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STUDIES IN EXTRACORPOREAL CIRCULATION

V. Anesthesia and Supportive Care During Intracardiac Surgery with the Gibbon-Type Pump-Oxygenator

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THE EXTRACORPOREAL APPARATUS

THE GIBBON-TYPE pump oxygenator is an extracorporeal heart-lung apparatus designed to meet the physiologic requirements of the body during the period of temporary exclusion of the heart and lungs from the circulation (1, 2). Especially important features which characterize a Gibbon-type apparatus are as follows: (1) The extracorporeal circuit is of constant volume. Variations in venous return from the patient are met instantaneously by the machine with appropriate and quantitatively equal variations in arterial return. (2) The apparatus has capacity for efficient operation at high flows, and oxygen saturation of 100 per cent has always been found in the arterial line. (3) Hemolysis is minimal. (4) The volume of blood required for filling exceeds the volume required for the operation of many other types of pump-oxygenators (a disadvantage). (5) An intracardiac sucker system (3) returns to the circuit of the machine all blood which flows into the open chamber of the heart. This feature reduces loss of blood significantly and contributes to high flow. (6) The apparatus is easily maintained and operated by two technicians. (7) Air embolism has not been associated with the use of this type of pump-oxygenator.

The pump-oxygenator system is represented schematically in figure 1. Fresh heparinized blood is added to the priming reservoir. This blood is obtained from a number of group-compatible donors whose blood is compatible with that of the patient. From each, 470 cc. of blood is drawn into a vacuum bottle containing 30 cc. of normal saline solution and 15 mg. of heparin, and is maintained at 37 C. The total volume of blood required varies with the number of screens used in the oxygenator, which number is determined from the surface area of the

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patient. Since a mixture of one part of concentrated serum albumin with four parts of saline solution is isosmotic, concentrated salt-poor human serum albumin* is added to the blood used to prime the machine. The total amount of albumin is calculated to render isosmotic the total volume of heparinized saline used in collecting the blood.

The venous return from caval cannulae moves through the venous inflow line to the venous reservoir. This is facilitated by the maintenance of slightly less than ambient pressure in the venous reservoir. A level-sensing device in the venous reservoir controls the rate at which

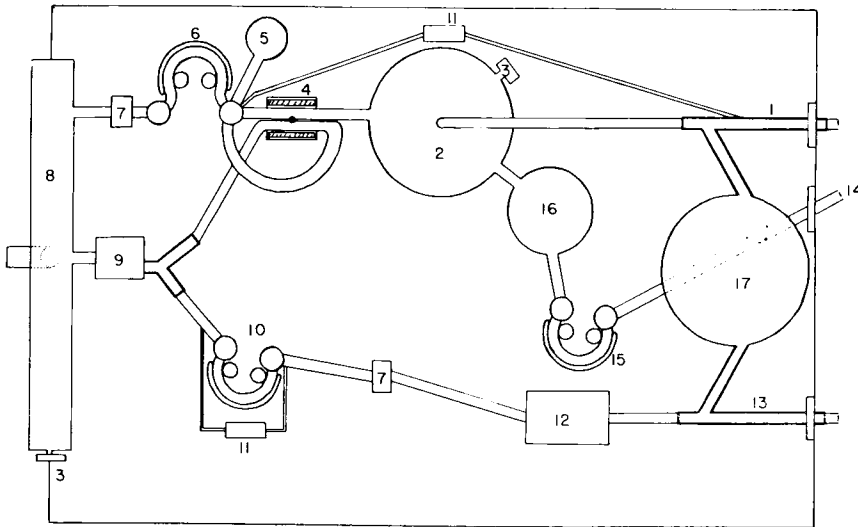


Fig. 1. Schematic representation of the pump-oxygenator system: 1, the venous-inflow line; 2, the venous reservoir; 3, level-sensing devices; 4, occluder; 5, burette for the administration of blood and fluids; 6, recirculation pump; 7, high-pressure stops; 8, oxygenator; 9, holder for pH electrodes; 10, arterial pump; 11, arterial and venous cuvette oximeters; 12, arterial filter; 13, arterial output to patient; 14, coronary-sinus inflow; 15, coronary-sinus pump; 16, coronary-sinus reservoir; 17, priming reservoir. (Reprinted by permission from Jones, R. E., and others: *Proc. Staff Meet. Mayo Clinic* 30: 105, 1955.)

the recirculation pump moves the venous blood to the oxygenator. Connected in this route is a 300-cc. burette to facilitate input of blood, fluids, and therapeutic agents.

The oxygenator consists of a variable number of stainless steel wire-mesh screens, each 12 by 18 inches, mounted vertically in a Lucite case. The venous blood flows down the individual screens and collects in the lower reservoir of the oxygenator. The number of screens to be used is calculated from the expected physiologic requirements of the patient and can be varied from four to 14. Metered flows of oxygen and carbon dioxide are introduced to the oxygenator, which is vented to the outside of the building. A standard Heidbrink ether vaporizer is incorporated in the gas inflow line of the oxygenator. All the gases in this input line flow through a water vaporizer. In most instances the oxygen flow

* The concentrated salt-poor human serum albumin was supplied by the American Red Cross.

is 9.5 liters per minute, the carbon dioxide flow is 0.35 liters per minute, and the ether vaporizer is set at 3 to 5. A level-sensing device in the lower reservoir of the oxygenator controls the rate of the arterial pump to keep the level constant.

The three pumps in the apparatus are DeBakey nonocclusive roller pumps. The recirculation pump sends the blood to the upper reservoir of the oxygenator. The coronary-sinus pump moves the intracardiac return to the venous reservoir. The arterial pump moves the arterialized blood through the arterial filter and aortic cannula to the patient.

The occluding mechanism consists of a vertical roller which can compress the venous inflow line or the recirculation line and restrict or completely halt the flow of blood through either of these lines. The appropriate degree of occlusion of either line is controlled automatically by variations in the level of the blood in the venous reservoir.

ANESTHESIA

The management of anesthesia for the patients undergoing intracardiac surgery by means of a Gibbon-type pump-oxygenator differs in no important respect from the anesthetic management of patients for ordinary intrathoracic procedures.

Premedication.—Preoperatively, no special drugs are given. Atropine and scopolamine are not included in the premedication. A suitable barbiturate is given to adults and older children orally the night before operation and again 2 hours before the induction of anesthesia. Infants and younger children receive an appropriately small amount of barbiturate rectally 2 hours before operation. In addition, children weighing more than 25 pounds and adults receive morphine sulfate intramuscularly 1 hour before the induction of anesthesia. The approximate dose for children is 1 mg. per 10 pounds. The average dose for adults is 10 mg.

Induction and Intubation.—Critically ill infants are intubated while awake, and anesthesia is induced with cyclopropane. In older infants and most children anesthesia is induced with cyclopropane and intubation is performed subsequently. In other older children and adults anesthesia is induced with a small amount of thiopental sodium and intubation is accomplished with the assistance of 20 to 40 mg. of succinylcholine chloride.

Maintenance.—Anesthesia for all patients is maintained throughout the procedure with a mixture of ether and oxygen. The level of anesthesia is monitored electroencephalographically and is maintained at level I (4). A closed technique is used and carbon dioxide is absorbed by means of a circle filter or to-and-fro canister. Control of respiration is achieved through manual hyperventilation before the chest is opened. Control is maintained until the chest is closed and pronounced airtight, except during the period of open cardiotomy and total by-pass. At that time movement of the lungs is suspended, and they are filled with a

mixture of 50 per cent helium and 50 per cent oxygen. The airway pressure during this period is maintained at 5 cm. of water.

MAINTENANCE OF ADEQUATE HEMODYNAMICS

The maintenance of adequate hemodynamics is the major item in the supportive care of patients undergoing surgical operations on the heart. In order to accomplish this, precise information on the nature and extent of any hemodynamic alteration must be available, and the means by which these alterations can be rectified must be at hand.

Observations.—Information on alterations in hemodynamics is obtained through the monitoring of certain physiologic variables. After induction of anesthesia, a large plastic needle is inserted in a vein of the left forearm. During the operative period this is connected to a strain gauge and galvanometer by means of which venous pressure is continuously recorded. The needle is kept in place during the early postoperative period for administration of blood or fluids and intermittent determination of venous pressure. Throughout the operation arterial pressure is continuously monitored by means of a strain gauge and galvanometer connected to a catheter passed into the lower part of the abdominal aorta through a needle inserted in the femoral artery. This catheter is removed at the end of operation. Needle electrodes placed in the scalp overlying the frontal and occipital regions and in the right arm and left leg are connected to a two-channel ink-writing recorder with oscilloscopic screen and furnish an electroencephalogram and electrocardiogram. A cuvette oximeter connected in the venous line of the pump-oxygenator provides saturation values for mixed venous blood during by-pass. The rate of flow of oxygenated blood to the patient during perfusion is obtained from the speed of rotation of the arterial pump and its relationship to the size of the arterial cannula.

Preparatory Measures.—The means by which hemodynamic alterations can be corrected include blood, drugs, and fluids given intravenously. The intravenous routes are made ready as soon as the patient is asleep. In infants a plastic catheter is placed by the surgeon in the saphenous vein at the ankle. This is used for the administration of whole blood. In older patients blood is given through a 15-gauge needle or plastic catheter placed in the saphenous vein at the ankle. A three-way stopcock with connecting tubing is placed in the intravenous line established in the forearm. Through it venous pressure may be measured or drugs may be administered. The absolute dependability of each route is established at the start and is checked from time to time.

The route which is to be used for the intravenous administration of blood is maintained by an extremely slow drip of 5 per cent glucose in water or in 0.2 per cent saline solution. A potent solution of levarterenol bitartrate is prepared by adding 4 mg. of it to 250 cc. of 5 per cent glucose in distilled water. An intravenous set is attached to the flask and filled with the solution. Then this is plugged into a

three-way stopcock. Also, for possible emergency use, a 10-cc. syringe is labeled and filled with the levarterenol solution. Other drugs which are kept available for intravenous use in the operating room include heparin sodium, protamine sulfate, lanatoside C, atropine sulfate, procainamide hydrochloride, isoproterenol hydrochloride, and neostigmine methylsulfate. A defibrillator and a pacemaker are maintained in the operating room in good working order at all times.

Blood crossmatched with that of the recipient is drawn 24 hours before use and citrated. Each 600 cc. contains 120 cc. of A.C.D. solution to which is added 30 cc. of concentrated serum albumin. Citrated blood is used sparingly, and only before heparin and after protamine has been given.

TIME AND REMARKS	Weighed Loss	Chest Suction and Glove's	Wall Suction	Visual and Misc.	Samples and Tubing	Gross Out	Table Saline	Net Out	Net In	Cit. Blood	Hep. Blood	Flush Saline	Albumin
#1 9:00	110	0	0	30	10	150	0	150	60	25	0	25	10
#2 9:35	145	25	25	40	20	255	0	255	80	30	0	40	10
#3 9:50	145	35	25	50	55	310	20	290	205	50	100	40	15
#4 10:05	175	100	35	50	55	415	20	395	255	50	150	40	15
#5 10:15	175	150	75	50	55	505	20	485	380	50	275	40	15
#6 10:25	175	160	75	50	55	515	30	485	415	50	310	40	15
#7 10:37	175	285	200	50	55	765	50	715	640	50	535	40	15
#8 10:45	175	400	225	50	55	905	50	855	810	50	685	60	15
#9 11:45	250	525	310	50	55	1190	135	1055	900	125	685	70	20
NAME										K-CITRATE	34		
NUMBER										BURETTE	100		
DATE										TOTAL	134		

FIG. 2. Record of loss and replacement of blood in a typical case. Abbreviations and terms are those used on the records.

Salt-poor concentrated human serum albumin is used to reduce the tendency of fluids given intravenously to leave the vascular compartment. The fluids administered during operation are principally the saline used to flush the catheter in the abdominal aorta and the diluent used to prevent coagulation in the citrated and the heparinized blood. To each, 1 cc. of concentrated albumin is added for each 4 cc. of fluid.

Measures to Combat Alterations in Hemodynamics.—Alterations in hemodynamics nearly always can be related to loss of blood, anesthesia, or surgical manipulation, or to the pathophysiology of the cardiac disorder.

DUE TO LOSS OF BLOOD.—Hemodynamic alterations due to loss of blood can be minimized if the amount lost is accurately ascertained and replaced. Meticulous attention therefore is given to the maintenance of a record (fig. 2) of blood lost and replaced.

The gross estimate of loss of blood is derived by adding figures for the following items:

(1) Weighed Loss.—Gain in weight of linen received from the operating table during the procedure is accurately ascertained by the circulating nurse and recorded on a blackboard visible to the anesthesiologist.

(2) Intercostal Suction.—The volume of blood received from bilateral intercostal suction tubes is determined. These tubes are placed in the chest and drain into a calibrated suction bottle during the operation. Before closure of the chest they are replaced by the standard postoperative drainage tubes which are connected to the Glover suction apparatus.

(3) Wall Suction.—The volume of blood and saline solution removed from the patient by the surgeon's suction tip is checked.

(4) Visual and Miscellaneous Loss.—The volume of blood lost from the patient by all other means is estimated.

(5) Samples and Tubing.—The volume of blood removed from the patient for analysis and for filling the tubes attached to the arterial and venous cannulae is recorded.

The net amount of blood lost is computed by subtracting from the figure for gross loss the volume of saline used at the operating table for moistening exposed tissues.

The total of citrated blood, heparinized blood, saline solution used for flushing, and concentrated albumin represents the net volume of blood replaced.

The blood-volume balance sheet is filled out routinely at certain stages of the procedure and whenever there is a question as to the status of the blood loss and replacement. The tally always is made before by-pass is begun, before it is stopped, after it is stopped, and after the thorax is closed. This final appraisal is written on the first sheet of the postoperative record of the patient (fig. 3).

Preoperative and postoperative determinations of the weight of the patient serve as a check on the accuracy of replacement of blood. The weighing is done with extreme care, using a scale accurate to 5 Gm. The calculations are placed on the postoperative sheet (fig. 3), and the net gain or loss in weight is determined.

Added information on blood volume throughout the operation is provided by the arterial and venous pressures. A persistently low level or progressive decrease in both pressures suggests that blood volume has decreased. Under these circumstances the record of blood volume is reassessed for error, and a search for unrecognized loss of blood is carried out. During the period of actual perfusion the values for arterial and venous pressure, rate of blood flow (5), and oxygen saturation of venous blood provide useful information on the blood volume of the patient. A decrease in these variables suggests that blood volume has decreased.

The volume of blood replaced never exceeds the measured loss. Blood replacement is considered to have been ideal if the patient's postoperative weight is 0.5 to 1.0 per cent less than the preoperative

weight. In the event that hypotension exists when there is otherwise every indication of normal blood volume, we prefer to support the arterial blood pressure at a systolic level of 75 mm. of mercury or higher with an intravenous infusion of levarterenol.

DUE TO ANESTHESIA.—Among the hemodynamic alterations caused by anesthesia are myocardial depression and peripheral dilatation; these are included in the pharmacologic properties of ether. The degree of depression and dilatation is directly related to the depth of anesthesia. In order to minimize these effects, ether is admitted to the closed system intermittently in amounts just sufficient to maintain

WEIGHTS

	Pre op	Post op
Gross	23.270	23.010
Deductions	2.160	2.265
Net	21.110	20.745
	20.745	
Balance	-.365	

Deductions	Pre op	Post op
Board	2.0	2.0
Clothing	.160	
Bandage		.025
Catheters		.050
Clamps		.190
Total	2.160	2.265

Estimated insensible loss/24 hr. 380 c.c.

BLOOD—FLUIDS PRIOR TO CHEST CLOSURE

Blood volume guides	
Estimated blood loss	1050
Total blood administered	810
Heparinized	<u>685</u>
Citrated	<u>125</u>
Dye curve estimate	N.D.
Volume produced by albumin	90
Total blood volume given	900
Blood volume balance	-150
Amt. in Gloves when air tight	25

Fluids	
Normal saline	70
5% glucose in water	90
5% glucose in saline	20
Levophed <u>16</u> mgm./L 5/0	<u>15</u>
Total fluids	195
Albumin--Blood in machine	68
Cover saline	20
Blood for pt.	30

FIG. 3. Change in weight (kg.), loss and replacement of blood, and replacement of fluid in a typical case. These are copies from the records.

electroencephalographic level I. This level provides amnesia and analgesia for the patient and permits manual control of respiration. Application of positive pressure in the airway during the final stages of closure of the thorax frequently results in transient hypotension. Adequate blood pressure returns when the chest is airtight and the patient is permitted to resume spontaneous respiration.

DUE TO SURGICAL INTERVENTION.—Alterations in hemodynamics occur with any surgical maneuver which interferes with flow of blood into, through, or out of the heart. Such incidents occur with displacement of the heart from the pericardial bed, with obstruction of an orifice in intracardiac exploration with a finger, and with cannulation or dissection and torsion of the venae cavae. If any such action seriously interferes with cardiac output, it is called to the attention of the surgeon. Cessation of manipulation restores normal dynamics. Occasionally

the insertion of cannulae in the caval veins interferes with venous return or obstructs cerebral vascular flow sufficiently to cause transient alterations in the electroencephalogram. These rather often are observed with small children.

DUE TO PATHOPHYSIOLOGY OF THE HEART.—Variations in circulatory dynamics are frequently related to the pathophysiology of the underlying heart disease. These variations are not so easily prevented or controlled as those resulting from loss of blood, anesthesia or manipulation. Reduction of cardiac output may be caused by valvular obstruction, impaired myocardial contractility, or cardiovascular shunts. Manifestations of reduced cardiac output include arterial hypotension, increased venous pressure, and an alteration in the electroencephalogram. Direct observation reveals a dilated, poorly contracting heart. The influence of deep anesthesia, surgical manipulation, and variations in blood volume must be ascertained and eliminated before an alteration in hemodynamics may be ascribed to the underlying cardiac disorder.

A particularly troublesome complication occasionally appears in patients with a potential right-to-left shunt in whom systemic hypotension occurs. As systemic pressure decreases, the right-to-left shunt increases and coronary flow decreases. The myocardium, poorly perfused with desaturated blood, becomes less efficient; and the situation may become irreversible unless the systemic pressure can be elevated promptly by the infusion of levarterenol.

The decision to treat actively a hemodynamic alteration due to the inherent cardiac disease is based frequently on the electroencephalogram (6). A pattern of fast activity and low amplitude (fig. 4*a*) is characteristic of light ether anesthesia. The appearance of large, slow waves or a relatively flat line (fig. 4*b* and *c*) is associated with a reduction in cerebral blood flow or deep anesthesia. Since anesthesia is carefully maintained at a light level (fig. 4*a*), the appearance of large, slow waves or a flat line indicates that a serious reduction in cerebral blood flow has occurred. Under these circumstances levarterenol is infused in quantities sufficient to restore the cerebral blood flow and the electroencephalographic tracing to normal (fig. 4*d*).

Patients who undergo these operations are not digitalized preoperatively unless they have manifestations of cardiac failure. They are not ordinarily digitalized during the operation before extracorporeal perfusion, because unknown quantities of the drug may be lost in that process. Indications for digitalis following perfusion include supraventricular tachycardia or unequivocal evidence of myocardial failure. Lanatoside C is given intravenously in doses of 0.03 mg. per pound for patients weighing less than 20 pounds, 0.02 mg. per pound for those weighing 20 to 50 pounds, and 0.01 mg. per pound for patients weighing more than 50 pounds.

Complete heart block may follow repair of ventricular septal defect or repair of atrioventricularis communis. If the ventricular rate is sufficient to maintain adequate cardiac output, no treatment is neces-

sary, but sometimes output is so reduced that treatment is necessary. Then 0.1 mg. of isoproterenol hydrochloride is administered intravenously. Occasionally a solution of 1 mg. in 250 cc. of 5 per cent dextrose in water must be infused to maintain an effective heart rate.

Ventricular tachycardia or fibrillation has been observed during perfusion at the cessation of asystole, but invariably reversion to a normal rhythm has followed electrical defibrillation. An essential feature of successful defibrillation is adequate total perfusion at the time.

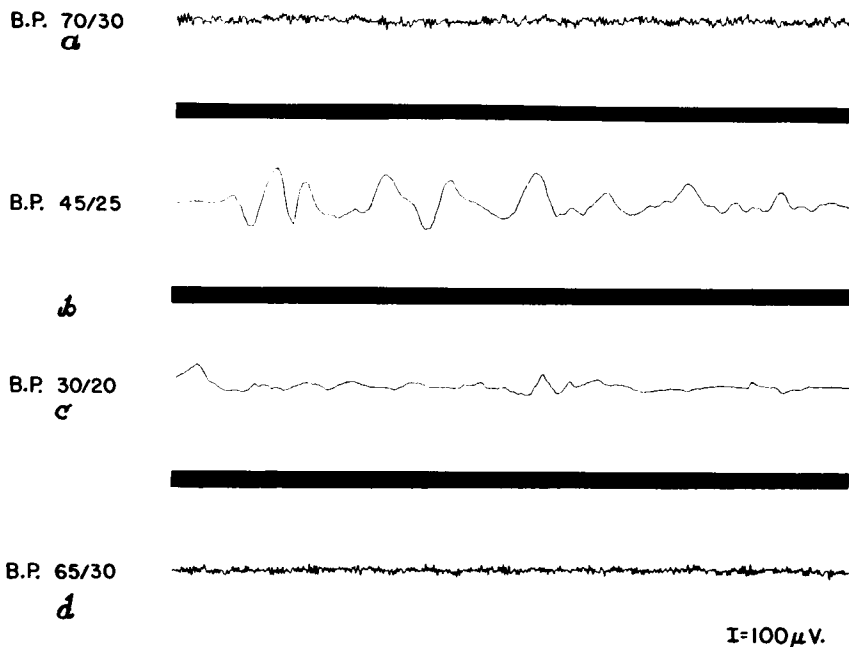


FIG. 4. An electroencephalographic tracing demonstrating: *a*, the pattern characteristic of light ether anesthesia; *b* and *c*, the patterns associated with a serious reduction in cerebral blood flow (infusion of levarterenol was started at *b*); and *d*, the pattern after treatment.

It should be emphasized that proper support of hemodynamics in these patients is directed primarily toward prevention rather than treatment. Anesthesia is maintained at a light level. Variation in blood volume is minimized. Surgical manipulation is anticipated. Such measures aid in the prevention and recognition of hemodynamic alterations associated with heart disease. Treatment is directed toward cause rather than effect when circulatory deterioration does occur.

PREVENTION OF COAGULATION OF BLOOD

It is necessary to heparinize the blood of the patient in order to prevent coagulation of blood in the arterial and venous cannulas and in the machine. This is done in two stages. The total dose of heparin given to the patient is 3 mg. per kilogram of body weight. One-half

of this, or 1.5 mg. per kilogram of body weight, is given intravenously 3 minutes before the arterial cannula is inserted. The remaining half is given intravenously with the insertion of the two vena caval cannulas. Protamine sulfate is given after the perfusion is completed and the venous and aortic cannulas are removed. The total dose is 3 mg. per kilogram of body weight, given intravenously in intermittent injections.

MAINTENANCE OF BODY TEMPERATURE

Another measure of support is maintenance of body temperature during perfusion. A reduction of body temperature results from the loss of calories from the blood as it is circulated through the machine, which is at room temperature. In order to offset the loss of heat the patient is warmed during the procedure. The patient lies on a full-length mattress, and a half-length mattress is placed over the lower part of the body of older children and adults. Sponge rubber pads are placed between the patient and the mattress at all pressure points. Refrigerant solution at 43 C. is circulated through the tubing of the mattresses.

A CHRONOLOGICAL RECORD OF PROCEDURE

The mechanics of applying the extracorporeal heart-lung apparatus to the patient complicate the surgical procedure and cannot be dismissed or discussed as a separate item. To assist in comprehension of the sequence by which the separate events gradually form the whole process, they will be presented in brief as they occurred in a typical operation (7). The patient, a 6-year-old girl, had entered the hospital for repair of a ventricular septal defect.

Events of the night preceding operation

1. Anesthesiologist visits patient.
2. He orders premedication: pentobarbital sodium, 45 mg. rectally at bedtime and at 5:30 a.m.; and morphine sulfate, 5 mg. at 6:30 a.m.

Setting up of equipment in operating room

Initial operative measures

3. Net preoperative weight of patient is determined: 21.110 kg. (fig. 3).
4. Anesthesia is induced with cyclopropane, and intubation is carried out. From this point, anesthesia is maintained with ether at electroencephalographic level I.
5. Warming unit is turned on at setting of 43 to 45 C.
6. Intravenous needles are placed.
7. Electrocardiographic and electroencephalographic leads are placed.
8. Rectal thermistor is inserted.
9. Pressure catheter is placed in abdominal aorta.

Incision, and establishment of extracorporeal circulation

10. Bilateral anterior thoracotomy is performed.
11. Respiration is controlled by hyperventilation produced manually.

12. Citrated blood is started.
13. Pump-oxygenator is readied.
14. Blood balance tally 1 is recorded (fig. 2).
15. Left subclavian artery is isolated and divided.
16. Bilateral intercostal drainage tubes are placed and connected to calibrated suction bottle.
17. Tapes are placed around superior and inferior venae cavae.
18. Blood balance tally 2 is recorded (fig. 2).
19. Oxygenator is filmed.
20. Heparin, 32 mg., is given intravenously.
21. Citrated blood is replaced by heparinized blood.
22. Left subclavian artery is cannulated.
23. Loop is passed from machine to table, filled, clamped, and divided.
24. Arterial line is adapted to arterial cannula and air is removed by filling from patient.
25. Interior of heart is palpated by surgeon through right atrium.
26. Heparin, 32 mg., is given intravenously.
27. Cannulas are passed into inferior and superior venae cavae via right atrium.
28. Venous line is adapted to venous cannulas, and air is removed by filling from patient.
29. Blood balance tally 3 is recorded (fig. 2).
30. Ether is started on by-pass lung.
31. Administration of 50 per cent oxygen and 50 per cent helium to patient is started.
32. Arterial line is unclamped.
33. Venous line is unclamped 1 second later.
34. Stopwatch 1 is started at unclamping.
35. Inferior and superior vena caval tapes are tightened around cannulas.
36. Aorta is clamped.
37. 34 cc. of potassium citrate is injected in proximal part of aorta.
38. Asystole is achieved.
39. Stopwatch 2 is started.
40. Blood balance tally 4 is recorded (fig. 2).

Ventriculotomy and repair of defect

41. Right ventricle is opened.
42. Intracardiac sucker is inserted.
43. Manual ventilation is suspended and anesthetic reservoir bag is left with a positive pressure of 5 cm. of water.
44. Ventricular septal defect is repaired.
45. Blood balance tallies 5 and 6 are recorded (fig. 2).

Return to systole

46. Intracardiac sucker is removed.
47. Aortic clamp is removed.
48. First 100 cc. of blood returned to heart is removed by wall suction.
49. 100 cc. of blood is given to patient from burette on machine.
50. Resumption of heart beat.
51. Stopwatch 2 is stopped (total time, 29 minutes).
52. Right ventricle is closed.

Disengagement of by-pass machine

53. Manual ventilation is resumed.
54. Blood balance tally 7 is recorded (fig. 2).
55. Inferior and superior vena caval tapes are released.
56. Cannula is removed from superior vena cava; cannula is withdrawn from inferior vena cava to right atrium.
57. Arterial and venous lines to pump are clamped. Patient is off by-pass; stopwatch 1 is stopped (total time, 31 minutes).
58. Inferior vena caval cannula is removed; aortic cannula is removed.
59. Blood balance tally 8 is recorded (fig. 2).
60. 64 mg. of protamine sulfate is given intravenously.
61. Heparinized blood is replaced by citrated blood.

Final steps

62. Permanent chest tubes are placed and connected to Stedman pumps.
63. Chest is closed.
64. Chest is pronounced airtight.
65. Respiration is returned to voluntary control.
66. Final blood balance tally 9 is recorded (fig. 2).
67. Dressing is applied.
68. Net postoperative weight is determined: 20.745 kg. (fig. 3).
69. Patient is removed to special postoperative recovery unit.

Figure 5 shows the course of several physiologic functions during this perfusion. Several points are of special interest. The total

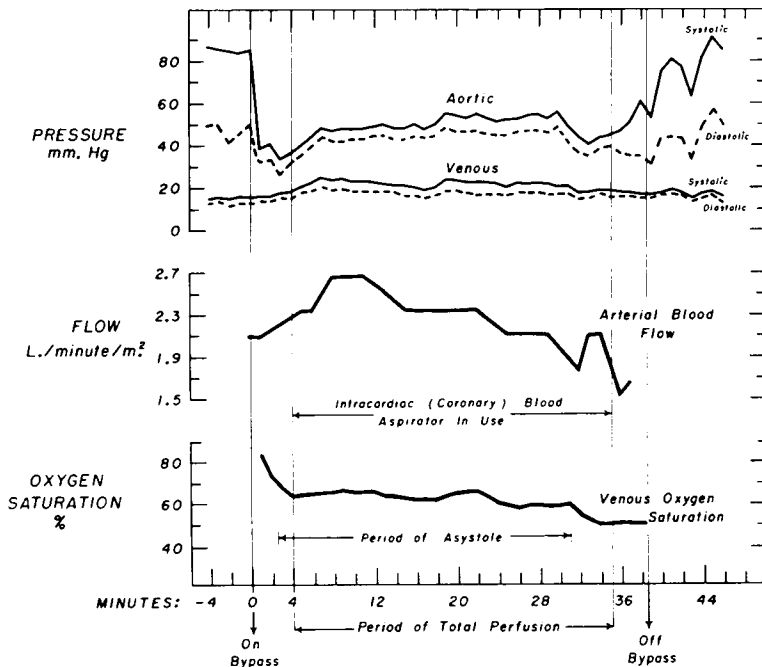


Fig. 5. Certain physiologic variables measured during a typical period of perfusion. Patient was a girl, 6 years old, who weighed 22.5 kg. and whose surface area measured 0.86 square meters.

arterial blood flow was maintained during total perfusion at an average of 1.97 liters per minute, which was 87.5 cc. per kilogram per minute, or an average cardiac index of 2.29 liters per minute per square meter.

Aortic blood pressure decreased rapidly after the start of partial by-pass procedures and remained at a low level until the by-pass procedure was stopped, after which it rose rapidly. In this case the average aortic pressure for the 5 minutes prior to perfusion was 85 mm. of mercury systolic and 47 diastolic, as measured from the photokymographic record. During total perfusion it averaged 49/43, and for the 5 minutes immediately after perfusion the average was 69/38. Average venous pressures for the same periods were 15/13, 21/17 and 16/14.

SUMMARY

The anesthetic and supportive management of patients undergoing intracardiac surgery with the Gibbon-type pump-oxygenator is described. Orientation of the reader is provided by a description of the mechanics of this apparatus. Anesthesia for patients using extracorporeal circulation provided by the Gibbon-type heart-lung machine does not differ from the anesthesia for patients undergoing cardiovascular operations without such by-pass. Supportive care is concerned primarily with the management of alterations in hemodynamics. These alterations usually can be ascribed to loss of blood, effect of anesthesia, or surgical manipulation, or to the underlying cardiac disorder. Alterations due to the latter can be recognized and treated effectively if other causes can be minimized or eliminated. Heparin sodium and protamine sulfate are used to control clotting. Body temperature is maintained by warming the patient. Management of a typical patient in relationship to the surgical procedure is presented in sequential form.

REFERENCES

1. Jones, R. E., Donald, D. E., Swan, H. J. C., Harshbarger, H. G., Kirklin, J. W., and Wood, E. H.: Apparatus of Gibbon Type for Mechanical Bypass of Heart and Lungs; Preliminary Report, Proc. Staff Meet. Mayo Clin. **30**: 105 (March 23) 1955.
2. Kirklin, J. W., Donald, D. E., Harshbarger, H. G., Hetzel, P. S., Patrick, R. T., Swan, H. J. C., and Wood, E. H.: Studies in Extracorporeal Circulation; Applicability of Gibbon-type Pump-oxygenator to Human Intracardiac Surgery; 40 Cases, Ann. Surg. **144**: 2 (July) 1956.
3. Donald, D. E., Harshbarger, H. G., and Kirklin, J. W.: Studies in Extracorporeal Circulation; Method for Recovery and Use of Blood from Open Heart During Extracorporeal Circulation in Man, Ann. Surg. **144**: 223 (Aug.) 1956.
4. Courtin, R. F., Bickford, R. G., and Faulconer, Albert, Jr.: Classification and Significance of Electro-encephalographic Patterns Produced by Nitrous Oxide-ether Anesthesia During Surgical Operations, Proc. Staff Meet. Mayo Clin. **25**: 197 (April 12) 1950.
5. Donald, D. E., and Moffitt, E. A.: Studies in Extracorporeal Circulation; Relation of Blood Flow and Blood Volume During Extracorporeal Circulation in Man, Am. Coll. Surgeons Clin. Congress (42nd), Proc. S. Forum **7**: 264, 1957.
6. Theye, R. A., Patrick, R. T., and Kirklin, J. W.; Electroencephalogram in Patients Undergoing Open Intracardiac Operations with Aid of Extracorporeal Circulation, unpublished data.
7. Harshbarger, H. G., Kirklin, J. W., and Donald, D. E.: Studies in Extracorporeal Circulation; Surgical Technics, Surg. Gynec. & Obst., in press.