Hypothermia and Extracorporeal Circulation for Open Heart Surgery: *

Its Simplification with a Heat Exchanger for Rapid Cooling and Rewarming

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The combination of hypothermia and low flow extracorporeal circulation has many theoretical advantages as an adjunct to open heart surgery. This has been confirmed by other reports [16, 22] from the Duke University Medical Center and the laboratory studies of Gollan [7] and Peirce.[15] In early experiences with this combination using surface cooling to induce hypothermia, it soon became evident that ventricular fibrillation was not a serious problem. On the other hand, the inexact, time consuming, and even uncontrollable technic of inducing hypothermia by external cooling was found to be the principal deterrent to the use of the combination. In 1957, Brown, Emmons, and Smith [2] described a safe and efficient blood heat exchanger that could be incorporated into the pump-oxygenator circuit. This instrument permitted precise control of the body temperature making the combination of hypothermia and extracorporeal circulation a practical method of cardiopulmonary bypass. It is the purpose of this report to review the experiences with this technic, to describe the facility of cooling and rewarming, and to relate some of the problems encountered with core induced hypothermia.

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Materials and Methods

The method of achieving cardiopulmonary bypass and hypothermia with a modified DeWall-Lillehei [5] pump-oxygenator containing a heat exchanger in the arterial line has been described in previous reports.[16, 22] The original heat exchanger (Fig. 1) has been found to have adequate heat exchange capacity for moderate hypothermia (30° to 32° C.) in patients of any size but was found to be inadequate for deeper hypothermia in large adults.

Recently, we have used two of our original exchangers coupled in series for deep hypothermia and for all levels of hypothermia in large adults. This device exchanges heat between the blood and circulating water, the temperature of the latter being regulated by a precision mixing valve. When esophageal temperatures of 28° to 30° C. were needed, ordinary tap water was sufficient. If still lower esophageal temperatures were desired, a supplementary system was used to circulate water of 2° to 3° through the instrument. On rewarming, the maximum water temperature used was 43° C.

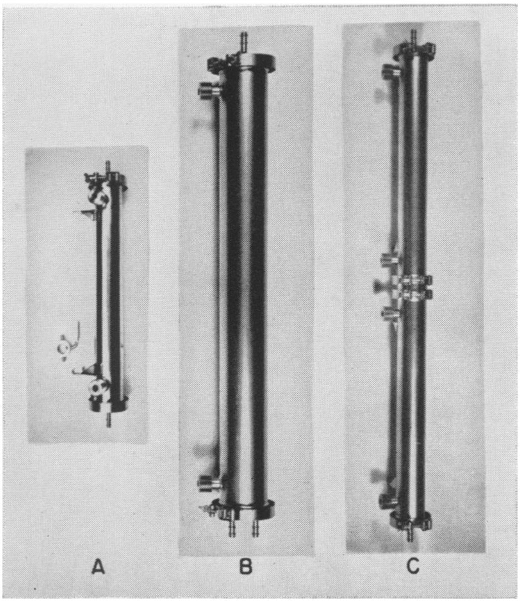

FIG. 1. This is a photograph of the three heat exchangers employed to induce hypothermia during extracorporeal circulation. The Figure A is the first exchanger designed. It has a capacity of 175 cc. and is adequate for small patients or moderate hypothermia. Figure B is a larger instrument but has been discarded because of the large volume of blood (625 cc.) needed to prime it. The instrument in Figure C is two smaller units joined together and is now employed for profound hypothermia.

Cooling and rewarming were achieved just as rapidly as the perfusion rate and the characteristics of the heat exchanger would permit. In all patients, the temperatures were monitored in the midesophagus and midrectum. In some of the patients temperatures were also recorded from the muscles of the thigh and buttocks, brain, the jugular bulb, the inflow arterial blood, and the outflow venous blood both from the superior and the inferior venae cavae. Unless otherwise specified, the temperatures referred to in this report are those in the midesophagus.

Perfusion rates in the pump-oxygenator did not exceed 2,400 cc. per minute for any patient. Patients who weighed less than 30 kg. were perfused at flow rates of 40 to 60 cc. per kg. per minute, while patients who weighed more were perfused at rates of 20 to 40 cc. per kg. per minute.

Connection to the extracorporeal system was through a cannula placed into the femoral artery. Venous return from the superior vena cava was by a cannula introduced through the right auricular appendage. Return flow from the lower part of the body was withdrawn from a large cannula inserted through the sapheno-femoral bulb into the inferior vena cava.

A fronto-occipital lead electroencephalogram and lead 2 of the electrocardiogram were recorded during the entire operative procedure. Arterial samples were obtained from the femoral or radial artery, while mixed venous samples were withdrawn from the common venous outflow lines. The oxygen saturation, pH, CO_2 content were all determined by standard laboratory methods. The blood buffer base was derived from the nomogram of Singer and Hastings.[21]

In those instances where cardioplegia was used, a potassium-magnesium-prostigmine solution was injected into the coronary arteries as described in a previous report.[17] At the completion of the intracardiac portion of the operation and just before final closure of the ventriculotomy wound, the aorta was opened and the rewarming started. In a small group of patients treated recently, cardioplegia was induced by cooling the patients to temperatures between 9° and 20° C.

A list of the various cardiac diseases treated with this combination of techniques are shown in Table 1. In interventricular defects, repair of the larger ones was with compressed Ivalon while the smaller defects were closed by direct suture. In patients with tetralogy of Fallot, the interventricular defects were likewise repaired with a patch of Ivalon. The outflow tract, with one exception, where an Ivalon prosthesis was used, was opened only as much as its anatomical configuration would permit. In all of the patients requiring ventriculotomy, cardiac standstill was employed. For the atrial defects of the secundum type, a right thoracotomy was used and direct closure of the defect carried out. In three of the septum primum defects, it was possible to close them directly, but in the other two it was necessary to use an Ivalon patch. In aortic stenosis, the approach to the valve was through the aorta. The mitral valve was always exposed from the right side, and intermittent aortic occlusion was used whenever there was an associated incompetent aortic valve.

TABLE 1. *Intracardiac Operations Using Extracorporeal Circulation and Heat Exchanger*

No. Pts.	Diagnosis	Deaths
23	Atrial septal defects	0
19	Ventricular defects	3
17	Mitral valvular disease	4
19	Tetralogy of Fallot	4
4	Pulmonic stenosis	0
9	Aortic stenosis	2
2	Anomalous pul. ven. drainage	1
2	Complete transposition	2
95		16 (17%)

Results

The mortality rate associated with surgery for various defects is listed in Table 1. There have been only two deaths in children with interventricular defects and both have had blood pressures that were equal in the pulmonary and systemic systems. One child died 12 hours and another 48 hours following surgery. Both patients did not show a drop in the right ventricular pressure following satisfactory perfusion and repair. Three of the tetralogy of Fallot patients who succumbed were extremely cyanotic. One had had a previous subclavian-pulmonary artery anastomosis that produced a pressure in the pulmonary artery of 35 mm. of mercury. In spite of this, the patient was incapacitated. At operation temporary closure of the shunt from the subclavian artery caused a fall in the pulmonary pressure to 10 mm. of mercury. This, in retrospect, very likely indicated serious pulmonary arterial disease probably on the basis of multiple pulmonary thrombi. The remaining patients, age 8 and 6 years, had small pulmonary outflow tracts. The other death in this group was in an adult and was the result of a technical error.

In the patients with aortic stenosis, it was obvious that the deaths were from their underlying disease rather than from any errors or problems with perfusion.

In the mitral valve group, the causes of death were more difficult to analyze. The first death occurred 14 days after surgery, after the patient first developed renal shut down due, unquestionably, to failure to properly replace the blood volume after perfusion. In the recovery period and after beginning diuresis, the patient suddenly died from ventricular fibrillation. There were two patients who had such serious valve distortions that improvement in function did not follow the operation. They both succumbed. Two patients developed uncontrollable aortic incompetency during perfusion, so that it was not possible to obtain good coronary perfusion and adequate total body perfusion simultaneously. One patient with total anomalous pulmonary venous drainage died from air emboli introduced through the open left atrium. A patient with complete transposition died because of the injury to the aorta from the occlusive tourniquet.

In the patients who survived, the complications have been few. There have been no wound infections or blood stream infections in any of the patients. There was one patient with recurrent mitral stenosis who had an air embolus to the brain, the point of entry being through the left auricle.

When this technic of rapid cooling and rewarming with the pump-oxygenator was first introduced, it was feared that intravascular oxygen bubbles might be released, particularly in areas of turbulence. At the temperatures employed there is an increased volume of oxygen in physical solu-

TABLE 2. *Incidence of Ventricular Fibrillation in Moderate Hypothermia*

Diagnosis	No. Pts.	Esoph. Temp. °C.	Ventr. Fibr.	Spontaneous Reversion	Electrical Reversion
Auricular septal defect	22	27–32	0		
Pul. stenosis	4	27–31	0		
Interventricular septal defect	18	26–31	6	4	2
Tetralogy of Fallot	19	26–30	0	0	0
Aortic stenosis	8	27–30	3	0	3
Mitral valve disease	15	26–30	6	4	2

tion; however, oxygen embolism has never occurred either in clinical studies or in our laboratory experiments.[13, 18, 19]

The electroencephalogram has shown, in some patients, greatly reduced electrical activity at the beginning of the perfusion. This is now thought to be due to one of two causes. In some the difficulty may have been from a partially occluded superior vena cava. The more common cause, however, has been a reduction in the blood volume at the start of the perfusion period. It is now our practice to administer blood through the arterial side of the pump before the venous side is opened. This may vary from 100 cc. in small individuals up to 400 cc. in an adult. In patients whose temperatures were reduced to below 20°, the electrical activity in the brain disappears at 16° to 20° C. only to return to normal with the elevation of temperature above this point.

The incidence of ventricular fibrillation is shown in Table 2. In the group where the ventricle was not opened, or where the heart was not made ischemic, ventricular fibrillation did not occur (atrial septal group and pulmonic stenosis group). When fibrillation did occur and when it did not spontaneously revert to normal, electrical defibrillation always has been possible. Where cardioplegia has been used the heart has restarted promptly even when the esophageal temperature was 28° to 30° C.

Two patients with ventricular defects have developed postoperative heart block. This was transient, and both patients had high pulmonary arterial resistances.

During much of the pumping time, the perfusion has been partial rather than complete. Table 3 summarizes the cooling and warming times in some of our patients.

The drainage from the two venous catheters to the extracorporeal system may be an important factor in the distribution of the body temperature gradients. Figure 2 shows a comparison of the temperature in the esophagus and the rectum when first the only venous outflow is from the inferior vena cava. It will be noted that the rectum cools more rapidly than does the esophagus. This trend can be reversed if the lower or inferior vena caval catheter is occluded, and all the venous outflow taken from the superior vena cava. This graph also shows the relationship of the temperature of the arterial and venous blood with first the inferior cava open and then the superior cava open. Note how stable the temperature remains. On rewarming the return flows have to be readjusted again to control the temperature. On complete bypass, the temperature differences level off. Temperatures in the muscle areas show a marked

TABLE 3. *Time for Cooling to 26° to 31° C. and for Rewarming to 33° to 36° C.*

No. Pts.	Kg. of Wt.	Average Flow Rates ml./Kg./min.	Cool min.	Warm min.
11	5 to 20	60	11	17
18	20 to 50	40	11	13
10	50 to 96	25	22	18

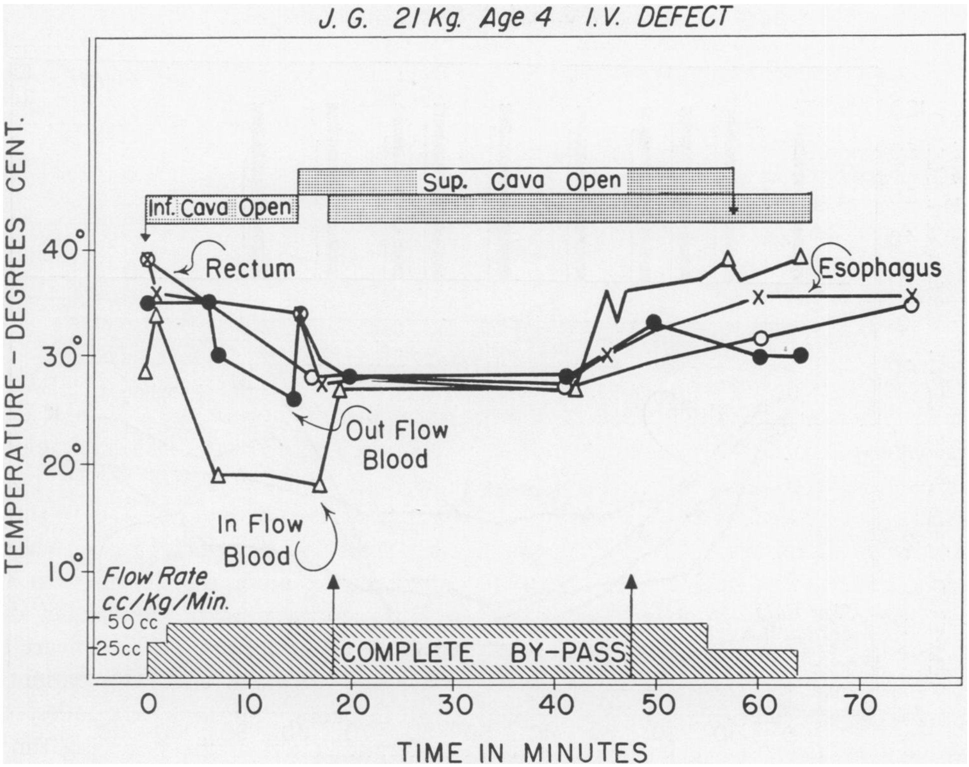

FIG. 2. This is the perfusion data showing the relationship of the site of venous outflow to the temperature gradients in the rectum and esophagus. The temperature of the blood entering and leaving the patient is shown. The venous outflow temperature is greatly influenced by the venous outflow site, indicating that much of the heat exchange efficiency is lost when the perfusion blood enters and leaves the lower one half of the body. If the blood, which enters the femoral artery, is withdrawn from the superior cava, a more efficient heat exchange occurs.

lag and frequently follow closely the temperature in the rectum. An example of this is shown in Figure 3.

The metabolic data on patients undergoing surgery with this technic of cardiopulmonary bypass is shown in Table 4. The venous oxygen levels have remained, with one exception, above 60 per cent throughout perfusion. In instances where the temperature has been reduced to very low levels, the oxygen level has been close to 90 per cent saturation (Fig. 3). In Figure 4 a comparison of oxygen consumption at various temperatures is shown on a bar graph. The oxygen consumption has been calculated at 10°, 15°, 20°, and 30° on the patients in this series. This is compared with the reports of Kirklin [11] and DeWall [6] at normothermia and with Clark,[4] Nadas,[14] and Keith's [10] observations on patients not undergoing cardiopulmonary bypass. It is of interest to note that a marked drop in oxygen consumption occurs from 37° to 20° C., but there is less reduction from 20° to 10° C. This is similar to the observations reported by Horvath,[17] who noted 50 per cent reduction in oxygen consumption at 27° C.

Problems of blood clotting resulting from the perfusion have not occurred in any of the patients. No unusual blood destruction has been observed, and this may be partially explained by the utilization of little if any of the coronary sinus return for maintenance of the blood volume in the pump.

For perfusion of children, 3,000 cc. of

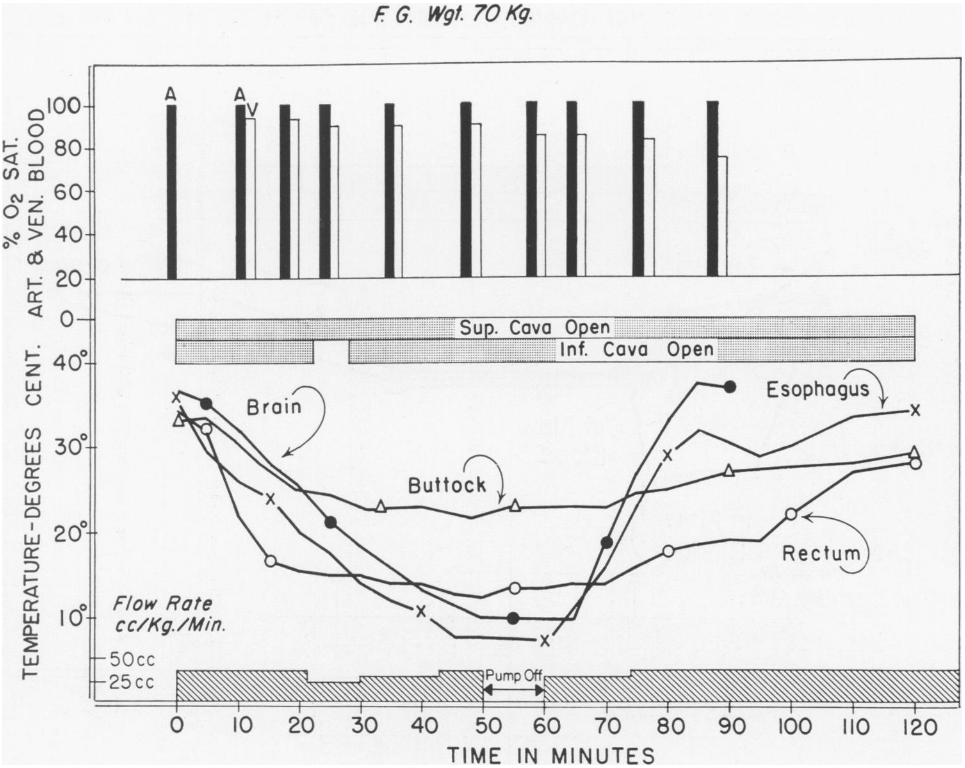

FIG. 3. This is a graph of the perfusion data in a patient who had an operation for an extracardiac lesion and is used to show the temperature gradients in rectum, esophagus, brain, and the muscles of the buttock. This also demonstrates the relationship between venous oxygen levels and temperature.

donor blood were used both to fill the system and to compensate for blood loss. For adults 4,000 cc. were usually needed, and at the end of the operation there were usually 1 to 2 liters of blood remaining in the coronary sinus reservoir.

In several patients it has been possible to tailor the pump-oxygenator system to the patient by the use of hypothermia. In patients who weigh more than 80 kg., it is difficult to give adequate perfusion at normal body temperatures; however, with the induction of hypothermia with partial perfusion, it is possible to lower the temperature to the point that complete bypass for long periods of time is possible at a low

TABLE 4. *Data Showing Venous Oxygen Saturation and Blood Buffer Base During Extracorporeal Circulation and Hypothermia (28°–31° C.)*

No. of Cases	Weight	Flow Rate ml./Kg./min.	Flow Rate L./m.²/min.	Av. Venous O_2 Sat. %	Blood Buffer Base (ml./L.)* Control	Bypass	2–6 Hrs. Later
19	35 Kg. Av. 22.6	54	1.37	71	42.6	38.2	38.4
15	35 Kg. Av. 55.8	31	1.07	66	45.4	40.4	41.1

* Buffer base data from 27 patients.

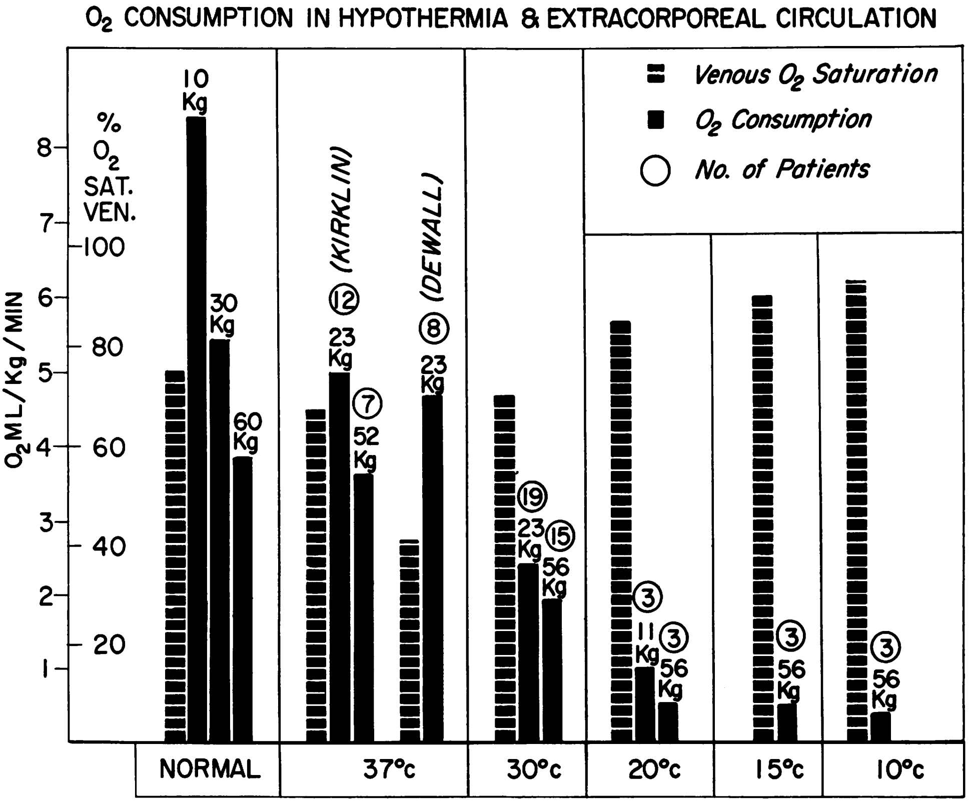

FIG. 4. This is a bar graph that shows the oxygen consumption in our series of hypothermic patients and compares this with Kirklin's and DeWall's series at normothermia. The data of Clark, Keith, and Nadas on normal patients is included. The venous oxygens are also shown and emphasize their marked rise with the fall in temperature of the body.

perfusion rate. This technic has been used in three patients.

A similar problem of high perfusion rate may be encountered in infants. The flow rate demands per kg. of weight of this size individual may be so high that it is difficult to perfuse them safely through easily accessible vessels. The high flow rates needed may result in marked blood loss from the open heart making it difficult to adjust the blood volume of the patient after perfusion. In one patient weighing 11 kg., this technique has been unusually satisfactory.

Profound hypothermia of 9° to 20° has been used in seven patients. The pertinent data in this group is listed in Table 5. Four of the patients survived, while three died. The cause of death was obvious in all three and did not result from the hypothermia. One patient with an I.V. defect had a pulmonary artery pressure of 100 mm. of mercury before closure and this did not change after closure. Three of the patients had ventriculotomies using cold induced cardioplegia (Fig. 5). Some of the periods of partial bypass were unusually long, but this included pumping needed for prolonged circulatory support. It required about 20 to 30 minutes to both cool and to rewarm the patients who survived. There were no complications in the survivors.

Discussion

The clinical observations reported in this communication support the contention that hypothermia with extracorporeal circula-

TABLE 5. *Extracorporeal Circulation and Profound Hypothermia (Below 25° C.)*

Diagnosis	Age	Wt. Kg.	Esoph. Temp.	Flow ml./Kg./min.	Min. Total Perfusion	Min. Complete Bypass	Fibrillation	Spont. Reversion	Comment
Transposition of great vessels	4	9.3	20°	25	180	63	Yes	Yes	Died. Injury to aorta.
Mitral stenosis and insufficiency	32	5.0	20°	20–40	150	50	Yes	No	Died. Aortic insufficiency.
I.A. Septum primum	6	22	20°	25–50	76	43	Yes	Yes	Survived.
I.V.	4	12	18°	35–70	45	24	0	0	Cardioplegia. Died. Fixed pul. resistance.
I.V.	11 mos.	6	18°	25–40	43	22	0	0	Survived.
Tetralogy	4	12	9°	25–50	55	29	0	0	Survived.
Tetralogy	4	12	14°	25–50	46	32	0	0	Survived.

tion is a safe and practical method of cardiopulmonary bypass when the hypothermia is controlled by the extracorporeal circuit. In an almost quantitative manner, one can adjust the flows required by the temperature levels employed, and therefore gain the many advantages of a simple oxygenator with a small blood volume capacity. In fact, the optimum technic for cardiopulmonary bypass probably will be attained when the heart-lung machine can be discarded entirely. The use of cold for reduction of metabolic processes is at present the nearest practical approach to this concept.

There are several problems posed with this technic. Some were anticipated, and others appeared with its clinical application. The magnitude of the temperature gradients that occurred was of interest. An example is shown in Figure 3. Apparently the muscle as represented by the buttock temperature was not perfused as well as the other areas as shown by its temperature lag. In animal experiments,[13] a similar phenomenon was noted, and venous blood removed from these areas was markedly unsaturated. A similar finding has been observed in the liver.[8] The importance of this phenomenon lies in the slowing effect on the warm up time.

The brain, of course, is the organ most vulnerable to hypoxia; and if body cooling is unequal, it is possible that the brain temperature may be at a dangerously high level when the esophagus is at the desired range. The temperature change in the brain does lag behind the esophagus but cools faster than the slow muscle areas (Fig. 3). Numerous studies on the dog at the same temperature ranges confirm the observations in man. Both in dog and man, the electrical activity of the brain disappears when the temperature in the brain reaches 16° to 20° C. The disappearance of this activity in the electroencephalogram may be used as an indirect indicator of the temperature.

The peculiar temperature gradients encountered with core cooling may be influenced by several maneuvers. Variation in the location of the venous outflow will influence the area that is cooled or rewarmed the most rapidly. Earlier in this study, cooling was begun by using only the femoral artery and the inferior vena cava for perfusion. This resulted in a slow fall in temperature in the upper half of the body where it

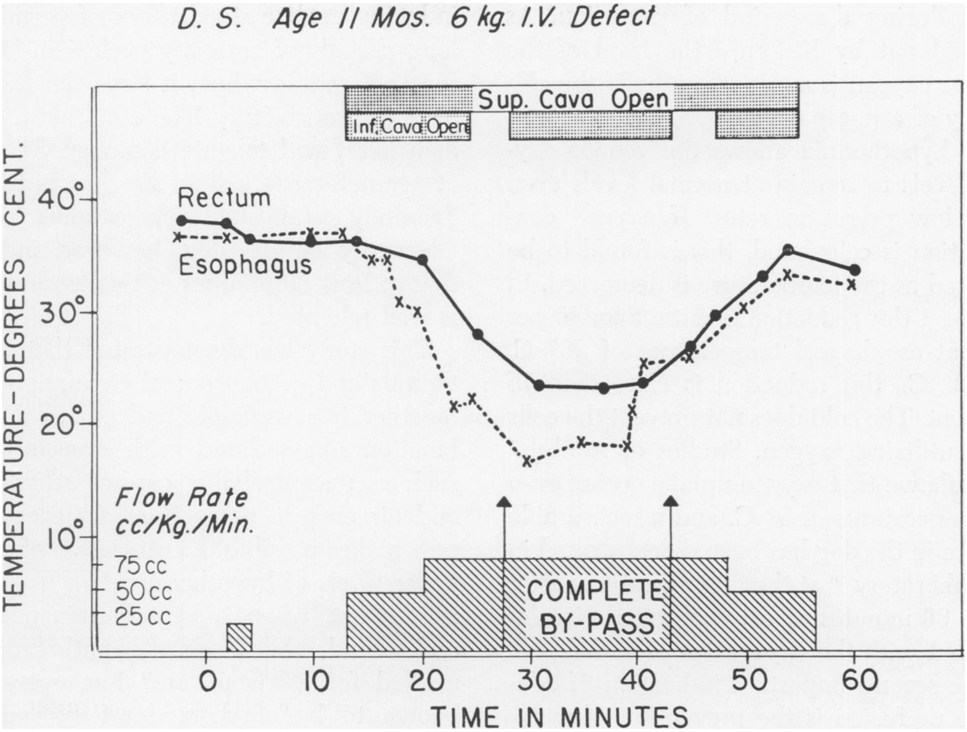

FIG. 5. This is the perfusion and temperature data on a patient who had cold induced cardioplegia for repair of a ventricular septal defect. Ventricular fibrillation did not occur. Sinus rhythm returned spontaneously at 23° C. (esophageal).

was needed. However, there was a rapid reduction in the rectal and buttock temperature, which would go to much lower levels than desired. This then would require a long rewarming period. With the venous return coming only from the superior vena cava during cooling, this trend can be changed and the upper half of the body cooled first, which of course is where cooling is needed most. Just why this occurs is not entirely clear, but perhaps the most likely explanation is on the basis of the distribution of the patient's own cardiac output. Cold blood placed in the femoral artery goes to the lower portion of the body, then emerges through the inferior vena cava. Measurements of the blood temperature coming from this area under these peculiar conditions have shown that this blood may absorb very little heat on its passage through the lower half of the body (Fig. 2). If, instead of being withdrawn through the inferior vena cava, this cool blood is allowed to return to the heart, it is then redistributed throughout the body, particularly to the superior half. Therefore maximum internal heat exchange is accomplished.

The efficiency of this heat exchanger is amply shown by these studies. It would be possible, of course, to have a still more efficient apparatus; but this can only be obtained at the expense of a very large blood volume capacity as shown in B, Figure 1. It has now been found that coupling together two of the standard instruments gives an efficient and practical exchanger for larger patients with a minimum blood priming requirement of only 350 cc.

The critical measure of efficiency of this system of cardiopulmonary bypass is the maintenance of normal metabolic relationships during the period of perfusion. As pointed out by Kirklin,[12] the level of the venous oxygen is a critical index of the efficiency of a pump-oxygenator system. Moderate hypothermia allows the venous oxygen levels to remain at normal levels even with low perfusion rates. If oxygen consumption is calculated, this is found to be lowered as the temperature is decreased. In Figure 4 this reduction is more than 40 per cent at esophageal temperature of 30° C. At 20° C., this reduction is more than 75 per cent. The cold does not prevent the cells from utilizing oxygen. Studies of Adolph[1] have shown that oxygen uptake occurs even at temperatures of 5° C. and a measurable uptake in the dog has been demonstrated in our laboratory[20] at these temperatures after 60 to 90 minutes of extracorporeal circulation but with the oxygenator excluded.

The second important indication of adequate perfusion is the prevention of metabolic acidosis. With the technic described, the blood buffer base has remained within the limits expected for any major operative procedure.

Ventricular fibrillation has occurred infrequently, and its control has not been difficult. We do not feel that hypothermia, regulated by a pump-oxygenator, has any greater incidence of ventricular fibrillation than does normothermia with extracorporeal circulation.

Where cardioplegia has been used with prolonged periods of coronary occlusion, there is experimental evidence[8, 18] to indicate that cold protects the heart muscle from ischemia. It is noteworthy that in the patients in whom cardioplegia has been achieved by potassium, magnesium, and prostigmine, there have been no complications attributed to the use of the cardioplegia per se. Left heart distention and pulmonary congestion have not occurred. It would be desirable, of course, to achieve cardiac arrest without the use of a drug. The possibility has been explored of using hypothermia alone as a method of either inducing cardiac standstill or of permitting long periods of coronary occlusion. In the four patients in whom it has been used, it has been satisfactory. The time that the human heart will tolerate coronary occlusion at temperatures below 20° has not been definitely established. The studies in our laboratory on the dog, however, indicate that at least 60 minutes at this temperature is well tolerated.

This study has demonstrated that hypothermia and extracorporeal circulation used together is a workable and practical combination unassociated with unusual risks such as uncontrollable cardic arrhythmias and air emboli. Since the heat exchanger now makes possible the utilization of much lower levels of hypothermia, two questions arise. First, when is hypothermia needed; and second, what levels of hypothermia are needed for a given case? For operations known to be of short duration, such as secundum atrial defects or pure pulmonic stenosis, very little temperature reduction is actually needed, though in this study temperatures from 28° to 32° C. were employed. At present, temperatures of 31° to 32° C. are advised for this group since it does not add greatly to the perfusion time and is an added safety factor. If the patient is over 70 kg. or unusually small, hypothermia is mandatory if a low flow extracorporeal system is employed. In longer operations, particularly where the heart is stopped for 30 minutes or less, a temperature from 26° to 30° is needed and exerts a definite protective action on the ischemic heart. From our observations on patients, a temperature of 15° to 20° offers almost as much reduction in oxygen needs as temperatures below 10° C. Since this level of hypothermia (15° to 20°) (Table 5) does not require a long period of perfusion, it would seem advantageous and practical, when the intracardiac procedure requires more than 30 minutes. Should return flow from the lungs be unusually profuse, intermittent circulatory standstill is possible at this temperature. Profound hypothermia may not only protect the heart from ischemia but be used to induce standstill.

Summary

Experiences are recorded with 95 patients who had open heart surgery using core induced hypothermia and extracorporeal circulation for cardiopulmonary bypass. The simplicity and safety of this method is emphasized. Clinical trials with profound hypothermia of 9° to 20° are reviewed, and it is suggested that the benefits of this temperature level should be employed in the correction of the more complex cardiac lesions.

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Discussion

Dr. Barnes Woodhall: Brain surgeons are very much interested in this concept of profound hypothermia because it may be of potential value in treating some of our patients who have very formidable intracranial lesions. I refer, for instance, to those patients with early and continuing hemorrhage in the syndrome of acute subarachnoid hemorrhage where the initial mortality ranges in the neighborhood of some 25%. We are also interested in those patients with progressive mental deterioration who have apparently inoperable arteriovenous anomalies of the brain.

Three noncardiac cases are mentioned in Dr. Sealy's manuscript and these represent instances of craniotomy during profound hypothermia. Such craniotomies may be called perhaps hypothermic cardioplegic craniotomy or perhaps designated as craniotomy under conditions of profound hypothermia and protected cardiac asystole.

The first slide shows a patient of mine in the chemotherapy series who apparently had an invasion of his longitudinal sinus with a tumor. Following Gollan's original observation that quinidine protected the heart from ventricular fibrillation during rewarming, an observation confirmed repeatedly by Dr. Sealy and his group in our medical school, this patient was treated with 100 mg. increments of quinidine intravenously while I began the craniotomy and Dr. Sealy began his extracorporeal circulation. The relative fall in brain temperature was recorded by a thermistor placed in the subcortical structures after the brain was exposed. An eventual esophageal temperature was obtained of 5° C. and a brain temperature of 11° C. The period of cardiac asystole lasted approximately 52 minutes during a period of extracorporeal circulation of 74 minutes.

Various parameters recorded at the operating table show the asystole beginning at an esophageal temperature of 23° C. with the heart being completely quiet at 11° C. and remaining so until the rewarming was developed. At 16° C., isolated but normal beats occurred and at an esophageal temperature of 22° the normal cardiac rhythm was re-established. Electrical cortical activity disappeared at about 21° brain temperature and showed beginning reactivity during re-warming at 16° C.

Craniotomy here was much simpler than had been expected since the subcortical tumor was affixed only to the falx and had not invaded the sagittal sinus. The extracorporeal circulation, therefore, was stopped for only a period of some 12 minutes. The craniotomy, of course, was extraordinarily simple during this condition of an avascular brain.

The last photograph shows the normo-thermic brain at 37° with widening of the parasagittal convolutions suggesting an underlying tumor. At 15°, with the extracorporeal circulation in action, the venous vessels of the brain show a high oxygen saturation. The brain is slack and the Slyvian fissure is beginning to open. At a brain temperature of 11° C., with both the extracorporeal circulation off and the heart in asystole, the brain appears completely relaxed, an ideal situation for difficult intracranial surgery.

We are proceeding with this study, of course, slowly and cautiously. Thank you.

Dr. Henry Swan, II: I should also like to compliment Dr. Sealy and his group for his study of the combination of hypothermia and perfusion. We, too, have been using this combination recently, and we think that it has a lot to offer in terms of the safety of prolonged perfusion.

It is always difficult to guess what the perfusion rate should be in order to have it as optimal as possible, and I think when we add hypothermia to perfusion we compound the difficulties of making that guess. Certainly we all agree that guessing before-hand about any given individual's oxygen consumption at normothermia proves in many instances to be wrong, and I think we tend to perfuse a little more than necessary, often, in an attempt to keep the venous oxygen saturation above 60, although it is to be admitted that 60 is certainly not normal and presumably should not be maintained for an indefinite period of time.

Now, when you add hypothermia, of course, you try and guess how much this modality will reduce the oxygen needs, so I think your error is compounded. Frequently, I think Dr. Sealy will agree, that when there are such wide gradients within the body, this guess is additionally difficult.

We see in his data that his venous oxygen saturations varied from a low of 60, I believe, up to as high as 90. Perhaps 90 is too high. And then there is finally, of course, the other problem that enters in, and that is the relationship of the shunts existing, where red blood is seen in the heart and is sucked out, so that this blood actually did not supply the oxygen needs of the body. This is a third component.

For these reasons we have maintained, and I think that may of you would agree, that if you