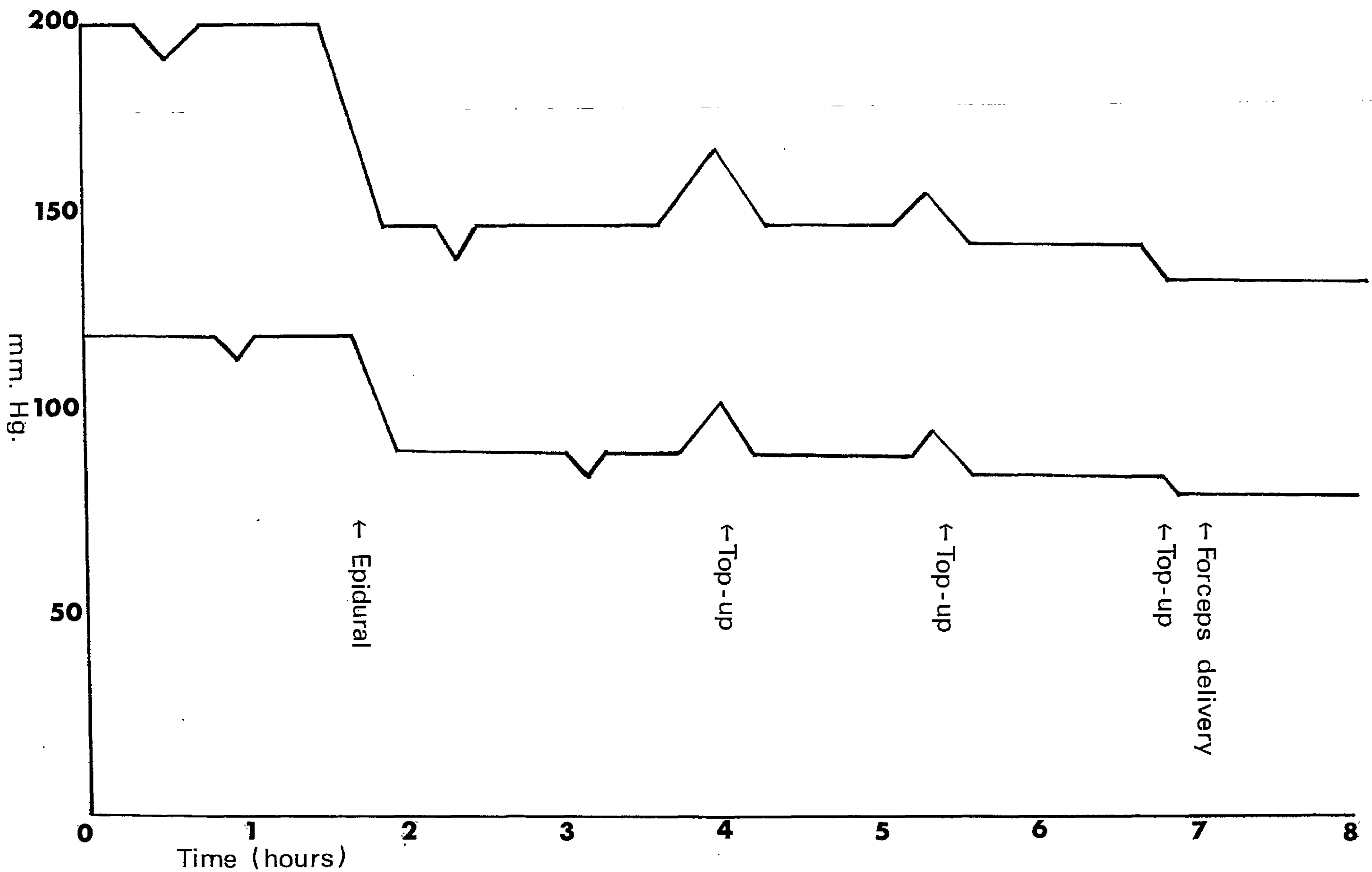


Figure 4.

Record of systolic and diastolic blood pressures before and during epidural block in a patient with severe pre-eclampsia.

36 primigravidae. The period of gestation was less than 36 weeks in 6 patients and less than 38 weeks in 8 patients.

All patients were established in labour when epidural analgesia was induced and labour was usually painful. The analgesic effect of epidural block was of value, in addition the hypotensive effect. Uterine action was inco-ordinate in 10 patients and in these labours, the improved rate of cervical dilatation which is usually associated with epidural analgesia was also valuable. The high incidence of painful and even inco-ordinate labours may be due to the fact that 86 per cent of the patients were primigravidae. Also there may have been a tendency to select epidural analgesia for painful labours.

The technique of epidural analgesia was that described on pages 17 to 19 for obstetric analgesia or for forceps delivery and two per cent lignocaine with 1:200,000 adrenaline was used. An important modification was made when administering top-up injections. It was observed that hypertension often recurred about 30 minutes before the pain of uterine contractions was again felt. Top-up injections were therefore given when the blood pressure began to rise and not when pain recurred. Injections were commonly required at intervals of about 90 minutes, rather than at the 120 minute intervals usual when epidural analgesia was used solely for pain relief. Figure 4 illustrates a typical record of blood pressure in a case of severe pre-eclampsia managed with continuous epidural analgesia.

There were 38 forceps deliveries or vacuum extractions, 3 spontaneous deliveries and one Caesarean section. The Caesarean section was performed for inco-ordinate uterine action and cephalo-pelvic disproportion, rather than for pre-eclampsia.

Perinatal Mortality. There were 4 perinatal deaths. The total perinatal mortality rate was 9.5 per cent. One of these infants died of severe congenital abnormalities, incompatible with life. The corrected perinatal mortality rate was 7.1 per cent. The single stillbirth resulted from intra-uterine death in patient who had a blood pressure of 240/150 mm.Hg., albuminuria and oedema at only 34 weeks gestation. The foetus died of hypoxia during labour. There were two neonatal deaths, the first from intra-cranial haemorrhage and the second from the respiratory distress syndrome in a premature infant. None of these deaths was attributable to epidural analgesia and a corrected perinatal mortality of 7.1 per cent is substantially lower than is usually observed in severe pre-eclampsia (Secton et al, 1950; Browne and Veall, 1953; Baird et al, 1957; Eastman and Hellman, 1961; Greenhill, 1965).

Hypotensive response. In table 40 the 42 patients in this series are divided into groups, according to the systolic and diastolic blood pressures before epidural block.

TABLE 40

Blood pressures before epidural block in 42 patients with severe pre-eclampsia in labour.

Systolic blood pressure		Diastolic blood pressure	
Range(mm.Hg.)	No.of cases	Range(mm.Hg.)	No. of cases
200 - 240	6	140 - 170	5
180 - 199	19	120 - 139	18
160 - 179	17	100 - 119	19

The maximum fall in systolic and diastolic blood pressure was noted after each epidural injection including top-up injections. There were 135 injections in 42 patients. Table 41 shows the average changes in blood pressure after these injections.

TABLE 41

Mean reductions in systolic and diastolic blood pressure after 135 epidural injections in 42 patients with severe pre-eclampsia in labour.

	Absolute reduction		Percentage reduction	
	Systolic BP. (mm.HG.)	Diastolic BP. (mm.Hg.)	Systolic BP.	Diastolic BP.
Mean$\pm$1 Stand Devn.	38.2$\pm$18.4	27.6$\pm$14.6	23.7$\pm$10.9	26.4$\pm$11.8
Range	0 to 100	0 to 75	0 to 56	0 to 53

DISCUSSION

The aetiology of pre-eclampsia is uncertain although much is known concerning certain aspects of the disease and the factors associated with pre-eclampsia.

Approximately 75 per cent of patients are primigravidae (Gemmell, 1954; Clough, 1958; Eastman and Hellman, 1961). Labour in primigravidae is usually more painful and prolonged than in multigravidae and in such cases the use of epidural analgesia can relieve pain as well as control hypertension. According to Bonica (1965) the uterine tonus and the intra-amniotic pressures are often high during labour in patients with pre-eclampsia. This situation is likely to be associated with a painful and perhaps prolonged labour and such labours occurred in 11 patients (26 per cent) of the present series. As has been already suggested, the high incidence of inco-ordinate labour may have been due to a bias towards chosing epidural analgesia when both hypertension and prolonged labour were present together. The systolic blood pressure in normal patients rise between 10 mm.Hg. and 20 mm.Hg. with each uterine contraction in labour (Hendricks, 1958; Adams and Alexander, 1958) and there is an impression that the restlessness sometimes associated with painful contractions is particularly likely to raise the blood pressure further in pre-eclampsia.

The perinatal mortality is high in pre-eclampsia. Mild pre-eclampsia has an average perinatal mortality of 10 per cent and severe pre-eclampsia, which is defined by workers in this field as pre-eclampsia associated with a blood pressure above 150/100 mm.Hg., has an associated foetal loss of about 27 per cent (Sexton et al, 1950; Brown and Veall, 1953; Eastman and Hellman, 1961; Greenhill. 1965). The perinatal mortality was 7.1 per cent in the present small series of severe cases. Some of the perinatal deaths in pre-eclampsia are due to prematurity, which is often associated (Baird et al, 1957) and prematurity was prominent in the present series. Intra-uterine death of the foetus may occur and may be due to hypoxia consequent on a reduced utero-placental blood flow. There is evidence that the utero-placental blood flow is between 25 per cent and 50 per cent of normal in severe pre-eclampsia (Morris et al, 1955; Wright et al, 1958; Little and Bannister, 1959). The placenta is prematurely aged; there is a reduction in size of the inter-villous space and areas of ischaemic necrosis and infarction are common. Although the healthy placenta appears to have a blood supply which is more than adequate for its needs, the situation in severe pre-eclampsia may be perilous for the foetus. Intra-uterine death from abruptio placentae may occur in pre-eclampsia. There were no such cases in this series, a factor which may have contributed to the low perinatal mortality.

Severe pre-eclampsia may have associated effects which influence the choice of anaesthesia and analgesia. Liver function may be impaired (Diekmann et al, 1951) and hepatic blood flow may be reduced (Murrell and Taylor, 1947). In severe cases, pulmonary functions may be affected. There is congestion and oedema of the mucous membranes of the entire respiratory tract with excessive amounts of tracheo-bronchial secretions and pneumonitis and pulmonary vascular resistance may be increased (Bonica, 1965). Renal blood flow may be reduced and renal function impaired.

Pre-eclampsia and its complications still account for a number of maternal deaths. Until recently, approximately one quarter of the maternal deaths in the U.S.A. were due to pre-eclampsia and eclampsia (Eastman and Hellman, 1961). Hypertension directly causes some of these maternal deaths from cerebro-vascular accidents or left ventricular failure.

It is genrally believed that the widespread effects of pre-eclampsia can be explained on a basis of generalised arteriolar spasm which is caused by a circulating pressor substance (Hunter and Howard, 1961; Eastman and Hellman, 1961).

Most treatments for severe pre-eclampsia and eclampsia are based on the depression of the central nervous system with large doses of sedative and narcotic drugs. Occasionally ganglion-blocking drugs have been used to lower blood pressure in very severe cases.

Basal narcosis by the rectal administration of bromethol was introduced by Dewar and Morris (1947) and is still probably the most popular treatment for severe pre-eclampsia and eclampsia in the United Kingdom. Although often effective in reducing blood pressure and in preventing convulsions; there are dangerous side-effects of this form of therapy. The patient becomes unconscious if large doses are administered and pulmonary complications are common. Bromethol may cause further hepatic damage to a liver whose function and blood supply are already impaired. Absorbtion from the rectum is uncertain and an unknown quantity of the drug may be expelled from the rectum. Bromethol is a poor analgesic and restlessness and hypertension may occur in association with painful uterine contractions. Bromethol and all known sedative and analgesic drugs freely cross the placental barrier and may cause respiratory depression at birth in an infant who is often premature and may already have suffered from hypoxia in utero.

Bonica (1965) believes that conduction analgesia is specially indicated in patients who have severe pre-eclampsia in labour and that continuous lumbar epidural analgesia is the method of choice. The writer shares this belief. There is a fairly predictable hypotensive effect from epidural block. In the present series the systolic and diastolic blood pressures fell by 24 $\pm$ 11 per cent and 26 $\pm$ 12 per cent, respectively. A dangerously high blood pressure of 220/130 mm.Hg. is likely to fall to about 165/100 mm. Hg. after epidural block and a blood pressure of 160/100 mm.Hg. will probably be reduced to approximately 120/75 mm.Hg. Bonica (1965) rightly stresses the danger to the fetus of excessive maternal hypotension and suggests restricting the fall to 35 per cent or to a lower limit of 100 mm.Hg. systolic. Excessive hypotension and consequent impairment of the utero-placental blood flow is probably the only serious hazard of properly administered epidural analgesia. Hypotension will usually respond to placing the patient in the left lateral position and if essential a vasopressor drug may be given.

If hypertension constitutes a real threat to the mother(s life and health, the risks of excessive hypotension for the foetus may be considered acceptable. The risk to the foetus is small if the maternal blood pressure is carefully monitored and treatment is immediately instituted for the correction of hypotension.

Bonica (1965) lists the advantages of epidural analgesia as effective control of hypertension; complete analgesia and reduced excitability during uterine contractions with less hypertension associated with the contractions, increased uterine blood flow; absence of harmful effects on the heart, lungs, kidneys and liver; the avoidance of respiratory depression in mother and newborn infant; a reduced load on the heart because of a reduced venous return and the ability to perform Caesarean section if required and to continue epidural block into the postpartum period.

Severe pre-eclampsia becomes less common as antenatal care improves. When it does occur there is a challenge to the obstetrician and to the anaesthetist who is willing to accept the challenge. It is the writer's belief that when hypertension presents a real risk to the mother in labour then epidural analgesia is at present the treatment of choice. Epidural analgesia should reduce blood pressure to reasonable levels and reduce the risk of the potentially fatal complications of hypertension. It is not implied that reducing the maternal blood pressure will always prevent the development of eclampsia.

The writer acknowledges the assistance of Dr. James Willocks in the collection of the data concerning the earlier cases in this series and in the discussion of some of the obstetric aspects of the problem of hypertension in labour. The views expressed are, however, entirely those of the writer.

INADEQUATE ANALGESIA FROM CONVENTIONAL METHODS

This was the indication for 132 (32 per cent) of 408 continuous lumbar epidural blocks. All the patients were primigravidae and their labours were more painful and sometimes more prolonged than usual. These labours were not classed as being inco-ordinate. The foetal occiput was in a posterior position in 81 cases (61 per cent) and this malposition is often associated with a rather prolonged and painful labour, particularly in primigravid patients.

In retrospect, many of these patients seemed to be psychologically ill-suited to childbirth. There were a number of young unmarried mothers. Patients of very high and very low intelligence seemed to be common.

In these normal and nearly normal labours, continuous epidural analgesia was required for an average of 5.1 hours and tachyphyllaxis was not a problem.

Method of Delivery Delivery was by forceps or vacuum extractor in 123 patients (93 per cent) and by Caesarean section in 2 patients (1.5 per cent). There were 7 spontaneous vertex deliveries (5 per cent).

Perinatal Mortality There were 2 stillbirths (twins) and one neonatal death. The perinatal mortality rate was 2.3 per cent. The neonatal death was due to congenital malformations and the corrected perinatal mortality rate was 1.5 per cent.

The twin stillbirths were probably due to intra-uterine hypoxia during an episode of maternal hypotension during epidural analgesia. The supine hypotensive syndrome may be commoner and more severe in twin pregnancy because the large and heavy uterus with its contents may press more heavily on the inferior vena cava.

DISCUSSION

The immediate benefit of epidural analgesia in a normal but painful labour is simply the prompt and sustained relief of all pain. It has proved to be of considerable value to know that this relief is available when conventional analgesics fail.

Most patients obtain an acceptable degree of pain relief from systemic and inhalational analgesics and epidural analgesia is not necessary for these patients. Nor would it, at present, be desireable to use epidural analgesia in the majority of normal labours. Anaesthetists and obstetricians could not cope with the work load which would be created and the high percentage of forceps deliveries involved would radically alter obstetric policy and displace the midwife from her present position.

Nevertheless, a substantial minority of women suffer a good deal of pain in labour and this pain is not always satisfactorily relieved by conventional methods. A recent survey in Sheffield (Beazley et al, 1967) indicated that 40 per cent of recently delivered women considered that they had received inadequate relief of pain in labour. Systemic analgesics, including pethidine, morphine and diamorphine had been freely administered and inhalational analgesics and paracervical blocks had also been used.

In normal labour epidural analgesia should be induced when the presenting part of the foetus is engaged and the cervix is 6 cm. to 7 cm. dilated in primigravidae and 5 cm. to 6 cm. dilated in multigravidae (De Jong, 1961; Moore, 1966). At these times labour is well established in the active phase (Friedman, 1955 and 1956) and is entering its most painful stage. Epidural analgesia should then only be required for a few hours. In the writer's series, analgesia was maintained for 5.1 hours on average in normal labours and 11.1 hours in inco-ordinate labours. In inco-ordinate labours, epidural block was often induced when the cervix was less than 7 cm. dilated in primigravidae.

Graphic analysis of labour and intra-uterine manometry have shown that epidural analgesia has usually no effect on the progress of normal labour although in a few cases progress is speeded (Friedman, 1955; Friedman et al, 1960; Vasicka and Kretchmer, 1961; Cibils and Spackman, 1962; Alexander and Franklin, 1966). Probably the only important effect of epidural analgesia on uterine activity in normal labour is the transient inactivity which may accompany maternal hypotension (Vasicka et al, 1964; Moir and Willocks, 1966). The action of the uterus is essentially autonomous during established labour and interruption of its sensory or motor innervation seems not to affect contractibility (Moore, 1966). There is thus probably an important difference between normal labour and inco-ordinate labour. In the case of inco-ordinate uterine action, there is thought to be overactivity of the sympathetic nerves of the uterus (Willson and Alesbury, 1951, Caldegro-Barcia et al, 1960) and epidural analgesia, as has been demonstrated often improves uterine action, perhaps by the associated sympathetic blockade (Hunter, 1963).

The forceps delivery rate was 93 per cent in this series of 132 painful, but not inco-ordinate labours. However, the foetal occiput was in a posterior position in 61 per cent of these patients during labour, so that forceps delivery would often have been required, whatever the method of analgesia. Moore (1966) has found that with antenatal and intrapartum tuition and encouragement, 50 per cent of patients can have a spontaneous delivery under epidural analgesia. Even when obstetric conditions are suitable for spontaneous delivery, the patient does not usually make involuntary expulsive efforts in the second stage of labour. This is because if perineal anaesthesia is present, Ferguson's reflex is interrupted. Voluntary expulsive efforts are still possible and, as the writer has demonstrated, there is no important degree of paralysis of the abdominal muscles during epidural analgesia (Moir, 1963 and this thesis). It appears that the skillful use of the obstetric forceps in the absence of mechanical difficulty may be associated with a perinatal mortality which is no greater than that associated with spontaneous vertex delivery (Nyirjesy and Pierce, 1964; Tennent, 1965).

The advantages of continuous epidural analgesia in normal labour are perfect pain relief and the avoidance of drug incuded neonatal respiratory depression. Should operative delivery be required, then general anaesthesia with its attendant risks is avoided. There is a substantial reduction in blood loss at delivery (Moir and Wallace, 1967).

One disadvantage of epidural analgesia is the associated higher forceps delivery rate, which will not be less than 50 per cent and may be over 90 per cent. There is also the impracticability, in most British hospitals, of providing a 24 hour service by suitably experienced anaesthetists. The high forceps delivery rate increases the demand for the services of specialist obstetricians in an obstetric service which is based on the conduct of safe, spontaneous deliveries by midwives.

Finally, if epidural analgesia is to be used in normal labour, its risks although small, cannot be discounted. The principal risk is maternal hypotension with the possibility of causing intra-uterine foetal hypoxia. In the late first stage of normal labour, the intra-amniotic pressure may rise to 70mm.Hg. during contractions and if the patient's systolic blood pressure falls below 80 mm.Hg. utero-placental blood flow may cease (Alvarez and Caldeyro-Barcia, 1950; Moore, 1966).

An alternative to epidural analgesia in painful normal labour is paracervical block. This technique is usually performed by the obstetrician and the presence of an anaesthetist is unnecessary. Paracervical block has several important disadvantages and dangers. The success rate is usually between 80 per cent and 85 per cent and so is much lower than with epidural analgesia (Seeds et al, 1962; Cooper and Chassar Moir, 1963; Pitkin and Goddard, 1963; Brown et al, 1965; Gad, 1967). If lignocaine is used, analgesia lasts for only 75 minutes on average. If repeated blocks are performed there is a considerable risk of overdosage, intravascular injection and sepsis. Foetal bradycardia occurs in from 3 per cent to 20 per cent of cases and although often ignored, may be due to the transference of large amounts of lignocaine to the foetus following direct absorption into the uterine arteries (Gad, 1967). The use of bupivacaine (Marcaine) should prolong analgesia and in practice paracervical block can be a reasonably safe and effective technique although its efficiency and safety are lower than usually associated with epidural analgesia.

CARDIAC DISEASE

Painful labour, maternal distress and grade III or IV heart disease (New York Heart Association Classification) were the indications for continuous lumbar epidural analgesia in 6 patients (1.5 per cent of 408 continuous epidural blocks).

All patients had rheumatic valvular disease and 3 patients who had mitral valve disease had developed acute left ventricular failure during the first stage of labour, before epidural analgesia was induced. The clinical signs of left ventricular failure disappeared in each case within 30 minutes of epidural block. This improvement was associated with a reduction in the maternal heart rate from more than 120 beats per minute to less than 90 beats per minute. It is thought that the initial tachycardia was partly due to pain but was also associated with anxiety. The rapid heart rate probably diminished cardiac filling during diastole, so that cardiac output fell and pulmonary vascular congestion and hypertension ensued. An important effect of epidural block was the relief of pain and anxiety and therefore a slowing of the heart rate. Epidural analgesia also effects a "bloodless phlebotomy" by increasing the capacity of the vascular bed and it has been shown (pages 129to133) that epidural analgesia reduces the central venous pressure. Although labour is often short and easy in patients with heart disease (Donald, 1964), the mother is often afraid and the dangerous tachycardia may be due as much to fear as to pain. The complete relief of pain by epidural block seems in itself to alleviate anxiety and may be combined with sedative drugs.

Delivery was by forceps in all 6 patients. These were easy forceps deliveries and were performed to shorten the second stage of labour and to avoid the maternal effort of spontaneous delivery. Forceps delivery is frequently indicated in the presence of severe heart disease, whatever the method of analgesia (Donald, 1964).

Cardiac failure is particularly prone to develop after delivery of the child (Montgomery et al, 1958; Donald, 1964). Major haemodynamic changes occur in the third stage of labour. Blood is expelled from the now shruken uterus into the general circulation, oxytocic drugs are sometimes administered and blood may be lost from the uterus. Epidural analgesia can be maintained after delivery and the enlarged vascular bed may minimise the effects of a sudden increase in blood volume in the third stage of labour.

There were no cases of hypertensive heart failure in this small series, but epidural analgesia might prove of value in such cases by reducing the peripheral resistance and reducing the work-load on the heart. Jackson and his colleagues (1965) used epidural analgesia during labour in a patient who had recently had a myocardial infarction.

RESPIRATORY DISEASE.

RESPIRATORY DISEASE.

Gross impairment of pulmonary function was the indication for 4 (1 per cent) of 408 continuous epidural blocks.

Two patients had advanced chronic bronchitis and emphysema (obstructive airways disease), one patient had status asthmaticus and pneumothorax and the fourth patient had advanced pulmonary tuberculosis, for which a thoracoplasty had been performed.

The last mentioned patient has been described on pages 68 to 69 . She was admitted to hospital during her pregnancy, unconscious and in respiratory failure due to an acute respiratory infection superimposed on her chronic pulmonary disease. She recovered from this episode and the pregnancy proceded to term. Labour and forceps delivery were conducted under epidural analgesia and no sedative or analgesic drugs were administered. The mother and her infant survived. The mother died a few months later of respiratory failure and cor pulmonale in another hospital.

A patient was admitted to hospital at 40 weeks gestation. She had been in status asthmaticus for two days and had had an antepartum haemorrhage. Bronchodilator drugs did not relieve the bronchospasm. A small pneumothorax was noted on the chest radiograph. Anaesthesia was induced with halothane and oxygen in this seriously ill patient. Examination under anaesthesia failed to detect a placenta praevia. Labour began soon after this examination and severe bronchospasm persisted. Continuous epidural analgesia was induced when labour became painful. Immediately after the epidural injection, the patient collapsed, becoming unconscious, profoundly hypotensive and almost apnoeic. An accidental subarachnoid injection or a reaction to the local anaesthetic were suspected. A colleague noted the signs of a tension pneumothorax and an intra-pleural drain was immediately inserted. Recovery was dramatic and labour and forceps delivery completed uneventfully. It was recollected that the patient had coughed before her collapse. This cough must have converted a simple pneumothorax into a valvular, tension pneumothorax and almost cost this patient her life. This case has been described elsewhere by a colleague (Vance, 1968) and illustrates that complications which occur during epidural analgesia are not always due to the analgesic technique.

Two patients had severely impaired pulmonary function due to chronic bronchitis and emphysema. Epidural analgesia was given when pain relief became necessary during labour. Labour and forceps delivery were uneventful and no depressant drugs were administered.

When epidural analgesia is employed in cases of severe respiratory disease, further impairment of ventilation is avoided. Narcotic analgesics are not needed and so drug-induced respiratory depression is prevented. It has been shown that epidural analgesia does not affect resting ventilation, nor does it impair the ability to cough effectively and to breathe deeply (Moir, 1963; Moir and Mone, 1964).

Severe respiratory disease is unusual in women of child-bearing age, but these cases illustrate the value of epidural analgesia in relieving pain and avoiding further impairment of ventilation when the problem does arise.

FORCEPS DELIVERY

Single-shot epidural analgesia was administered in the second stage of labour for 58 forceps deliveries and 15 vacuum extractions. In addition, there were 293 forceps deliveries and 41 vacuum extractions under continuous epidural analgesia, which had been commenced during the first stage of labour. In total, 351 forceps deliveries and 56 vacuum extractions have been conducted under epidural block.

Epidural analgesia is particularly suitable for the more difficult operative vaginal deliveries. There is complete analgesia, such as is not always attained with pudendal nerve block. Manoeuvres such as rotation of the foetal head are facilitated by the relaxation of the pelvic floor muscles. Obstetricians, and patients too, have often commented favourably on the conditions at delivery.

Single-shot epidural block is a suitable alternative to general anaesthesia where this is requested by the obstetrician for a difficult delivery or because of maternal hypertension in the second stage of labour. Epidural analgesia is not suitable if immediate delivery is indicated, as in foetal distress, because at least 15 minutes must elapse before complete analgesia develops and general anaesthesia can be induced more rapidly than this. Vacuum extraction, especially if undertaken before full dilatation of the cervix, is sometimes a prolonged procedure and epidural analgesia avoids exposure of the foetus to protracted general anaesthesia. During epidural analgesia, the conscious patient can add her own expulsive efforts to the traction of the vacuum extractor, should this be desired by the obstetrician.

An important advantage of epidural analgesia is the avoidance of the risk of inhaling regurgitated or vomited stomach contents. Drug-induced neonatal respiratory depression is avoided.

Epidural analgesia of course carries its own risks and the hazards of general anaesthesia and epidural analgesia, although different, are related to the skill of the anaesthetist with either technique. The mortality associated with epidural analgesia in obstetrics can be much lower than that associated with general anaesthesia. Reference has been made earlier to 125,000 obstetric epidural blocks conducted without a maternal death (Chaplin and Renwick, 1958; Bush, 1959; Eisen et al, 1960; Norris et al, 1960; Hingson et al, 1961; Evans et al, 1962; Hellman, 1965; and Moore, 1966). About 2 per cent of maternal deaths in Great Britain are due to the pulmonary aspiration of stomach contents under general anaesthesia (Ministry of Health Report, 108, 1963) and epidural analgesia is particularly suitable when the patient is known to have, or believed to have a full stomach.

A final advantage of epidural analgesia for forceps delivery is that blood loss is halved in comparison with delivery under general anaesthesia (Moir and Wallace, 1967.).

CAESAREAN SECTION.

Only 14 Caesarean sections were performed under epidural analgesia alone. Eleven of these patients had single-shot epidural analgesia induced for this operation and three patients were already receiving continuous epidural analgesia.

The principal reason for administering epidural analgesia for Caesarean section was a strong desire on the patient's part to be awake at the delivery of her child. Such sentiments were very unusual and the great majority of British patients although agreeable to forceps delivery under epidural analgesia, will not contemplate abdominal surgery while conscious. Modern light general anaesthesia, with muscle relaxants is very satisfactory for Caesarean section and causes little or no neonatal depression (Crawford, 1962), although it does carry the inescapable hazards of vomiting and regurgitation. Consequently, epidural analgesia is only used when a patient specially requests it or if the vomiting risk appears to be unusually great. Analgesia was usually excellent in the present small series, but occasionally traction reflexes proved troublesome.

Others consider that epidural analgedia is the technique of choice for Caesarean section, especially if the foetus is at high risk and in cases of pre-eclampsia and diabetes mellitus (Ebbli and Barricalla, 1959; Flowers, 1960; Bodell et al, 1962). Stenger and his colleagues (1965) measured the oxygen saturation, pH and Pco_2 of the umbilical vein at delivery by Caesarean section under epidural and subarachnoid analgesia. The oxygen saturation under spinal (subarachnoid) analgesia was only half the value obtained when epidural block was used and there was a respiratory and metabolic acidosis in the babies delivered under subarachnoid analgesia which was not seen under epidural analgesia.

Nevertheless, it has proved to be ill-advised in the writer's experience to try to force a reluctant and already firghtened patient to accept abdominal surgery while conscious and without preliminary sedation. Patients in other countries, notably the United States of America, seem to accept the idea of major surgery without general anaesthesia more willingly than their British counterparts.

CONTRAINDICATIONS

There are a few generally accepted contraindications to epidural analgesia and there are a number of obstetric conditions which are absolute or relative contraindications.

Epidural analgesia should not be used in the presence of existing disease of the nervous system or where there is sepsis in the lumbar region. Severe deformity of the lumbar spine may make epidural puncture impossible and in such cases caudal analgesia may be used. In shock, hypovolaemia and severe anaemia, the autonomic blockade may upset compensatory mechanisms and epidural analgesia should rarely be used. Epidural analgesia is not advised if there has been an antepartum haemorrhage, because there is always the risk of sudden torrential haemorrhage.

Epidural analgesia should be avoided if there is obstetric defibrination because there may be bleeding from the epidural veins. An epidural haematome may cause nerve damage (Hellman, 1965).

There are circumstances in which epidural analgesia should be used with caution or not at all. Little and Friedman (1958) recorded an increased incidence of neonatal asphyxia in second twins delivered under epidural analgesia in comparison with other anaesthetic techniques and thought that there may have been premature separation of the placenta due to the vigorous uterine retraction which is often associated with epidural analgesia. Others have failed to confirm this observation

(Aaron and Halperin, 1955, Hingson and Hellman, 1956) and there is always a higher incidence of asphyxia in second twins, whatever method of anaesthesia is used (Johnstone and Kellar, 1961).

In breech delivery, if epidural analgesia is first induced, obstetric manipulations can be performed with ease and the hazards of inducing general anaesthesia in the lithotomy position for delivery of the head are avoided. Assisted breech delivery requires active maternal expulsive efforts and these may be inadequate during epidural analgesia. Breech extraction may then be required. Bonica (1965) has found that maternal efforts are adequate for assisted breech delivery, but this has not always been the writer's experience.

Extensive intra-uterine manipulations, although now rarely performed. should not be done under epidural block. The uterus will not be relaxed, and there is a risk of uterine rupture.

The presence of a uterine scar from a pevious Caesarean section increases the risk of rupture of the uterus in a subsequent labour. Epidural analgesia may mask the signs of uterine rupture. Epidural analgesia has been used with great caution in a few patients who had previously been delivered by Caesarean section (Moir and Willocks, 1966 and 1967) and in one of these patients impending rupture of the uterus was successfully diagnosed.

Finally, when immediate delivery is indicated, as in foetal distress or prolapse of the umbilical cord, general anaesthesia can be induced more rapidly than epidural analgesia.

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TABLE A

The Effects of high epidural block on ventilation in 30 patients with normal respiratory function.

Patient	Age	Sox	Resting tidal vol. (ml.)		Resting minute vol. (ml.)		Vital Capacity (ml.)		Peak exp.flow (L/min.)	
			Before block	During block	Before block	During block	Before block	During block	Before block	During block
1	58	M	580	600	7820	8140	3070	2880	432	412
2	40	M	620	650	8360	8390	5140	5100	575	589
3	72	M	560	530	7720	7910	3220	3200	380	353
4	61	M	560	550	7100	7090	3200	2960	410	394
5	39	M	590	610	8020	8040	5200	4930	624	587
6	49	M	520	460	7900	7840	4910	4680	491	469
7	55	M	530	490	7680	7640	4100	3420	436	413
8	73	M	610	650	7820	7860	3060	2840	345	335
9	48	M	590	610	8020	8060	4430	4260	604	569
10	42	M	600	620	7620	7640	5070	4810	578	571
11	50	M	540	500	7900	7860	4110	3730	482	458
12	47	M	530	470	7740	7680	4700	4410	546	529
13	59	M	600	630	7720	7750	3060	2730	425	400
14	44	M	530	470	7780	7720	5130	4840	610	558
15	53	M	550	510	7660	7980	3760	3580	447	412
16	50	M	530	490	7920	7620	3850	3710	460	451
17	67	F	600	630	7700	7730	2790	2520	406	391
18	43	F	590	610	7800	8040	3700	3440	582	571
19	37	F	570	550	8060	7820	3010	2730	605	585
20	52	F	540	510	8120	7990	3040	2910	441	416
21	70	M	510	480	7910	7370	2520	2210	353	326
22	36	F	650	720	7300	7880	3870	3660	584	581
23	38	F	580	560	7740	7820	3810	3750	607	572
24	45	F	580	590	7550	7560	3440	3310	562	539
25	51	F	560	540	7730	7916	3200	2790	484	467
26	57	M	620	660	767[illegible]	7810	3070	2600	440	439
27	67	M	560	530	7930	7900	2830	2980	398	363
28	34	M	570	570	7700	7680	5930	5710	579	562
29	56	M	590	610	8140	8180	3350	2960	475	455
30	59	M	570	550	7820	8000	3040	2930	426	394

TABLE B

The effects of high epidural block on ventilation in 12 patients with broncho-pulmonary disease

Patient	Age	Sex	Resting tidal vol. (ml.)		Resting minute vol. (Ml.)		Vital Capacity		Peak exp. flow (L./min.)	
			Before block	During block	Before block	During block	Before block	During block	Before block	During block
1	35	M	450	480	8100	7310	3810	3120	322.5	285
2	60	M	490	520	6860	6760	2300	2100	210.5	185
3	74	M	470	450	6580	5850	1840	1610	120	90
4	57	F	600	550	7200	7150	2590	2420	172.5	154
5	52	M	550	490	5850	6370	3130	3020	217.5	222.5
6	56	M	490	480	6860	7200	3250	3360	380	350
7	48	M	540	590	8100	9120	2800	2210	267	243
8	59	F	580	630	6720	7520	2910	2530	270	237.5
9	58	M	540	560	7560	7840	1940	1780	143.5	123.5
10	70	M	480	480	6720	7680	2180	2220	260	225
11	51	M	620	680	9720	9600	3320	3040	280	242.5
12	62	M	550	570	7280	7980	2570	2360	212.5	210

TABLE C

Tidal and minute volumes in 20 patients during hysterectomy under high epidural block

Patient	Age	Tidal volume(ml.)		Minute volume(ml.)	
		Lowest	Highest	Lowest	Highest.
1	49	520	900	6370	8500
2	55	440	860	6560	8130
3	42	560	1150	7100	8820
4	47	450	920	6110	7500
5	41	480	1060	6700	8250
6	44	600	1450	7450	8720
7	59	460	730	6620	7380
8	55	500	680	7050	8320
9	47	530	800	6470	9200
10	40	550	1280	7300	9640
11	43	490	900	7090	8260
12	46	440	1320	6720	8940
13	56	420	750	6250	7650
14	62	380	960	6400	7330
15	48	460	890	6940	8800
16	50	570	1140	7670	9060
17	57	430	780	6200	7340
18	42	500	1060	7550	9840
19	48	440	880	6380	8150
20	44	470	1030	6710	8400

TABLE D

PH, P_{CO_2} and standard bicarbonate in twelve patients without respiratory disease, before and during epidural block

Patient	Age	Sex	pH Before block	pH During block	P_{CO_2} (mm.Hg.) Before block	P_{CO_2} (mm.Hg.) During block	Stand.Bicarb. (m.Equiv./L.) Before block	Stand.Bicarb. (m.Equiv./L.) During block
1	57	M	7.39	7.37	48	44	26	23.5
2	54	F	7.40	7.40	40.5	41	24.5	24.5
3	68	M	7.40	7.38	39	40	23	23
4	36	M	7.39	7.40	45	38.5	25	24
5	38	M	7.37	7.39	46	39	25	23
6	50	M	7.42	7.42	35	32	23	22
7	29	M	7.43	7.37	38	41	25	23
8	28	M	7.40	7.42	40	39	24	24
9	46	M	7.38	7.40	43	39	24	23
10	48	F	7.43	7.44	41	35	26	24
11	36	M	7.40	7.38	38.5	44	23.5	24
12	60	M	7.46	7.42	32	37	24	24

TABLE E

pH, P_{CO_2} and standard bicarbonate in eight patients with bronchopulmonary disease, before and during epidural block

Patient	Age	Sex	pH Before block	pH During block	P_{CO_2} (mm.Hg.) Before block	P_{CO_2} (mm.Hg.) During block	Stand.Bicarb. (m.Equiv./L.) Before block	Stand.Bicarb. (m.Equiv./L.) During block
1	57	M	7.47	7.46	30.5	28.5	25	23
2	48	M	7.37	7.39	29	35	19	22
3	44	F	7.39	7.36	41	47	24	25
4	62	M	7.45	7.39	39.5	42.5	26.5	23.5
5	44	F	7.42	7.41	37	36	22	23
6	56	M	7.42	7.38	36	42	23	23
7	74	M	7.37	7.37	39	38.5	22	22
8	57	F	7.39	7.37	40	42	24	21

TABLE F

Vital capacity and peak expiratory flow rate in 12 patients with respiratory disease, before and after prostatectomy under continuous epidural analgesia.

Patient	Age	Vital capacity(ml.)		Peak expiratory flow (L./min.)	
		Before operation	after operation	before operation	after operation
1	62	2450	2040	255	170
2	64	2200	1870	206	184
3	78	1860	1780	111	82
4	60	2930	2800	304	211
5	73	2150	1880	186	143
6	59	2860	2600	320	266
7	72	1720	1640	167	109
8	68	2340	1970	194	178
9	75	1410	1380	142	94
10	69	1890	1670	160	114
11	61	2460	2300	211	180
12	67	2350	2090	204	147

TABLE G

SKIN BLOOD FLOW.

Skin blood flow, index of vascular resistance and mean arterial blood pressure during epidural block in 6 female patients.

		Temperature gradient(°C) Zero flow	Temperature gradient(°C) Resting flow	Zero flow minus resting flow (°C)	Percentage flow	Index of vascular resistance.	Mean arterial B.P mm.Hg.	Mean arterial B.P Percentage of control
	Before block (control)	3.45	3.37	0.08	100	-	77	100
Case No.1	10 mins.	3.45	3.37	0.08	100	0.97	75	97
	25 mins.	3.42	3.25	0.17	213	0.45	73	95
	40 mins.	3.32	3.22	0.13	163	0.51	63	82
	Before block (control)	3.02	2.85	0.17	100	-	72	100
Case No.2	10 mins.	3.00	2.75	0.25	147	0.57	58	81
	25 mins.	3.00	2.75	0.25	147	0.51	58	81
	40 mins.	3.00	2.73	0.27	159	0.51	58	81
	Before block (control)	3.24	3.18	0.06	100	-	80	100
Case No.3	10 mins.	3.25	3.14	0.11	183	0.39	57	71
	25 mins.	3.22	3.08	0.14	233	0.26	48	60
	40 mins.	3.22	3.10	0.12	200	0.30	48	60
	Before block (control)	3.30	3.25	0.05	100	-	73	100
Case No.4	10 mins.	3.30	3.17	0.13	260	0.26	50	68
	25 mins.	3.30	3.17	0.13	260	0.25	48	66
	40 mins.	-	-	-	-	-	-	-
	Before block (control)	3.22	3.10	0.12	100	-	72	100
Case No.5	10 mins.	3.20	2.88	0.32	267	0.21	42	58
	25 mins.	3.20	2.95	0.25	208	0.28	42	58
	40 mins.	3.20	2.88	0.32	267	0.21	42	58
	Before block (control)	3.32	3.21	0.11	100	-	92	100
Case No.6	10 mins.	3.28	3.04	0.24	218	0.35	70	76
	25 mins.	3.28	3.02	0.26	236	0.32	70	76
	40 mins.	3.25	2.98	0.27	246	0.29	65	71

TABLE G.

The figures in column 3 are the differences between the temperature gradient (^{o}C) at zero flow (with tourniquet inflated) and at resting flow. The value in column 3 is a measure of blood flow. The percentage flows in column 4 are the relationships between the values in column 3 expressed as percentages of the control value.

The calculation of the Index of Vascular Resistance is described on page 271 of this Appendix.

TABLE H

MUSCLE BLOOD FLOW.

Muscle blood flow, index of vascular resistance and mean arterial blood pressure during epidural block in 6 female patients.

		Temperature gradient (°C) Zero flow	Resting flow	Zero flow minus resting flow (°C)	Percentage flow	Index of vascular resistance	Mean arterial B.P mm.Hg.	Percentage of control
	Before block (control)	3.45	3.40	0.05	100	-	77	100
Case	10 mins.	3.45	3.40	0.05	100	0.97	75	97
No.1	25 mins.	3.78	3.70	0.08	160	0.60	73	95
	40 mins.	3.82	3.80	0.02	40	2.05	63	82
	Before block (control)	3.52	3.48	0.04	100	-	72	100
Case	10 mins.	3.52	3.48	0.04	100	0.81	58	81
No.2	25 mins.	3.60	3.57	0.03	75	1.08	58	81
	40 mins.	3.60	3.57	0.03	75	1.08	58	81
	Before block (control)	3.47	3.40	0.07	100	-	80	100
Case	10 mins.	3.62	3.57	0.05	71	1.0	57	71
No.3	25 mins.	3.68	3.65	0.03	43	1.39	48	60
	40 mins.	3.68	3.65	0.03	43	1.39	48	60
	Before block (control)	3.25	3.12	0.13	100	-	73	100
Case	10 mins.	3.40	3.35	0.05	38	1.79	50	68
No.4	25 mins.	3.32	3.25	0.07	54	1.22	48	66
	40 mins.	-	-	-	-	-	-	-
	Before block (control)	3.42	3.33	0.09	100	-	72	100
Case	10 mins.	3.42	3.35	0.07	77	0.72	42	58
No.5	25 mins.	3.51	3.46	0.05	55	1.06	42	58
	40 mins.	3.51	3.46	0.05	55	1.06	42	58
	Before block (control)	3.36	3.28	0.08	100	-	92	100
Case	10 mins.	3.30	3.24	0.06	75	1.01	70	76
No.6	25 mins.	3.30	3.24	0.06	75	1.01	70	76
	40 mins.	3.30	3.25	0.05	63	1.13	65	71

TABLE II

The figures in column 3 are the differences between the temperature gradient (^{o}C) at zero flow (with tourniquet inflated) and at resting flow. The value in column 3 is a measure of blood flow. The percentage flows in column 4 are the relationships between the values in column 3 expressed as percentages of the control value.

The calculation of the Index of Vascular Resistance is described on page 271 of this Appendix.

APPENDIX I

Calculation of the Index of Vascular Resistance.

$$\text{The Index of Vascular Resistance} = \frac{\text{Blood pressure index}}{\text{Flow index.}}$$

$$= \frac{\text{B.P. 2}}{\text{B.P. 1}} \div \frac{\text{Flow 2}}{\text{Flow 1}}$$

B.P. 1 = The mean arterial blood pressure before epidural block (mm.Hg.)

B.P. 2 = The mean arterial blood pressure at time X during epidural block (mm.Hg.)

Flow 1 = The temperature gradient ($^{\circ}$C) at zero flow minus the temperature gradient ($^{\circ}$C) at resting flow, before epidural block.

Flow 2 = The temperature gradient ($^{\circ}$C) at zero flow minus the temperature gradient ($^{\circ}$C) at time X.

For example, the calculation of the Index of Vascular Resistance for skin in Case No.1 (Appendix G) 25 minutes after epidural block is as follows:-

$$\text{Index of Vascular Resistance} = \frac{\text{B.P. 2}}{\text{B.P. 1}} \div \frac{\text{Flow 2}}{\text{Flow 1}}$$

$$= \frac{73}{77} \div \frac{0.17}{0.08}$$

$$= \frac{0.95}{2.13}$$

$$= 0.45.$$

That is, the vascular resistance has fallen to 45 per cent, the blood flow has increased to 213 per cent and the mean arterial blood pressure has fallen to 95 per cent, 25 minutes after epidural block.