ANAESTHESIA FOR OPEN HEART SURGERY IN THE Calf

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SUMMARY
Fifty-four calves have been anaesthetized for the insertion of a pulmonary valve prosthesis by a technique using nitrous oxide, halothane and gallamine. Anaesthetic supplementation during cardiopulmonary bypass was achieved with methohexitone 1 mg/kg. Post-perfusion hypoxaemia and pulmonary complications were avoided by carefully controlled ventilation and postoperative oxygen supplementation.

The calf is a suitable animal for experimental open heart surgery. At 4–8 weeks of age the anatomical disposition and size of its heart and great vessels are similar to those of man, and it tolerates cardiopulmonary bypass well. Its tractability makes the calf a good subject for aftercare. However, it is said to present certain anaesthetic problems including sensitivity to barbiturates (Tavernor, 1960) and muscle relaxants (Wright and Hall, 1961). Postoperative pulmonary complications, atelectasis, alveolar rupture and intrapulmonary haemorrhage have also been reported (Larson, Moffitt and McGoon, 1963).

We have developed a technique for anaesthetizing calves for the replacement of the pulmonary valve by a new leaflet prosthesis. Anaesthesia was achieved using nitrous oxide, halothane and a muscle relaxant until perfusion was begun. Halothane was then withdrawn and anaesthesia supplemented with methohexitone during perfusion. A total of 54 calves have been anaesthetized and in only 4 has death been attributed to anaesthesia.

No premedication was given, but emphasis was placed on quiet and gentle handling. The animal was brought to the anaesthetic room and a blood sample drawn from a jugular vein for haemoglobin estimation and clotting tests. A face-mask was applied and after the initial apprehension had subsided a Wright respirometer was used to obtain an estimate of minute volume. The mask was then attached to a Magill circuit and 12 l./min of a 70% nitrous oxide and 30% oxygen mixture given. Only gentle restraint was required. The concentration of halothane was increased steadily and the calf fell quietly to the floor in 2–3 min. Anaesthesia was deepened with the animal in the lateral position and tracheal intubation was quickly accomplished without a laryngoscope. The tongue was drawn forward, the larynx held with the right hand and a 12- or 14-mm curled tube inserted. The gas mixture was adjusted to 50:50 N₂O:O₂ and the halothane concentration reduced to 0.5–1.5%. A Fluotec Mark III vaporizer was used for the delivery of halothane.

A foal-size stomach tube (10 mm o.d.) was introduced to maintain gastric decompression and a thermistor probe placed in the thoracic oesophagus to monitor body temperature. An intravenous infusion of sodium bicarbonate was begun at approximately 1 m.equiv/min.

After suitable preparation the calf was transferred to the operating table and placed in the right lateral recumbent position, with a 10° head-down tilt. Muscular relaxation was obtained with gallamine, 3 mg/kg initially followed by 1.5 mg/kg as required. The calf was ventilated using a Minivent ventilator and a non-rebreathing circuit. Initially the minute volume was set to the value obtaining in the conscious calf before induction and was subsequently adjusted to maintain a PaCO₂ of approximately 40 mm Hg. The airway pressure was...
measured. A pressure-limiting device set to blow off at pressures in excess of 30 cm H\textsubscript{2}O was incorporated between the ventilator and the endotracheal tube. The ventilator was set at approximately 20 breaths per minute.

A polythene catheter 2-mm o.d. was introduced into a femoral artery, and connected to a Bell and Howell transducer and a Devices MX2 amplifier system. The system was calibrated with a mercury manometer. A similar catheter was placed in the right atrium via the left jugular vein and connected to a low pressure transducer and amplifier as before. The signals were displayed on a calibrated oscilloscope (fig. 1). A catheter was also introduced into a femoral vein for infusions. Needle electrodes were applied to the limbs to record lead II e.c.g. which was also displayed on the oscilloscope.

A catheter with removable stilette was introduced into the urethra to record urine flow. This requirement dictated the choice of female calves; the penile urethra in the male undergoes a sigmoid flexure and defies catheterization.

Measurements of Pa\textsubscript{O\textsubscript{2}}, Pa\textsubscript{CO\textsubscript{2}}, pH and calculation of base excess were made at 30-min intervals using a Radiometer electrode system with digital display. Calibration with standard buffers and gas mixtures was repeated at 2-hourly intervals.

Intermittent sighing, by manual compression of the Minivent bag with the side arm closed, was used in the post bypass period, particularly when arterial oxygen tensions were low.

Blood was drawn at hourly intervals for estimation of serum sodium, potassium and calcium concentrations by flame photometry (Eppendorf) and blood glucose and blood urea concentrations using an autoanalyser (Technicon).

Total cardiopulmonary, normothermic, high flow bypass was accomplished using a disposable Rygg bubble oxygenator and a Melrose pump. Venous blood was obtained via a 10-mm o.d. cannula in each vena cava and returned by a 9 mm cannula to the left carotid artery. Cardiotomy suction was returned to the oxygenator through an antifoaming bag. Perfusion flow rates were 100 ml kg\textsuperscript{-1} min
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except in the two largest animals (63 and 70 kg) in which rates of 70–80 ml kg\(^{-1}\) were achieved. The extracorporeal circuit was primed with 1 l. of Ringer lactate (Hartmann's) solution, 500 ml of 6% dextran in 5% dextrose solution (Macrodex), 100 ml of 25% mannitol and 5 m.equiv of calcium as the borogluconate. The priming volume did not exceed 35 ml kg\(^{-1}\). Oxygen 7 l. min\(^{-1}\) and 5% CO\(_2\) in oxygen 5 l. min\(^{-1}\) were supplied to the oxygenator.

The animals were anticoagulated with heparin, 3 mg/kg followed by 2 mg/kg every 30 min. Bypass time varied from 50 to 100 min with a mean of 60 min. Oesophageal temperature was maintained at 37–38°C by a heat exchanger in the bypass circuit.

During bypass the lungs were ventilated with a 50:50 mixture of nitrous oxide:oxygen at half the previous minute volume. Respiratory rate was maintained at approximately 20 b.p.m.

Halothane was discontinued at the start of bypass and anaesthetic supplementation achieved by adding methohexixone 1 mg/kg, accompanied by gallamine 1.5 mg/kg if necessary, to the perfusate. Additions were made only when spontaneous diaphragmatic or skeletal movements occurred. All visible atelectasis was carefully removed by gentle manual inflation of the lungs before chest closure. Only very occasionally was any further anaesthetic supplementation required after termination of bypass, halothane being used if necessary. Heparinization was reversed by protamine sulphate 1.5 mg per mg of heparin.

Reversal of the effects of gallamine was not required; spontaneous respiratory movements usually began during the late stages of wound closure when a Cyclator ventilator with patient trigger was substituted for the Minivent. The Cyclator was set to an inflation pressure of 25 cm of water and entrained air, thus providing approximately 30% oxygen.

On completion of surgery the calf was supported in a specially designed sling bed in the upright position (fig. 1) and removed to a recovery room. Assisted ventilation was discontinued as soon as spontaneous respiration was adequate, usually about 1 hour after completion of surgery. Minute volume at this stage usually exceeded pre-anaesthetic values by 10–20%. The tracheal tube was removed when pharyngeal reflexes had returned and supplemental oxygen, 1–2 l./min, was given via a fine rubber nasal catheter for the next 6–12 hours.

Analgesia was obtained with small doses of pentazocine (15–30 mg i.v.) as indicated. Ampicillin 500 mg was given twice daily for 5 days.

Fluid intake was supplemented by a 5% dextrose infusion and the calves usually drank milk by the 6th to 8th postoperative hour. Transfusion of fresh blood was given as required until the haemoglobin concentration exceeded 10 g/100 ml, 0.5–1 l. usually being required.

Monitoring equipment was removed on the morning following operation and the animal was returned to her pen.

RESULTS

In this series 54 calves have been anaesthetized and four deaths attributable to anaesthesia have occurred. Two calves died as a result of postoperative hypoxia, a third from accidental overinflation and consequent rupture of the lungs and the fourth from a mechanical failure of the ventilator. Twenty-five animals survived the surgery and 8 are still alive up to 28 months after operation.

Mean arterial pressure was 130 mm Hg after induction of anaesthesia and decreased to 110 mm Hg on opening the chest. During bypass the pressure was maintained at 80–90 mm Hg and returned to previous levels when the circulating volume was adequate as judged by c.v.p. measurement (fig. 2).

Ventilation was adjusted to maintain a \(\text{PaO}_2\) close to 40 mm Hg. The 30 cm inflation pressure limit allowed adequate oxygenation (fig. 3) but prevented lung damage from overdistension.

Oxygen tensions greater than 250 mm Hg were avoided during bypass. Oxygenation was adequate with oxygen supplementation in the immediate postoperative period but the \(\text{PaO}_2\) decreased to 70–90 mm Hg on the 1st postoperative day.

A mild metabolic acidosis, the base deficit seldom exceeding 5 m.equiv/l., was treated with sodium bicarbonate before bypass but adequate base was available thereafter from the Ringer lactate pump prime.

Urine flow was deemed to be satisfactory if it exceeded 30 ml/hr (fig. 4). No significant change was observed in blood urea concentration. Profound haemoglobinuria followed perfusion using a blood prime in the first 5 animals but was not observed when a bloodless technique was used. The addition of 100 ml mannitol to the prime assisted urine flow provided pump output was adequate. The only striking serum electrolyte finding was a decrease in potassium concentration following perfusion (fig. 5).
Potassium, 5 m.equiv, was given at the conclusion of the procedure and then as indicated by serum electrolyte analysis or the appearance of spontaneous arrhythmias on the e.c.g. monitor. The mean (n=25) additional potassium requirement was 8.0 m.equiv (SE 1.3) with a range of 0–20 m.equiv.

Blood haemoglobin concentration before operation was 12.1 g/100 ml ± 0.52 (mean ± SE) and was reduced to 6.96 g/100 ml ± 0.49 at the end of cardiopulmonary bypass. The value obtained on the morning of the 1st postoperative day was 10.45 g/100 ml ± 0.75. The low value at the end of surgery was the result of blood loss and dilution since almost all the perfusate was returned to the animal at the end of perfusion.

**DISCUSSION**

Anaesthetic techniques for cardiac surgery in calves, based largely upon halothane, have been described by Short et al. (1968) and by Singh, Elliott and Melrose (1971). Short et al. list the problems of anaesthesia in the calf as fragile lungs, hypotension and bradycardia, inadequate muscular relaxation and prolonged recovery. Bradycardia and hypotension
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FIG. 4. Urine flow (hatched bars) and blood urea concentration. The time scale is the same as the previous figures. Mean values for 7 calves. Almost all the perfusate was returned to the animal at the end of bypass and the excess water was rapidly eliminated through the kidney.

Fig. 5. Mean blood glucose and serum potassium concentrations in the previous group of 10 calves. The decrease in K+ coincides with the uptake of glucose after cessation of perfusion.

were the most frequent complications described particularly in calves undergoing open heart procedures. This may have been associated with the amount of halothane required in the absence of nitrous oxide or muscle relaxants. Hypotension has not been encountered in our series and the three occasions when atropine was required to counter bradycardia were all associated with extensive manipulation of the heart during atrial cannulation.

In contrast to other workers we have used a muscle relaxant and found it both safe and effective. The calf is less sensitive to gallamine than the dog; even 3 mg/kg did not abolish all diaphragmatic movement. The duration of the block was 12-15 min following a single dose. Repeat doses were given at half the initial rate. Minimal tachycardia was observed after gallamine, the heart rate rarely increasing by more than 5 b.p.m. The use of the Minivent and a normal level of alveolar ventilation made the use of a relaxant highly desirable, particularly in the early part of the procedure. The function of the Minivent was easily upset by spontaneous respiratory effort.

An airway pressure of 30 cm H2O did not produce lung damage in our series and was an important factor in maintaining adequate oxygenation both before and immediately after cardiopulmonary bypass. Similar results have been obtained in calves undergoing open heart surgery by Robinson et al. (1971). Sighing, by gentle manual inflation of the lungs, was carried out frequently in the immediate post-perfusion period and occasionally thereafter. This procedure materially assisted oxygenation in those animals where low blood oxygen tensions were observed after bypass (table I), and suggests that sighing can improve the alveolar/arterial Po2 difference in this situation.

TABLE I. The effect of a “sigh” manoeuvre 3-4 times per min every 3 minutes for 15 min. Results in 3 calves 15, 20 and 100 min after termination of bypass. Interval between measurements 30 min. Inspired gases 50:50 O2:N2O, MV 10 l.

<table>
<thead>
<tr>
<th>Before sighing</th>
<th>After sighing</th>
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<tr>
<td>Pao2 (mm Hg)</td>
<td>Paco2 (mm Hg)</td>
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<tr>
<td>48.1</td>
<td>134.8</td>
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<tr>
<td>47.0</td>
<td>122.7</td>
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<td>41.0</td>
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The decrease in serum potassium concentration after bypass was probably associated with the cellular uptake of glucose which occurs at this time. During bypass insulin secretion is inhibited by catecholamine release (Allison, 1971).

The rumen presents special problems during anaesthesia. For example, regurgitation and gastric tympany (Collan, 1970) may occur. Induction of anaesthesia in the standing position followed rapidly by tracheal intubation and the passage of a gastric
tube have satisfactorily controlled the problem in this series. Prolonged fasting is not effective in emptying the rumen and can lead to a starvation acidosis.

Periods of anaesthesia from 4.5 to 6 hours were required for surgery of this nature. The technique did not differ greatly from those used for human cardiac surgery (Gilston, 1971) and the emphasis was on light anaesthesia, normoventilation and monitoring to ensure that appropriate action could be taken when required. The calf has not proved to be a difficult subject to anaesthetize satisfactorily using this technique.

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REFERENCES

BOOK REVIEW


The effect of a drug, including an anaesthetic agent, depends upon its concentration at the site of action. Therefore it is essential, for the proper control of anaesthesia, to understand how this concentration is related to the inspired concentration of any inhaled anaesthetic, or to the dose or drip rate of an intravenous agent, and how it is affected by the physiology of the patient.

There are three landmarks in the development of the theory of the uptake and distribution of anaesthetics. The first was Seymour S. Kety's classical review of 1951. The second was the New York conference on the subject in 1962, the proceedings of which are to be found in the volume "Uptake and Distribution of Anesthetic Agents" edited by Papper and Kitz. The third is this book by Eger which brings the account up to date.

At the New York conference different workers presented no less than four theoretical models of uptake and distribution. They all had a lung compartment and three or four tissue compartments and this basic configuration has stood the test of time: it has served to explain the vast majority of clinically-observable phenomena.

Eger's book is primarily a systematic account, in terms of this model, of the general pattern of uptake and distribution and then of how this pattern is modified by various changes in circumstances and physiology; by changes in the composition of the inspired mixture (the concentration and second-gas effects), by changes of ventilation and of cardiac output and its distribution, and by changes of the solubility of the anaesthetic in blood and tissues. In addition, the effects of pulmonary and peripheral shunting, of metabolism, and of diffusion, as well as the effect of the anaesthetic system, are all considered and explained as far as present knowledge permits.

But coverage is not confined to the uptake and distribution of inhaled anaesthetics. The book begins with an account of the actions of anaesthetics: there are clear expositions of the concepts of MAC and of transmission in the nervous system, and M. J. Halsey contributes an excellent review of possible mechanisms of general anaesthesia. The book concludes with chapters on the actions and on the uptake and distribution of other agents: of barbiturates, by L. J. Saidman, of muscle relaxants by R. A. Epstein and Eger himself, and of local anaesthetics by R. H. Levy and M. Rowland.

The book can be used in several ways. The basic approach is mainly theoretical but the deductions are supported by comprehensive references to previous theoretical and experimental studies; the book will therefore be welcomed as a fully documented review of the last 12 years' work in this field. At the same time the explanations are so clear that the book can make entirely acceptable armchair reading. Finally, for the reader who wants to make sure he has understood what he has read, each chapter concludes with a summary and a set of questions.

This book should undoubtedly be in every anaesthetic library and very many anaesthetists will wish to possess their own copy.

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