OPEN HEART SURGERY UNDER HYPOTHERMIA

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This article records 7 cases of congenital cardiac abnormalities which have been treated by 'open-heart' surgery under hypothermia. There were 4 cases of Fallot's tetralogy, 2 of pulmonary stenosis, and 1 of auricular septal defect. It was recognized that, whereas it was possible to cure the cases of pulmonary stenosis and auricular septal defect by operation, the condition of the 4 children suffering from Fallot's tetralogy could only be improved, but not cured, by this method, because the heart could not be 'open' long enough to permit of the repair of the ventricular septal defect. These 4 patients, however, were so severely incapacitated that the decision was made to attempt to improve the pulmonary blood flow by operation under hypothermia; open heart surgery under by-pass was not then available, and the ventricular septal defect could always be repaired at some future date.

All the cases had been assessed clinically and had been catheterized, and in 6 of them pulmonary stenosis was present, 3 showing definite infundibular chambers. The 7th case showed the presence of a large auricular septal defect, the flow across the defect being measured as 14 litres per minute. The hazards of 'open-heart' operation on the Fallot cases were recognized, particularly the danger of air embolism.

The experience derived from operating on these cases has been invaluable. One case was thought to have a very tight pulmonary valvular stenosis, and great anxiety was felt when the catheter failed to pass through the valve opening. The conclusion was that the valve opening was so narrow that

it was occluded by the catheter tip. The right ventricular pressure was very high. Pre- and post-operative tracings are reproduced to illustrate the findings (Fig. 2). In this case the plan of operation was to perform the pulmonary valvotomy through the pulmonary artery after inflow stasis had been produced. However, once the pericardium had been opened it became clear that the case was one of infundibular stenosis, the infundibulum being visible as well as palpable. As there was no ventricular septal defect there was no anxiety about letting air into the left side of the heart.

The surgical approach was similar in all the cases. The differences in technique are discussed with specific reference to the problems that were encountered.

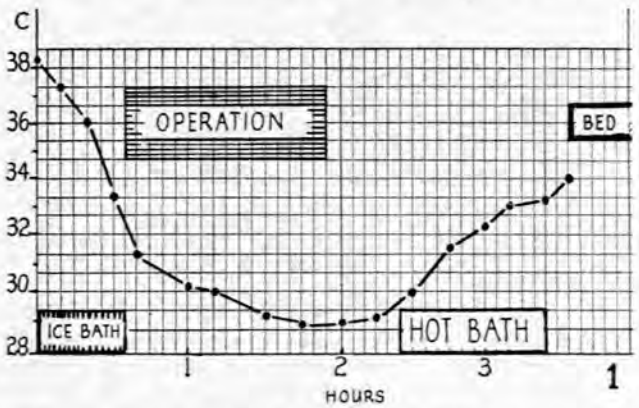
THE OPERATIONS

Premedication. Pethidine, chlorpromazine and scopolamine are given 1 hour before operation.

Anaesthesia. Induction is done with Pentothal and a relaxant. The vocal cords are then sprayed with Xylocaine, and once the endotracheal tube has been placed in position, gas, oxygen and ether are employed to maintain the anaesthesia.

Temperature Control. Careful temperature recordings are made on the thermocouple before hypothermia is started, and throughout the operation. This instrument is incorporated in an oesophageal tube which is inserted under anaesthesia.

*Hypothermia.** The anaesthetized patient is placed in a bath containing ice water at a temperature varying from 0° to 7°C, depending on the amount of ice placed in the cold water. Electrocardiograph leads are placed in position on the patient in order to observe changes on the oscilloscope and record them on film. The time taken to cool a patient depends on his weight. The average time for a 37-lb. child is about 45 minutes. The anaesthetist must try and prevent shivering,



and extreme care must be taken to ensure that the oesophageal temperature does not drop below 33°C. At this level the patient is removed from the bath, dried rapidly, and prepared for the operation (Fig. 1). The temperature will continue to drift lower after the operation has started, and again measures, even to the extent of re-warming, must be taken to avoid its dropping below 30°C. It is an advantage to have the patient lying on a water-warmed mattress so that the temperature can be raised if necessary.[2]

* The pioneer work was done by Bigelow.

Position of the Patient. The patient should lie in the supine position with the right arm abducted and the left arm at the side. The surgeon operates from the right side, with the two assistants on either side of the patient. The instrument tables are placed over the foot and to the sides of the operating table, from which position the theatre sister passes the instruments to the surgeon.

Intravenous Tubes. Intravenous tubes are used for the administration of intravenous anaesthesia as well as for the blood and saline transfusions. The arm veins and the long saphenous vein are chosen, and polythene tubing should be inserted through a needle into the veins; it can be maintained in position for as long as is necessary.

Operation Incision. A bilateral incision should be made over the 4th ribs, curving slightly round the breast regions, and passing from one axilla across the sternum to the opposite side. The skin and subcutaneous fat are separated, the position of the 4th rib is palpated, and the pectoral muscles are then divided. The periosteum of the 4th rib, which is cut from the axilla to the sternum, is then elevated, and the pleural cavity opened on the right side. The same procedure is carried out on the left side, but over the 3rd rib. The sternum is then divided obliquely across the mid-line to join up the two pleural incisions. The divided internal mammary vessels must be carefully ligatured. The incision is opened up by placing a rib-spreader between the divided edges of the sternum. When the spreader has been opened wider, the pericardium and thymus must be separated from the under surface of the upper part of the sternum. The thymus must be reflected upwards so that the great vessels above the pericardium can be clearly viewed.

Incision of Pericardium. A large pericardial flap is made, in the shape of an inverted U between the two phrenic nerves. This large tongue-shaped part of pericardium is then reflected downwards to cover the edges of the sternum, and can be kept in position with a couple of stitches.

Examination of Heart. A quick examination is made to ascertain whether there is any abnormality of the venous return, such as a left superior vena cava draining into the coronary sinus. The site of abnormalities such as an infundibular chamber or ridge must be noted, as well as whether pulmonary valve stenosis is present.

Mobilization of the Venae Cavae. The venae cavae must be dissected in order to pass tapes round them. The superior vena cava is readily exposed, and a tape is passed round it just proximal to the point of entry of the azygos vein. It is often more difficult to expose the inferior vena cava, because the pericardium has to be divided and dissected at the site where the vessel enters the pericardial cavity, and damage to its wall must be avoided. When the venae cavae have been exposed and the tapes have been placed round them, rubber tubing is placed over the tapes so that they can be pulled taut, thus occluding the vessels. Umbilical tape serves this purpose most satisfactorily.

Arterial Occlusion. The position of the transverse sinus can be readily determined; it separates the aorta and pulmonary artery in front from the atria behind. When this sinus has been identified, a large flat clamp should be placed in position and tested. Closure of the blades will achieve complete occlusion of the aorta and the pulmonary artery.

The operation site has now been prepared, and all is ready for inflow stasis and open heart procedures.

Preliminary Pressure Recordings. The appearance of the heart will often suggest the presence of an infundibular stenosis, an infundibular chamber, or pulmonary valve stenosis. In case of doubt, a cardiac catheter should be passed into the right ventricle and then into the pulmonary artery. Continuous recordings will demonstrate the presence of any of these abnormalities, as well as providing pressure records for comparison with post-operative readings. Although pressure readings are not essential, this comparison will provide a valuable guide to the success of treatment. Two stitches are placed in the right ventricular wall to act as retractors, and the cardiac catheter is introduced into the ventricle through a short incision in the myocardium.

Palpation of Atrial Cavity. The outstanding feature of a case of auricular septal defect is the increase in size of the right auricle. Pre-operative catheter investigation may have helped to show the exact site and size of the defect. The defect must still be palpated and a digital examination of the pulmonary outflow track from the right ventricle must be made. When the surgeon has confirmed that he is dealing with an 'ostium secundum' type of defect, the operation can proceed. If doubt exists the surgeon will decide against open-heart surgery under hypothermia, and the operation will have to be performed under by-pass conditions with a heart-lung machine. Repair of atrio-ventricular defects takes too long to permit of its being done under hypothermia.

The exploratory incision into the right atrial cavity is then closed, inflow stasis is instituted, and the operation for correction of the defect is commenced.

Inflow Stasis. All apparatus should be checked before the circulatory arrest is started, and all manoeuvres must be timed with a stopwatch. The two vena-caval tapes are tightened. The aortic and pulmonary artery clamps must be placed sufficiently far from the aortic valves to allow of the injection of Prostigmin. This clamp is placed across the two vessels about 15 seconds after the two vena-caval tapes have been tightened, because this time interval allows the heart to empty itself of most of its blood. Prostigmin in about 5 c.c. of normal saline is injected into the aorta, between the clamp and the aortic valves. This ensures that the Prostigmin, which reduces the liability to ventricular fibrillation, will enter the coronary vessels.

The Ventriculotomy. The incision is made into the right ventricle between the two stay sutures previously inserted, and must incorporate the small incision employed for the cardiac catheterization. This incision must be sited where it will cause minimum injury to the coronary vessels, and it must be below the position of any muscle ridge as seen in infundibular stenosis. This ridge can usually be palpated through the wall of the right ventricle, or it can be seen if there is a thin-walled infundibular chamber. The aim of the surgeon is to approach the obstruction either from a position directly above it or, preferably, from below. The incision in the ventricular wall can be lengthened upwards towards the pulmonary artery if necessary. When the ventricle has been opened, the edges of the incision are retracted, blood is removed by the suction tube, and the site is then examined.

Infundibular Stenosis (see Figs. 2 and 3). Infundibular stenosis may be due to muscular hypertrophy giving rise to a crista supraventricularis. This excess muscle can be cut away with a scalpel and scissors, care being taken that no small pieces of muscle are dropped into the ventricular chambers. In cases of Fallot's tetralogy a piece of muscle might conceivably be dropped into the left ventricle through the ventricular septal defect. The pulmonary valve should be inspected after the excess muscle tissue has been removed. If the valve is out of sight, dilators of a reasonable size should be introduced to determine the presence of any obstruction. Any valvular stenosis should be treated by direct incision of the stenosed area, the valve being opened to its normal size.

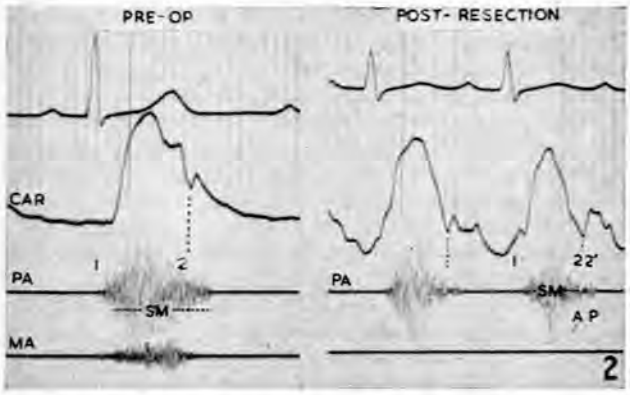


Fig. 2. Phonocardiograms in case of infundibular stenosis with intact ventricular septum.

A. The pre-operative phonocardiogram reveals a loud, very prolonged systolic murmur (SM) that extends well beyond and completely obscures the aortic second sound (2). The position of this sound is shown by the dicrotic notch of the carotid tracing (CAR), which denotes the end of left ventricular systole. Although the pulmonary second sound is so soft as to be unrecordable, the marked prolongation of the systolic murmur beyond the aortic second sound is sufficient indication of the prolonged duration of right ventricular systole and, hence, of the severity of the stenosis.[4] In this case, severe stenosis was predicted from auscultation.[5] This was confirmed by the high right ventricular systolic pressure of 225 mm. Hg (see Fig. 3).

B. Two weeks after the infundibular resection the murmur was found to be much shorter in duration, stopping at the aortic second, which it did not obscure and the width of splitting of the second sound was only 0·04 seconds. From these observations it was inferred that the duration of right ventricular systole had become much shorter, in keeping with mild to moderate stenosis, thus indicating a successful resection. This was confirmed by the post-operative cardiac catheterization, which shewed that right ventricular pressure had fallen to 63/0 mm. Hg. (see Fig. 3).

(From Vogelpoel and Schrire.[4])

Time Recording. The time must be recorded and called out to the surgeon in a clear voice by the anaesthetist. The recordings should state at half-minute intervals the passing of time since the commencement of inflow stasis. The intervals are therefore ½ minute, 1 minute, 1½ minutes, etc., and the surgeon has to see that his procedure is completed in the specified time of between 6 and 8 minutes. The surgeon will soon realize if he is taking too long. The anaesthetists' records will show that the ventriculotomy was completed 1 minute after inflow stasis commenced, and the resection of the infundibular ridge and inspection of the pulmonary artery have taken 3 minutes, i.e. that about 4 minutes elapsed before closure of the ventriculotomy was started.

Closure of the Ventriculotomy Incision. The ventricular cavity and the chest cavity are flooded with saline preparatory

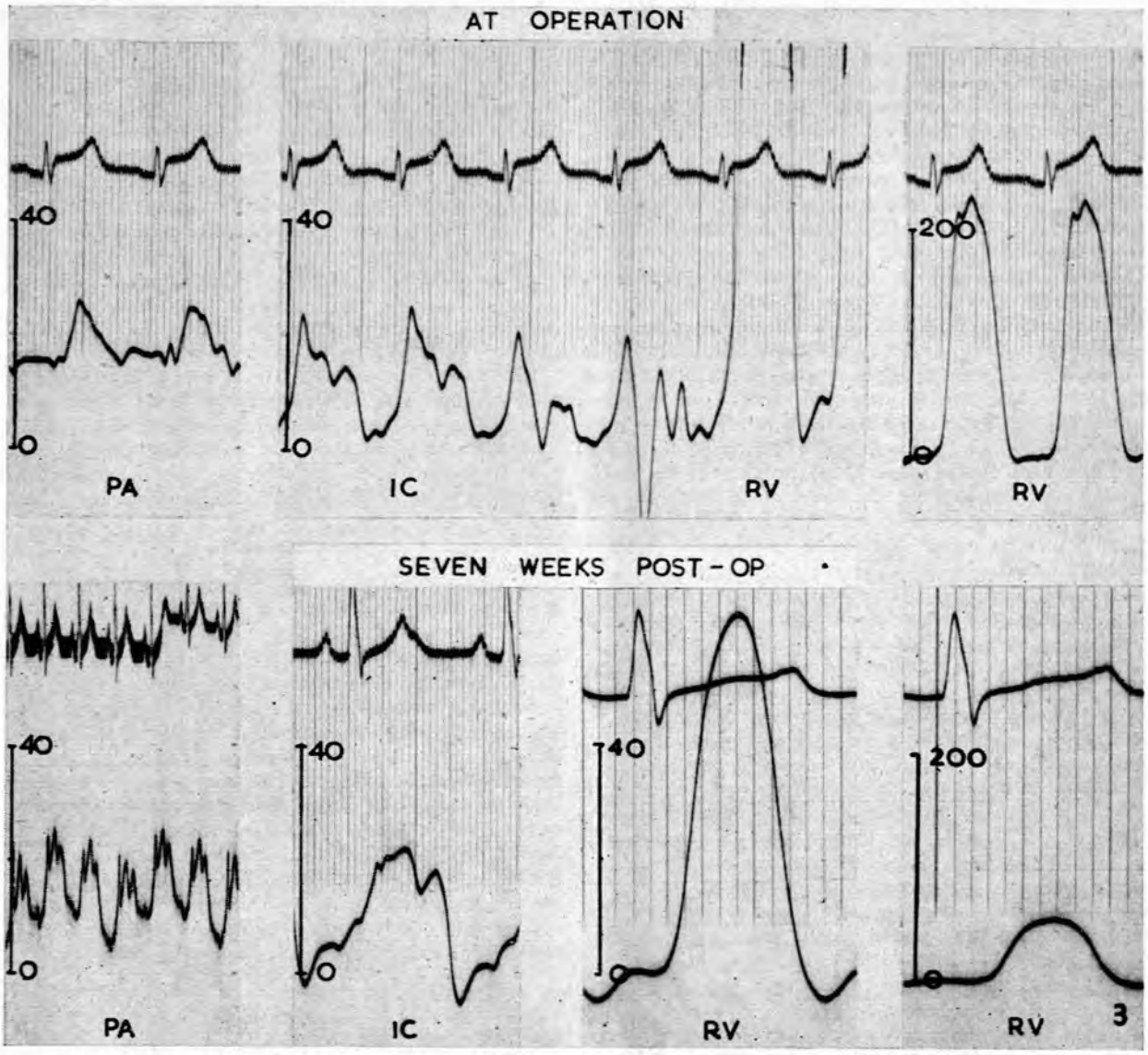


Fig. 3. Cardiac catheterization in case of infundibular stenosis with intact ventricular septum. At operation, the pressure in the pulmonary artery (PA) was 25/17, infundibular chamber (IC) 25/1 and right ventricle (RV) 225/0 mm. Hg. Cardiac catheterization 7 weeks after resection of the infundibular stenosis revealed a considerable fall in the right ventricular pressure (RV) to 63/0, with a pulmonary artery pressure (PA) of 25/15 and an infundibular chamber pressure (IC) of 22/1.

to closing the incision in the ventricle. The heart is pressed downwards towards the posterior mediastinum in order to immerse the whole organ in saline. During this manoeuvre feeble heart contractions will help to expel air bubbles, and as soon as the surgeon is satisfied that no air is trapped in the ventricles, continuous suture of the incision is commenced. This will take another minute or two and, when the incision is relatively well closed, the circulation must be restored. The operating table is tilted into the Trendelenburg position in the hope that, in the event of air entering the aorta, it will not enter the head region. The vena-caval tapes are released and, if air is present in the ventricles, the first beat will squeeze it through the incompletely closed incision in the muscle. After a beat or two the clamp over the aorta and the pulmonary artery can be released. The heart should then take over its normal rhythm. Resuscitatory measures should be started early if there is any evidence of abnormality of heart action.

Repair of the Auricular Septal Defect. The repair of the auricular septal defect must be done through the right atrium. The operative procedures described above apply to these cases, up to the stage of inflow stasis. The incision into the atrial wall is made immediately after the injection of Prostigmin into the aorta. The incision is about 3 inches in length, which allows the surgeon ample room in which to work as well as to see. The margin of the defect, the position of the

caval openings, and the entrance sites of any unusually situated pulmonary veins, are quickly identified. The defect must be closed, care being taken to avoid directing the flow of veins into the wrong atrium. Suturing of the defect can be done either by continuous or interrupted sutures. Throughout the procedure the anaesthetist should be calling out the time every half minute. All air must be expelled from the atrial chambers before the incision in the auricular wall is repaired. The normal cardiac circulation can be restored as soon as the surgeon is satisfied that there will be no leak of blood from the atrium. The repair can be completed while the heart is already beating. This operation has been well described by Sellors *et al.*[3]

Temperature Recordings. The anaesthetist should report the temperature from time to time. It will continue to drift downwards slowly while the chest is open, particularly during inflow stasis. The surgeon may derive some comfort from the fact that the undesirably low temperature will provide him a slightly longer operating time. The case of auricular defect described in this paper bore circulatory arrest for 10 minutes without ill-effect, the temperature having drifted to 28°C. The defect was of such a size as to require extra time to close it by continuous suture reinforced with some interrupted sutures.

Resuscitatory Measures. If the heart fails to beat properly, cardiac massage should immediately be started. As a rule the heart takes up a good rhythmic contraction, and when the anaesthetist reports the pressure of a pulse, the closure of the ventricular or auricular incisions can be completed. Any sign of a change in rhythm or in the force of contractions should serve as a warning of impending fibrillation, and a shock or two with a defibrillator should be applied. The heart should be beating at about 80 beats per minute, and cardiac massage may be necessary as an adjunct to the defibrillator. It is important to remember to massage the heart fast enough, and to continue the massage for a considerable time, even when recovery seems remote.

Re-warming the Heart. When the heart has recovered the pleural cavity and heart region should be flushed out with saline warmed to at least body temperature. Hot water should be circulated through a rubber water-bed underneath the patient.

Drainage Tubes. The cardiotomy incision having been closed and the heart rate restored, drainage tubes must be placed into both pleural cavities. These tubes should be connected with underwater drainage bottles to which negative pressure of about 15 cm. water has been applied.

The Thoracic Incision. The divided portions of the sternum must be approximated and held in position by stout catgut sutures, or with well-placed wire sutures. The chest wall is closed in layers, and one can dogmatically state that no attempt should be made to close the pericardium. The incision should be closed as quickly as possible and the entire area as well as the stab wounds for the drainage tubes are then treated with a Nobecutane spray, to make the incisions water-tight.

Total Body Re-warming. The patient is placed in a bath of hot water at a temperature of 40°C and kept there until the body temperature reaches 34°C. This temperature recording is again read on the oesophageal recording instrument. As soon as the temperature has reached this 34°C level, the patient is removed from the bath, dried off, and put to bed.

Post-operative follow-up. The post-operative follow-up is essentially the same as for any major thoracic surgical case, and this implies special nursing for the first 48 hours. Until normal body temperature has been restored, temperature recordings must be charted with the routine periodic examinations of pulse, respiration, and blood pressure.

RESULTS

Two deaths occurred in the 7 cases reported. One of these was a child who was severely ill with Fallot's tetralogy. The operation proceeded according to plan, a marked infundibular ridge was removed, but at the completion of the operation, the re-warming appeared inadequate, and it was not possible to restore a normal range of temperature for almost 6 hours. The cause of death was uncertain. The second death occurred in an adult patient in whom a pulmonary stenosis was treated by direct operation on the pulmonary artery. All went well until the third day, when he developed acute pulmonary oedema which failed to respond to restorative measures. Apparently the strict instructions about fluid intake had been relaxed, and it was stated that visitors had provided him with extra fluid in the form of cold drinks. His death was very sudden, and one is entitled to presume that the extra fluid intake was a contributory factor in the left heart failure.

The other cases have done well.

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