ANAESTHESIA FOR CARDIAC CATHETERIZATION IN CHILDREN

BY

AILEEN K. ADAMS AND JAMES PARKHOUSE

From the Nuffield Department of Anaesthetics, Oxford, England

CARDIAC surgery owes much of its present success to the fact that the anatomy and functional consequences of the abnormality can be demonstrated pre-operatively in a high proportion of cases. To this end, however, clinical examination of the patient must be supplemented by special investigations such as cardiac catheterization and angiography. These investigations are prolonged and unpleasant for the patient and, since they must often be carried out on children, sedation or anaesthesia is required. Anaesthesia for angiography presents no special difficulty but the preparation of children for cardiac catheterization has given rise to much speculation and dispute. The problem is generally agreed: the patient must be at rest for a prolonged period; there must be no significant disturbance of haemodynamics and no interference with the analysis of blood gases. These conditions must be provided in the complete darkness of an X-ray room, in patients who may be very poor risks. In this paper a brief historical review will be presented of the attempts that have been made to meet these requirements. Following this a description will be given of a small series of cases anaesthetized by a technique not previously described for cardiac catheterization.

HISTORY

The whole literature concerning anaesthetic methods for cardiac catheterization in children is coloured by the general assumption that any form of inhalation anaesthesia is unacceptable. Nitrous oxide and ether are known to interfere with blood gas analysis by the Van Slyke method but, quite apart from this difficulty, any anaesthetic technique involving the administration of more or less than the atmospheric concentration of oxygen will result in alterations of blood oxygen saturation. For these reasons, inhalation anaesthesia came to be ruled out and numerous alternative expedients were devised, some of which are still in common use.

Most of the earlier papers described methods involving heavy sedation, usually by the rectal route. Holling and Zak (1950), having found that both trichloroethylene and paraldehyde interfere with blood gas analysis, used avertin supplemented with thiopentone. They recognized that this technique probably altered the physiological state of the patient, but they rightly felt that it did so less than crying and struggling. J. A. Smith (1950) suggested rectal thiopentone supplemented with the same agent intravenously. Light, Livingstone and Adams (1950) found rectal avertin satisfactory as the sole agent but reported only 16 cases. Lee (1950) suggested premedication with atropine and pentobarbitone, followed by intravenous thiopentone, local infiltration, and subsequent injection of thiopentone through the cardiac catheter. Inglis (1954) found that if rectal thiopentone was followed by pethidine instead of intravenous thiopentone, narcosis was less prolonged. Fieldman et al. (1950) also noted slow recovery, and remarked on the 4–5 per cent fall in arterial oxygen saturation which resulted from supplementary injections of thiopentone.

Kepes, Livingston and Escher (1955) reviewed the disadvantages of heavy sedation and observed that even small doses of drugs given by rectum occasionally disturb circulatory compensation: they illustrated this with a case report. Their desire to provide a steady physiological state led them to prefer general anaesthesia with nitrous oxide and oxygen, although they admitted that this may cause some alteration of blood oxygen saturation. Despite their misgivings about the circulatory effects of rectal sedation, the authors seemed happy to supplement their anaesthesia with intravenous thiopentone when necessary. The problems of the darkened X-ray room, the explosion
danger and the hazards of radiation were referred to. The paper is also one of the few which mention the importance of measuring and replacing lost blood.

An interesting technique was described by Keown, Fisher, Downing and Hitchcock (1957) using avertin, followed by intramuscular thiopentone with hyaluronidase. Unfortunately few details were supplied although the series comprised 1,018 cases. Respiratory depression was the most significant complication.

In recent years the use of “tranquillizing agents” has become widespread and it was inevitable that their merits should be exploited in the management of children undergoing cardiac catheterization. The usual combination has been pethidine, chlorpromazine and promethazine, and varying degrees of success have been claimed. Mitchell and Minor (1958) found the mixture safe, easy to use and effective. They believed that it reduced postoperative complications and minimized the need for nursing care. In a total of 89 patients, they had 3 instances of hypotension and 6 of tachycardia. C. Smith, Rowe and Vlad (1958), using a similar combination of drugs, admitted one death in 670 cases. Many of the children required supplementary sedation and 2.7 per cent still remained restless and were regarded as failures. Lundy (1958, 1959) uses rectal thiopentone followed by methorphinan and levallorphan, phenergan and alphaprodine (NNR), and local infiltration for venostomy. Finally, bemegride and amiphenizole are given, with oxygen and vasopressors if necessary. This technique, when last reported, had been used in 133 cases and was claimed to be satisfactory, although it was admitted that some children are difficult to manage. Three cases of hypotensive death had occurred. The detailed instructions to be followed, and the multiplicity of drugs, make the method time-consuming and exacting.

Keats, Telford, Kurosu and Latson (1958) expressed dissatisfaction with all the above techniques, pointing out that the data obtained are difficult to interpret if the level of anaesthesia and degree of oxygenation are uneven. They found that a steady state could be obtained with trichloroethylene in air following heavy sedation and at the time of their publication they used this method in 225 cases. The importance of a clear airway was stressed, all patients under 2 years of age, and many others, being intubated. They found that the method did not appreciably interfere with blood gas analysis, even by manometric methods. It was admitted that induction was slow and that there was a tendency to tachypnoea, tachycardia and arrhythmia; they felt, however, that if a more satisfactory non-flammable agent were available, the method would approach the ideal. Their paper is important because it describes a return to the use of general inhalation anaesthesia for cardiac catheterization in children. It is the first published account of the administration of a volatile agent in air for this procedure.

PERSONAL EXPERIENCES

In the Nuffield Department of Surgery, the first children presenting for cardiac catheterization were managed by methods derived from the literature, but these gave only moderate satisfaction. The first 30 cases were premedicated with pethidine and phenothiazine derivatives, administered on a weight basis. The mixture used contained pethidine, promethazine and chlorpromazine in the proportions of 4:1:1 and this mixture was administered, intramuscularly, on the basis of 25 mg of pethidine per 20 lb. body weight. These doses were reduced by one-third for cyanosed patients. This premedication was supplemented as required, either with small intravenous or intramuscular doses of the same mixture, or with intravenous thiopentone. The results were unpredictable and it was not possible to achieve the high degree of success claimed by the Canadian workers who described the use of the mixture (Smith, Rowe and Vlad, 1958). It may be that British children are less sophisticated than their transatlantic contemporaries and more easily frightened by the complex appurtenances of up-to-date hospital investigation. Intravenous use of the mixture was soon abandoned because of the relatively high incidence of tachycardia, which was attributable to the drugs in at least 7 of the 30 cases. Intravenous injections also produced transient falls in arterial pressure and respiratory minute volume, with consequent disturbance of haemodynamics and oxygen saturation.
Case 1. Intravenous pethidine and promethazine gave rise to auricular tachycardia at a rate of over 300 per minute for 5 minutes.

Case 2. Intravenous promethazine and chlorpromazine caused a rise in heart rate from 125 to 160 per minute. The child developed congestive cardiac failure in the postoperative period.

Case 3. In this case intravenous injection of the same drugs caused an immediate rise in pulse rate from 88 to 140 per minute. This tachycardia persisted for 20 minutes.

It was also noted that when repeated doses of these drugs were required, severe postoperative circulatory and respiratory depression sometimes occurred.

Case 4. This 7-year-old child required large doses of drugs to maintain quiescence during catheterization, at the end of which she was pale and hypotensive, with depressed respiration. Nalorphine and respiratory stimulants were required before the child could be returned to the ward. Angiocardiography which had been planned, was postponed on account of her unsatisfactory general condition.

As a result of these experiences a change was made to the use of rectal thiopentone. This was found to produce much more reliable results. However, it rarely lasted long enough and intravenous supplements had the same disadvantages as with the previous medication. In addition, there was a tendency for the anaesthesia to wear off suddenly and for the child to become restless without warning. This sometimes interfered with the catheterization findings.

Case 5. A pulmonary artery oxygen saturation of 72 per cent had been recorded, and a few minutes later the child suddenly woke up and struggled. Fifty milligrams of thiopentone were administered intravenously, and a second sample from the same position then showed and oxygen saturation of 62 per cent. In view of this discrepancy, a third sample from the same site was taken some 10 minutes later and this showed 70 per cent saturation. Such fluctuations could clearly be misleading in the diagnosis of an intracardiac shunt.

PRESENT TECHNIQUE

In addition to the disadvantages already discussed, neither of the above methods could be regarded as satisfactory from the anaesthetist's point of view, since in a dark room, surrounded by apparatus, contact with the patient was much too tenuous. We decided, therefore, to approach the problem afresh.

After consulting our laboratory colleagues, we concluded that none of the conventional objections to inhalation anaesthesia was unsurmountable. We felt that the use of light general anaesthesia, with endotracheal intubation, would provide much greater safety for the patient. We also felt, with other workers, that diagnostic oxygen saturation determinations would be more reliable and consistent during an evenly maintained anaesthesia than during the alternate restlessness and depression which result from other methods. The principal objection was, of course, to the use of oxygen-rich mixtures and anaesthetic gases, but we felt that we could overcome this difficulty by using low concentrations of a volatile agent vaporized in room air.

The agent we selected for anaesthesia was the azeotropic halothane-diethyl ether mixture. Our previous experience with this mixture had convinced us of its safety when used in low concentrations, even for prolonged periods of time and in bad risk patients. The impressively low incidence of cardiac arrhythmias under circumstances when these are particularly liable to arise has previously been noted (Adams, Lambrechts and Parkhouse, 1959). The azeotrope is one agent which fulfills the criteria of Keats, Telford, Kurosu, and Latson (1958), being potent and rapidly eliminated. In clinically used concentrations it is also nonexplosive. We make no claim that it is the only volatile agent suitable for the technique we describe, nor that it possesses any innate superiority; it is merely the agent that we chose to employ.

Our next problem was whether or not to use controlled ventilation. The advantages of controlled ventilation in paediatric anaesthesia are well known (Rees, 1958), but we anticipated some opposition to its use during catheterization on the grounds of possible interference with differential intravascular and intracardiac pressure recordings. However, after some early experiences in which spontaneous respiration was allowed to persist, we came to feel that the advantage of having absolute control over the tidal and minute volume of the patient would more than outweigh any theoretical disadvantage. Furthermore, with complete muscular paralysis a sick child can be spared the effort of breathing and immobility can be ensured at the lightest possible level of anaes-
Arterial oxygen saturation is not significantly altered during controlled ventilation with air. Hyperventilation will, of course, alter carbon dioxide tension but this is rarely measured during catheterization and in any case, if the patient's minute volume is regulated according to the Radform (1955) nomogram or Nunn's suggested modification (Nunn, 1959), gross departures from normal carbon dioxide tension should not occur.

Intermittent positive pressure ventilation, when properly applied, produces only slight changes in the haemodynamics of the normal subject (Cournand, Motley and Werko, 1947). Figure 2 is a tracing obtained during catheterization of a child without significant cardiac abnormality; it shows simultaneous femoral arterial pressure, tracheal pressure, and right auricular pressure during intermittent positive pressure ventilation. Even in patients with cardiac disease, including those with intracardiac shunts, it is unlikely that gentle passive ventilation of the lungs will cause any significant disturbance, and it is worthy of note, in this connection, that for many years intermittent positive pressure ventilation has been an accepted part of anaesthetic technique during angiocardiography and also during thoracotomy in such patients. It is well known that the child with an intracardiac shunt may become deeply cyanosed during crying or straining but in these circumstances the intrathoracic positive pressure is much higher and much more sustained than during controlled ventilation. The case report below (Case 7) is an example of a child with a ventricular septal defect who was subject to frequent cyanotic attacks during crying. This child received intermittent positive pressure ventilation during catheterization, and again during thoracotomy for the repair of his defect, without any evidence of reversal of his shunt. It has been reported from some centres (Hodgson, 1959) that, in patients with bi-directional shunts and approximately equal left- and right-sided pressures, the institution of controlled ventilation may be sufficient to cause cyanosis and serious deterioration in general condition. This possibility should certainly be borne in mind, although workers in other centres, with an equally large experience of congenital heart disease, have not reported the complication.

METHOD

A standard anaesthetic technique is now employed for all cardiac investigations in children. Pre-medication is with phenergan 0.5 mg/lb., and pethidine 1 mg/lb., these doses being reduced for patients in very poor physical condition. On arrival in the angiocardiography room, anaesthesia is induced either with the azeotrope or with a small intravenous injection of thiopentone, according to the age and preference of the child. Full muscular relaxation is then obtained either with intravenous gallamine or with intermittent suxamethonium injections. The patient is intubated and his ventilation is controlled throughout the procedure with air containing 0.4–0.6 per cent azeotrope.* Very young infants are intubated without anaesthesia and in the rare cases in which veins are not accessible intramuscular suxamethonium is used; for smaller children and infants a non-return system is provided by intermittent digital occlusion of a suitably drilled Rowbotham connector. A specially modified and calibrated E.M.O. inhaler is used to deliver known concentrations of the azeotrope and the patient's lungs are inflated by means of a child's inflating bellows mounted on the standard O.I.J. base (Parkhouse, 1960).

With this technique the tidal volume and minute volume can be measured at any stage by attaching a Wright anemometer to the F.M.O. inlet, due allowance being made for the distensibility of the corrugated tubing. Figure 1 illustrates the complete arrangement of anemometer, inhaler, children's bellows, Rowbotham connector with hole drilled for intermittent positive pressure ventilation and Oxford endotracheal tube.

During maintenance of anaesthesia a change to ventilation with 100 per cent oxygen can be accomplished at any time for diagnostic or other purposes by leading oxygen from a rotameter to the E.M. inlet port. Other gases can be added in the same way, so that it is possible to demonstrate shunts either by the nitrous oxide method or by the Valsalva technique. If desired, the

* These are total concentrations, i.e. 0.6 per cent azeotrope indicates 0.4 per cent halothane with 0.2 per cent ether.
FIG. 1
Anaesthetic apparatus used during cardiac catheterization in children. A Wright anemometer is shown at the E.M.O. inlet and the Rowbotham endotracheal connector is drilled to permit intermittent digital occlusion.

FIG. 2
Simultaneous recording of e.g. femoral arterial pressure, tracheal pressure and right auricular pressure during intermittent positive pressure ventilation. Note the absence of significant haemodynamic effects of controlled ventilation. The calibrations (from left to right) are for the tracheal pressure, right auricular pressure, and femoral arterial pressure.
Fick principle for the measurement of cardiac output can be applied by collecting expired air from the nonreturn valve. For this purpose we have found the Ruben valve most convenient. Rapid blood oxygen determinations are made during catheterization by means of a Densitometer and accurate confirmation is subsequently obtained with a spectrophotometer. The minimal concentrations of halothane and ether used in this technique have not caused any significant interference with the results obtained by these methods.

Angiocardiography can be performed at any stage, without delay, the anaesthetist having full control of the patient's respiratory movements during this procedure. Finally, and most important from the point of view of the patient, the anaesthetist is in a position to deal promptly with any complication that may occur.

RESULTS

Azeotrope-air anaesthesia has been administered on 30 occasions for cardiac investigations in children. The age range of the patients has been from 4 weeks to 16 years, and the investigations carried out have included venous angiography, right and left heart catheterization, and angiocardiography. Spontaneous respiration was present throughout the procedure on 2 occasions and in 1 case controlled ventilation was instituted during catheterization in order to obtain more satisfactory conditions. In the remaining 27 cases, respiration has been controlled throughout. The muscle relaxant employed has been intramuscular suxamethonium in 5 cases, intermittent intravenous suxamethonium in 7 cases and gallamine in 17 cases. We have found gallamine much more satisfactory than intermittent suxamethonium and we now use it routinely. Bradycardia was noted in 2 cases early in the series, during spontaneous respiration with relatively high concentrations of the azeotrope. Using controlled ventilation with minimal concentrations of the azeotrope, bradycardia has not been observed and this may, in part, be due to our use of gallamine. There has been 1 death in this series, which was due to cardiac tamponade.

Twelve of the 30 investigations have been carried out on cyanosed children and in these cases it has been possible to demonstrate the presence of intracardiac shunts and to measure any rise in arterial oxygen saturation which may occur when such a patient is ventilated with pure oxygen.

Case 6. This 11-year-old boy was cyanosed when right heart catheterization and angiocardiography were performed. During controlled ventilation with air at 6 l./min, his femoral arterial oxygen saturation was 85 per cent. When ventilated at the same minute volume with 100 per cent oxygen, this arterial saturation rose to 95 per cent. Two weeks later a left heart catheterization was performed on the same child. His condition had deteriorated; his cyanosis was much more marked, and the lungs were noticeably more difficult to inflate. Arterial oxygen saturation in the aorta was 67 per cent during ventilation with air, and 83 per cent during ventilation with oxygen.

As would be expected, ventilation with pure oxygen has been found to make little difference to the arterial oxygen saturation of non-cyanosed patients. Two further cases are summarized below to illustrate the potentialities of the technique.

Case 7. T.L., aged 14 months. Catheterization under azeotrope-air and gallamine with controlled ventilation.

<table>
<thead>
<tr>
<th>Findings</th>
<th>Pressure</th>
<th>Per cent oxygen saturation</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.V.C.</td>
<td></td>
<td>58*</td>
</tr>
<tr>
<td>S.V.C.</td>
<td></td>
<td>61*</td>
</tr>
<tr>
<td>Mid rt. atrium.</td>
<td></td>
<td>68</td>
</tr>
<tr>
<td>Low rt. atrium.</td>
<td></td>
<td>78</td>
</tr>
<tr>
<td>High rt. ventricle</td>
<td></td>
<td>83</td>
</tr>
<tr>
<td>Mid rt. ventricle</td>
<td>60/0</td>
<td>84</td>
</tr>
<tr>
<td>Main pulm. art.</td>
<td>60/30</td>
<td>83</td>
</tr>
<tr>
<td>Lt. pulm art.</td>
<td></td>
<td>82</td>
</tr>
<tr>
<td>Fem. art. (patient breathing air)</td>
<td></td>
<td>91</td>
</tr>
<tr>
<td>Fem. art. (patient breathing oxygen)</td>
<td></td>
<td>94</td>
</tr>
</tbody>
</table>

Cardiac output determination by Fick principle, using Ruben valve (controlled ventilation).

Minute volume = 4.67 l./min
Oxygen uptake = 72.8 ml/min
R.Q. = 0.930
Systemic flow = 1.52 l./min
Pulmonary resistance = 13.4 units

* It was Fieldman et al. (1955) of the Mayo Clinic who first observed that during catheterization under anaesthesia the superior vena caval oxygen saturation is often higher than that of the inferior vena cava. This is a reversal of the normal finding during catheterization of the unanaesthetized subject and Fieldman et al. suggested that it may be due to reduced oxygen consumption by the brain under anaesthesia.
ANAESTHESIA FOR CARDIAC CATHETERIZATION IN CHILDREN

The large and consistent step-up in oxygen saturation in the region of the tricuspid valve, together with the low systemic blood flow, indicated a diagnosis of ventricular septal defect with considerable left-to-right shunt. This diagnosis was subsequently confirmed at operation and the defect was closed with the aid of extracorporeal circulation.

Case 8. Six-year-old male child with basal systolic murmur and history of severe bronchitis. Catheterization under azeotrope-air and gallamine, with controlled ventilation.

<table>
<thead>
<tr>
<th>Findings</th>
<th>Per cent oxygen saturation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main pulm. art.</td>
<td>71.8</td>
</tr>
<tr>
<td>Lt. pulm. art.</td>
<td>71.0</td>
</tr>
<tr>
<td>Pulm &quot;wedge&quot;</td>
<td>9 (Mean)</td>
</tr>
<tr>
<td>Rt. ventricle</td>
<td>25/0</td>
</tr>
<tr>
<td>Lt. atrium</td>
<td>+1/1</td>
</tr>
<tr>
<td>Aorta</td>
<td>100/70</td>
</tr>
<tr>
<td>Brachial art.</td>
<td>96.2</td>
</tr>
</tbody>
</table>

Cardiac output determination by Fick principle, using Ruben valve (controlled ventilation).

Minute volume = 4.87 l./min
Oxygen uptake = 154 ml./min
R.Q. = 0.877
Cardiac output = 4.0 l./min

The normal oxygen saturations, normal pressures and normal cardiac output in this child indicated absence of any serious cardiac lesion. Central venous pressure and right atrial pressure were within the normal range, despite intermittent positive pressure ventilation.

SUMMARY AND CONCLUSIONS

General anaesthesia has for long been regarded as unsuitable for cardiac catheterization in children because arterial oxygen saturation is altered, and because nitrous oxide and ether interfere with Van Slyke determinations. However, if general anaesthesia is maintained by means of minimal quantities of an anaesthetic vapour added to room air, and if arterial oxygen determinations are made by means of a spectrophotometer or an oximetric method, these objections disappear. This paper describes a technique for the maintenance of light general anaesthesia with intubation and controlled ventilation. The minute volume can be adjusted to any required level and complete immobility of the patient can be ensured with minimal quantities of the anaesthetic agent. In a small series of cases this method of anaesthesia has proved superior to previously used alternatives.

ACKNOWLEDGMENTS

We are grateful to Professor P. R. Allison and Dr. Grant Lee for permission to publish details of cases anaesthetized in the Nuffield Department of Surgery, Oxford University.

REFERENCES