CONCERNING SOME TECHNICAL POINTS OF CARDIAC SURGERY
CONDUCTED UNDER TOTAL CARDIOPULMONARY BY-PASS

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The complete repair of congenital abnormalities such as ventricular septal defects, the tetralogy and pentalogy of Fallot and the complex defect of canalis atrio-ventricularis communis (ostium primum defect of the atrial septum) is only possible at present under conditions of total cardiopulmonary by-pass. The ultimate application of by-pass procedures to the correction of stenotic and regurgitant lesions of the mitral and aortic valves may become universal but at the moment of writing it is premature to force this issue.

Many feel that atrial septal defects of the secundum type can be safely and adequately closed by open surgery carried out during circulatory arrest with hypothermia; aortic stenosis can be relieved under the same conditions but some surgeons prefer to use by-pass procedures. Pure pulmonary valve stenosis can be corrected during circulatory arrest without hypothermia but the presence of infundibular stenosis necessitates careful excision of muscle which should always be done with a cardiopulmonary by-pass.

It is proposed here to consider the surgical aspects of some congenital cardiac defects: those discussed are the lesions commonly dealt with in most centres.

Ventricular septal defects.

Isolated ventricular septal defect is common but the prognosis is poor. Many of the infants are seriously ill and some authorities (Friedberg, 1958) state that half of them die in the first year of life if the defect is large. The survivors are liable to repeated respiratory infections and usually fail to grow normally. After the second year illness is less common but few live beyond the fourth decade.

All large ventricular septal defects cause progressive pulmonary hypertension. The exact relation of clinical signs with the stages of progressive changes in the pulmonary vessels in pulmonary hypertension associated with ventricular septal defects has been beautifully demonstrated by Heath and Edwards (1958).

Pulmonary hypertension can be relieved if operation is carried out before irreversible damage has been done to the pulmonary arterioles. In practice surgery is still possible if evidence can be produced that the shunt is still left to right, or if bi-directional at times, is principally from the left to the right ventricle: once the right ventricular pressure consistently exceeds that of the left, producing cyanosis, the state is inoperable, because of the permanence of damage to the small pulmonary arterial branches.

By means of adequate investigation it is possible to state clearly the indications and contraindications to the surgical repair of these defects. Repair is not required for patients with a normal sized heart, a normal e.c.g., and where cardiac catheterization has failed to reveal pulmonary hypertension or a sufficiently large shunt; it is too late to offer surgery when persistent cyanosis has developed and the shunt has reversed into a right to left one. Surgery must always be considered if repeated episodes of lung infection and/or cardiac failure exist in patients with an enlarging heart, pulmonary hypertension and with evidence of a considerable left to right shunt causing pulmonary plethora. The elucidation of the facts that provide information enabling the cardiologist to opt for or against surgery cannot be obtained on clinical examination alone.

The clinical appearances that demand full investigation of the heart.

The growing opinion that many ventricular septal defects should be closed in childhood has
led to the demand for more and more accurate diagnosis in patients with cyanotic heart disease. The almost fortuitous discovery of a systolic murmur in an apparently healthy child must lead to the fullest cardiological assessment; on routine clinical examination the future gravity of the lesion may be overlooked if it is not realized that the shunt may be a large one with a great increase in pulmonary circulation. Auscultatory and radiological signs may be deceptive; radiological studies, especially of the size of the right or left ventricle are often incorrect; at operation this is often demonstrated. Since, however, open repair of this lesion has proved dangerous before the age of two, every attempt should be made to treat infants with respiratory symptoms and early cardiac failure by medical means and with a prolonged stay in hospital.

The surgeon is particularly interested in the information provided by cardiac catheterization. This investigation provides information on the site of the shunt and on the pressure within the right ventricle and pulmonary artery. Pulmonary hypertension of more than 70 per cent of the systemic arterial pressure greatly increases the risk of operation.

Ciné-angiography is of great help, as in straightforward ventricular septal defects it provides exact information on the size and site of the defect and can demonstrate ventricular septal defects too small to allow significant left to right shunts. This is especially important in the presence of pulmonary stenosis where the increase in right ventricular pressure prevents a shunt, so that this direct radiological evidence enables one to diagnose the presence of the ventricular septal defect, thus providing an indication for surgery with cardiopulmonary by-pass for the correction of the pulmonary stenosis.

E.c.g. evidence is of great value. All patients who have a left to right shunt at ventricular level show evidence of left ventricular hypertrophy. When the right ventricle becomes excessively hypertrophied due to high pulmonary artery pressures, e.c.g. evidence of left ventricular hypertrophy is overshadowed by right ventricular complexes. Under these circumstances operation carries a very high risk and is unlikely to relieve the patient.

**The tetralogy of Fallot.** (Ventricular septal defect with obstruction to the flow of blood from the right ventricle to the lungs, associated with obvious cyanosis.)

The brilliant work of Blalock, who introduced systemic pulmonary artery anastomosis for the relief of cyanotic children with obstructions in the outflow tract (either infundibular stenosis or pulmonary valve stenosis), has not only led to the relief of thousands of patients but stirred up interest in the whole subject of the tetralogy. Brock's direct attack on infundibular or valvular stenosis also played a great part in the story of the surgery of this defect. It is obvious today that future treatment will require total repair of the defect as was first executed by Lillehei. The operation is a grave one and still causes a mortality rate of 16 to 20 per cent even in the hands of such masters as Kirklin (1959).* Many of these children die before the age of five and operation has to be done at an earlier age than is ideal: the setting up and performance of the by-pass procedure is more difficult in the very young because of the small calibre of the blood vessels.

It is found from experience that if these cyanotic patients can be kept in hospital the death rate in the pre-operative year can be greatly diminished by expert nursing, oxygen therapy and the use of antibiotics for intercurrent infections. Anastomotic operations of the Blalock or Potts type (aortico-pulmonary anastomosis) still have a place in certain patients with tricuspid atresia and truncus arteriosus when there is undoubted pulmonary oligaemia.

**Pre-operative treatment.**

Usually the patient will have been fully investigated before admission to the surgical ward: since the preliminary assessment has inevitably involved the procedure of cardiac catheterization and usually ciné-angiography, the small wounds necessarily made in the arm or groin for these examinations must be completely healed before by-pass procedures are employed. A reasonably long preliminary spell in the ward is valuable; the patient, usually a child, will require to become

*In the paper discussing these results, Kirklin was able to report that in his last ten patients there had been no death.
fully acquainted with the nurses who will care for him postoperatively, to learn simple exercises under the instruction of the physiotherapist and to be taught to lose all fear of oxygen masks and oxygen tents. The normal pre-operative examinations are made; a radiography taken on the pre-operative day is essential as unexpected lung infections are occasionally demonstrated. Children with the tetralogy of Fallot have a tendency to develop pulmonary tuberculosis and are notorious for the high incidence of dental caries and infections, and these conditions must be looked for particularly.

Blood preparation.

Before operation blood is collected for use in the extracorporeal circulation and also for replacement of blood loss before and after the by-pass procedure. The blood for charging the extracorporeal circulation and sufficient to make up any loss that may occur during the cardiotomy (8–10) bottles is collected into heparin. The volume of anticoagulant should be kept to a minimum so that the blood is not unduly diluted. In this centre each bottle contains 18 mg of heparin in 25 ml of isotonic dextrose and is filled to 500 ml with blood. Great care is taken during collection to ensure that the heparin is well mixed with the blood. In some centres siliconed bottles are used. The heparinized blood must be taken less than 24 hours before the operation, preferably on the same day.

In addition, four bottles of citrated blood are cross-matched.

The operative procedure.

Premedication and the choice of anaesthetic agent are considered elsewhere (Moffitt and Theye, 1959); although inevitably details vary in different hospitals, the universal acceptance of the need for the lightest plane of anaesthesia has greatly lowered the risk of cardiac surgery, the anaesthetist in my own department is in charge not only of anaesthesia but of the administration of most drugs and infusions given parenterally, apart from those delivered by the pump-oxygenator; for example he makes up the deficit of blood lost in the phase before the extracorporeal circulation is established, working in the closest collaboration with the nurse responsible for measuring blood loss (see later): he is responsible for the intravenous administration of heparin to the patient at the appropriate stage and its correction later by the use of protamine sulphate. He constantly checks the reading of the oesophageal temperature.

Weighing the patient.

As a check on the pre- and postoperative blood volume of the patient, weighing is a most important aid. As soon as the patient has been anaesthetized and is ready to be placed in the correct operative position he is weighed to within 5 gm (10 gm in adults).

Monitoring.

Throughout the operation continuous records are made of the arterial and inferior vena caval pressures, the e.c.g. and the e.e.g. (see page 387 of this symposium). The oesophageal thermistor is put in place so that the patient’s temperature can be constantly observed. The e.e.g. provides information of the depth of anaesthesia and has proved useful to the anaesthetist in maintaining a very constant light plane of anaesthesia. During cardiopulmonary by-pass it provides information on the adequacy of the cerebral circulation.

The positioning of the patient.

With the table at the correct height the patient is placed in the supine position, sometimes lying on a "hypothermia" blanket made of plastic material through which warm water can be circulated if the temperature shows a tendency to drop (see also page 415 of this symposium); such a blanket may be omitted; if it is used the greatest care must be taken to place appropriate padding over the usual pressure points where burning can take place, especially if the circulating water is hot during periods of hypotension. Before any towels are put in place, e.e.g. and e.c.g. leads are put firmly in position. In this department the pump-oxygenator is placed to the right of the table, and the manometer heads, which will subsequently be connected to the fine nylon catheter in the aorta and inferior vena cava, are fastened to the table near the right foot of the patient. An intravenous drip is set up. The patient is covered with towels after skin preparation so that small areas of both upper thighs and the anterior chest wall are exposed.
Exposure of the vessels in the thigh.

One common femoral artery is exposed through an incision overlying it which extends from just above the inguinal ligament down to the level half an inch below the origin of the profundis femoris. The neighbouring internal saphenous vein is used to provide a route for a fine nylon cannula which is placed in the inferior vena cava for a pressure manometer. If a femoral artery is used as a route for placing a catheter in the aorta for arterial pressure, the opposite superficial femoral artery is exposed and cannulated. Many surgeons prefer to use an internal mammary artery for this purpose.

The thoracic exposure.

Excellent access is obtained by a median sternotomy incision: a vertical incision is made from just below the suprasternal notch well down on the abdomen to reach halfway between the xiphisternum and the umbilicus. To avoid excess bleeding after the subsequent injection of heparin the most elaborate haemostasis is essential: the incision made in the skin with the scalpel is only deep enough to divide the true skin, the remainder of the incision being made by the diathermy knife down to the periosteum of the sternum: the upper border of the sternum is cleared of adventitious tissue down to the suprasternal ligament: usually a vein crosses this and requires division and ligation: at the lower end of the sternum the xiphisternum is exposed, and lifted upwards by a tissue forceps. By blunt dissection the loose areolar tissue behind the sternum is cleared as far upwards as possible: this process being completed from above so that a free tunnel exists with each pleural sac displaced laterally. The sternum is then divided either by a Gigli saw or a Lebsch’s chisel. The two halves of the divided sternum are separated by manual traction exerted through two double-hook retractors. Horsley’s bone wax is rubbed firmly into the cut section of the bone to stop oozing. With gauze swabs placed on each side of the incision the sternal fragments are widely retracted by a powerful rib spreader (Price-Thomas, Tuffier or Finochietto type). If the internal mammary vessels are damaged or look likely to be torn, they are divided and ligated. Usually the pleural spaces remain intact: should one or other be damaged, the appropriate pleural cavity will subsequently require water-sealed drainage at the close of the operation.

The exposure and opening of the pericardial sac.

The sterno-pericardial ligaments are divided with diathermy, any small vessels in these or in the fibro-fatty tissue overlying the pericardium being coagulated with great care: the parietal pericardium is opened by an incision in its mid-line; this opening is carried down caudally as far as the diaphragm. At the cephalic end the incision is converted into a “Y” shape, each limb of the “Y” skirting the lower poles of the thymus gland: this manoeuvre avoids the need to enter the slightly vascular area of thymic tissue and gives excellent access. Several sutures are passed through each side of the pericardial sac so that traction can be applied to them. When the heart exposure has been completed the previously placed retractor is further opened.

The systematic examination of the heart.

Although modern preoperative investigations enable a high degree of exact diagnosis to be made, certain important lesions may have been missed: before any procedure is started on the heart the operator carries out a systematic visual and manual examination. This is best done by answering a routine list of questions read out by the cardiologist who notes down the replies; the questionnaire covers the circulatory route; the size, the quality of the tissue (atrophy or hypertrophy); the presence of thrills, etc., of the following structures is noted in this order; the caval vessels, the right atrium, the right ventricle including its inflow and outflow tract, the pulmonary artery, the ligamentum arteriosum or the ductus (if persistent), the left atrium, the pulmonary vein (both sides), the left ventricle and the aorta. Invariably the operator must answer the questions: “Is there a ductus arteriosus?” If this is overlooked severe bleeding may be encountered after the heart has been opened. “Is there a left superior vena cava?” This if present will open into the coronary sinus and be a serious source of bleeding once the cardiotomy has been started. “Is there any other venous anomaly, e.g. an inferior vena cava opening into the left atrium?” If these anomalies exist they require
Preparation of the heart for the establishment of cardiopulmonary by-pass.

The superior and inferior venae cavae are encircled by thin rubber tubes: these are threaded through a large size rubber tube to act as snares, so that subsequently these vessels can be closed round the cannula to stop the flow of venous blood to the right atrium. The aorta is dissected sufficiently freely from the pulmonary artery to enable a clamp to be placed across it later; this step is necessary whether cardiac arrest by potassium citrate or other agents is to be used or not: If arrest (which is almost routinely used) is not employed the aorta may require periodic clamping to stop the coronary flow during the cardiectomy; without arrest, periodic release of the clamp is necessary to allow an intermittent adequate coronary artery flow.

Finally a drainage tube is placed at the bottom of the pericardial sac: this is connected to separate motor suction apparatus so that the minute by minute loss of blood from this source can be easily measured and rapidly replaced together with that estimated by swab weighing. The head of the drainage tube is protected by a perforated metal end to avoid soft tissue being sucked into it.

Setting-up the artificial circulation.

(a) Arterial cannulation. Before cannulae are placed in the arterial and venous channels the patient is heparinized—3 mg of heparin per kilogram is injected into the intravenous drip leading to the arm vein by the anaesthetist: the femoral artery—previously prepared—is encircled by a heavy ligature and bull-dog arterial clips placed above and below the proposed site of cannulation: an incision is made in the femoral artery and a bevelled nylon cannula introduced. When it is firmly in place the upper bull-dog clamp is removed. The cannula is firmly held in place in the artery by a noose of thick silk which encircles the vessel and its contained cannula. The end of the silk noose is threaded through a rubber tube and held firmly by the application of an artery forceps to it against the end of the rubber tubing. The cannulae vary according to the size of the patient and many surgeons use metal ones; we have used sizes varying from 2.5 mm to 6 mm in diameter.

(b) Venous cannulation. A Brock’s mitral clamp is placed on the right atrial appendage: a purse string suture is placed around the grasped atrial tissue which is then incised: a finger (usually the little one) explores the atrium, after the clamp has been removed temporarily to exclude or confirm the presence of an atrial septal defect. The clamp is then re-applied; two venous plastic cannulae are then selected: their diameter varied from four to nine mm according to the size of the patient: the lips of the atrial incision are held apart by fine silk sutures; when these are held up vertically a tunnel is formed into which the two cannulae held together are “dropped”. The clamp is then removed and the two tubes introduced into the atrium. The tunnel is then converted into a double-barrelled tube by applying an artery forceps to both lips of the atrial incision between the cannulae. Throughout this manoeuvre the cannulae are held vertically upright—they are easily manoeuvrable by means of a malleable metal stilette. One cannula is guided into the inferior vena cava for a distance of three to four inches and then withdrawn so that about one inch remains inside: this is usually just at the edge of the diaphragm as it surrounds the vessel. The superior vena cava is cannulated and the tip palpated to make sure it is not beyond the entrance of the brachio-cephalic vein: the purse string suture in the atrial wall is then tightened to keep the cannulae firmly in place and to stop the escape of atrial blood. The correct placement of these cannulae is obviously of the greatest importance to enable the total venous return from the caval vessels to reach the pump by gravity drainage.

Throughout the operation except during the period of total cardiopulmonary by-pass the anaesthetist replaces blood loss, keeping a few c.c. ahead of the amount charted by the nurse carrying out swab weighing.

Institution of cardiopulmonary by-pass.

The arterial and venous hoses of the machine, which is set up and checked before operation, are brought on to the operating table and connected to their appropriate cannulae. All air must be excluded from the arterial line when this con-
nection is made but very small quantities of air in the venous line are not important. The lie of the venous cannula is carefully checked and the hoses are fastened to the towels so that they will not be kinked or moved.

When the surgeon is satisfied that the machine is properly connected to the cannulae and perfectly positioned it is turned on. The patient is then on partial cardiopulmonary by-pass and the combination of the action of the heart and the pump appears on the arterial trace. The venous return into the machine is checked. If this is satisfactory the caval snares are tightened so that the total venous return is diverted through the machine and total cardiopulmonary by-pass established. The mean arterial and venous pressures should remain normal and the e.e.g. should show evidence of adequate cerebral circulation (grades 1 or 2; see page 387 of this symposium). In the first two minutes there is usually a drop in the arterial pressure and a change in the e.e.g. This usually corrects itself quickly. It has been found that if the arterial and venous pressures are kept within normal limits then the patient’s blood volume remains at its pre-operative level. It is very easy to produce a negative venous pressure and this should be corrected by the appropriate means, varying with the machine used. Figure 1 shows the changes at the onset of cardiac by-pass in a boy of eleven; it will be seen that at 50 seconds the e.e.g. showed a high amplitude and low frequency despite the slow rise in arterial pressure. After a further minute the e.e.g. had returned to normal levels. When total cardiopulmonary by-pass runs smoothly the heart can be arrested if desired or opened if the operation is to be done without arrest.

**Induction of cardiac asystole.**

Most surgeons employ the method of Melrose (1955) and it is a routine in this clinic. The method of Kirklin as used at the Mayo Clinic is admirable (Harshbarcer et al., 1958). Eight c.c. of 25 per cent solution of potassium citrate are mixed with 80 c.c. of heparinized oxygenated blood taken from the tubing of the arterial side of the machine: this is assembled in a two-way...
syringe system, in which small rubber tubing joins the syringe to the needle to provide some elasticity, thus minimising the risk of an aortic tear during the injection of fluid. With the aortic cross clamp in place but open, the needle is inserted between the clamp and the heart and the solution rapidly and smoothly injected, the clamp being closed after the injection starts. The injection is stopped immediately after the heart becomes flaccid and motionless. The hole in the aortic wall is closed with a fine suture on an eyeless needle.

At the close of the intracardiac procedure the potassium citrate solution is washed out of the heart by releasing the aortic clamp: the perfusion of the coronary arterial system does this rapidly and effectively: the blood flowing into the heart immediately after the aorta has been re-opened is sucked away to prevent the retention of potassium citrate solution in the circulation. At this stage ventricular fibrillation may follow: this invariably responds to electrical defibrillation; manual massage may be required.

The cardiotomy.

(1) Right ventricular approach. Unless there is a complex defect such as a canalis atrio-ventricularis communis or a pentalogy of Fallot, the approach to the correction of a ventricular septal defect, or the total repair of a tetralogy of Fallot or the radical excision of pure infundibular stenosis, will be through the right ventricle. The incision starts in the outflow tract just below the pulmonary valve ring, and is carried down for about 1 ½ to 2 ½ inches, depending on the size of the heart in the bare area of the right ventricle. Only a small opening is made at first so that a cardiac sucker can be introduced and the heart emptied. The incision is then completed. Continued intracardiac suction is necessary—despite clamping the aorta—because the bronchial circulation reaches the heart through the pulmonary veins. This flow varies and may be considerable in patients with cyanotic heart disease; it also seems to be greater in those with severe pulmonary hypertension.

The technical details of the intracardiac repair of the different lesions will naturally depend on the situation present; certain principles are common to all repairs. The surgeon must always ensure that any obstruction to the outflow of blood from the right ventricle is corrected as thoroughly as possible. Such measures include the deliberate incision of stenosed pulmonary valves, wide excision of hypertrophied muscle masses in the outflow tract of the right ventricle, and often removal of large portions of the crista supraventricularis: if the obstruction is due to an infundibular stenosis (which in the type of case under discussion is far commoner than pulmonary stenosis) the excision of obstructing tissue must be thorough. If the obstruction of blood flow is accompanied by a ventricular septal defect, the closure of the latter, unless associated with adequate opening up of the outflow tract, may place such a burden on the right ventricle that failure of its muscle can well occur in the immediate postoperative period.

Before any attempt is made to close a ventricular septal defect a full assessment of the site and size of the opening must be made; the defect may be in one of four sites (Kirklin, 1957).

(a) High up, just below the opening of the pulmonary artery.

(b) In the outflow tract of the right ventricle below the crista supra-ventricularis.

(c) In the inflow tract of the right ventricle beneath the septal leaflet of the tricuspid valve.

(d) In the muscular part of the septum near the apex.

The large group of ventricular septal defects consists of types a and b, the commoner being type b.

Firm repair of a defect sited entirely in the membranous part of the septum is more likely than those with muscular edges; most defects are repaired by direct suture: large defects may, however, require closure by the use of an Ivalon sponge patch. During the repair of the defect its edges are defined by the judicious use of the cardiotomy sucker and suitable retraction of the papillary muscle and the chordae tendinae which often cross the defect. At the top edge of high defects the position of the cusps of the aortic valve must be constantly seen, as it is easy to damage one of them by the needle point as this is sunk into the dense tissues of the aortic root.

The position of conduction tissue (the bundle of His) is usually in the posterior-inferior area in the common type of defect, that is the one in the
outflow tract below the crista supra-ventricularis: the bundle is particularly liable to damage when there is no remnant of membraneous septal tissue in this region; the production of heart block is a serious occurrence and is still a not uncommon sequel to the closure of certain ventricular septal defects.

If muscle has to be excised from the right ventricle, this is done before the septal defect is repaired. It is important not to close the defect (and thus the left ventricle) before cardiac action has been restored; otherwise the left ventricle may become stretched by the return through the pulmonary vein (if this does not succeed in finding its way back round the pulmonary circulation into the pulmonary artery and thus into the open right ventricle). If the pressure in the left atrium becomes too high it may cause small haemorrhages in the lungs which greatly embarrass respiration. Infection readily follows. If the left ventricle is overstretched it may take a considerable time to recover its full power of contraction.

In order to avoid this complication the posterior half of the defect is closed and the sutures in the anterior part are placed but left untied. The aortic clamp is removed thus allowing coronary perfusion and washing out the potassium. The heart usually starts beating very quickly. Occasionally ventricular fibrillation occurs which is corrected with the defibrillator. The action of the left ventricle can be seen by the force of the jet of blood which comes through the partly closed defect, and once this appears to be forceful the sutures are pulled tight and the arterial trace observed for signs of left ventricular ejection, which should occur after a very few contractions. If they are not observed immediately the defect is opened again and this manoeuvre is repeated after a short rest. Once left ventricular ejection into the aorta has been observed the defect is completely closed and the incision in the right ventricle is closed with interrupted 000 silk sutures. If the perfusion pressure falls at this time the pump output may need to be increased.

(2) Atrial and atrio-ventricular approach. It is probably still considerably safer to repair the true atrial septal defects (ostium secundum) by atriotomy under hypothermic conditions than by the use of cardiac by-pass with a pump-oxygenator. Pulmonary valve stenosis associated with a secundum type of atrial septal defect is also best treated under hypothermia; the pulmonary valve is first dealt with after occlusion of the venous return to the right atrium through an incision in the pulmonary artery. When this has been effected the normal heart circulation is restored, and after a pause of ten minutes, the inflow and outflow of cardiac blood are again temporarily occluded before the right atrium is opened to permit deliberate suture of the atrial septal defect. If, however, a low atrial septal defect of the ostium primum type exists, or there is an atrial septal defect associated with a ventricular septal defect and obstruction to the outflow of blood from the right ventricle to the lungs (the pentalogy of Fallot), right atriotomy combined with right ventriculotomy can only be done under conditions of total cardiopulmonary by-pass.

It the pre-operative investigations have suggested the possibility of an atrial septal defect being present in addition to a ventricular septal defect, with or without obstruction in the pulmonary outflow tract of the right ventricle, an exploration of the right atrium by means of a finger (usually the little one) is carried out before the atrial cannulae are introduced. Should the presence of a sizable atrial defect be detected, the extracorporeal circulation is instituted and the necessary intracardiac work needed is done within the right ventricle. This ventriculotomy incision is almost completely closed before the right atrium is opened widely by a long incision in its lateral wall, through which the atrial septal defect is repaired by interrupted silk sutures.

In the case of the very complex defect of the canalis atri-ventricularis communis, repair is carried out through the right atrium. There is usually a cleft in the mitral valve cusp which is repaired by suture before the defect leading to a communication—usually between both atria and ventricles—is closed: this closure, an extremely difficult one, usually calls for the use of an Ivalon patch. When the repair of the right ventricle is completed the snares on the vena cava are opened so that some of the venous return enters the heart,
and the venous cannulae are withdrawn into the right atrium so that there cannot be any caval obstruction. The pump is then slowly turned down so that the heart takes a gradually increasing proportion of the circulation. Usually the blood pressure is normal at this stage and if the action of the heart appears satisfactory the pump is turned off.

Heart block.

Complete heart block occurs frequently during recovery from potassium arrest. The idio-ventricular rhythm usually provides adequate circulation. When the rate is very slow it can be increased using the artificial cardiac pacemaker, the electrodes being applied to the surface of the ventricles. If heart block persists for more than ten or fifteen minutes it is likely either to be permanent, or at least to continue for some time. Under these circumstances it is advisable to insert a cardiac electrode for attachment to the pacemaker after the operation. We find braided stainless steel wire inserted in a very fine nylon tube satisfactory for this purpose. The wire is inserted into the anterior surface of the right ventricle so that half an inch is buried in the muscle and no bare wire is exposed. It is held in place with a fine silk stitch and the wire is then passed out through the pericardium and taken out through a small stab incision in the epigastrium. A second wire electrode is inserted in the skin lateral to the apex of the heart. These two electrodes are then connected to the pacemaker so that its action can be observed before the chest is closed. It is usually found that a rate of about a hundred produces the most adequate circulation.

Neutralization of heparin.

When the pump-oxygenator is no longer needed 5 mg of protamine per kg of body weight are injected over a period of 5 minutes. The cannula is then removed from the femoral artery which is repaired with 00000 silk.

Closure of the median sternotomy incision.

A careful examination of all bleeding is made; particular attention being paid to the cardiotomy incision, the edges of the pericardial incision, the loose tissue in the areas of the thymus and at the root of the neck in the jugular notch area.

The pericardium is left widely open and provision for adequate drainage made: usually three subcostal catheters are used to the pericardial area to avoid any risk of cardiac tamponade and to allow an exact estimate to be made postoperatively to blood loss: these catheters are connected to graduated water-seal bottles.

The two portions of the sternum are brought together by means of strong thread: the closure is completed by interrupted silk sutures placed through the periosteum and the pectoral muscles on each side followed by skin closure.

Immediate postoperative treatment.

Recovery of consciousness is almost invariably prompt. The patient is then weighed and the swab counting and total blood loss carefully rechecked, any deficit being made good by the transfusion of whole blood. The patient must be treated in a postoperative recovery unit staffed night and day by experienced medical and nursing staff.

However satisfactory the status of the patient has been during perfusion and open cardiotomy, serious complications may follow the most uneventful of operations. Complications can follow any surgical operation, but in addition those peculiar to thoracic and cardiac operations may supervene. They may be listed as:

1. Haemorrhage.
2. Interference with adequate pulmonary ventilation.
3. Cardiac tamponade.
4. Cardiac failure due to overloading of the circulation and to metabolic and electrolyte disturbance.
5. Infection.
6. Neurological (due to anoxia or partly the result of the antifoam detergent used in the pump oxygenator).

The postoperative recovery room unit must be fully equipped so that all types of oxygen administration are possible; close at hand must be apparatus ready and sterilized so that bronchoscopy, tracheotomy and emergency thoracotomy could be carried out at a moment's notice.

A balance chart is kept both of blood loss and replacement and of the patient's ordinary fluid intake and output. We have found it necessary to replace blood loss with an equivalent volume of whole blood. The volume of citrate in bank blood
must be accounted for during replacement and this must be added to the patient's ordinary fluid intake on the chart.

Most of our patients have not complained of pain from the incisions but they are often restless; it is advisable to sedate small children sufficiently to stop them continuously wriggling. This enables them to sleep a little between their half-hourly turning and coughing and the disturbance caused by quarter-hourly measurement of blood pressure, pulse and respiration.

If heart block is present and is being treated with the pacemaker it is advisable to record the e.c.g. continuously for the first few days. Any temporary changes in rhythm can then be observed. Usually the recurrence of sinus rhythm is heralded by the appearance of QRS complexes between the pacemaker beats. If these are seen the voltage of the pacemaker can be gradually turned down so that it is no longer effective and the rhythm observed. If the heart rate is inadequate the pacemaker is gradually turned on again until it controls the heart's action. This manoeuvre is preferable to suddenly switching the instrument off or on, which has been known to precipitate ventricular fibrillation. The electrode becomes a little loose in the heart muscle after about ten days and if it is no longer needed it can then be pulled out.

Isoprenaline is said to be useful in increasing the idio-ventricular rhythm.

Patients who have had very high right ventricular pressures are liable to develop cardiac failure insidiously during their first week after operation while appearing to be doing well on casual inspection, so a careful watch must be kept for this complication.

Haemorrhage is not a common complication: if obviously occurring through the intercostal drainage tube its management is clearly along the lines of any thoracic emergency of this type: bleeding, however, may be occult, causing cardiac tamponade with the features of pallor, poor pulse and hypotension; if suspected the sternotomy wound should be re-opened, the clot removed and all bleeding points secured.

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