The great advances in the surgical correction of congenital cardiac abnormalities have necessitated ever increasing accuracy in their diagnosis, and cardiac catheterization is now widely used for this purpose. The validity of the measurements obtained depends on the patient remaining throughout in a steady physiological state.

Initially it was claimed that satisfactory results could be obtained in adults without recourse to drugs but, when the technique was extended to children, it became obvious that some form of sedation was required to facilitate the procedure. Now an anaesthetist is a member of most cardiac diagnostic teams.

The problems encountered are many and varied. The examination is carried out in an X-ray room, partly in darkness, and under circumstances which make access to the patient difficult for considerable periods. The patients are all suffering from some cardiac lesion and many are grave anaesthetic risks. Finally the technique itself imposes certain limitations on the anaesthetist and the methods he may employ. Before considering the anaesthetic or sedative mixtures which may be used it is essential to understand fully the technique of cardiac catheterization and the conditions necessary for its satisfactory performance.

CARDIAC CATHETERIZATION

Technique.

The patient who has fasted for at least 4 hours is brought to the X-ray table and placed comfortably on a soft foam mattress. A vein, either the median cubital or saphenous, is exposed under local anaesthesia and the largest possible Courmand catheter inserted. Heparinized saline is allowed to drip slowly through the catheter which is manipulated under fluoroscopic control into the various chambers of the heart and into the great vessels. Intracardiac pressures are recorded by connecting the catheter to an electromanometer, and the oxygen content of serial samples—removed in quick succession from adjacent sites within the heart—is measured, either directly by means of a cuvette oximeter, or by placing blood samples under oil for subsequent estimation with a haemoreflector or by Van Slyke analysis. Simultaneously with the withdrawal of a mixed venous sample, blood is removed from an artery and the patient's oxygen consumption is measured. From these data the cardiac output may be calculated. This forms the basic technique carried out, with slight individual modifications, in most centres.

Information obtained from cardiac catheterization.

While the catheter is being manipulated within the heart and great vessels under fluoroscopic control, it may pass into abnormal channels such as a patent ductus arteriosus or through a septal defect. Such abnormal positions are easily recognized by screening in various positions. Much of the information is derived from a comparison of the blood pressure and the oxygen values obtained from the chambers of the heart.

In drawing a sample of blood from the right atrium care must be taken to obtain a mixed atrial sample as the three vessels draining into the atrium—the venae cavae and the coronary sinus—discharge blood with different oxygen saturations. With this proviso there should be little difference in the oxygen content of right heart blood and any increase in the oxygenation of one chamber suggests the presence of a left-to-right shunt at that level. A pressure gradient between the right ventricle and pulmonary artery indicates pulmonary stenosis.

To make these readings strictly comparable the patient's respiration and circulation must be in a steady state throughout the investigation, as
fluctuations in the level of oxygen saturation due to respiratory variations will later affect the right side of the heart.

THE STEADY STATE

Although most writers dealing with cardiac catheterization stress the need for a "steady state", few attempt to define its parameters. Basically it implies stable levels of blood pressure throughout the heart concomitant with minimal fluctuations in the oxygen saturation at each site. The factors liable to cause changes in these values are worthy of consideration.

Emotion.

Anxiety causes marked fluctuation in cardiac rate and output (Altschule, 1951) and the changes in systemic blood pressure caused by emotion are well known. Barratt-Boyes and Wood (1958) have shown that a similar rise in right ventricular and pulmonary artery pressure also accompanies anxiety. Even when there are no outward signs of emotion, anxiety can cause a rise in oxygen consumption (Ziegler and Levine, 1925) and "potentially stressful stimuli" can lower arterial oxygen saturation (Doust and Schneider, 1955).

Respiratory variations.

The direct effects of changes in intrathoracic pressure during respiration have been well demonstrated by Hamilton, Woodbury and Harper (1944). Right heart pressures in the auricle, ventricle and pulmonary artery rise during expiration and fall during inspiration. The variations increase markedly with increased depth of respiration and coughing and straining produce wide fluctuations. Barratt-Boyes and Wood (1958) have shown that under these circumstances the right ventricular pressure varies less than the pulmonary artery and systemic pressures. Hyperventilation in a person previously breathing normally will cause a rise in the arterial oxygen saturation which will not regain its previous level for 5 minutes (Van Lingen and Whidborne, 1952). Extreme variations in respiration during straining or struggling cause marked fluctuation of intracardiac pressures and oxygen values (Holling and Zak, 1950). This may alter the amount of blood flowing in a left-to-right shunt or even reverse the direction of flow. The degree to which this takes place and the danger to life involved varies with the lesion present.

Variations in alveolar oxygen and carbon dioxide levels.

Changes in alveolar oxygen levels are soon reflected in the arterial oxygen saturation (Dripps and Comroe, 1947). The pulmonary artery pressure varies inversely with the alveolar oxygen content (Motley et al., 1947), as do the cardiac output, pulse rate and systemic blood pressure. Wide fluctuations in the oxygen saturation of patients with congenital heart disease consequent on the reversal of their shunts have thus been shown to follow variations in the content of the inspired air (Burchell, 1950).

Only a slight rise in pulmonary artery pressure accompanies the marked rise in systemic pressure produced by carbon dioxide retention or administration (Cournand, 1950; Shephard, 1954).

Sleep.

A fall in systemic blood pressure, pulse rate (Kleitman, 1929), pulmonary artery pressure (Halmagyi et al., 1953), oxygen consumption, carbon dioxide production, alveolar and total ventilation (Robin et al., 1958), have been shown to accompany sleep. These changes are considered by Benedict (1915) to represent the true basal or resting state and so long as sleep persists they are constant and reproducible.

Intravenous anaesthetic or analgesic drugs.

Respiratory and circulatory depression, although transient, will frequently follow the administration of thiopentone or pethidine. The effects produced have been reported in detail by Barton, Wicks and Livingstone (1946) and Elam and Brown (1956) respectively. Swerdlow (1957) found that with thiopentone this respiratory depression was greater with each subsequent injection of the drug.

Factors contributing to the induction and maintenance of a steady resting state.

It would seem reasonable to assume that the patient will remain in a steady resting state when the following conditions obtain:

1. Anxiety is absent.
2. Respiration is free and regular but of sufficient depth to allow normal gaseous exchange.
3. The composition of the inspired gases remains constant.
4. Oxygen consumption does not vary appreciably.
(5) Muscular movements are minimal.
(6) Changes in heart rate are minimal.
(7) Intermittent administration of drugs is avoided.
(8) The patient remains asleep or awake during the procedure but does not lapse from one to the other.

Most of these conditions are satisfied in the sleeping patient breathing air.

THE PATIENT

The physical state of patients presented for cardiac catheterization varies considerably. At one extreme is the symptom-free child found at routine medical examination to have a cardiac murmur, while at the other is the child in cardiac failure. Many of the patients have had repeated chest infections. Gibson (1952) found a high proportion of cyanotic children to be irritable and fretful. Although not all patients submitted to cardiac catheterization are children, many of the teenage patients and even some of the adults are emotionally labile. In part this is due to the tendency for other abnormalities—including mental defects—to accompany congenital heart disease.

Pulmonary hypertension has been found in conjunction with almost all forms of acyanotic congenital heart disease and such patients are liable to effort syncope (Dressier, 1952; Howarth and Lowe, 1953). Cardiac arrhythmias are present in some patients, particularly those with atrial septal defects.

It is essential for the patients' safety, quite apart from the successful performance of the cardiac catheterization, that they remain calm and quiet during the procedure. The examinations are carried out in varying lighting conditions, for some of the time in total darkness. The patients are surrounded by a mass of complicated—and to them fearsome—apparatus worked by a team speaking a language they do not understand. They have to remain thus for a long period of 2 to 3 hours—a trial indeed for most. It is usual, therefore, to sedate all patients, the younger ones to the point of sleep.

METHODS OF SEDATION AND ANAESTHESIA

In most centres older children and adults are catheterized after the administration of a fairly heavy dose of a suitable sedative. This may take the form of a barbiturate, an opiate or a combination of drugs. It is profitable to combine this with reassurance and distraction by someone known to the patient, often the ward nurse, when the patient remains fairly alert.

For younger patients and those not considered likely to be easily managed by simple sedation, one of three techniques may be employed.

(1) Basal narcosis.
This consists of the administration of a precalculated dose of a hypnotic drug usually by rectal injection. Prior to the enema, it is customary to give a mild sedative such as a small dose of barbiturate to make the child sleepy. The rectal injection itself is normally composed of either bromethol or thiopentone, the choice being governed by a number of factors. Thiopentone requires a much smaller volume of solution for its administration and is quicker in onset. On the other hand its duration of action at the required depth seldom exceeds 1 to 1 1/2 hours, and supplementary injections of thiopentone or pethidine (Inglis, 1954) are required if the catheterization lasts longer than this. These injections upset the steady state and for this reason many prefer to use bromethol which has a longer duration of action at the required depth. Although this drug requires a larger volume of solution to dissolve it and entails extra care in preparing the enema, it is possible to carry out a high percentage of the examinations without further drugs (Fieldman et al., 1955).

The rectal administration of either of these drugs enables the patient to be put quietly to sleep in the familiar surroundings of his bed by a nurse or sister known to him. This usually ensures a peaceful transition from wakefulness unaccompanied by tears or struggling. However, the administration of a drug via the lower bowel may result in uncertain absorption and a variable degree of sedation. This variation can be minimized by ensuring that a skilled nurse or sister regularly gives the enema and that it is carefully prepared in advance. Variable results also follow the use of a dose of drug precalculated on the basis of body weight. This is a problem not peculiar to basal narcosis and is discussed later.

A recent report by Feldman et al. (1961) describes a technique which combines many of the
advantages of these methods without one of the drawbacks. Hydroxydione is given intravenously after suitable sedation and the results are similar to those with rectal thiopentone. Although absorption is thus controlled, intravenous injections in small children of hydroxydione, which may cause pain and subsequent venous thrombosis despite careful use (Robertson and Williams, 1961), can be a poor substitute for rectal thiopentone or bromethol. Smith and Jeffries (1959) consider that rectal medication is still the method of choice in dealing with difficult children.

While these techniques produce excellent results in a high percentage of patients, they are time-consuming and require the attention of an anaesthetist before and during the procedure and skilled nursing afterwards. Alternative methods have therefore been sought which produce a lighter level of narcosis.

(2) **The “lytic cocktail.”**

Smith, Rowe and Vlad (1958) and Mitchell and Minor (1958) described a technique in which they gave intramuscular injections of a mixture of pethidine, chlorpromazine and promethazine. More recently Ordish and Mair (1961) have used promazine in place of chlorpromazine. The drugs are given 1 to 1½ hours before the catheterization is due to commence and supplements either of the mixture or of pethidine alone are given intravenously when required. The aim is to underdose initially and to use supplements freely; they recommend that the doses of the mixture be reduced particularly in cyanosed and gravely ill patients. They claim to produce adequate sedation with less circulatory and respiratory depression and, as the level of unconsciousness is such that the child is easily roused, less medical and nursing supervision is required. Some physicians welcome this method since they can dispense with the services of an anaesthetist, but the technique has disadvantages. The intramuscular injection of this mixture is a painful procedure which may result in crying and struggling, lasting for several minutes. Further, the use of smaller doses and the variable results produced by the precalculated dosage result in Smith et al. (1958) reporting 33 per cent of children crying or struggling when the needle is inserted, thus requiring intravenous supplementation. A small percentage of these children remained failures throughout the investigation. When larger doses of the mixture are used, or supplements have to be given, the length of time to recover after catheterization is almost indistinguishable from that after basal narcosis. Finally, the effects of the mixture given intravenously, reported by Adams and Parkhouse (1960), are not conducive to the maintenance of a steady state.

(3) **Inhalational anaesthesia.**

Inhalational anaesthesia has long been avoided as a method to be used in patients undergoing cardiac catheterization, because most of the volatile agents and nitrous oxide interfere with the performance of Van Slyke analysis. It was also generally believed that the level of oxygen saturation would vary during the procedure and any rise or fall in the inspired concentration of oxygen alters many of the parameters being measured. Finally, the administration of a suitable volatile anaesthetic is beset with difficulties due to the circumstances of cardiac catheterization.

Some of these disadvantages may now be overcome. An oximeter or a spectrophotometer may be used for the oxygen analysis and it is also possible to vaporize the volatile agent with compressed air. This has led to a recent interest in the use of inhalational anaesthesia in this field. Trichloroethylene in air (Keats et al., 1958), or with nitrous oxide and oxygen (Eggers et al., 1959), has been recommended, but the high incidence of severe tachypnoea renders this agent of little value.

Kepes et al. (1955) describe a technique using nitrous oxide and oxygen but they induce anaesthesia with ether and supplement if necessary with thiopentone intravenously. Few anaesthetists would be attracted to this method.

Norton and Kubota (1960) use halothane, vaporized by compressed air and administered by face mask, and present impressive data in support of their method. However, the dangers of attempting to maintain a very light anaesthetic in the dark and under a fluoroscopic screen are considerable, and the radiation to which the anaesthetist’s hand would be subjected when supporting the chin, would be a disadvantage, despite the use of a modern well-screened X-ray unit with an image intensifier (Norris, 1961).

The use of an endotracheal tube would appear to answer the difficulties of maintaining an airway, but this in turn requires a deeper level of anaes-
the use of a belladonna derivative.

When using basal narcosis or inhalational methods, it is usual to administer either atropine or hyoscine as part of the premedication. This has been criticized by some because of the tachycardia which may be caused or aggravated. However, the increased risk of troublesome salivation and the dangers of thiopentone or halothane without previously giving atropine or hyoscine are considerable. Finally the practice of following the catheterization with angiocardiography under suxamethonium-induced apnoea makes atropine highly desirable.

Control of arrhythmias.

The prevention of the arrhythmias which commonly occur during cardiac catheterization remains a problem. Prophylaxis is generally attempted by administration of either quinidine or procaine amide. The views of various authors are widely divergent, some (Scherf, 1953; Heymans, 1951) holding that the attempt is worth while, others (Bing, 1952; Adelman et al., 1952) stating that the administration of these drugs is positively dangerous. It is quite certain that the drugs will not prevent the development of arrhythmias during catheterization. Whether they diminish their incidence is almost impossible to establish. Most anaesthetists will discuss the problem with the physician concerned and act accordingly.

DISCUSSION

The work of Courmand and Ranges (1941) established cardiac catheterization as a practical clinical investigation and for many years basal narcosis with bromethol was the accepted method of sedating young and apprehensive patients. This was condemned on three grounds: firstly, the technique required constant skilled supervision over a lengthy period; secondly, the results were variable because of the erratic absorption from the large bowel; and lastly, respiratory and circulatory depression were caused.

The first objection is valid but it should be possible to provide adequate supervision by anaesthetists and nursing staff in units undertaking such investigations. The second objection can be largely met by ensuring that staff skilled in the technique employ it regularly. Respiratory and circulatory depression must be considered more fully against the background of the changes which are known to accompany normal sleep. It was noted previously that natural sleep is associated with a fall in systemic blood pressure, pulse rate and oxygen consumption. A slight fall in arterial oxygen saturation occurs and the arterial Pco₂ rises, again slightly. It can scarcely be expected that sleep induced by drugs will produce any lesser changes in these parameters which are mainly reflections of the diminished requirements and activity of the subject. It is important when considering respiratory depression to measure blood gas changes rather than tidal or minute volumes as these latter will be reduced during sleep in accordance with the reduced metabolic demands. Provided that the blood gas analysis is essentially normal, quiet breathing is an advantage during cardiac catheterization. Recent work (Norris, 1961) has shown that in 90 per cent of patients examined under bromethol the systolic blood pressure fell less than 25 mm Hg and the arterial oxygen saturation was within 2 per cent of resting values. While greater changes were found in the remaining 10 per cent, these were largely associated with lesions where the cardiac output was restricted. Even greater changes were found in the same proportion of similar patients examined in the conscious state but sedated with a variety of other drugs.

The intravenous use of a steroid appears to have much to offer where venepuncture can be easily carried out, but the recent work of Robertson and Williams (1961) suggests that a new steroid will be required if full advantage is to be taken of this method.
On theoretical grounds the use of the "lytic cocktail" appears unlikely to produce a steady state. Any method which does not render the patient unconscious will have a certain number of failures and the intravenous use of the drugs in the cocktail can certainly produce some dramatic respiratory and circulatory changes. Even omitting chlorpromazine from the cocktail we have found severe hypotension and tachycardia to occur at least as frequently as with bromethol and the sedation to fall short of that desired. It may be as Adams and Parkhouse (1960) suggest, that British children are less sophisticated than their transatlantic contemporaries!

The previous methods have one problem in common, namely the calculation of the dose of drug to be given to produce the desired effect. Two methods are available to the anaesthetist: he can use the dose calculated on the basis of body weight which will invariably produce adequate sedation and expect to produce deeper sleep in a few instances; alternatively, as recommended by Smith et al. (1958), he may reduce the dose initially and supplement as required.

Superficially the latter method appears the more desirable but many of the patients who are gravely ill have been receiving heavy doses of sedatives—a colleague (Levy, 1961) mentions a child of 19 lb. who had been receiving morphine sulphate 1/12 grain (5 mg) s.o.s. Also, Lucas (1958) has pointed out that anoxic children are often resistant to sedative drugs. In these patients reduced doses of drugs, instead of inducing sleep, produce a restless unco-operative child. Struggling and consequent administration of supplementary intravenous agents can be extremely dangerous.

Admittedly overdosage is also hazardous but Fieldman et al. (1955) point out that using bromethol in a dose of 120 mg/kg instead of 100 mg/kg, they found that the main difference was in the length of sleep which followed. The patients required much less supplementation and produced more reliable data. This has been my own experience, and in a small number of patients given alternative doses on different occasions the fall in blood pressure was almost identical. These remarks apply only to reasonable pharmacopeal doses.

Inhalational anaesthesia appears to offer a solution to many of the problems associated with the use of non-volatile agents. However, it presents problems of its own, and the inability to use gasometric analysis, and the risks of coughing or straining with spontaneous respiration, or interference although slight with intracardiac pressures with controlled respiration, have to be faced.

CONCLUSIONS

The anaesthetist selecting a technique for sedating patients undergoing cardiac catheterization must first familiarize himself with the problems associated with this investigation and the type of patient on whom it is performed. He should then decide which method is likely on theoretical grounds to provide a steady resting state safely. If he is prepared to devote adequate time to the procedure and is supported by an efficient nursing staff he will find that rectal narcosis has still much to offer, particularly in younger children. Intravenous steroids are a useful alternative where venepuncture can be achieved without upsetting the child.

Where anaesthetic cover or adequate nursing supervision is restricted it may be wiser to aim for safer though less satisfactory conditions with, for example, small doses of a "lytic cocktail" than to risk basal narcosis.

At present it is felt that inhalational methods will appeal only to a limited number of cardiac diagnostic teams. Whatever method is employed the anaesthetist should try to monitor such physiological variables as he can in order to determine whether he is producing a steady state and what relationship it bears to the patient's resting state. Only in this way can the various techniques be finally evaluated.

In patients undergoing cardiac catheterization the anaesthetic technique must be impeccable; anoxia, for example, resulting from even a minor airway obstruction may be disastrous. At all times the anaesthetist must be prepared to deal with sudden respiratory or circulatory failure.

SUMMARY

The anaesthetic problems of cardiac catheterization are examined. The factors involved in the production of a steady resting state during the procedure are considered. The available methods of sedating patients are described and their
CARDIAC CATHETERIZATION AND THE ANAESTHETIST

limitations and applications, with some of the difficulties encountered, are discussed.

REFERENCES


