ANESTHETIC MANAGEMENT FOR CARDIOPULMONARY BYPASS IN A COMMUNITY HOSPITAL

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THE Hospital of Saint Raphael is a 370-bed nonprofit community hospital where closed heart surgery has been successfully carried out for ten years. More recently, it has been apparent that there were and continue to be patients available in our locale requiring open heart surgery using cardiopulmonary bypass for correction of their congenital and acquired heart lesions. The work done at large research clinics throughout the country [1, 2, 3] intrigued the cardiothoracic surgeons and anesthesiologists at our hospital, and this work appeared applicable at the community hospital level. A "team" of anesthesiologists and cardiothoracic surgeons was formed, all of whom are engaged in the private practice of their respective specialties. The time and effort required to become proficient in the new methods and techniques in the laboratory was taken from their respective private practices, thus proving that research projects of considerable magnitude can be successfully undertaken at the community hospital level.[4] The expenses were met with funds provided by the hospital, local Heart Association, and on occasion the use of personal funds, as necessitated.

This paper presents the methods, results, and comments on the first 50 consecutive cases. The first 6 cases were reported elsewhere in a preliminary report.[5]

METHODS

The anesthetic management of these patients has been one of constant change. We have benefited from the work at large centers, as reported in the literature, and by personal trips to these centers, observing their methods and techniques. However, the methods used in the currently reported series, are essentially those which have been reported [5] and are reviewed briefly, mentioning any pertinent changes.

The heart-lung apparatus in use is a screen oxygenator, the Mark G-K. It is similar in its basic operation to the one used by Kirklin as reported by Patrick.[1] A Brown-Harrison blood-heat exchanger is connected in series with the output or arterial side of the pump. In earlier cases, it was on the input or venous side. This change was made to effect more rapid temperature changes during hypothermia. Oxygen is supplied to the heart-lung apparatus from the piped system in the operating room, passing through a Fluotec vaporizer arranged to deliver from 0.25 per cent to 0.7 per cent halothane vapor to the screening chamber.

In earlier cases, the screening chamber was heated by means of heating wires passing through the plastic walls. Though the wires are still present, they are no longer used for reasons which will be discussed later. DeBakey nonocclusive pumps are employed to propel the blood. This heart-lung apparatus employs the so-called high flow principle wherein the output on the arterial side (*i.e.* perfusion index) is regulated to simulate the calculated normal cardiac output for the particular patient and is based upon the principle that the normal cardiac output is a function of the surface area of the body.[6]

All patients were seen in consultation the day prior to surgery. Many were seen previously during their cardiac catheterization, and the anesthesiologist was familiar with their physical and mental condition. A brief explanation is given to the patient, discussing what to expect in the operating room prior to anesthesia. This is tempered by his insight, age and mentality. Premedication consists of a barbiturate, meperedine, and promethazine in dosage according to the patient's age, weight and estimated reflex excitability, keeping in mind the response to previous medica-

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tions at the time of cardiac catheterization. The first 31 patients received a belladonna derivative (atropine or scopolamine). Currently these drugs are not administered to patients undergoing cardiopulmonary bypass at our hospital.

Anesthesia in adults and older children was induced with a hypnotic dose of 2.5 per cent sodium thiopental. Oral endotracheal intubation is accomplished while the patient is under an apneic dose of 0.2 per cent succinylcholine chloride administered by continuous intravenous drip. Anesthesia is maintained with a flow of 6 liters of nitrous oxide and 2 liters of oxygen aided by a muscle relaxant. In the present series the first 17 cases received intermittent doses of *d*-tubocurarine chloride, while the last 33 patients were given a continuous intravenous drip of 0.2 per cent succinylcholine chloride. A Fluotec vaporizer was used in the last 23 cases to administer 0.25 to 0.7 per cent halothane as a supplement to nitrous oxide-oxygen mixtures.

Cyclopropane-oxygen or nitrous oxide-halothane-oxygen mixtures are used to induce anesthesia in small children in whom a venipuncture is often difficult. The maintenance period for such children is similar to that used in adults and larger children.

Throughout anesthesia and surgery, the electroencephalogram, the electrocardiogram and the body temperature are monitored continuously with the use of a Twin Beam Cambridge Scope and a Yellow Syringe Telethermometer, respectively. In our first 31 cases all efforts were made to maintain normothermia. In the last 19 cases rapidly induced moderate hypothermia [7] was brought about using the Brown-Harrison heat exchanger after the onset of cardiopulmonary bypass.

The blood pressure is taken by the palpatory, auditory, or visual method when the patient is not on cardiopulmonary bypass. When bypass exists, it is no longer obtainable by the usual methods, and at this time we depend upon the electroencephalogram, the patients' color and the size of the pupils to inform us of the patient's general condition.

Before the insertion of the cannulae for bypass, the patient receives an adequate dose of heparin (1.5 mg./kg.) for the prevention of blood coagulation. At the termination of bypass, hexadimethrine bromide (Polybrene) is administered to neutralize the heparin.

Throughout surgery, all blood loss is accurately replaced. This blood loss is continuously measured by weighing sponges and determining the quantity that gathers in the suction bottle. To this is added the estimate of the blood loss which accumulates on the drapes.

Results

Table 1 summarizes the pertinent data in the reported series. There were 5 (10 per cent) deaths during the operative period. It was believed by both surgeons and anesthesiologists, that none of these were anesthetic deaths in the strictest interpretation. The first operative death was case number 9. Potassium citrate was used to arrest cardiac action [8] so as to facilitate repair of mitral insufficiency. At the conclusion of repair, it was impossible to restart cardiac function. This technique for the production of cardiac arrest is no longer used. The second operative death, case number 11, followed repair of an interventricular septal defect. Cardiac exploration revealed pulmonary stenosis and an interauricular septal defect. Following cardiopulmonary bypass, the patient was unable to maintain his own cardiovascular status and in spite of heroic measures, the patient died.

The third operative death occurred in case number 18, which is also listed as case number 4, since the patient came to surgery on two occasions. At the first operation, the lesion that was felt to be an infundibular pulmonary stenosis, was corrected by an ivalon patch placed in the pulmonary outflow tract. In the months following discharge from the hospital, the presence of a pulmonary artery aneurysm was diagnosed. This was corrected at a second operation and, at the conclusion of cardiopulmonary bypass, the patient was unable to maintain her own cardiovascular status and again, heroic measures failed. Post-mortem examination revealed a tetralogy of Fallot. This case emphasizes the surgeons dependence on a correct interpretation of the findings at cardiac catheterization.

TABLE 1

PERTINENT DATA ON FIFTY CONSECUTIVE CASES OF OPEN HEART SURGERY WITH CARDIOPULMONARY BYPASS

Case Number	Age	Lesion	Physical Status	Perfusion Time (minutes)	Bypass Temperature (degrees Centigrade)	Result
1	7	PS	2	29	37.0	Improved
2	36	IASD	2	40	37.0	Expired ten days
3	4	IASD	2	30	37.2	Improved
4 (18)	26	PS	3	46	36.8	Seemed to improve
5	44	IASD	2	33	37.4	Improved
6	6	IASD	2	39	37.6	Improved
7	39	IASD	3	47	36.6	Improved
8	38	PS	3	38	37.0	Improved
9	32	MI & MS	3	98	36.8	Expired on table
10	38	IASD	2	26	37.0	Improved
11	16	IVSD	3	117	36.2	Expired on table
12	5	Tetralogy	3	95	37.0	Improved
13	39	IASD	2	61	36.6	Improved
14	36	MI & MS	2	119	34.5	Improved
15	37	IASD	3	88	37.0	Improved
16	20	PS	2	35	36.6	Improved
17	5	IVSD	2	65	37.4	Died 20 hours postoperative
18 (4)	28	Tetralogy (post-mortem diagnosis)	3	106	37.0	Expired on table
19	4.5	AS	2	110	37.0	Improved
20	47	IASD	2	41	37.0	Improved
21	5	Tetralogy	2	91	37.0	Improved
22	28	PS	2	54	37.0	Improved
23	52	IASD	3	37	37.0	Improved
24	28	MI & MS	3	117	37.0	Improved
25	2.5	Tetralogy	2	76	36.8	Died 15 hours postoperative
26	43	MI & MS	2	54	37.0	Improved
27	53	AS	3	47	37.0	Improved
28	27	MI & MS	3	56	37.0	Improved
29	52	MI & MS	3	54	37.0	Improved
30	35	Tetralogy	3	91	36.8	Improved
31	57	AS	2	58	37.0	Improved
32	50	MI & MS	3	61	35.5	Died 3 days postoperative
33	46	MI & MS	2	61	35.5	Died 4 days postoperative
34	40	MI & MS	3	58	32.5	Improved
35	43	AS	2	91	33.5	Improved
36	32	MI & MS	3	94	30.5	Improved
37	50	MI & MS	3	113	31	Improved
38	50	MI & MS	3	94	31	Improved
39	47	MI & MS	3	210	26	Died on table
40	52	AS	3	101	30	Improved
41	6	Tetralogy	3	83	33	Improved
42	55	AS	3	97	32	Died on table
43	38	MI & MS	2	98	31	Improved
44	13	Tetralogy	2	84	31	Improved
45	20	PS	1	28	34.5	Improved
46	56	MI & MS	2	62	32	Improved
47	37	MI & MS	3	82	32	Improved
48	54	MI & MS	2	78	31.5	Improved
49	43	IASD	2	38	32	Improved
50	50	IASD	2	54	31.5	Improved

PS = Pulmonary stenosis. IASD = Interauricular septal defect. MI & MS = Mitral insufficiency and mitral stenosis. IVSD = Interventricular septal defect. AS = Aortic stenosis. Tetralogy = Tetralogy of Fallot.

TABLE 2

LISTS THE TYPE AND NUMBER OF EACH LESION DONE AND THE NUMBER AND PERCENTAGE OF MORTALITY

Lesion	Number of Cases	Died at Operation	Mortality in Hospital of Those Surviving Surgery	Over-all in Hospital Mortality
Mitral insufficiency and stenosis	17	2	2	4 (23.5%)
Interauricular septal defect	12	0	1	1 (8.3%)
Pulmonary stenosis	6	0	0	0 (0%)
Tetralogy of Fallot	8	2	1	3 (37.5%)
Interventricular septal defect	1	0	1	1 (100%)
Aortic stenosis	6	1	0	1 (16.6%)
Total	50	5	5	10 (20%)

A fourth operative death occurred in a patient with mitral stenosis and insufficiency, case number 39, in whom moderate hypothermia had been planned in anticipation of aortic occlusive cardiac arrest to facilitate mitral plasty. However, the electroencephalogram became markedly depressed with the onset of cardiopulmonary bypass and her temperature was rapidly lowered from 36.5 C to 26 C over a ten-minute period. The patient was subsequently rewarmed after sixty-one minutes of continuous aortic occlusion at hypothermic levels and, with the rewarming, cardiac action gradually became satisfactory. However, an irreversible ventricular fibrillation developed as the chest was being closed. No post-mortem examination was done.

The fifth fatality, case number 42, occurred in a patient with aortic stenosis. The patient's temperature was lowered to 32 C with the onset of cardiopulmonary bypass, to protect the brain which was inadequately perfused as indicated by a severely depressed electroencephalogram. The aorta was subsequently clamped for forty-two consecutive minutes. When the clamp was released, an irreversible ventricular fibrillation followed. Post-mortem examination revealed a massive right ventricular infarct. It is difficult to say when this complication occurred. However, up to the time of occlusive arrest, the electrocardiogram was consistent with left ventricular hypertrophy which had been present preoperatively.

Of the 45 patients surviving surgery, 5 (11 per cent) died during their hospital stay. Thus, we have an over-all in-hospital mortality of 20 per cent. The first postoperative death occurred ten days after surgery in a 36 year old patient, case number 2, who had undergone a repair of an interatrial septal defect. At this time the patient gradually developed pulmonary edema and died. Post-mortem studies revealed that the sutures had pulled out of the defect which had been closed without the use of an ivalon patch. Case number 17 was the second postoperative death. The patient was a five year old child who had undergone an uneventful repair for an interventricular septal defect. The patient died suddenly twenty hours postoperatively and post-mortem examination was completely negative. Case number 25 had a similar course, expiring one and a half hours postoperatively after an uneventful correction of a tetralogy of Fallot.

A fourth postoperative death, case number 32, occurred on the third postoperative day in a patient with mitral stenosis and regurgitation associated with an undiagnosed aortic regurgitation. This patient complained of severe abdominal pain in the presence of a soft nonsurgical abdomen. His condition gradually deteriorated and he died. Post-mortem examination again was negative except for his cardiac lesions.

The fifth and final postoperative death in this series, occurred in case number 33 following repair of mitral stenosis and regurgitation. This patient never regained consciousness postoperatively and cerebral embolization was suspected. This was confirmed at post-mortem examination wherein multiple cerebral and renal infarcts were found. These prob-

ably resulted from calcific emboli arising from the calcified mitral valve. Table 2 summarizes these results.

An interesting complication, not previously recorded in the literature as far as we know, was the development of alopecia areata in 8 patients (20 per cent) at the site of the insertion of the fronto-occuptil needle electrodes of the electroencephalogram. The hair started to fall out two to three weeks postoperatively and this process was usually complete in four weeks. Regrowth began four weeks after a complete bald spot appeared and within three months, complete regrowth occurred. No permanent alopecias resulted. One male, whose frontal area was bald before surgery, grew a small lock of hair at the site of insertion of the frontal electrode.

Two patients, case numbers 35 and 47, had permanent left sided Horner's syndromes after recovery from anesthesia. This probably represented surgical interruption of the sympathetic nerve supply to the brain. Case number 35 had a sternal splitting incision with femoral artery cannulation, while case number 47 had a lateral incision with subclavian artery cannulation.

All patients have been in a respiratory alkalosis at the conclusion of the cardiopulmonary bypass as indicated by elevation of the *p*H and a depression of arterial P_{CO_2}. One patient developed homologous serum hepatitis postoperatively. Five patients had a rise in their total serum bilirubin; however, only one of these developed a clinically detectable jaundice which was of short duration. Postoperatively, free plasma hemoglobin levels have been within normal limits except in one patient, case number 6, whose free plasma hemoglobin level rose to 600 mg. per cent during the first postoperative day and then gradually returned to normal. His serum bilirubin surprisingly did not rise, nor did he become clinically jaundiced. Urine output in all survivors has been considered satisfactory in the postoperative period.

Comments

Since the publication of the preliminary report [5] of the experiences gained in the anesthetic management of patients undergoing open heart surgery using cardiopulmonary bypass, changes have occurred that are related to the clinical situation. Thus, this paper describes the actual methods used at the present time and does not attempt to delineate future changes. It is quite certain that even these changes in method may later be surpassed by further advances in open heart surgery with cardiopulmonary bypass. A dynamic attitude must be maintained in order to take advantage of all future knowledge so that such advances can be applied to present techniques, especially wherein simplification and better anesthetic management can be achieved.

The use of a belladonna drug as part of the patient's premedication was discontinued in an effort to overcome any cause for tachycardia. These patients coming to surgery without atropine or scopolamine, have not produced secretions to any extent and vagal reflexes have not been a problem. We have not encountered any ill effects due to the lack of a belladonna drug in premedication and the slower heart rate is of marked help to the surgeon.

With the experience gained employing halothane in patients undergoing other types of surgery and after reviewing the report of Dawson,[9] it was decided to use this agent in our series. Halothane offered the advantage of nonexplosibility and supplemented nitrous oxide. The addition of halothane also helped to reduce the amount of the muscle relaxant needed for surgery and thus reduced the possibility of a prolonged apnea. The use of halothane, as described in this series, turned out to be an excellent choice and none of the untoward effects frequently ascribed to halothane were noted.

Another innovation was the replacement of *d*-tubocurarine chloride by succinylcholine chloride. The quantity of succinylcholine chloride has always been kept at a minimum. In patients of poor physical status, with reduced metabolic processes, agents which are not easily removed from the body must be administered judiciously. Our technique was most successful in preventing depressed patients postoperatively.

The pharmacological advantages of hexadimethrine bromide over protamine were noted

and this drug has now been used to return the normal clotting mechanism after heparinization. Cardiovascular collapse or other vagovagal reflexes attributed to protamine are not a hazard when employing hexadimethrine bromide.

The most important change that has taken place since the first series, was the use of moderate hypothermia [7] during the time of bypass. There were a number of reasons for this choice of technique, but the most significant one centered on the difficulties encountered with patients during the critical period of going on or coming off bypass. It had been noted frequently in the past that the electroencephalographic derangement at this period was frequently severe enough to occasion concern about hypoxia of the brain. By the use of a rapid, moderate hypothermia,[7] it was believed that the central nervous system would be better protected to withstand hypoxia. This has been substantiated by a smoother course during the bypass period. Moderate hypothermia was likewise of great value in prolonging the period of occlusive cardiac arrest. In this latter technique, the aorta is temporarily cross-clamped and cardiac arrest follows. This period of arrest facilitates the surgical repair upon the heart or its valves. Producing cardiac arrest by this method was much superior to potassium citrate arrest used in case number 9, in that potassium citrate arrest proved irreversible. Restarting the heart under moderate hypothermia and occlusive arrest is accomplished more easily as the heart and the remainder of the patient's body is rewarmed. Temperatures were monitored with the electrode of a telethermometer placed in the rectum, but a multiple 12-channel recording thermometer is now to be used to monitor other parts of the body and perfusing system. This, we believe, will allow more careful control of the patient's temperature for more profound hypothermia in the future.

An incidental finding noted postoperatively in 8 patients was the appearance of a localized alopecia, especially around the area of insertion of the electrodes for electroencephalographic monitoring. This complication is only temporary as the hair eventually grows back. It is believed to be due to an electrolysis occurring at the electrode site and may occur due to interference from the cautery unit. In an effort to avoid this, the electroencephalographic inlet plug is removed from the system whenever the cautery is in use. Interestingly enough, this complication which occurred early in the series has recently reappeared after having been absent for a number of cases. We do not know the explanation for this peculiar sequence at present.

Many laboratory procedures were done in our early cases to help coordinate more closely the patient's condition to the surgical procedure. However, as further experience was gained, some of these procedures were omitted because nothing new was added to our knowledge. It was gratifying in the early part of the series, to see the perfusion system work so efficiently, especially in regard to hemolysis, oxygen and CO_2 studies.[5]

The problem of respiratory alkalosis due partly to a purposeful hyperventilation, has not caused any discernible difficulties. The high oxygen flow rate plus the high output of the pump, probably helped to accentuate the alkalosis. However, patients make a rapid readjustment following the bypass period, and complications from this imbalance have not occurred. We have, for this reason, avoided the use of CO_2 in the atmosphere surrounding the screening or oxygenating chamber.

It is contemplated to use a modified new pump-oxygenator in the future and possibly to add a profound hypothermic state in patients requiring cardiac arrest for the completion of the surgical procedure. Proper studies will be done in the dog laboratory before these changes are incorporated in the clinical management to assure greater efficiency and safety for cardiopulmonary bypass. The problem of obtaining enough donors and compatible blood for each patient are serious enough to consider the use of a pump-oxygenator requiring less blood for priming. The use of profound hypothermia may offer even better protection to the patient under total arrest than is available with the present system. However, until laboratory studies indicate that this goal is attainable with these changes, there will be continued dependence upon the present proved system.

SUMMARY

Anesthetic experiences for open heart surgery using cardiopulmonary bypass have been described in 50 consecutive cases at a community hospital. We believe that procedures of this magnitude are applicable at this level if sincere effort is applied to the problem by all concerned. Experimentation should be avoided and left to those with extensive facilities for such work. The prime purpose at the community hospital level should be operative intervention carried out as expeditiously and safely as possible.

The cases in this series were the private and ward patients of Max G. Carter, M.D., and George L. Wilson, M.D. of the Section of Cardiothoracic Surgery of the Hospital of Saint Raphael.

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HYPOTHERMIA Dogs were cooled to 9–18 degrees centigrade and observed until death. Heparin and glucose infusions were administered without harmful effect. Massive pulmonary edema and atelectasis were noted in dogs who received phenylephrine. Increased blood pressure and increased capillary permeability are possible causes. No other major pathologic changes were observed. (*Caranna, L., Neustein, H., and Swan, H.: Pathologic Changes in Experimental Hypothermia, A. M. A. Arch. Surg. 82: 147 (Jan.) 1961.*)

HYPOTHERMIA Both general hypothermia with crushed ice and focal cooling of the conus area of the right ventricle was studied in dogs and cats. The electrocardiographic changes were observed at frequent intervals. These changes included progressive bradycardia, defective A-V conduction, prolongation of the electrical systole, and a characteristic J deflection at the junction of the QRS and the S-T segment. Ventricular fibrillation was a more frequent occurrence in dogs than in cats. The changes, excluding ventricular fibrillation, proved reversible on rewarming and restoration of normal temperature. Focal cooling of the right ventricle gave rise to a small J wave similar to that seen in general hypothermia. (*Wynne, N. A., Fuller, J. A., and Szekely, P.: Electrocardiographic Changes in Hypothermia, Brit. Heart J. 22: 642 (Nov.) 1960.*)