

# Anesthetic Management During Open Intracardiac Surgery

Richard A. Theye, M.D., Emerson A. Moffitt, M.D., John W. Kirklin, M.D.

THIS presentation will describe the current anesthetic management at the Mayo Clinic of patients during all phases of open intracardiac surgery. The first open-heart operation at the Mayo Clinic was performed in March, 1955. By June 1962, 2,400 such operations had been performed on infants, children, and adults at this institution.

## Basic Principles

The basic principles of management of these patients are maintenance of light levels of anesthesia, adequate ventilation, good operating conditions, and an appropriate volume of blood. A light level of anesthesia assures minimal reduction in cardiac output from the anesthetic agent *per se*. Choice of the agent is less important than the level of anesthesia. Adequate gas exchange is provided by manual ventilation sufficient to eliminate spontaneous ventilatory efforts. This assures, in the absence of deep anesthesia and relaxants, that ventilation is sufficient and, in addition, results in a quiet surgical field. Attention to blood volume prior to establishing perfusion is rarely necessary. An appropriate blood volume immediately after perfusion is, in general, that which allows for subsequent loss of blood and provides maximal allowable ventricular diastolic filling. This is ordinarily achieved by transfusion of heparinized blood from the pump-oxygenator until atrial pressures of 20 mm. of mercury (mean) are reached.<sup>1</sup>

In these patients the basic pathologic condition, operative technique, and corrective operation are capable of effecting changes in the

relationship of blood volume, filling pressure, and cardiac output. Accordingly, venous and arterial pressure, the peripheral pulse, and events in the surgical field are assessed and changes are interpreted in relation to these parameters.<sup>1</sup> The use of a complete blood loss-blood replacement record<sup>2</sup> is no longer necessary. Venous pressure is measured directly by means of a plastic needle in the left external jugular vein. Change in venous pressure is considered ordinarily to reflect change in right ventricular end diastolic filling pressure. Usually right and left atrial pressures are measured directly as perfusion is being discontinued. The relative pressure observed at this time is borne in mind in arriving at the appropriate value for venous pressure at later times. In order to avoid the deleterious effects of citrated blood on myocardial function and the clotting mechanism, blood lost during the later phases of the operation is not replaced unless the loss is obviously excessive or cardiac output appears to be falling in association with a decreasing venous pressure. When a reduction in cardiac output is associated with an increased venous pressure, search for and correction of causes other than hypovolemia are carried out. These include arrhythmias, coronary air embolism, deep anesthesia, mechanical interference with cardiac filling or ejection, and hypoxia.

## Preoperative Medication

Agents for preoperative medication usually are pentobarbital and morphine. Infants weighing less than 10 pounds are not given premedication. Young children receive pentobarbital (1 mg. per pound of body weight by mouth or 2 mg. per pound by rectum) the night before and two hours before operation and morphine (1 mg. per 10 pounds intramuscularly) one hour before the induction of anesthesia. Older children and adults are

Presented at the Annual Meeting of the American Society of Anesthesiologists, New York, October 26, 1962; accepted for publication August 17, 1962. Drs. Theye and Moffitt are in the Section of Anesthesiology, and Dr. Kirklin, Section of Surgery, Mayo Clinic and Mayo Foundation, Rochester, Minnesota.

given pentobarbital (60 to 100 mg.) orally the night before and two hours before operation and morphine (5 to 10 mg.) intramuscularly one hour before operation. The practice of not including atropine or scopolamine in the premedication of patients undergoing heart operations has been continued primarily because untoward effects from this omission have not been observed. Demerol (25 to 75 mg.) occasionally is substituted for morphine.

### Induction and Maintenance of Anesthesia

Originally, anesthesia was maintained with ether at the electroencephalographic level 1. The introduction of electrocautery prompted a change to thiopental and nitrous oxide and intermittent use of succinylcholine.<sup>3</sup> Large amounts of succinylcholine (1.5 to 2.0 Gm.) were used at times. The introduction of halothane<sup>4</sup> minimized the intravenous use of barbiturates, opiates, or relaxants and retained a nonflammable mixture. Patients are awake and usually capable of managing their ventilation and secretions at the end of the surgical procedure. Carbon dioxide retention has not been observed in the postperfusion or postoperative period.<sup>5-7</sup> While a mild degree of arterial desaturation is present in these patients the first few days after operation, the magnitude is similar to that observed in thoracic, nonbypass procedures.<sup>6,7</sup> In these patients, the use of 40 per cent oxygen in the inspired air is associated with arterial oxygen saturations of 95 to 100 per cent in the absence of intracardiac right-to-left shunt. Halothane is used in low concentrations (0.5 to 1.0 per cent) with trouble-free results.

Anesthesia is induced in children by either cyclopropane or a mixture of nitrous oxide-halothane-oxygen. Endotracheal intubation is accomplished with the aid of intramuscular injections of succinylcholine (2 mg. per kilogram of body weight). In large children and adults, anesthesia is induced with thiopental (100 to 200 mg. given intravenously), and endotracheal intubation is performed with the aid of succinylcholine (60 to 80 mg. given intravenously). Infants occasionally are intubated while awake. Anesthesia is maintained in all patients by manual hyperventilation with halothane (0.5 to 1.0 per cent) in nitrous oxide (3 liters per minute) and oxygen

(2 liters per minute). A Bloomquist circle absorber is used for patients weighing less than 30 pounds. In all other patients a regular carbon-dioxide circle absorber is used. Excessive gases are eliminated by the semiclosed technique. After perfusion, adequate anesthesia usually is obtained without the addition of halothane to the nitrous oxide-oxygen mixture.

The effect of certain types of heart disease on anesthetic practice deserves mention. Patients with long-standing aortic or mitral insufficiency have a reduced cardiac output and an increased central blood volume and circulation time. The latter prolong the time interval between injection and maximal effect of drug and may be misleading in that the initial injection may seem to be ineffective. Induction with intravenously administered thiopental therefore requires unusual care. It is prudent not to exceed a total of 200 mg. of thiopental in these patients and to approach this total dose by giving an initial dose of 75 mg. followed by a minimum of three minutes between each 50-mg. increment. Patients with tetralogy of Fallot have a reduced pulmonary blood flow. A portion of the systemic venous return recirculates via the intracardiac shunt without passage through the lungs. Induction with the usual concentration of inhalation agents is prolonged and may be unsatisfactory.

### Monitoring During Anesthesia

Initially the electrocardiogram, electroencephalogram, arterial and venous pressure, and blood balance were followed throughout the procedure, and total flow rate and arterial and venous oxygen saturations were measured during the perfusion. At present, temperature, blood pressure (cuff), venous pressure (external jugular), electrocardiogram and perfusion flow rate are observed. Increased knowledge permitted this simplification. For example, the electroencephalogram was included in the original monitoring equipment primarily in order to know depth of anesthesia during perfusion. It soon became apparent that not only changes in depth of anesthesia but also severe reduction in cerebral blood flow, obstruction to cerebral venous outflow, and reduction in brain temperature produced

changes in the electroencephalogram.<sup>8</sup> These observations contributed to increased awareness of the importance during perfusion of (1) controlled administration of anesthesia, (2) knowledge of carbon dioxide pressure ( $P_{CO_2}$ ), total flow rate, and the presence of systemic-pulmonary anastomotic connections (for example, patent ductus arteriosus), (3) size and placement of venous cannula, and (4) temperature control.

Reflections of this experience in the present technique include (1) a Fluotec vaporizer installed on the pump-oxygenator chassis with gas flows of 10 liters per minute, (2) control of arterial  $P_{CO_2}$  during perfusion, knowledge of total flow rate, and routine search for and elimination of systemic-pulmonary anastomotic connections, (3) measurement of left external jugular venous pressure (upstream from the common point of obstruction of cerebral venous flow) and adequate caval cannulae accurately placed, and (4) a Brown-Harrison-type heat exchanger (originally included primarily for maintenance of temperature of 37° C.). Arterial  $P_{CO_2}$  under these conditions of perfusion at 37° C. and at a flow rate of 2.2 to 2.4 liters per minute per square meter is between 22 and 33 mm. of mercury.<sup>9</sup> Accordingly, routine monitoring of the electroencephalogram is no longer believed to be necessary. In the same manner studies of (1) hemodynamics during perfusion and the relation of flow rate and venous oxygen saturations,<sup>10</sup> (2) the performance characteristics of the oxygenator,<sup>11</sup> and (3) the relation between systemic flow rate and total perfusion rate in patients with a large bronchial collateral circulation<sup>12</sup> (tetralogy of Fallot) have rendered routine measurement during perfusion of arterial pressure and arterial and venous saturation unnecessary.

### Management During Perfusion

The techniques for maintenance of anesthesia prior to perfusion are continued during the perfusion. This practice is most appropriate when potent inhalation agents are used. A predictable concentration of agent is almost a necessity during perfusion since cardiac and pulmonary functions are provided artificially and assessment of depth of anesthesia is limited to nonventilatory and noncirculatory signs.

The concentration of nonvolatile drugs is difficult to follow and predict, since total circulating blood volume is increased with the addition of extracorporeal circulation and additions and withdrawals of blood may occur. In addition, the distribution and elimination of the nonvolatile drugs are influenced by the alterations in blood flow, organ function, and temperature change which may occur during a perfusion. In contrast, the concentration of a volatile agent is readily controlled by the concentration of the agent in the gas phase of the oxygenator. Nonpotent inhalation agents are limited in applicability since most artificial oxygenators require a high partial pressure of oxygen in the gas phase for efficient operation.

Oxygen (98 per cent) and carbon dioxide (2 per cent) at 10 liters per minute are passed through a Fluotec vaporizer set to deliver 0.5 to 1.0 per cent halothane into the oxygenator for ten minutes before and throughout the perfusion. Succinylcholine (60 to 100 mg.) is given prior to electric defibrillation. The lungs are not ventilated. Whenever possible the pleural spaces are left intact prior to perfusion. This and slight inflation with a mixture of helium and oxygen minimize collapse of the lungs during perfusion. Helium was chosen for this originally because of the qualities of low solubility and slow removal from nonventilated air spaces. No information has been obtained that suggests the practice to be harmful or in need of change. When profound hypothermia is induced prior to a period of total circulatory arrest, the concentration of carbon dioxide is increased to 5 to 10 per cent. In the laboratory, this change in procedure has been shown to increase the rate of brain cooling.<sup>13</sup>

At present, the Mayo-Gibbon pump-oxygenator is primed with a mixture of 5 per cent dextrose and albumin (one third) and heparinized blood (two thirds). A flow rate of 2 liters per minute per square meter is used in conjunction with mild hypothermia (30° C. nasopharynx). In general these flow rates, in contrast to rates of 2.4 liters per minute per square meter, result in improved surgical exposure since smaller collecting cannulas are required and intracardiac return is reduced. In addition, lower flow rates permit the use of a smaller extracorporeal apparatus with re-

duced priming volume. Reduction in the volume of homologous blood required is advantageous in many respects, one being the possible minimization of an untoward reaction reported to result from sequestration of blood.<sup>11</sup> At this temperature oxygen uptake probably is as high at this flow rate as it is at higher rates. The advantages generally inherent in the approach are thought to outweigh the possible disadvantage of a slightly lower venous oxygen content. The magnitude of the post-perfusion reduction in buffer loss and the pattern of spontaneous return to normal acid-base profile are not different in patients managed by the former and by the present technique.<sup>5-7</sup> Ischemic cardiac arrest achieved by cardiac cooling and aortic cross-clamping is used in the repair of most congenital lesions. Direct coronary artery perfusion is utilized during correction of acquired aortic valve disease.

"Going on" and "coming off" bypass deserve mention as well as do some features of the perfusion itself.<sup>15</sup> The introduction of collecting cannulas into the cavae may obstruct venous return to the heart, although this is uncommon with the flow rates presently employed. Bypass is only partial until body temperature (nasopharynx) reaches 33° C. This permits the heart to contribute to systemic flow. A similar plan is followed during rewarming after repair.

During perfusion the rate of venous return is a function of the pressure gradient across the collecting system and the resistance to flow through the system. An adequate collecting system permits the desired rate of venous return at low venous pressures. If venous return is inadequate, a defective collecting system or hypovolemia exists. Direction of change in venous pressure with cannulation and initiation of perfusion is helpful in the differential diagnosis. Defects in the collecting system usually result in an elevated venous pressure. These include improper placement of caval cannulas (for example, superior vena cava cannula in innominate vein, inferior vena cava cannula in hepatic vein), occlusion of a cannula by a tape or kink, excessively long or narrow cannulas or connections, or inadequate vacuum or syphonage. Anomalous systemic venous drainage systems (for example, per-

sistent left superior vena cava) may compound the difficulties of appropriate venous collection. Hypovolemia usually is associated with a reduced or normal venous pressure and is corrected by transfusion of the patient from the pump-oxygenator.

"Coming off" bypass returns the work of pumping blood to the heart. The ease and safety in accomplishing this is related directly to the ability of the heart to perform the necessary amount of useful work. The safety with which bypass can be discontinued may not be known precisely prior to this time. For these reasons, once the patient's temperature reaches about 35° C., an orderly increase in opportunity for the heart to receive the venous return is effected by reducing the vacuum or syphonage. As this is done, sufficient blood is transfused to maintain normal or slightly elevated venous pressures. Adequacy of cardiac output is estimated continually. A satisfactory response consists of an adequate cardiac output at normal venous pressures with diminishing venous return to the machine. Perfusion is then discontinued.

If cardiac output is inadequate, search for the basis is carried out. Hypovolemia is associated with low venous pressures and is corrected by transfusion. Arrhythmias are evident on visual inspection of the heart and appropriate treatment is instituted. Adequacy and appropriateness of repair are assessed. The choice to return to total bypass and carry out further corrective measures is occasionally made. Support of the patient with an inadequate cardiac output not correctable by these measures may include a prolongation of partial bypass, further transfusion of blood (until right or left atrial pressures reach 20 to 25 mm. of mercury), use of epinephrine or calcium chloride (by intravenous drip), digitalization (digoxin up to 0.9 mg. per square meter of body surface in divided doses intravenously), and possibly the use of sodium bicarbonate (2 mEq. per kilogram of body weight given intravenously once or twice). Considerations appropriate to digitalizing these patients include any digitalis received preoperatively, the occasional tendency of whole-body perfusion to increase the sensitivity to digitalis, and the tendency for partial heart block to become complete with digitalization.<sup>16</sup>

### Summary

In a description of present anesthetic management of patients during open intracardiac surgery an effort has been made to point out, when pertinent, the origin and basis for current practices. It is apparent that procedures in this area of medicine are re-examined constantly and are revamped in the light of additional knowledge. Nevertheless, all practices revolve around principles common to all anesthesia practice, namely, minimal interference with and maximal preservation of cardiac and total body function.

### References

1. Theye, R. A., and Moffitt, E. A.: Blood transfusion therapy during anesthesia and operation, *Anesth. Analg.* **41**: 354, 1962.
2. Patrick, R. T., Theye, R. A., and Moffitt, E. A.: Studies in extracorporeal circulation: anesthesia and supportive care during intracardiac surgery with the Gibbon-type pump-oxygenator, *ANESTHESIOLOGY* **18**: 673, 1957.
3. Moffitt, E. A., and Theye, R. A.: Management of anesthesia, perfusion and supportive care during open intracardiac operations and extracorporeal circulation, *Brit. J. Anaesth.* **31**: 411, 1959.
4. Dawson, B., Theye, R. A., and Kirklin, J. W.: Halothane in open cardiac operations: a technic for use with extracorporeal circulation, *Anesth. Analg.* **39**: 59, 1960.
5. Taylor, L. M., Theye, R. A., Devloo, R. A., and Kirklin, J. W.: Patterns of acid-base changes during surgical convalescence, *Surg. Gynec. Obstet.* **114**: 97, 1962.
6. Rehder, Kai, Kirklin, J. W., and Theye, R. A.: Physiologic studies following surgical correction of atrial septal defect and similar lesions, *Circulation*, In press.
7. Theye, R. A., and Kirklin, J. W.: Physiologic studies following surgical correction of ventricular septal defect, Unpublished data.
8. Theye, R. A., Patrick, R. T., and Kirklin, J. W.: The electroencephalogram in patients undergoing open intracardiac operations with the aid of extracorporeal circulation, *J. Thor. Surg.* **34**: 709, 1957.
9. McGoon, D. C., Moffitt, E. A., Theye, R. A., and Kirklin, J. W.: Physiologic studies during high flow, normothermic, whole body perfusion, *J. Thor. Cardio. Surg.* **39**: 275, 1960.
10. Moffitt, E. A., Patrick, R. T., Swan, H. J. C., and Donald, D. E.: A study of blood flow, venous blood oxygen saturation, blood pressure and peripheral resistance during total body perfusion, *ANESTHESIOLOGY* **20**: 18, 1959.
11. Levin, M. B., Theye, R. A., Fowler, W. S., and Kirklin, J. W.: Performance of the stationary vertical-screen oxygenator (Mayo-Gibbon), *J. Thor. Cardio. Surg.* **39**: 417, 1960.
12. Moffitt, E. A., Kirklin, J. W., and Theye, R. A.: Physiologic studies during whole-body perfusion in tetralogy of Fallot, *J. Thor. Cardio. Surg.* **44**: 180, 1962.
13. Payne, W. S., Theye, R. A., and Kirklin, J. W.: Effect of carbon dioxide on rate of brain cooling during induction of hypothermia by direct blood cooling, *J. Surg. Res.*, In press.
14. Gadboys, H. L., and Litwak, R. S.: Personal communication to the authors.
15. Kirklin, J. W., and Theye, R. A.: Whole-body perfusion from a pump-oxygenator for open intracardiac surgery, In Gibbon, J. H., Jr.: *Textbook of Thoracic Surgery*. Philadelphia, W. B. Saunders Company, In press.
16. Browning, R. W., Hara, M., Lincoln, B. M., Williams, D., Dungan, W. T., and Baker, J.: Digitalis tolerance in dogs following extracorporeal circulation, *Surg. Forum* **12**: 194, 1961.