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Hypothermia for Open Heart Surgery

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THE SUCCESSFUL DEVELOPMENT within five years of two different technics for performing operative manipulations within the open heart has been a surgical achievement of real magnitude. Both hypothermia and cardiopulmonary bypass can now be said to be technics of proven merit. Both have advantages and disadvantages, and both have clearly definable limitations. It would appear, at the present time, that the surgeon should be familiar with both technics in order to offer the cardiac patient the lowest possible risk, employing one or the other for specific operative problems. Both methods are in frequent use in our own clinic. Since hypothermia was clinically successful before the pump-oxygenator, this modality through familiarity has reached a stage of safety which the latter technic has yet to achieve. It is the purpose of this communication to discuss the dangers which have been successfully overcome and the limitations which must be applied in order to make circulatory arrest during hypothermia a technic essentially without risk.

At the University of Colorado, research in the field of hypothermia was stimulated by the report of Bigelow[1] in 1950. Our first studies in the laboratory,[2] and our subsequent clinical experience[3] emphasized to us that risks of hypothermia lay in several different quarters, but as our experience has increased, and as the limitations of the technic have been painfully learned from experience, a methodology has emerged which, we believe, can be applied to produce an intrinsic risk approaching zero.

Twelve precautions and limitations which we believe to be of real significance are as follows:

1. The temperature range employed is 30° to 32° C., rectally. This is the lowest level reached after drift. Every effort, including use of diathermy, is made to prevent the temperature from falling below 30° C.[4]

2. Cooling is external, by immersion in ice water. The patient, premedicated by demerol or barbiturate and *small* doses of scopolamine (not morphine or atropine), is anesthetized to the second surgical plane with ether. He is then immersed in a tub containing lukewarm water. When all vital signs appear stable, cubes of ice (about 50 to 75 pounds) are added to the tub. The water is constantly stirred. An adult may take 20 to 25 minutes, a small child 8 to 12 minutes, to cool to 34° C., at which temperature he is removed to the operating table. The end temperature will usually be about 30° to 30.5° C. with this method.[5]

3. Throughout the induction, the course of cooling, the operation, and the recovery period, deliberate respiratory alkalosis is maintained by hyperventilation.[6]

4. Throughout the entire course of the procedure, a constant drip of 5 or 10 per cent dextrose is maintained at 30 to 40 drops a minute. A deliberate

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hyperglycemia is thus achieved. A beneficial effect of intravenous nutrients on the myocardium during hypothermia now appears to be confirmed.[7]

5. The first two pints of blood used for transfusion are freshly drawn, heparinized, in plastic bags. The presence of platelets, fibrinogen, and other enzyme elements of the clotting mechanism, together with absence of citrate, are considered to be helpful in avoiding the bleeding diathesis formerly seen in hypothermia.[8] A low blood volume is scrupulously avoided, since hypothermia has a deleterious effect in acute hemorrhage.[9]

6. A bilateral sternum-splitting incision is used in every patient. Good exposure of the entire heart is always desirable.[10]

7. The patient is very carefully positioned so that the cardiotomy will be the most superior aspect of the heart. Thus, for auricular defect the patient is tipped to the left with head elevated, for pulmonary valve, to the right with head markedly elevated, etc. The air may thus escape from all chambers of the heart through the cardiotomy at the time of retreat from the heart.[11]

8. At the onset of the circulatory occlusion period the heart is slowed by the injection of 1:4000 neostigmine given by coronary perfusion. From one to two mm. of this solution will slow but not stop the hypertrophied hypothermic heart. The heart should stay pink almost throughout the occlusion period. It will resume its beat readily once coronary circulation is allowed.[12-14]

9. The root of the aorta is always clamped (except with aortic stenosis) in order to prevent coronary blood flow during occlusion. This helps prevent coronary air embolism, maintains the bradycardia, and diminishes the coronary return to the heart insuring a dry operative field.[10]

10. The period of circulatory occlusion must not exceed six minutes. If it is apparent that the complete operation cannot be accomplished in this period of time, the procedure should be stopped and escape from the heart effected, bringing out any unfinished sutures. Circulation is restored. After 10 or 15 minutes to allow reestablishment of normal myocardial metabolism, the occlusion may be repeated. At least 10 to 12 safe minutes of intracardiac time may thus be achieved.[15]

11. The patient is warmed by internal heating, namely diathermy, applied to the pelvis. He is breathing spontaneously and beginning to respond before being returned to the recovery room. Careful drying and padding, and intermittent use of the diathermy are essential to avoid skin burns of the sacral area.[5]

12. Postoperative anticoagulants are given to patients who have gross enlargement of the pulmonary vascular bed (atrial septal defect). It is realized that marked slowing of the circulation through the lungs occurs immediately after the closure of a septal defect and the obliteration of the shunt. The volume flow is suddenly diminished, the enlarged vascular bed remains unchanged, so the rate is markedly reduced. No doubt pooling of blood in some areas also occurs. The stage is set for postoperative intravascular thrombosis. Antiprothrombin agents, therefore, are continued for three weeks, then tapered to discontinuance.[16]

With these dozen considerations carefully adhered to, the mortality rate in all types of patients following hypothermia has steadily declined. Analysis of

TABLE 1.—*Progressive Incidence of Significant Cardiac Arrhythmias in 280 Cases of Hypothermia*

	Fibrillation	Died	Standstill	Died
First 100 Cases	15	12	7	1
Second 100 Cases	8	4	1	1
Last 80 Cases	3	1	0	0

earlier cases showed the major risks to be related to cardiac arrhythmias and to alterations in the clotting mechanism, either hemorrhage or thrombosis. Table 1 illustrates the trend of events in relation to significant cardiac arrhythmias. All the patients in the last 80 to undergo ventricular fibrillation had clear-cut causes other than hypothermia, namely coronary air embolism, inadvertent clamping of the right coronary artery, and thrombosis of the right coronary artery. We feel that with our current program ventricular fibrillation due to hypothermia is essentially nonexistent.

Table 2 illustrates the steady improvement that has been achieved in avoiding disturbances in the clotting mechanism. We have come to believe, therefore, that our current precautions are proving effective in eliminating disasters relating to hemorrhage or thrombosis.

The effect of these measures on the over-all mortality rate in the hypothermic patients subjected to open-heart direct-vision procedures is seen in table 3. It is emphasized that this table shows the total mortality rate, not the mortality due to hypothermia per se. A major cardiac operation obviously carries some risk in itself, irrespective of the general modality employed. It is gratifying, however, that the last 48 patients have been operated upon with only a single death.

On the basis of these considerations, it is our feeling at the present time that those cardiac operations which can be done adequately and well under direct vision in 10 minutes of operating time should be done during circulatory occlusion under hypothermia, since the method itself has been demonstrated to be so safe.

Among the congenital lesions for which the open operation fits within this category, the following might be listed as particularly suited to this technic

TABLE 2.—*Progressive Incidence of Clotting Disturbances during or after Hypothermia (280 Cases)*

	Bleeding	Thrombosis	Died
First 100 Cases	4	2	6
Second 100 Cases	3	2	5
Last 80 Cases	2	1	0

TABLE 3.—*Progressive Mortality in All Patients Undergoing Open Heart Procedures during Hypothermia (192 Cases)*

	Died	Rate
First 48	8	16%
Second 48	6	12%
Third 48	6	12%
Fourth 48	1	2%

of reparative surgery: (1) pulmonary valvular stenosis; (2) pulmonary infundibular stenosis; (3) atrial septal defect, secundum; (4) atrial septal defect combined with pulmonic stenosis (trilogy of Fallot); (5) congenital aortic stenosis; (6) pulmonic stenosis combined with aortic stenosis.

Both valvular and infundibular pulmonic stenosis occurring as single lesions yield readily to open plastic repair. The beneficial result of the open operation in restoring normal hemodynamics and eliminating the stenotic obstruction has been shown to be superior to closed methods.[17] Table 4 shows our total cumulative experience with these two lesions. The circulation has been restored essentially to normal in almost all of these patients, and there have been no deaths. With the risk rate so low and the results so satisfactory following open operation during hypothermia, it seems unwise at this time to recommend either a closed procedure or the increased risk of cardiopulmonary bypass for isolated pulmonic stenosis.

Atrial septal defect of the so-called "secundum" variety is a lesion with many intrinsic variations. Aberrant return of one or more pulmonary veins to the right auricle, multiple septal defects, and unusual prominence of the valve of the inferior vena cava are all commonly associated with this lesion. It seems hardly necessary any longer to cite the many obvious advantages of an open technic in the cure of this lesion. In spite of its infinite variety, the lesion can be sutured in such a fashion that the pulmonary veins are transplanted to the left auricle in less than six minutes of open operating time in the majority of instances. In our experience, this can always be accomplished in ten minutes (two-five-minute circulatory occlusions). Thus, the repair of this defect fits within the limitations of the hypothermic technic. Table 5 illustrates our experience with open operation during hypothermia in the treatment of this disease. In view of the fact that the last 46 patients have been cured without mortality, we feel little urge to change to a pump-oxygenator.

The combination of pulmonary valvular stenosis and atrial septal defect (trilogy of Fallot) presents certain special problems. In most instances the patient will be cyanotic, in some cases extremely so. We at first thought that the disease should be treated by operation on the pulmonary valve, thinking that relief of the stenosis alone might be sufficient to effect cure of the symptoms. However, in some patients following this procedure, the cyanosis persists, while in others a large left-to-right shunt through the atrial septal

TABLE 4.—*Results of Direct Vision Repair of Pulmonic Stenosis during Hypothermia (Intact Septa)*

Type	Patients	Cured	Improved	Deaths
Valvular	35	33	2	0
Infundibular	4	4	0	0

TABLE 5.—*Results in Direct Vision Repair of Atrial Septal Defect (Secundum) during Hypothermia*

	Cured	Died	Rate
First 43 Patients	36	7	16%
Last 46 Patients	46	0	0%

defect occurs, resulting in cardiomegaly and even cardiac failure. It is our current policy to perform a curative operation at a single session, first repairing the pulmonary stenosis with the first circulatory occlusion, then closing the atrial septal defect at the second. The results of this policy in the last five patients has been very satisfactory. Table 6 lists our results in the management of this disease. Some of the earlier patients who have had only a single-stage procedure may need a subsequent closure of their atrial septal defect in order to achieve a completely satisfactory result.

Finally, we have been exploring the use of hypothermia as a means of achieving open operation on the aortic valve. The fact that the coronary ostia are exposed to air during the procedure was shown not to be a critical deterrent. Methods for avoiding coronary air embolism under these conditions were developed, and have been published.[18]

In the treatment of both valvular and subvalvular congenital obstruction, and of *early* acquired valvular disease, the open approach has proved to be a satisfactory technic. The results of our experience to date in this endeavor are shown in table 7. To relieve adequately the stenosis, yet not to create insufficiency, is the objective of the procedure. The limitations which must be observed in cutting the commissures of the valve are learned with increasing experience. We are sufficiently pleased with the technic to plan to continue its use. We feel it is much superior in our hands to any blind or digital technics.

To summarize, in the five conditions listed above as being best suited for repair during hypothermia, our experience has comprised 164 patients. Of these, 14 have died, an over-all mortality rate of 8.5 per cent. The current risk rate for isolated pulmonic stenosis and atrial septal defect is apparently less than 2 per cent.

Summary

Hypothermia is now an extremely safe technic for open heart surgery in those conditions in which the reparative procedure can be accomplished in 10 minutes or less. Both the risk and the results are superior to blind procedures for atrial septal defect, pulmonic stenosis, and aortic stenosis. For open opera-

TABLE 6.—*Results of Direct Vision Surgery during Hypothermia in Patients with Trilogy of Fallot*

Patients	Operations	Total Cure	Improved	Died
17	19	7	7	3

TABLE 7.—*Results of Direct Vision Repair of Aortic Stenosis during Hypothermia*

	Patients	Improved	Died
Congenital:			
Valvular	12*	9	2
Subvalvular	3	1	2
Acquired:	4	2	0

*One patient had associated pulmonic stenosis.

tions requiring more than 10 minutes, the currently more dangerous method of cardiorespiratory bypass is required.

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