Reprinted from The Journal of the American Medical Association
November 21, 1953, Vol. 153, pp. 1081-1085

SURGERY BY DIRECT VISION IN THE OPEN HEART DURING HYPOTHERMIA

Henry Swan, M.D., Irvin Zeavin, M.D.
S. Gilbert Blount Jr., M.D.
and
Robert W. Virtue, M.D., Ph.D., Denver

The heart for centuries was suspected of being a delicate organ; the slightest injury was said to be uniformly fatal. Both the great Billroth and Sir Stephen Paget decreed the organ to lie outside the domain of possible surgery. Yet in reality the heart is a compact muscular organ that, by virtue of highly specialized intrinsic properties, functions continuously throughout the lifetime of the individual. It has an extraordinary capacity to adjust to the changing needs of body circulation. Its inner compulsion toward perpetual function is one of the most critical aspects of the life drive of individuals and species. Only when poisoned or deprived of its flow of nutrient requirements will this persistent organ lie still or lose itself in the quivering death of disorganized activity. A great ability to withstand trauma and to adjust to the stresses imposed by intrinsic disease emphasizes its essential vitality. Given half a chance, the heart will beat.

In the period from 1895 to 1913, Di Vecchio, Haecker, Schepelmann, Elsberg, and Carrel, as well as many others, showed in the experimental laboratory that the heart could withstand surgical trauma and that many complex operative procedures could be performed with relative safety. The main principles of cardiac surgery were well demonstrated and established. The medical tradition of centuries, however, could not be so easily set aside—the heart was delicate and should not be touched!

This study was aided by a grant from the United States Public Health Service.

From the departments of surgery and medicine, University of Colorado School of Medicine.

Accordingly, for 25 years the treatment of acute trauma was the only clinical application of this knowledge. In 1938, an event of great import occurred. Pediatrician John Hubbard, of Boston, requested Robert Gross to operate on a child suffering from a patent ductus arteriosus. The successful repair of this congenital "heart" lesion provided the stimulus that has since resulted in the general recognition that the heart is not unique among the organs of the body: it is amenable to surgical therapy.

REVIEW OF SURGICAL PROCEDURES

For the past 15 years in the surgical laboratories and clinics both in the United States and abroad, the principles underlying cardiac surgery have been reexplored and the human application of these techniques has been gradually expanded. In almost all instances, however, these operations have been performed by closed methods; that is to say, the maneuvers within the heart have been done blindly, guided only by the "feel" of the palpating finger. This type of procedure, while often effective, is at best a compromise. To obtain an unimpeded view of the operative field is a fundamental principle of surgery. Adequate exposure for direct vision is an essential component of every safe surgical procedure. In this regard, the interior of the heart has offered some special technical difficulties. Operations on the pericardium, neighboring great vessels, or the exterior of the heart chambers can be easily visualized. The necessity of maintaining circulation during operative maneuvers inside the heart, however, has led investigators to seek the solution of this interesting problem down two separate avenues of study.

The first and more obvious method, of course, was to provide a mechanical pump to furnish the driving force for the blood and then to remove temporarily the heart from the circulation. Either a single pump or two pumps in association with an oxygenator (the animal's own lung, a homologous lung, or a mechanical device) could be utilized, depending on whether one wished to open one or both sides of the heart and depending on whether defects existed in the cardiac septums. This approach to

the problem has been vigorously pursued in many laboratories, and recently a few clinical applications have been made.

The technical difficulties associated with this method are great. The instruments are costly and complex and require many skilled persons to use them. A major operative procedure is required to attach the machine to, and later remove it from, the patient's circulatory system, necessarily adding to the magnitude of the total operation and to the postoperative morbidity. The blood of the patient must be heparinized and its capacity to clot later restored with protamine. Overloading of the circulation must be avoided. Hemolysis and air embolism are hazards. Blood flows from the coronary vein into the right auricle and obscures the operative field unless special suction techniques are applied to the sinus. Even so, blood from the thebesian veins on the right and blood from the bronchial artery, via the pulmonary veins, on the left, appear to constitute inescapable flows. At its very best, then, the pump-oxygenators have not yet produced a dry field in which to operate, although the degree of blood flow may be compatible with intermittent visual operative maneuvers. The solutions to many of these problems associated with extracorporeal circulations have been found; others will also be solved; but the inherent characteristics of the technique seem unlikely to change. These adverse characteristics are (1) its complexity and expense, (2) the material increase in the magnitude of operation, and (3) its failure to provide a dry field for operation.

The other avenue of approach to the open heart has been the attempt to lower the metabolism of the patient until circulation can be interrupted for periods of time long enough to allow deliberate and extensive intracardiac maneuvers. It must be remembered that interruption of circulation experimentally was early utilized by Haecker, Schepelmann, and Carrel, and its limitations were explored. In the normal animal, two to three minutes appeared to be the maximum allowable time before cardiac or cerebral damage occurred. This technique has

recently been used clinically in a few instances,[1] but the need for longer periods of exposure has sharply limited the magnitude of the procedures that could be performed.

To Bigelow [2] and Boerema [3] must go the credit for the conception and demonstration that general hypothermia can be employed to allow cessation of circulation for as long as fifteen minutes in the dog. Since their initial reports, study of the modality of cold has been made in many laboratories. The risks appeared to be high when cooling was associated with interrupted circulation and the open heart. In Bigelow's original series, only 15% of the dogs survived. In the later studies of Lewis and Taufic [4] and of Cookson and co-workers,[5] the mortality was better but still high. The lethal complications were primarily related to two phenomena: ventricular fibrillation and coronary air embolism. To make the use of hypothermia safe for open cardiac procedures, these two complications must be effectively prevented or managed. Unfortunately, in one clinical trial made prior to the series reported herewith, the mortality was high (about 73%).[6] Much of this mortality was due to the desperate nature of the lesions treated, but some was due to the complications of hypothermia with arrest of circulation. In another series, successful closure of interauricular septal defect was achieved in three of six patients.[7]

---

1. Varco, R. L., in discussion on Muller, W. H., and Longmire, W. P., Jr.: Surgical Treatment of Cardiac Valvular Stenosis, Surgery **30**: 42, 1951. Swan, H.; Forsee, J. H., and Goyette, E. M.: Foreign Bodies in Heart, Ann. Surg. **135**: 314, 1952.

2. Bigelow, W. G.; Callaghan, J. C., and Hopps, J. A.: General Hypothermia for Experimental Intracardiac Surgery, Ann. Surg. **132**: 531, 1950.

3. Boerema, I.; Wildschut, A.; Schmidt, W. J. H., and Broekhuysen, L.: Experimental Researches into Hypothermia as Aid in Surgery of Heart, Arch. chir. neerl. **3**: 25, 1951.

4. Lewis, F. J., and Taufic, M.: Closure of Atrial Septal Defects with Aid of Hypothermia: Experimental Accomplishments and Report of One Successful Case, Surgery **33**: 52, 1953.

5. Cookson, B. A.; Neptune, W. B., and Bailey, C. P.: Hypothermia as Means of Performing Intracardiac Surgery Under Direct Vision, Dis. Chest. **22**: 245, 1952.

6. Downing, D. F.; Cookson, B. A.; Keown, K., and Bailey, C. P.: Hypothermia in Cardiac Surgery, exhibit at the American Medical Association Meeting, New York, June, 1953.

7. Lewis, F. J.: Personal communication to the authors.

EXPERIMENTAL STUDY

On the basis of extensive experimental evidence, together with clinical experience in 15 patients, we believe that hypothermia in association with cessation of circulation may now be performed with a degree of safety that warrants a more extensive clinical trial. In our standard experimental situation, a dog was anesthetized with veterinary pentobarbital (Nembutal) and cooled in ice water to a temperature of 20 to 25 C. Thoracotomy was performed; flow of blood into the heart was occluded for 15 minutes, during which time a right auricular cardiotomy was performed. No other pharmaceutical agents were employed. Artificial respiration was performed by means of a mechanical respirator with oxygen via an endotracheal tube. After operation the animal was warmed in water at 45 C. A great variety of physiological variables were studied with the hope of unearthing changes that might be related to the incidence of ventricular fibrillation. This work has been reported elsewhere.[8] In essence, however, two changes in body constants appeared related to fibrillation.

The first change was in the concentration of carbon dioxide in the blood (and probably the tissues). On the basis of our work together with that of others,[9] it appeared likely that a sudden fall in carbon dioxide from an abnormally high level toward normal was a fibrillatory stimulus in the dog. By means of hyperventilation to control carbon dioxide accumulation (deliberate respiratory alkalosis) the incidence of ventricular fibrillation in the experimental animal was reduced to a level of about 8%.

The second change was found to be a shift in the locus of potassium. During cooling and hyperventilation a fall in the potassium level in the serum was observed. The exact significance of this change in terms of ventricu-

8. Swan, H.; Zeavin, I.; Holmes, J. H., and Montgomery, V.: Cessation of Circulation in General Hypothermia: I. Physiologic Changes and Their Control, Ann. Surg. **138**: 360, 1953.

9. Miller, F. A., and others: Respiratory Acidosis: Its Relationship to Cardiac Function and other Physiological Mechanisms, Surgery **32**: 171, 1952.

lar fibrillation was not understood, but the well-known importance of this ion in relation to cardiac rhythm led us to investigate the use of potassium as a defibrillatory agent. Previously, in our hands, the use of electric shock had been entirely ineffective as a means of resuscitation of ventricular fibrillation in the hypothermic animal. We now found, however, that by means of a potassium chloride solution injected into the coronary circulation we could routinely defibrillate the cold dog's heart and restore normal rhythm.

On the basis of these two phases of the study we felt that ventricular fibrillation complicating hypothermia could be largely prevented; even if it occurred, an effective means of resuscitation was available. The other chief source of worry was related to the prevention of coronary air embolism. Extremely small volumes of air entering the coronary arteries are capable of causing myocardial ischemia and death. If the cardiac septums are intact and air enters the right side of the heart, a considerable volume may escape into the pulmonary circulation without lethal effect. Air admitted directly into the left side of the heart or indirectly via a right-to-left opening, such as a septal defect or pulmonary arteriovenous fistula, constitutes an immediate threat to life even if small amounts should escape into the aorta. For this reason, great care must be exercised to prevent this occurrence during open cardiac operations. On the basis of experience with the experimental creation of auricular septal defects, with the use of an open approach through the right auricle in the warm animal, a technique was developed to prevent this catastrophe.[10] Accordingly, in both our experimental and our clinical experience using hypothermia, this complication did not occur.

Surgeons who have had the opportunity to watch valvular function in the open beating heart are impressed with the dual phase of the act of closure of the atrioventricular valves. The first phase appears to be muscular

10. Swan, H.; Maresh, G.; Johnson, M. E., and Warner, G. W.: Experimental Creation and Closure of Auricular Septal Defects, J. Thoracic Surg. **20**: 542, 1950.

and involves an actual narrowing of the ring at the base of the valve. The second phase is hydrodynamic and requires the presence of sufficient fluid within the ventricle to swing the valve leaflets into the position of effective closure. If the ventricle is filled with air, the second phase does not occur, and the valve remains partially open. Under these circumstances, the ventricle develops no head of pressure to open the outflow valves and there is no forward propulsion of either fluid or air; the aortic and pulmonary valves remain closed.

The importance of these observations in terms of air embolism to coronary arteries is obviously great. Air embolism is unlikely to occur during the period when the heart is open. The dangerous moment occurs immediately after closure of the myocardial incision and the return of blood flow. Air trapped in the heart may now be propelled forward into the peripheral or pulmonary circulations. One of the prime means of prevention, therefore, is to remove all air from the heart before closure of the myocardial incision.

The technique evolved may be described as follows. Inflow of blood into the heart is stopped by occlusion of the venae cavae. About one minute is allowed for the beating heart to partially empty itself and the pulmonary circuit. A noncrushing clamp is now placed across the aorta and pulmonary arteries at their point of exit from the ventricles. It is our intent that this clamp should actually occlude the orifices of the coronary arteries as an added means of precaution. That it does so has been demonstrated experimentally by dye injection techniques. Movement of fluid through the exit valves of course ceases at this moment. The heart is now opened, allowing the residual blood to escape and air to enter. The operative procedure is performed within the allotted time limit. Just before closure of the heart incision, the chest cavity is rapidly flooded with Ringer's solution until the entire heart lies under water. As it beats, the air escapes through the cardiac incision that lies uppermost as the Ringer's solution fills the chambers. After a few beats, it can be clearly seen that no more air is bubbling up from the heart. A second noncrushing clamp is then applied (un-

der water) to the cardiotomy incision, closing the heart. The clamp across the aorta and pulmonary artery is now removed. The superior vena cava is released and blood flow allowed to resume. After about 30 to 60 seconds, when the heart seems to be tolerating its work load again, the inferior vena cava is released and total circulation is resumed. The cardiotomy may now be closed with deliberation. It is important not merely to try to fill the heart with Ringer's solution but to completely immerse the heart in the solution, just as one would submerge a sponge in a bucket.

REPORT OF CASES

CASE 1.—The patient was an 11-year-old cyanotic white boy who weighed 74 lb. (33.6 kg.). The clinical diagnosis of isolated pulmonic stenosis with patent foramen ovale was confirmed by catheterization. On Jan. 9, 1953, hypothermia was induced with the patient under thiopental (Pentothal)-cyclopropane-ether anesthesia. After 37 minutes, when his body temperature was 34 C, he was removed from the ice water. His lowest temperature was 28 C. A standard transventricular pulmonary valvulotomy was accomplished without circulatory occlusion. All observers agreed that the heart was unusually stable throughout the procedure. The patient had an uncomplicated convalescence.

CASE 2.—A 12-year-old white girl, who weighed 60 lb. (27.2 kg.), had cyanotic congenital heart disease due to transposition of the great vessels with an interauricular septal defect. A previous shunt operation had been done four years previously with improvement but had closed during the preceding year. At operation on June 9, 1953, hypothermia was induced with the patient under thiopental-cyclopropane-ether. After 35 minutes she was removed from the ice water, with a body temperature of 31 C. Her lowest temperature was 26 C. An intrapericardial anastomosis between the ascending aorta and right pulmonary artery was accomplished without arrest of circulation. The heart was very stable throughout. The patient had an uneventful convalescence.

CASE 3.—The cyanotic congenital heart disease of an 8-year-old white boy, who weighed 63 lb. (28.6 kg.) was confirmed by catheterization to be isolated valvular pulmonic stenosis. At operation on Feb. 19, 1953, hypothermia was induced with the patient under thiopental-cyclopropane-ether anesthesia. After 44 minutes he was removed from the ice water, with a body temperature of 39 C. His lowest temperature was 25.2 C. Circulatory arrest was accomplished by complete cardiac inflow occlusion for 7.5 minutes. Partial excision of the

stenosed pulmonic valve was accomplished under direct vision through an incision in the pulmonary artery. Auricular fibrillation occurred during cooling but disappeared on rewarming to 27 C. The patient had an uneventful convalescence.

CASE 4.—The patient was a 7-year-old white boy who weighed 51 lb. (23.1 kg.). Cyanotic congenital heart disease was diagnosed as probable infundibular pulmonic stenosis associated with tetralogy of Fallot. Hypothermia was induced with the patient under thiopental-cyclopropane-ether anesthesia. After 37 minutes he was removed from the ice water, with a body temperature of 30 C. His lowest temperature was 23.6 C. Circulatory arrest was accomplished by complete cardiac inflow tract occlusion for 2.1 minutes. The patient was found to have pulmonic valvular stenosis as part of the tetralogy. Half of the stenotic valve was excised under direct vision. Auricular fibrillation occurred during cooling and disappeared when the patient was rewarmed to 26.5 C. Convalescence was uneventful.

CASE 5.—The cyanotic congenital heart disease of an 8-year-old white girl, who weighed 66 lb. (29.9 kg.), was established by catheterization to be isolated valvular pulmonic stenosis. At operation on March 10, 1953, hypothermia was induced with the patient under thiopental-cyclopropane-ether anesthesia. After 39 minutes she was removed from the ice water, with a body temperature of 30 C. Her lowest temperature was 25.7 C. Circulatory arrest was accomplished by complete cardiac inflow occlusion for 2.5 minutes. Pulmonic valvuloplasty by incision in three places was performed under direct vision. Auricular fibrillation occurred and disappeared when the patient was rewarmed beyond 26 C. Convalescence was uneventful.

CASE 6.—The patient was a 9-year-old white boy who weighed 66 lb. (29.9 kg.). The clinical diagnosis of isolated pure pulmonic stenosis was confirmed by catheterization. At operation on April 14, 1953, hypothermia was induced with the patient under thiopental-cyclopropane-ether. After 35 minutes he was removed from the ice water, with a body temperature of 30.8 C. His lowest temperature was 23.7 C. Circulatory arrest was accomplished by complete cardiac inflow tract occlusion for 2.5 minutes. Pulmonic valvuloplasty by incision in three places was performed under direct vision. Auricular fibrillation occurred and disappeared on rewarming the patient beyond 26 C. Convalescence was uneventful.

CASE 7.—A 26-year-old white woman who weighed 104 lb. (47.2 kg.) had suffered progressive disability from a large interatrial septal defect confirmed by catheterization on two occasions. At operation on April 15, 1953, hypothermia was induced with the patient under thiopental-cyclopropane-ether anesthesia. After 77 minutes she was removed from the ice water, with a body temperature of 29 C. Her lowest tem-

perature was 22.3 C. Circulatory arrest was accomplished by complete cardiac inflow occlusion for 7.5 minutes. The large interatrial septal defect was closed with direct suture. Auricular fibrillation occurred and disappeared when the patient was rewarmed beyond 26.5 C. She was given a smaller transfusion than would have been usual in such an operation because of fear of heart failure. Shock occurring in the recovery room was successfully combated with 1,500 cc. of blood. Convalescence was slow, with shifting arrhythmias that complicated her course. Two months later the heart was smaller, and a great increase in exercise tolerance had occurred.

CASE 8.—The cyanotic congenital heart disease of a 10-year-old white boy, who weighed 70 lb. (31.8 kg.), was established as tetralogy of Fallot by catheterization. At operation on April 21, 1953, hypothermia was induced with the patient under cyclopropane-ether anesthesia. After 45 minutes he was removed from the ice water, with a body temperature of 31 C. His lowest temperature was 24.6 C. Circulatory arrest was accomplished by complete cardiac inflow occlusion for 8.5 minutes. An infundibular stenosis was excised under direct vision. An anomalous coronary artery frustrated attempt at a larger ventriculotomy to repair the interventricular septal defect. Cardiac arrest occurred during the operation but responded immediately to massage. Auricular fibrillation occurred during cooling and disappeared on rewarming the patient. Convalescence was uneventful.

CASE 9.—A 6-year-old white girl, who weighed 41 lb. (18.6 kg.), had suffered progressive disability from a large interatrial septal defect proved by catheterization. At operation on May 5, 1953, hypothermia was induced with the patient under thiopental-cyclopropane-ether anesthesia. After 40 minutes, she was removed from the ice water, with a body temperature of 29 C. Ventricular fibrillation was noted four minutes later, and cardiac massage was instituted rapidly. Defibrillation was performed with 0.5 mEq. of potassium chloride perfused into the coronary arteries. Her lowest temperature was 22.6 C. Circulatory arrest was accomplished by complete cardiac inflow occlusion for five minutes. A large interatrial septal defect was closed by direct suture. Cardiac arrest occurred after partial closure of the pericardium. Massage and intracardiac injection of 2 cc. of 2% calcium chloride were effective in restoring normal rhythm. Convalescence was uneventful except for temporary bilateral peroneal palsy of unknown cause.

CASE 10.—Isolated pulmonic valvular stenosis without cyanosis was confirmed in a 3-year-old white girl, who weighed 34 lb. (15.4 kg.), by catheterization. On June 12, 1953, hypothermia was induced with the patient under vinyl ether (Vinethene) and ethyl ether anesthesia. After 23 minutes she was taken from the ice water, with a body temperature

of 30 C. Her lowest temperature was 25.5 C. Circulatory arrest was accomplished by complete cardiac inflow occlusion for 2.17 minutes. Incision of the thick stenosed pulmonic valve was done in two places under direct vision, forming a bicuspid valve. The patient had an uneventful convalescence.

CASE 11.—The patient was a 4-year-old boy who weighed only 26 lb. (11.8 kg.). His interauricular septal defect with tricuspid regurgitation had produced a very large heart bordering on failure, in spite of digitalis therapy during the past two years. At operation on June 18, 1953, hypothermia was induced with vinyl ether-ethyl ether anesthesia. After 19 minutes the patient was removed from the ice water, with a body temperature of 29 C. His lowest temperature was 21.5 C. Technical repair of the septal defect was accomplished satisfactorily with seven minutes of inflow tract occlusion. The heart went into standstill during occlusion and shortly afterward into ventricular fibrillation. The patient was warmed to 33 C, while cardiac massage maintained the circulation. The ventricles were defibrillated with potassium. The beat, however, was never vigorous, and the patient died with a dilated failing myocardium.

CASE 12.—The frail stature of a 6-year-old boy, who weighed 40 lb. (18.1 kg.), was due to a large interauricular septal defect, although he had never been in frank heart failure. At operation on June 26, 1953, hypothermia was induced with the patient under thiopental-cyclopropane-ether anesthesia. After 35 minutes he was removed from the ice water, with a body temperature of 28 C. His lowest temperature was 25.5 C. A large interatrial septal defect was sutured under direct vision during occlusion of circulation lasting 6 minutes 15 seconds. Auricular fibrillation reverted to sinus rhythm on return of circulation. The patient's postoperative course was uneventful.

CASE 13.—The patient was a 3-month-old boy who was suffering acute heart failure associated with intense cyanosis. His condition improved with digitalis and oxygen, but three days later jaundice developed, thought to be hepatic in origin. On June 26, 1953, because of his large heart and his failure to improve, he was operated on, with a diagnosis of possible pulmonary valvular stenosis. Hypothermia was induced rapidly with the patient under thiopental-ether anesthesia. After 11 minutes he was removed from the ice water, with a body temperature of 30.8 C. His lowest temperature was 25.6 C. Exploration revealed idiopathic pulmonary hypertension. No therapeutic procedure was attempted. Immediate recovery was satisfactory, but the patient subsequently died of his cardiac malformation.

CASE 14.—The cyanotic heart disease of a 28-year-old white mother of 2 children had caused progressive disability for the

preceding two years. Two months before admission a right hemiplegia had occurred. Clinical diagnosis of tetralogy of Fallot was confirmed by angiocardiographic demonstration of infundibular pulmonic stenosis. At operation on July 1, 1953, cardiac standstill occurred after induction and intubation but before cooling was begun. Cardiac resuscitation was accomplished after 2 minutes 10 seconds by thoracotomy and massage. The wound was closed tightly with mattress sutures, and the patient then cooled in ice water for 47 minutes to 31 C. Her lowest temperature was 25.5 C. Cardiac arrest again occurred as the chest was being prepared for draping. The previous wound was rapidly reopened and the heart beat restored by massage at 1 minute 10 seconds. From this point on, the heart beat was remarkably stable. With circulatory arrest lasting five minutes, a tight infundibular stenosis was excised under direct vision through a right ventriculotomy. No attempt was made to close a very small interventricular septal defect. Immediately after the patient's recovery from anesthesia, cyanosis disappeared. The postoperative course was uneventful.

CASE 15.—The patient was a 20-month-old girl who weighed 18 lb. (8.2 kg.). Cyanosis during an upper respiratory infection led to the diagnosis of pulmonic valvular stenosis with patent foramen ovale. Operation was performed on July 9, 1953. Hypothermia was induced with the patient under thiopental-ether anesthesia. After 24 minutes she was removed from the ice water, with a body temperature of 31 C. Her lowest temperature was 27 C. Via an incision in the pulmonary artery, plastic revision and partial excision of the stenotic pulmonary valve was performed during circulatory arrest lasting 3 minutes 50 seconds. The patient's operative course was uneventful, and her immediate recovery was quite satisfactory.

COMMENT

These specific operations were chosen deliberately for the initial experience with human hypothermia, because the existing operations for the diseases treated have left much to be desired. As experience has accumulated in various clinics, it has become increasingly clear that the transventricular incision and dilatation of the stenosed pulmonary valve has given very disappointing objective results.[11] It is true the immediate clinical results are ex-

11. Bing, R.: Personal communication to the authors. Dodrill, F. D.; Gerisch, R. A.; Johnson, A. S., and Hill, E.: Pulmonary Valvuloplasty Under Direct Vision: Aid of Mechanical Right Heart, read before the American Association of Thoracic Surgery, San Francisco, March, 1953. Humphreys, G. H.; Powers, S. R.; Fitzpatrick, H. F., and Lanman, B. M.: Pulmonary Valvular Stenosis: Clinical and Physiologic Studies of 25 Cases Treated by Valvulotomy, read before the Meeting of Society for Vascular Surgery, New York, May, 1953.

cellent. But surgeons who have studied, by actual measurement, the residual right ventricular pressure weeks or months following operation in these same patients have found a disturbing number in whom this pressure is still markedly elevated, that is, a systolic pressure of 70 mm. Hg or more. This is a level approximately three times normal, and, although it is lower than it was preoperatively, it is still pathologically elevated. One cannot predict a normal life span for such a patient. It seems desirable, therefore, to attempt a more complete plastic revision of the valve, a maneuver easily made possible by the direct vision technique.

Resection of infundibular stenosis blindly with rongeurs has not appealed to many surgeons. Resection of a precise area under direct vision associated with the additional possibility of closing the ventricular septal defect in tetralogy of Fallot offers the potentiality of actually curing the patient of his intracardiac defects. Clearly, if the procedure is feasible and safe, this would be an objective superior to the addition of a shunt. Resection of the stenosis is not unduly difficult, but closure of the septal defect may prove more arduous.

The operations currently available for interauricular septal defects are all blind manipulations and carry a significant operative risk.[12] Certain types of defects, particularly septum primum lesions overlying the valves, are not amenable to treatment by these methods. An open operative approach to this problem seems worthy of trial.

To date, we have used cooling with cessation of circulation primarily in children, only two patients having been adult. There is good experimental evidence that the young tolerate this procedure with greater safety than the older age group. We hope to establish the safety of the procedure in this younger age group before proceeding to expand slowly into adult ranges.

---

12. Gross, R. E.; Watkins, E., Jr.; Pomeranz, A. A., and Goldsmith, E. I.: Method for Surgical Closure of Interauricular Septal Defects, Surg., Gynec. & Obst. **96**: 1, 1953. Swan, H.: Surgical Closure of Interauricular Septal Defects, J. A. M. A. **151**: 792 (March 7) 1953. Bailey, C. P., and others: Congenital Interatrial Communications: Clinical and Surgical Indications with Description of New Surgical Technique: Atrio-Septo-Pexy, Ann. Int. Med. **37**: 888, 1952.

We believe it is desirable to cool the patients as rapidly as possible, perform the procedure, and then warm to near normal temperatures at once. Cardiac irregularities occur with great frequency in these sick hearts at levels below 28 C. Auricular fibrillation, although common in the human patient, is not a matter of great concern, because, in our experience, if it occurs during cooling, a sinus rhythm will always return at approximately the same temperature during rewarming. Ventricular fibrillation has occurred twice but was successfully reverted on both occasions by the use of potassium. In one patient, however, sustained spontaneous beat could not be subsequently obtained, we believe, because of cardiac dilatation and myocardial failure. This was the only operative death in the series.

The importance of an adequate exposure of the heart and great vessels for this type of procedure must be emphasized. It is essential that all sides of the heart, the superior and inferior venae cavae, the ascending aorta and pulmonary artery, and the lung roots be readily reached. For this, in our experience, there is no incision equal to the bilateral transverse sternal-cutting intercostal incision in the fourth interspace. Although long, the incision involves the removal of no part of the thoracic skelton, is well tolerated by the patient, and heals quickly, with minimal postoperative discomfort.[2]

SUMMARY AND CONCLUSIONS

Fifteen patients have undergone cardiac operations while they were in a state of hypothermia, with body temperatures ranging from 21.5 to 26 C. In 13 of these patients, circulation was stopped for periods varying from 2 to 8½ minutes, and the operation was performed in the open heart under direct vision. There was one operative death in this group. The remainder of the patients have had excellent clinical results, save one on whom no therapeutic procedure could be performed.

Hypothermia was induced during anesthesia by immersing the patient in a tub full of ice water; warming was also achieved in the tub with warm water. Speed of cooling depended largely on body build; the less obese

patients cooled more rapidly. Prevention of shivering and hyperventilation were very important aspects of the cooling technique. Potassium appeared to be a valuable agent for combating ventricular fibrillation in the cold patient. The prevention of coronary artery air embolism was of great importance and was achieved by a combination of maneuvers, of which one of the most important was complete immersion of the heart in salt solution at the time of closure of the cardiotomy.

Direct vision intracardiac surgery should be further explored and possibly expanded in scope, since cessation of circulation in the presence of hypothermia allows an essentially bloodless field, with reasonable safety for periods up to at least eight minutes. It is surprising how much can be deliberately accomplished in this period of time. Various forms of pulmonic stenosis in nine patients and interauricular septal defects in four have been successfully repaired by this technique. Other stenotic or regurgitant valve lesions and defects of the ventricular septum may also prove to be amenable to therapy.

4200 E. 9th Ave. (7) (Dr. Swan).

Printed and Published in the United States of America