Perfusion Technic for Surgery on the Aortic Valves *

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AORTIC valvular disease is accompanied by massive left ventricular hypertrophy with relatively insufficient coronary supply. In such hypertrophic myocardium one can usually find areas of ischemic necrosis and the cut surface shows white areas with fibrous tissue. This badly vascularized myocardium is very sensitive to anoxia and Lillehei [1] has reported extensive necrosis of the ventricular myocardium after five minutes of complete myocardial ischemia at normal temperature. Operative Surgery on the aortic valves must therefore be performed with elective anoxia under press for time, or with retrograde coronary perfusion by cannulation of the coronary sinus, or with coronary perfusion after cannulation of the coronary arteries.

The aim of this paper is to report a technic of perfusion combining deep hypothermia with the pump oxygenator which preserves the myocardium in the best possible condition without difficult cannulation, and which provides prolonged safe operating time for exact surgery on the aortic valves and a meticulous closure of the aortic incision.

Method

The aortic leaflets are best approached through a median sternotomy. The incision is carried half way down to the umbilicus but not up on the neck. If a tracheostomy is necessary a sufficient bridge of tissue must be left between this and the sternotomy incision to keep them separate and prevent infection.

Cannulation. After heparinization with 5 mg. per kilo body weight the femoral artery, the left and right atrium are cannulated. For the femoral artery a metal cannula is used and for the left atrium one Bardic catheter through the left atrial appendix or the interatrial groove. For the right atrium only one No. 38 or 40 Bardic catheter is used.

The cannula from left and right atrium are connected to a common tube draining the blood into a receiving reservoir, into which also coronary blood is drained through a debubbler. From the receiving reservoir the blood goes via a settling reservoir through a spinning disc oxygenator and is then pumped by a roller pump through a heat exchanger and a filter back to the femoral artery. During the cooling and rewarming, when blood is drained only from the left atrium, the discs are not rotating in the oxygenator.

Perfusion, *Step 1.* Blood is drained from the left atrium, cooled in the heat exchanger and pumped back into the femoral artery (Fig. 1). By variation of the flow from 100 to 1,000 ml./min. and by adjustment of the temperature in the heat exchanger, the patient's temperature can be brought down to ventricular fibrillation within half an hour. The fibrillation may occur between 16° and 30° C. During this first step the discs are not running in the oxygenator. The time for cooling is utilized in the operative field for electrocoagulation of bleeding points and for preparation of the operative field, i.e. mobilization of the ascending aorta and application of snares around the aorta and pulmonary artery.

Step 2. If ventricular fibrillation occurs at a high temperature, and a long period of cardiac arrest is anticipated, the cooling is continued by draining blood from both atria having the discs spinning at a rate

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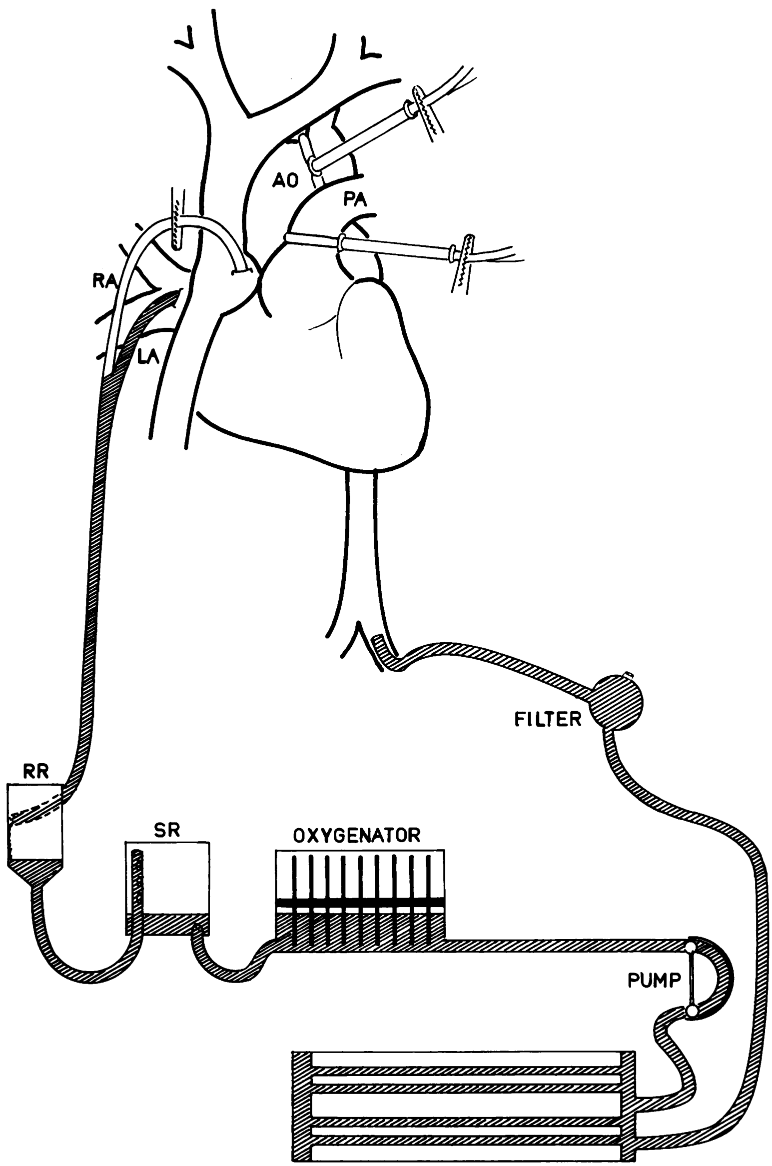

FIG. 1. Diagram of the perfusion technic for aortic valvular surgery. During the first step blood is drained from the left atrium (LA) to a receiving reservoir (RR), a settling reservoir (SR) and going through the oxygenator with the discs not rotating, pumped through a heat exchanger for cooling, and through a filter back to the femoral artery.

of 100 RPM in the oxygenator and going up in flow to 2,000 ml./min. in an adult patient. Thus the esophageal temperature may be quickly brought down to 12.8° C in a patient undergoing repair for aortic insufficiency (Case 1). If fibrillation occurs at esophageal temperature near 20° C. step 2 can be omitted (Case 2).

Step 3. The left atrial cannula is occluded, the right open (Fig. 2). Thus blood drains from right atrium to the spinning disc oxygenator through the heat exchanger which is immediately adjusted to warming. The flow rate is adjusted to the temperature which during the operation is slowly brought up to around 30° C. A flow of 2,500 ml. is adequate in an adult.

The aorta is occluded immediately thus excluding the heart from circulation. The rewarming of the rest of the body will continue but the heart is excluded at the lowest temperature. This temperature of the heart is brought down still more by application of crushed sterile ice in thin-walled plastic bags on the heart. One ice bag lies under the heart inside the pericardium, and another overlies the heart. This local application of ice will bring a dog heart, excluded from the circulation, from 37° C down to 20° C in 10 minutes. The ice is left around the heart during the whole step 3.

The pulmonary artery is then occluded. If this is not done the opening of the aorta is accompanied by a disturbing flow of blood from the left ventricle. This blood flows through the fibrillating right ventricle and the lungs, driven only by the pressure in the right atrium of the returning venous blood. The right atrial pressure will be seen to increase and one can observe also a very slow retrograde flow of dark blood through the coronary ostea.

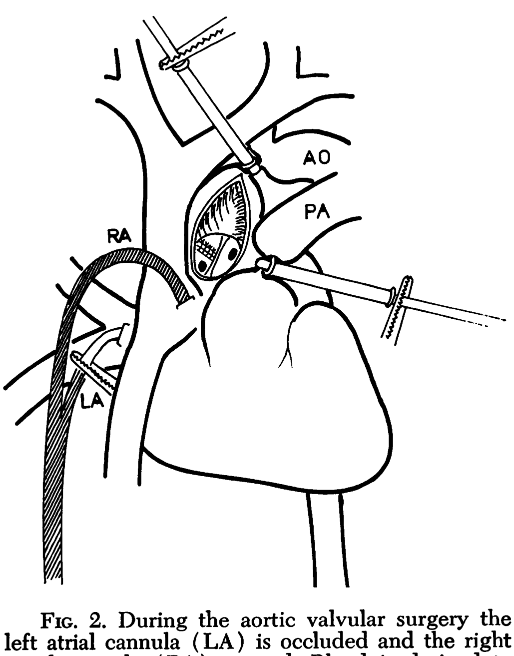

FIG. 2. During the aortic valvular surgery the left atrial cannula (LA) is occluded and the right atrial cannula (RA) opened. Blood is drained to the oxygenator, now in function with the discs rotating, pumped through the heat exchanger for rewarming and back to the femoral artery. The aorta (AO) and pulmonary artery (PA) are occluded and the heart excluded from circulation is packed in plastic bags with crushed ice.

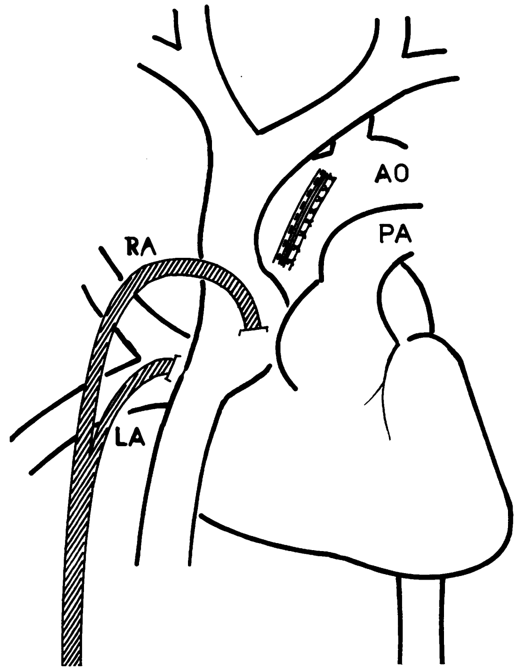

FIG. 3. When the aortic incision is closed both right and left atria are drained until the heart is rewarmed and defibrillated. When the heart keeps a good blood pressure the right cannula is removed and the left is used for partial perfusion with rewarming.

Although this retrograde flow is small and its oxygen content reduced to venous level, it helps to keep the cold hypertrophied left ventricular myocardium in the best possible condition during the prolonged arrest.

A longitudinal aortic incision is performed with a proximal curve parallel and just above the cusps which gives excellent visualization of the aortic cusps and prevents inadvertent tears.

The aortotomy is closed with 4- or 5-0 silk after a careful washing of the left atrium, the left ventricle and aorta with glucose solution through the left atrial cannula via a side branch. Once the proximal part of the suture line is completed and reinforced by mattress sutures through strips of Ivalon sponge on each side of the suture line a super Statinsky clamp is applied behind the aortotomy incision and the aortic clamp

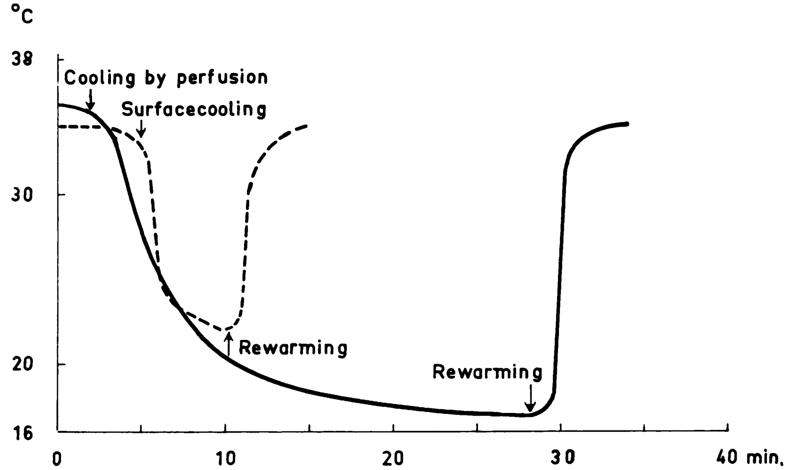

FIG. 4. Temperature-diagram from myocardium of an excluded dog heart undergoing surface cooling with ice bags. Temperature is brought down rapidly and rewarming performed by perfusion takes place even more quickly. Cooling of myocardium with isolated coronary perfusion of cold blood is quicker.

removed to permit coronary perfusion with rewarming of the myocardium. The ice bags are immediately removed from the myocardium. Closure of the aortotomy is then continued with two rows of 4- or 5-0 silk, and reinforced by mattress sutures through Ivalon strips. The cannula draining the left atrium is opened so that both left and right atria are now drained to the oxygenator.

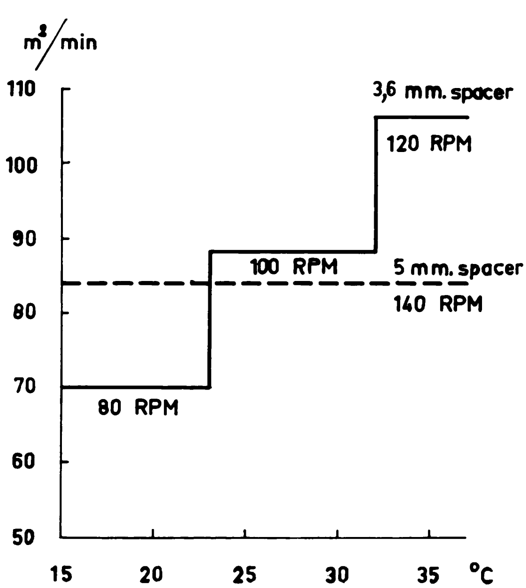

FIG. 5. Comparison using 5 mm. spacers and 140 RPM with the use of 3.6 mm. spacers and 120 RPM above 30° C. and 100 RPM between 30 and 20° C. gives a higher minute area of blood film exposed to oxygen when 3.6 mm. spacers are used. Only at a very low temperature is there an advantage of the bigger 5 mm. spacers. As it is more important to have the largest minute area of blood film at a higher temperature the 3.6 mm. spacers permitting more discs are preferred.

As the esophageal temperature after rewarming during the whole procedure in step 3 now is between 30° and 35° C. only ten minutes of coronary perfusion is needed before the myocardium has reached the same temperature and can be electrically defibrillated. Both right and left atria are drained with partial perfusion of 2,500 ml./min. for another 15 minutes, when digitalis and glucose solution are given intravenously and the heart is allowed to rebuild its glycogen content (Fig. 3). ECG is continuously improving; it remains in action during the whole procedure if temperature is kept above 20° C.

Step 4. The perfusion is stopped completely for a short time to test the heart's ability to maintain the blood pressure. If not, perfusion is continued. When the blood pressure is maintained, the right atrium is decannulated and partial perfusion from the left atrium with 500 to 2,000 ml./min. is continued for rewarming until a rectal temperature of 34° C. is reached. During this period when only the left atrium is drained the discs are not rotating in the oxygenator. After decannulation 1.0 mg. protamine sulfate per kg. body weight is given at intervals until the coagulation time is brought down to five minutes.

Local Cooling of the Excluded Heart. It should be noted that in children in whom deep hypothermia is absolutely contraindicated due to the risk of brain damage from vascular occlusion by aggregated platelets and white blood corpuscles, and in whom the myocardium will tolerate a longer period of anoxia, only the local application of ice bags direct on the heart is necessary. Perfusion with the pump oxygenator is performed without the heat exchanger in the extracorporeal circuit.

In dog experiments the heart, excluded from circulation, has been brought down from 37° to 20° C. in ten minutes. The temperature, measured in many different places inside the myocardium after local cooling, will vary considerably. The lowest temperatures are found in areas with direct contact with the ice bags.

This low temperature is also found deeper in the myocardium and in the interventricular septum. Adjacent areas of the heart but without direct contact with the ice bags may show a temperature 5° C. higher. It is important to use ice bags with crushed ice so that they have a maximum contact with myocardium (Fig. 4).

This technic was used in a 14-year-old boy with functional subaortic stenosis caused by an abnormally placed anterior mitral leaflet and a pressure gradient of 53 mm. Hg. The patient was perfused at normal temperature and the heart arrested by acetylcholine and surrounded by ice-

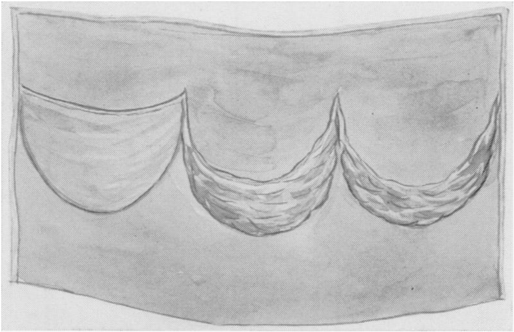

Fig. 6. Diagram of the incompetent right and posterior aortic cusps. Only the left cusp was normal, the other tended to be turned inside out.

bags. The heart was excluded from circulation for 45 minutes and the myocardial temperature was 28 to 29° C. at the end of the procedure, which consisted in creating a channel in the hypertrophied interventricular septum by removal of muscular tissue piece-by-piece; patient recovered.

Local cooling of the myocardium by separate coronary perfusion has been used both experimetally and clinically. The temperature of the myocardium is brought down to 20° C. in five minutes. A side branch is leading a small amount of blood through the heat exchanger for cooling and through a needle in the root of the aorta proximal to a clamp. This method has not been found as practical for aortic valvular lesions with intact ventricular septum, especially not for aortic insufficiency cases.

Optimum Speed of the Spinning Discs at Different Temperatures. Due to the in-

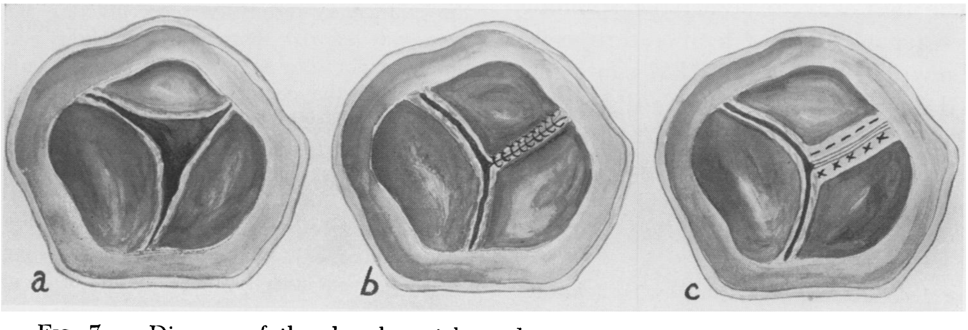

Fig. 7. a. Diagram of the shrunken right and posterior aortic cusps. b. First a row of isolated silk sutures were placed between the incompetent right and posterior aortic cusps for bicuspidalization. c. Mattress sutures through Ivalon strips were used for re-inforcement.

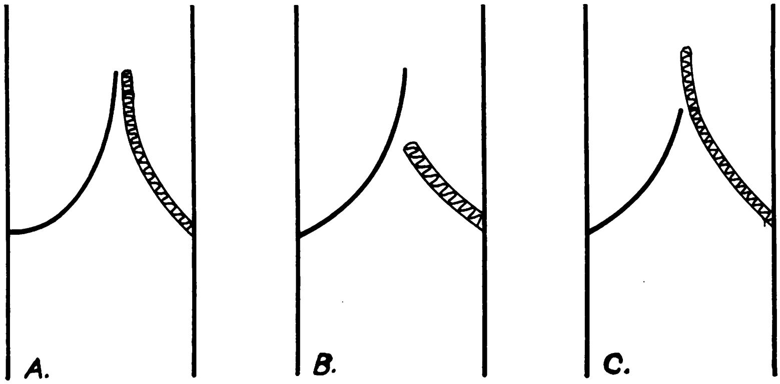

Fig. 8. A. Diagram showing how normal and bicuspidalized cusp must meet at same level during diastole to take stress away from suture line as much as possible. B and C. If the cusps do not meet at same level incompetence may persist.

creased viscosity at a lower temperature the spinning disc oxygenator must be adjusted to prevent foaming and filming between discs. I have tried two methods:

1. The spaces between the discs may be enlarged from 3.6 to 5 mm. Then it is possible to utilize a speed of 140 RPM at any temperature down to 15° C. The minute area of blood film exposed to oxygen will, however, significantly decrease, as fewer discs can be utilized. Only below a temperature of 20° C. can a slight gain of minute area of blood film exposed to oxygen be obtained as compared to the use of 3.6 mm. spacers and a lower disc speed (Fig. 5).

Although a maximal safety is obtained with the bigger 5 mm. spacers too much of the oxygenating capacity of the oxygenator is lost during the rewarming period. The method of increasing the distance between the discs has therefore been abandoned.

2. The best way to adjust the spinning disc oxygenator to the temperature is to slow down the speed; 120 RPM can safely be used down to 30° C. Then a disc speed of 100 RPM is used down to 22° C. Below this temperature a disc speed of 80 RPM can safely be used down to 10° C.

Case Reports

Case 1. A 23-year-old woman with a history of rheumatic fever 12 years earlier, complained of numbness in both arms and hands, tachycardia and fatigue. There was a harsh diastolic murmur along the left border of the sternum. The heart was enlarged (560 ml./m.^{2} body surface area) with a broad and heaving apex beat.

Left ventricular puncture with angiography showed a pressure of 192/8 in the left ventricle with a simultaneous pressure of 183/65 in the femoral artery. The left ventricular angiocardiography did not demonstrate any aortic valvular stenosis, but a decreased mobility of the aortic cusps. There was no regurgitation of contrast medium through the mitral orifice. Thoracic aortography demonstrated aortic insufficiency and the enlarged left ventricle completely filled with the contrast medium injected in the aorta. (Fig. 10 A, C).

At operation a median sternotomy was performed and the left and right atria cannulated as well as the femoral artery. With a perfusion of 500 ml./min. from the left atrium through the heat exchanger to the femoral artery the esophageal temperature was brought down to 27° C. in 20 minutes when ventricular fibrillation occurred. Then both left and right atria were drained for 7 minutes with a flow of 2,000 ml./min. and the temperature brought down to 14° C in the esophagus, when the heart was excluded for 86 minutes. When the aortotomy was performed the blood flow was too abundant until the pulmonary artery was occluded. The left cusp was normal, but both the right and the posterior aortic cusps were shrunken, too short to meet in the center and tended to be turned inside out (Fig. 6, 7). A bicuspidalization was made of the two diseased cusps; first a row of isolated 5–0 stitches were placed in the thickened edge of the cusps and this was then re-inforced by mattress sutures through thin strips of Ivalon sponge (Fig. 7). The difficulty was to get the bicuspidalized cusp to meet the normal cusp at exactly the same level in order to take the tension away from the suture line as much as possible. It was necessary to take away and replace sutures in the cusps three times before an exact approximation was obtained (Fig. 8).

The aortotomy was closed as previously described by two rows of continuous 5–0 silk sutures and one row of mattress sutures through strips of Ivalon sponge on each side of the incision. During the 86 minutes of cardiac exclusion a perfusion with 2,000 ml./min. was performed with the discs rotating in the oxygenator and the rewarming begun (Fig. 9). The esophageal temperature was 22° C. when the aortic occlusion was released and after 10 minutes perfusion, at a temperature of 32° C., the heart was defibrillated by an electric shock. The leftsided perfusion of 2,000 ml./min. was continued under 40 minutes for rewarming until 37.8° C. in the esophagus was reached. After completion of the operation with perfusion for nearly 3 hours there was a plasma hemoglobin of 8 mg.%. The highest value during perfusion being 94 mg.%. A tracheostomy was performed and postoperative respirator treatment continued for one day. After prolonged period of fever which subsided on chemotherapy the patient recovered and the postoperative thoracic aortography showed competent cusps without any back leakage of contrast to the left ventricle (Fig. 10). The heart volume had diminished from 560 to 480 ml./m.² body surface during the first 2 months after operation. After a year the patient is in excellent condition.

Case 2. A 40-year-old man had known of his heart disease since boyhood. For last 3 years he had complained of dyspnea and syncope on exertion. Over the heart and into the neck a long harsh systolic murmur could be heard. The heart was only 475 ml./m². body surface and the tomography showed extensive calcifications in the root of the aorta. Left ventricular puncture showed

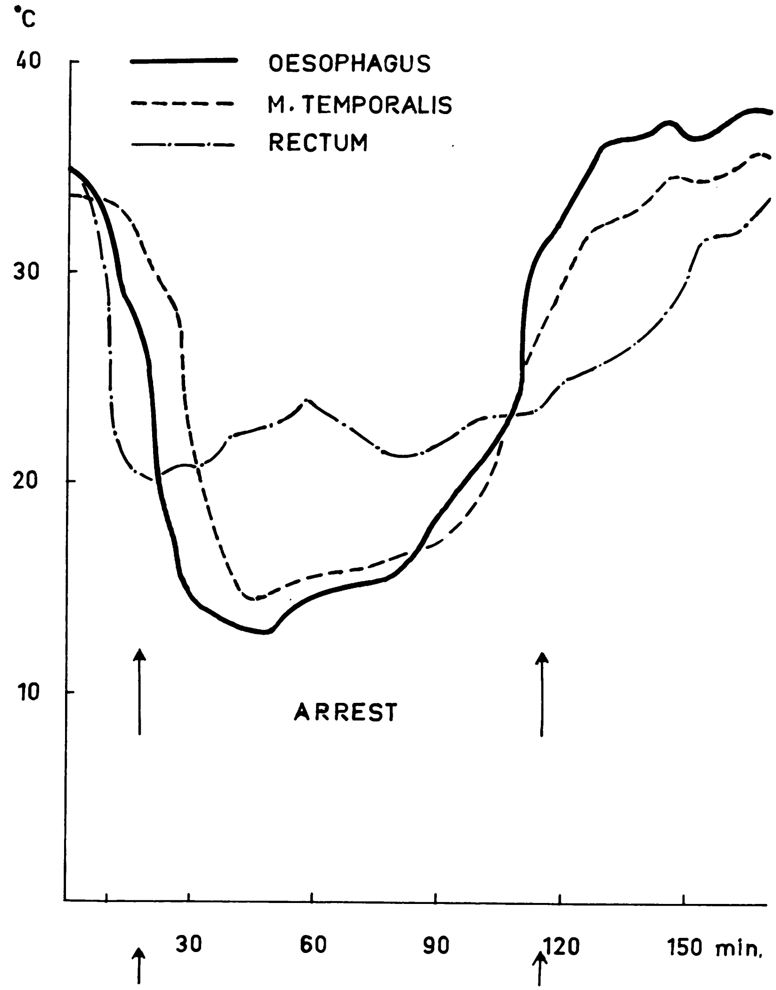

FIG. 9. Temperature-diagram from Case 1.

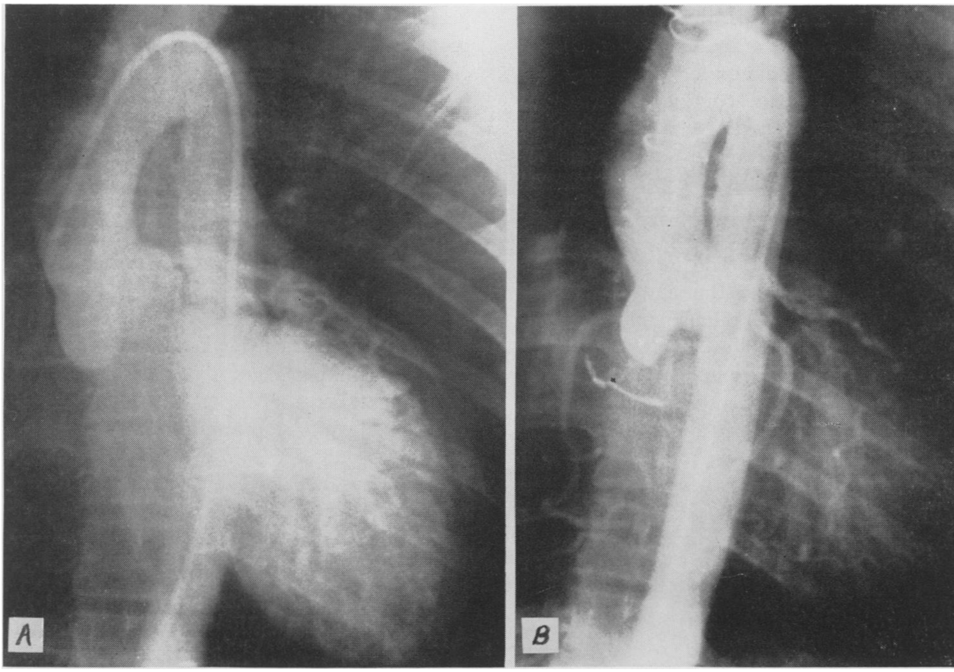

FIG. 10. Thoracic aortography performed before and after bicuspidalization of the aortic cusps in Case 1. After operation no regurgitation is found. A. Frontal view before operation. B. Frontal view after operation.

a pressure of 248/15 mm. Hg at the same time as the pressure in the femoral artery was 120 systolic. Contrast injection in the left ventricle demonstrated an aortic stenosis with cusps more than 4 mm. thick of negligible mobility. The operation was performed through a median sternotomy, with cannulation of the femoral artery and both left and right atrium. First a perfusion of 1,000 ml./min. from the left atrium to the femoral artery was performed, bringing the esophageal temperature down to 24° C. in 35 minutes when ventricular fibrillation occurred. The

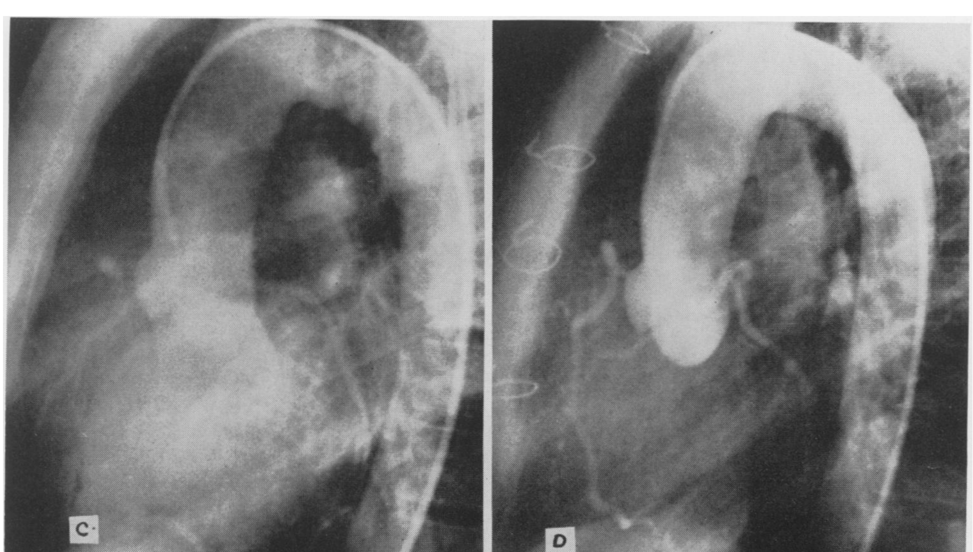

FIG. 10. C. Lateral view before operation. D. Lateral view after operation.

heart was now excluded from the circulation, the aorta and pulmonary artery were clamped and plastic bags with crushed ice placed around the heart. The rewarming was immediately started with perfusion from the right atrium through the oxygenator and heat exchanger to the femoral artery.

For 59 minutes the heart was excluded and the open operation performed. The left and right aortic cusps were found joined into a rock of calcium. There was a big posterior cusp, also immobile due to calcification. The long slit-like opening between these immobile cusps demonstrates that a pressure gradient cannot be abolished by a commissurotomy in calcific valves (Fig. 11). Therefore a meticulous removal of calcium, piece by piece from the posterior cusp was made, and it was transformed into a mobile cusp (Fig. 12). After closure of the incision in the aorta, the temperature in the esophagus had already reached 33.4° C. and perfusion through both left and right atrium was continued. Only 10 minutes of perfusion was needed before the heart could be defibrillated and another 15 minutes elapsed before the heart kept a good blood pressure and the right atrial cannula could be removed. Another 18 minutes of rewarming with 1,000 ml./min. from the left atrium was needed before an esophageal temperature of 35.6° C. was reached and the patient decannulated. Pressure measurements showed identical pressures of 90 mm. Hg in left ventricle and aorta at end of operation. The patient made uneventful recovery, but died 2 months later from incisional aneurysm.

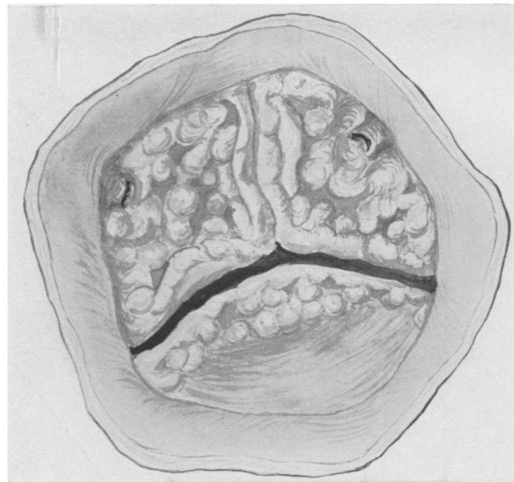

FIG. 11. Diagram of the left and right aortic cusps joined into a rock of calcium. There was a long and narrow slit-like opening. The posterior cusp was stiff and immobile from calcification.

Summary

The most important factor in the perfusion technic for operative surgery on the aortic valves is the prevention of anoxic injury to the hypertrophied and vulnerable left ventricular myocardium. The technic described utilizes deep hypothermia by extracorporeal cooling combined with surface cooling of the heart and a slow retrograde coronary perfusion by occlusion of the pulmonary artery under hypothermic cardiac arrest to protect the myocardium. Thus operation on the aortic valves can be completed on a flaccid, nonbeating heart without any press for time.

The rewarming is started immediately

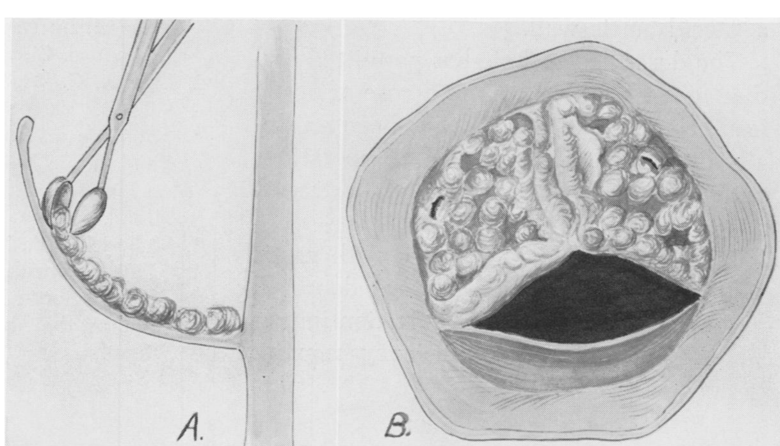

FIG. 12. A and B. After removal of calcium from the posterior cusp it was flaxid and mobile and the pressure gradient disappeared.

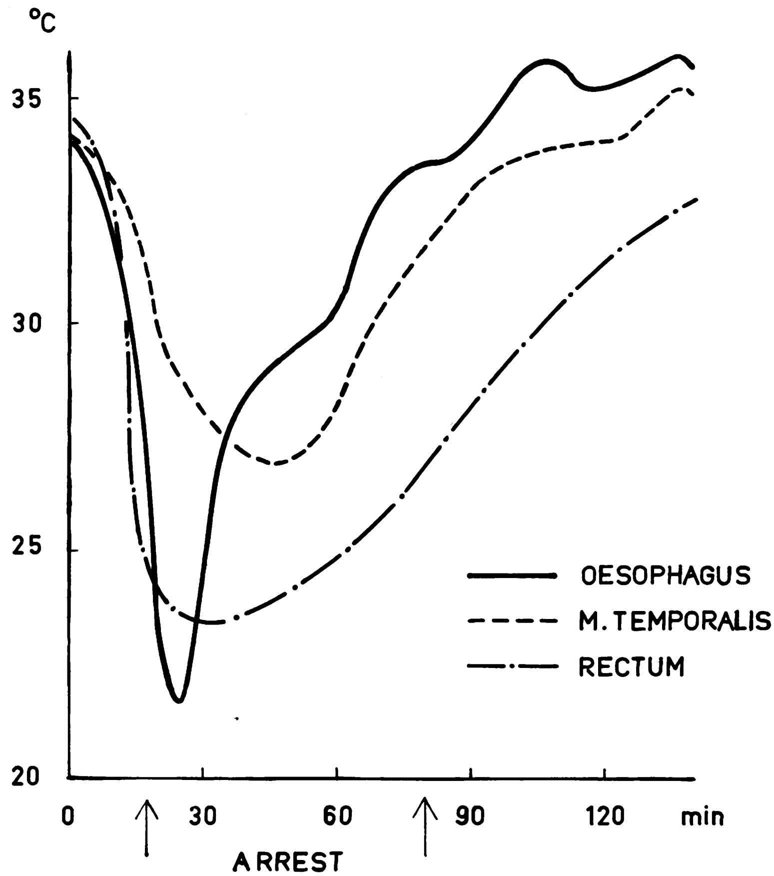

Fig. 13. Temperature diagram from Case 2. The rewarming was begun immediately after exclusion of the heart and therefore, not much time was lost.

after exclusion of the heart. Thus much time is gained, since rewarming, which is usually the most time consuming step, can be continued during the whole surgical procedure. The technic also permits time for a meticulous closure of the incision on a flaccid aortic wall.

The described technic has permitted cardiac arrest for 1½ hours in a case of aortic insufficiency. The method has been gardually developed in a series of 20 operations under deep hypothermia with extracorporeal circulation.

Unfortunately in most cases with aortic insufficiency all three cusps are damaged by disease making bicuspidalization impossible. If significant insufficiency remains after repair the possibility of survival is very small. Then utilization of one or more prosthetic cusps is necessary.

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