ANAESTHESIA FOR THE SURGICAL CORRECTION OF CONGENITAL HEART DISEASE

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DURING the past ten years operative procedures for the amelioration and cure of congenital heart defects have become increasingly common and at the same time more complex. This situation has stimulated, and to a large extent been made possible by, an increasing interest on the part of anaesthetists in cardiovascular physiology and pathology. While many anaesthetic techniques using a variety of agents have been devised, only those methods in current use at the Hospital for Sick Children, Toronto, will be presented, together with a few observations regarding the more frequent complications and their treatment. An experience of over 450 cases during the past six years provides the background for this report (1).

Any anaesthetic technique for cardiac cases must meet certain requirements. During operation, the administration of adequate oxygen and particularly the efficient elimination of carbon dioxide are of prime importance. The operative field must be maintained as nearly motionless as possible during the delicate surgical manoeuvres. Reflex activity, both respiratory ("bucking") and cardiovascular (arrhythmias, bradycardia, and arrest), must be depressed. Adequate means for the treatment of complications should be at hand. These include replacement solutions, various drugs, and an electrical defibrillator.

In addition, it is essential that the anaesthetist be familiar with the cardiac pathology of each patient, the type and degree of the deranged physiology and the contemplated operative procedure. The differential diagnosis, and the possibility of encountering, at operation, previously undetected anomalies necessitating changes in procedure, should be thoroughly understood before commencing the case. All cases posted for operation at this hospital are presented at weekly rounds and discussed by the cardiologist, surgeon, and anaesthetist before the decision to operate is made.

PREOPERATIVE MEDICATION

Patients in failure receive one of the digitalis preparations for several days before operation.

Children rarely require a sedative on the evening before operation, but in the older child a moderate dose of seconal is occasionally employed.

Until recently a combination of a belladonna alkaloid with a narcotic administered intramuscularly 45 minutes before operation was used routinely. Atropine was employed in most cases. While scopolamine has the advantage of inducing a degree of amnesia, it has the disadvantage of increasing vagal tone as a result of its central action. This has resulted in an increase in the frequency of reflex cardiac arrhythmias which have required the intravenous administra-

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tion of atropine for their abolition. Both morphine sulphate, 1 mg./10 lb. and demerol, 8 mg./10 lb. have proven satisfactory. The latter has the advantage of being vagolytic in contrast with morphine which increases vagal tone.

Recently, premedication with a combination of chlorpromazine, promethazine HCl, and demerol has given satisfactory results. Three techniques have been tried. Initially, the intramuscular injection of Laborit and Huguenard's (2) mixture number one (M1) was found to produce marked variations in the degree of sedation (Table I). The intravenous administration of this mixture

TABLE I
MIXTURE NUMBER ONE (M1)

	Chlorpromazine	Promethazine HCl	Demerol
Volumes used	- - - - - equal	- - - - -	- - - - -
mg/cc of commercially available solution	25	25	50
mg/cc of M1	8.3	8.3	16.7
Dosage used	- - - - -	1 cc/25 lb	- - - - -

during the hour before operation produced a disturbing degree of tachycardia in a second group of cases. The present routine provides uniform sedation without undesirable side effects. Chlorpromazine and promethazine HCl are both given in doses of 1 mg./3 lb. either orally or intramuscularly (depending on the size of the child) at 6 P.M. on the evening before operation and again at midnight. The dose is repeated at 6 A.M. the morning of operation and is followed by an intramuscular injection of atropine 45 minutes before operation (Table II). A variable degree of sedation is present when the child reaches the

TABLE II
DOSAGE OF ATROPINE SULPHATE

10 lb and under	gr 1/400
10-20 lb	gr 1/300
20-40 lb	gr 1/200
40-80 lb	gr 1/150
80 lb and over	gr. 1/100

operating floor, and this is augmented by giving small fractional doses of M1 intravenously until the point is reached at which the patient can still be roused but immediately falls asleep if not disturbed.

INDUCTION AND MAINTENANCE

Anaesthesia is induced in all cases with sodium pentothal given intravenously. The injection is made quite slowly until about two "sleep doses" of the drug have been administered, and oxygen is given immediately following loss of

consciousness. While a slight fall in blood pressure usually occurs at this time, frank cardiovascular collapse following sodium pentothal has not occurred. Immediately following the barbiturate, an injection of decamethonium, 1 mg./50 lb., plus succinylcholine, 1 mg./3 lb., is given and hyperventilation with oxygen carried on until apnoea supervenes. The trachea and larynx of the older children are then sprayed with cyclaine 5 per cent. Intubation is performed using the largest uncuffed portex tube that can be passed without trauma to the larynx. An endo-oesophageal stethoscope is introduced and placed for optimum auscultation of heart sounds (3). Continuous auscultation of cardiac and respiratory sounds is carried on throughout the operation.

Anaesthesia is maintained by a combination of non-explosive agents. Nitrous oxide and oxygen are administered throughout, the proportions depending on the degree of cyanosis and general debility of the patient. Small amounts of sodium pentothal are occasionally added, but the total dose rarely exceeds 4 mg./lb. When the expected duration of anaesthesia is greater than 1½ hours an additional dose of decamethonium is administered about one hour following induction. The only other agent used is succinylcholine in small doses just sufficient to maintain apnoea. The indication for additional succinylcholine is either the appearance of slight regular contractions of the diaphragm or increased resistance to manual inflation of the chest in spite of a free airway. Hyperventilation by controlled respiration is maintained at a point just short of interfering with the surgical procedure, and is interrupted each time a precise manoeuvre such as incising a vessel, placing a suture, or adjusting a clamp is made.

The present system appears to offer some advantages. Premedication with M1 reduces the amount of anaesthetic agent required, provides a basis for minimal anaesthesia and rapid return of consciousness, and results in a quiet, co-operative patient free from vomiting and requiring little narcotic for the control of postoperative pain. The non-explosive technique permits the use of various electrical apparatuses (electrocardiograph, oximeter, and hypothermia pump) near the head of the table and gas machine. The maintenance of apnoea with succinylcholine provides easy inflation of the contralateral lung with moderate degrees of positive pressure, a completely motionless field during the more exacting parts of the operation, and at the same time a rapid recovery of adequate respiratory exchange before the patient leaves the table.

COMPLICATIONS AND TREATMENT

The commonest serious complication during cardiac surgery is a more or less rapid failure in the force of cardiac contraction. This is shown by a dilating weakly beating heart, diminished peripheral pulse, fall in blood pressure, and muffling of the heart sounds. Pupillary dilatation indicates the presence of cerebral hypoxia. Cardiac failure is usually accompanied by a degree of bradycardia and may be secondary to it. Whether the primary cause is reflex vagal slowing or myocardial asphyxia is of little import since in either case progression to cardiac arrest may occur, and treatment should be directed toward both etiologic factors. Operative manipulation should be suspended, and the lungs

hyperventilated with 100 per cent oxygen. The intravenous administration of calcium chloride frequently improves the force of contraction, and atropine suppresses any vagal component involved. In practice a mixture of these agents has been quite efficacious (Table III). If immediate improvement in the condition

TABLE III
CALCIUM CHLORIDE-ATROPINE SOLUTION

	Amount used	Dose/cc mixture
Calcium chloride	5 cc of 10% CaCl_2 solution	33.3 mg
Atropine sulph	Three gr 1/400 tablets	gr 1/2000
Distilled water	10 cc	
Prophylactic dosage	1 cc/20 lb up to 3 cc, repeated p r n	
Therapeutic dosage	1 cc/10 lb up to 5 cc, repeated p r n	

does not occur, cardiac massage should be started before complete arrest occurs. The prophylactic administration of calcium chloride and atropine before clamping the pulmonary artery in the Blalock and Potts procedures, and on the slightest evidence of diminished cardiac activity in all cases, appears to have reduced the frequency of this complication.

Cardiac arrest may occur as a sequel to gradual cardiac failure, dislocation of the heart from its normal position, increased vagal reflexes, or to sudden loss of moderate volumes of blood from either pulmonary artery or aorta. Cardiac massage must be started immediately and maintained until the heart is capable of producing a palpable peripheral pulse. In those cases in which massage alone fails to restore the normal beat, an intracardial injection of epinephrine frequently initiates cardiac action. A preliminary intracardial injection of calcium chloride appears to set the stage for the more effective action of this stimulant. Any deficit in blood volume should be rapidly corrected.

Primary ventricular fibrillation is very rare but fibrillation secondary to cardiac arrest is not uncommon. The cause may be either myocardial, hypoxia, stimulation by the massaging hand, or overenthusiasm in the use of epinephrine. Defibrillation using a direct current is almost always effective, the ensuing arrest requiring treatment as outlined above.

Ventricular extrasystole is the commonest arrhythmia encountered without the assistance of the electrocardiograph. When this instrument is used throughout operation, periods of nodal rhythm and wandering of the pacemaker are frequently observed. In most cases arrhythmias appear to arise as a result of mechanical stimulation and respond to cessation of the surgical manipulation, the application of local anaesthetics to the operative field, the intravenous administration of atropine, and hyperventilation of the lungs.

Sudden loss of moderate to large volumes of blood may result from a variety of surgical mishaps. Some type of apparatus for the rapid administration of adequate replacement solutions should be set up for each case. The rapid

administration of large volumes of blood or plasma may in themselves depress cardiac activity as a result of infusing relatively large amounts of potassium ion. The injection of 10 per cent calcium chloride in 1 cc. increments to any rapidly running transfusion prevents this undesirable complication of treatment.

Acute pulmonary oedema may occur in a variety of conditions. Mechanical blocking of the small bronchioles by innumerable small bubbles, rather than the amount of fluid in the tracheobronchial tree, interferes with pulmonary ventilation. Passing the anaesthetic gases through a detergent such as ethanol in the ether chamber reduces the surface tension of these bubbles which disintegrate, leaving a thin bloody fluid which can be readily aspirated. The degree of positive pressure used during the inspiratory phase should be increased.

The sudden onset of deep inspiratory gasps is evidence of hypoxia stimulation of the carotid body chemoreceptors, and not of recovery from relaxants. This grave omen can occur even in the presence of complete relaxation and apnoea resulting from hyperventilation and the use of succinylcholine.

Dilatation of the pupils has already been mentioned as a sign of cerebral hypoxia. The persistence of dilatation despite efficient massage and the presence of a peripheral pulse is almost without exception prognostic of a fatal outcome.

Following ligation of a patent ductus the blood pressure rises sharply and there is a marked decrease in pulse pressure. The latter may be of such magnitude that a peripheral pulse is almost impossible to find, and undue alarm may be experienced by the anaesthetist unless the blood pressure is taken by auscultation.

A second benign situation which may be mistakenly considered serious is the presence of a large pericardial effusion. This may mask the true myocardial action beneath, producing the appearance of very feeble contractions. The presence of an adequate blood pressure and brisk heart sounds are reassuring, and the removal of the pericardial effusion by the surgeon permits constant observation of myocardial activity and cardiac size.

HYPOTHERMIC ANAESTHESIA

The reduction of metabolism and hence oxygen requirement by physical cooling of the body is now being used in both cardiovascular and intracranial surgery. A temperature of about 28°C is necessary for those procedures in which the entire circulation must be stopped for several minutes. As an adjunct in the surgery of less complicated cases, temperatures of 30 to 33°C. decrease oxygen requirements and provide an increased margin of safety for the patient. Temperatures in this range are now being used routinely for all cyanotic and poor-risk patients.

Infants are cooled by total immersion in a bath of cold tap water, and larger patients by wrapping in a mattress through which a refrigerant solution is circulated.

The routine system of premedication and anaesthesia described above is used. The inclusion of chlorpromazine in the premedication effectively prevents shivering during the cooling process, and the injection of 1 mg/5 lb of this agent in refractory cases accelerates the rate of cooling. Sodium pentothal is not repeated

following the induction dose, since its rate of elimination is decreased with decreased tissue metabolism.

At temperatures below 28°C. the likelihood of spontaneous ventricular fibrillation increases although it has been suggested by Bigelow (4) that the production of an alkalosis by hyperventilation may prevent this complication even at these temperatures. Electrical defibrillation of the cold heart is much more difficult than defibrillation at normal body temperature. Warming the heart by filling the chest with warm saline may facilitate defibrillation. Intracordial prostigmine 0.05 cc. of the 1:4000 solution per Kg., has been used in one refractory case with subsequent successful electrical defibrillation (5).

EXTRACORPOREAL HEART-LUNG PREPARATION

The correction of some intracardiac anomalies requires an open heart for periods of 15 to 20 minutes. In such cases the heart and lungs are completely by-passed by removing blood from the venae cavae, oxygenating it in either a mechanical or a biological lung, and pumping it back into the arch of the aorta. The anaesthetic management of these cases is again fundamentally the same as that for the more routine procedures. In order to maintain the apnoeic state during the by-pass, a small dose of decamethonium is given several minutes before the extracorporeal circuit is turned on.

If there is evidence of increased bronchial circulation to the lungs gentle inflation of the patient's lungs with oxygen during this period may result in further oxygenation of the circulating blood and the removal of some carbon dioxide. The problem of carbon dioxide elimination from the artificial lung should be appreciated and measures taken to reduce the mechanical dead space of the oxygenating system when a biological lung is used.

SUMMARY

A technique of anaesthesia for the correction of congenital heart defects is described. Premedication with chlorpromazine, promethazine HCl, and demerol is followed by induction with sodium pentothal and maintenance of anaesthesia with nitrous oxide, oxygen, and the depolarizing relaxants. A moderate degree of hypothermia is recommended for all cyanotic and debilitated patients. The more common complications are described, and reliance on calcium chloride and atropine in their treatment is emphasized.

RÉSUMÉ

L'auteur décrit une technique d'anesthésie dans la correction des maladies congénitales du cœur. Comme médication pré-opératoire, on donne du prométhazine et du chlorpromazine la veille de l'opération qu'on fait suivre d'un mélange de prométhazine, chlorpromazine et péthidine dans l'heure précédant l'opération. L'induction se fait au Pentothal sodique. On intube après injection de decamethonium et de succinylcholine. L'anesthésie se poursuit au protoxyde d'azote, oxygen et de petites doses intermittentes de succinylcholine. On maintient une hyperventilation tout au long de l'intervention avec respiration contrôlée durant les manipulations du cœur ou des vaisseaux.

Une hypothermie modérée est recommandée comme adjuvant dans les cas avec cyanose. Des températures aussi basses que 28°C. sont nécessaires quand l'action de pompe du cœur doit être arrêtée pour de courtes périodes.

La circulation doit être maintenue au moyen d'un extracorporel dans les cas qui demandent un arrêt de la fonction cardiaque pour de plus longues périodes.

La complication sérieuse habituelle au cours de la chirurgie est diminution progressive de l'action cardiaque allant parfois jusqu'à l'arrêt. La prophylaxie et le traitement de cette condition, soulignant l'emploi du chlorure de calcium et de l'atropine, est décrite.

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