THORACIC AND CARDIOVASCULAR SURGERY AT THE KAROLINSKA INSTITUTE

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Foreword

Thoracic and Cardiovascular Surgery is one of the youngest surgical specialities and is still making major strides forward. This publication presents glimpses of the work carried out at the Thoracic Surgical Clinic at the Karolinska Hospital and its predecessor, the Surgical Department at Sabbatsberg's Hospital, Stockholm. It is intended as an introduction for people working or interested in the field and is published to commemorate Professor Viking Olov Björk's sixtieth birthday.

Kim Böök *Stig Ekeström* *Axel Henze* *Staffan Lundberg*

Christian Olin *Luis Rodriguez* *Kjell Rådegran*

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"The surgeon who should attempt
to suture a wound of the heart
would soon lose the respects
of his colleagues."

THEODOR BILLROTH (1883)

"First successful suture of heart wound."

REHN (1896)

THE OPENING OF THE THORACIC CLINICS IN 1957

Christian Olin

The plans for the Thoracic Medical and Surgical Clinics at the Karolinska Institute originated already in the 1940's. There were several reasons for the erection of a separate building on the site of the Karolinska Hospital for the treatment of chest diseases. At that time there was no suitable hospital to which patients with thoracic diseases could be referred for diagnosis and therapy. The opportunities for teaching were also lacking. The facilities at the Sabbatsberg's Hospital were grossly inadequate and could not meet the demands of the expanding field of thoracic surgery.

The Swedish Government, in cooperation with the City of Stockholm and the Karolinska Institute, finally decided that a separate clinic for chest diseases should be built and that it should be located at the Karolinska Hospital. The building was completed at a total cost of approximately 15 million Swedish crowns in the beginning of 1957.

Stig Björkman was appointed Head of the Department of the Thoracic Medicine. He was a pupil of the late H. C. Jakobeus, the inventor of the thoracoscope and laparoscope. He was already an Assistant Professor at the Karolinska Institute and Head of one of the Medical Departments at the Sabbatsberg's Hospital in Stockholm. Clarence Crafoord was appointed Head of the Thoracic Surgical Clinic. He had become Professor in Thoracic Surgery in 1948 and was one of the world's leading thoracic surgeons. Bengt Jonsson was appointed Head of the Department of Clinical Physiology, Björn Nordenström, Head of the Department of Thoracic Radiology and Olof Norlander, Head of the Department of Thoracic Anaestesiology.

Thanks to the generous donation of 1 million Swedish crowns from the Rockefeller Foundation in 1952, a Thoracic Surgery Research Laboratory was included in the Clinic and Åke Senning, now Professor of Thoracic Surgery in Zürich, Switzerland, was appointed Head of this laboratory.

The Clinics were opened on a limited scale in April 1957 and officially inaugurated by His Majesty, the late King Gustaf VI Adolf, in May 1958.

THORACIC ANAESTHESIA AND INTENSIVE CARE

Staffan Lundberg

The desire to concentrate on surgery itself prompted the thoracic surgeon to solve the problems of supporting the vital functions of his patients during and after surgery. In Sweden, Clarence Crafoord (Fig. 1) was a pioneer in this field long before any thoracic anaesthesist appeared on the scene. Already in the 1930's, he realized the need for controlled mechanical ventilation during thoracic surgery and, together with Paul Frenkner and Emil Anderson (engineer at the AGA Company), introduced the first mechanical ventilator, the "spiro-pulsator" (Fig. 2). As early as 1916, Crafoord's teacher Knut Harald Giertz had advocated the use of rhythmic insufflation for ventilation during thoracic surgery. Giertz was in fact one of the first to suggest this simple, safe and well-controlled technique as an alternative to Sauerbruch's much more complicated "differential pressure method".

At the Sabbatsberg's Hospital in Stockholm, Crafoord in the 1940's started the first Swedish centre devoted to thoracic surgery. He succeeded in creating an atmosphere where highly different personalities could collaborate. The result was a team-work of outstanding quality (Fig. 3). Among the anaesthetists belonging to this team were: the head of the Department of Anaesthesia, Olle Friberg, as well as his associates Ingrid Nordén, Bertil Widman and Hans Feychting who all came to be involved in thoracic anaesthesia. In 1954, Carl Gunnar Engström joined the Crafoord group with his new ventilator (Fig. 4). Together with Viking Björk and Alvar Svensson, Engström introduced the ventilator for use during and after extensive lung operations. This ingenious and safe ventilator was one of the most well-known products originating from Swedish thoracic surgery and anaesthesia. Viking Björk realized at a very early stage the potential possibilities of the Engström ventilator and, together with Alvar Svensson, devoted very much pioneer work to the clinical application of this ventilator for thoracic surgery and intensive care.

Erik Carlens (Fig. 5) was another member of the Crafoord team at Sabbatsberg's Hospital who made important contributions to early thoracic anaesthesia.

Fig. 1. *Clarence Crafoord, Professor of Thoracic and Cardiovascular Surgery at the Karolinska Institute 1948—1966.*

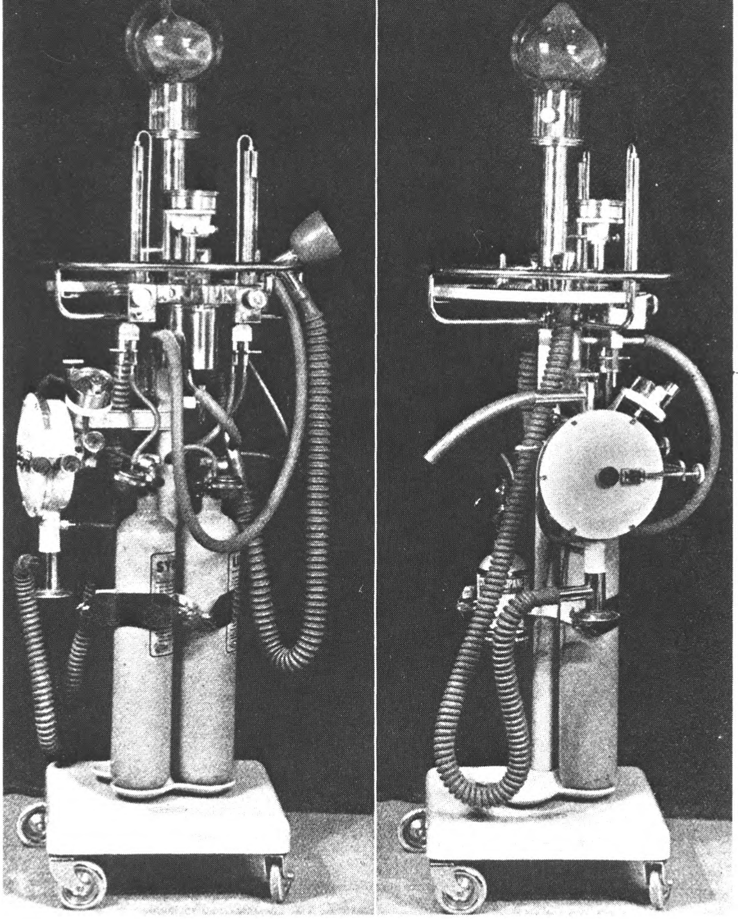
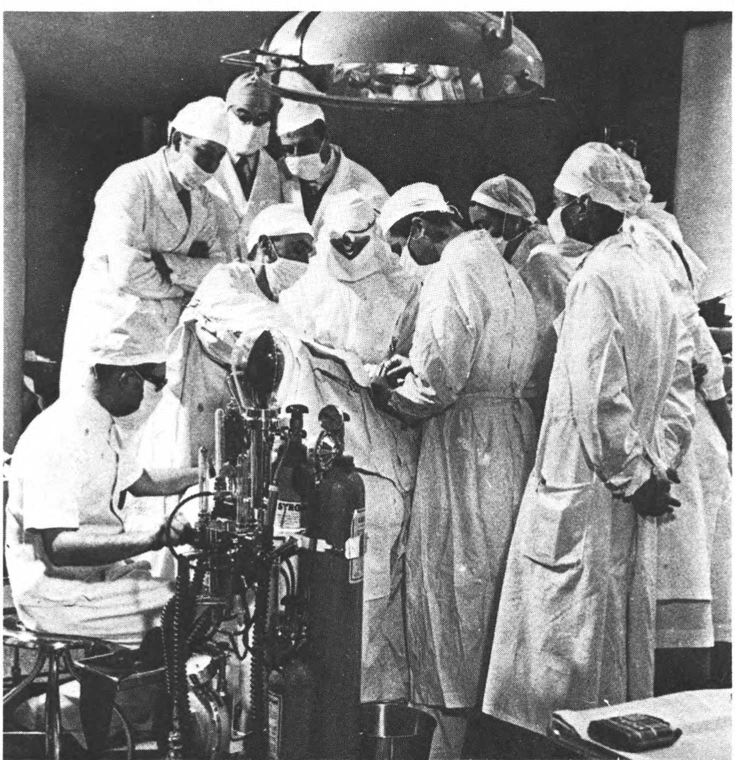


Fig. 2. *First mechanical ventilator, the "spiropulsator", constructed by Crafoord, Frenkner and Anderson.*

Fig. 3. *Operation at Sabbatsberg's Hospital. From left to right (spectators excluded): Friberg, Benichoux, Crafoord, Senning and Nurse Inga.*



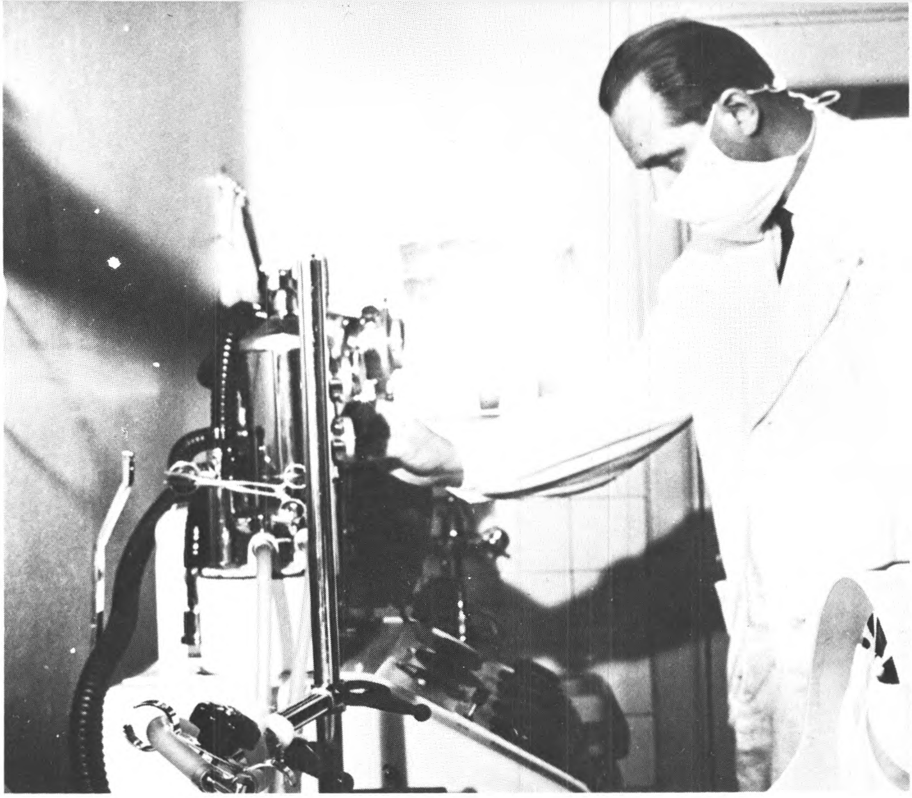


Fig. 4. *Dr. Alvar Svensson adjusting the Engström respirator.*

Fig. 5. *Professor Erik Carlens, bronchologist at the Sabbatsberg's Hospital and Thoracic Surgical Clinic until 1974 when he retired.*

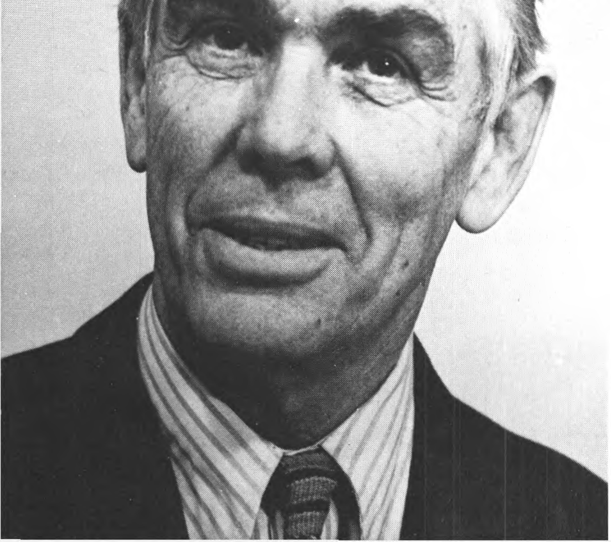
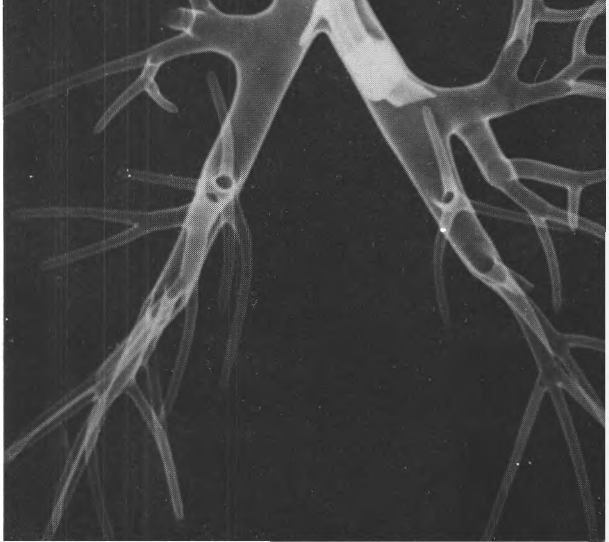


Fig. 6. *Carlen's double-lumen tube for separate ventilation of the lungs.*



Being a bronchologist, he developed among other things a double lumen tube for separate ventilation of the lungs. The Carlens' tube is another piece of equipment which has gained world-wide recognition and use (Fig. 6).

In 1957, when the surgeons moved to the Thoracic Clinics at the Karolinska Hospital, Olof Norlander became the first Head of the new Department of Thoracic Anaesthesia (Fig. 7). He held this position for 17 years until he was appointed Professor of Anaesthesia at the Karolinska Institute in 1974. Together with Ingrid Nordén he gave thoracic anaesthesia and intensive care clinical and scientific recognition. Norlander further developed the technique of supporting ventilation during and after heart surgery. With Carl-Gunnar Engström and Paul Herzog he made many important contributions to the further development of artificial ventilation and ventilatory care. He was one of the first to point out how expensive the "cost of breathing" could be for the thoracic patient and how this cost could be paid by the proper use of controlled mechanical ventilation.

Norlander together with the surgeons also planned, organized and directed the new Department of Intensive Care at the Thoracic Clinics. This department was early recognized and brought many visitors to the Clinic. A special feature of this department was and still is the very smooth and pleasant way it is conducted with close cooperation between surgeons and anaesthesists.

Fig. 7. *Professor Olof Norlander, Head of the Department of Thoracic Anaesthesia 1957— 1974.*

Present anaesthetic technique

Basically the same drugs and anaesthetic agents are used in thoracic as in general anaesthesia. In both fields there has been a trend away from the use of one or two universal anaesthetic agents to a polypharmacy, employing a variety of drugs with selective actions. The possible professional hazards of long-term exposure to volatile anaesthetic agents have promoted many centres, including our own, to rely more on intravenous agents. A short outline of our present anaesthetic technique is given below:

Premedication. For many years we have used a generous dose of morphine-scopolamine and we are not convinced that any of the modern tranquilizers can substitute this regime. However, we consider that the preoperative visit and comprehensive information from the responsible anaesthetist are more important than any premedication.

Infants and children are first premedicated rectally with barbiturate (sodium-pentobarbital), so that they will barely notice the morphine-scopolamine injection one hour later and are heavily sedated before induction of anaesthesia. The parents are always invited to stay with their child until anaesthesia is induced (Fig. 8).

Induction and maintenance of anaesthesia. After pre-oxygenation, anaesthesia is induced with intravenous barbiturate or diazepam. In wellsedated infants and children, the inhalation of oxygen/nitrous oxide is usually sufficient. Pancuronium or curare is used for relaxation and morphine or fentanyl for analgesia. Ventilation with oxygen/nitrous oxide is carried out by a volume-cycled ventilator.

Fig. 8. *Induction of anaesthesia in a small child. The patient's mother is sitting to the left.*

The bypass procedure. This procedure is described more in detail in another chapter of this volume. The responsibility is shared between the surgeon, the anaesthetist and the pump technician. As soon as bypass is established, the patient receives a generous dose of barbiturate and a relaxant. Our liberal use of barbiturate has two reasons: it keeps the patient asleep during bypass and

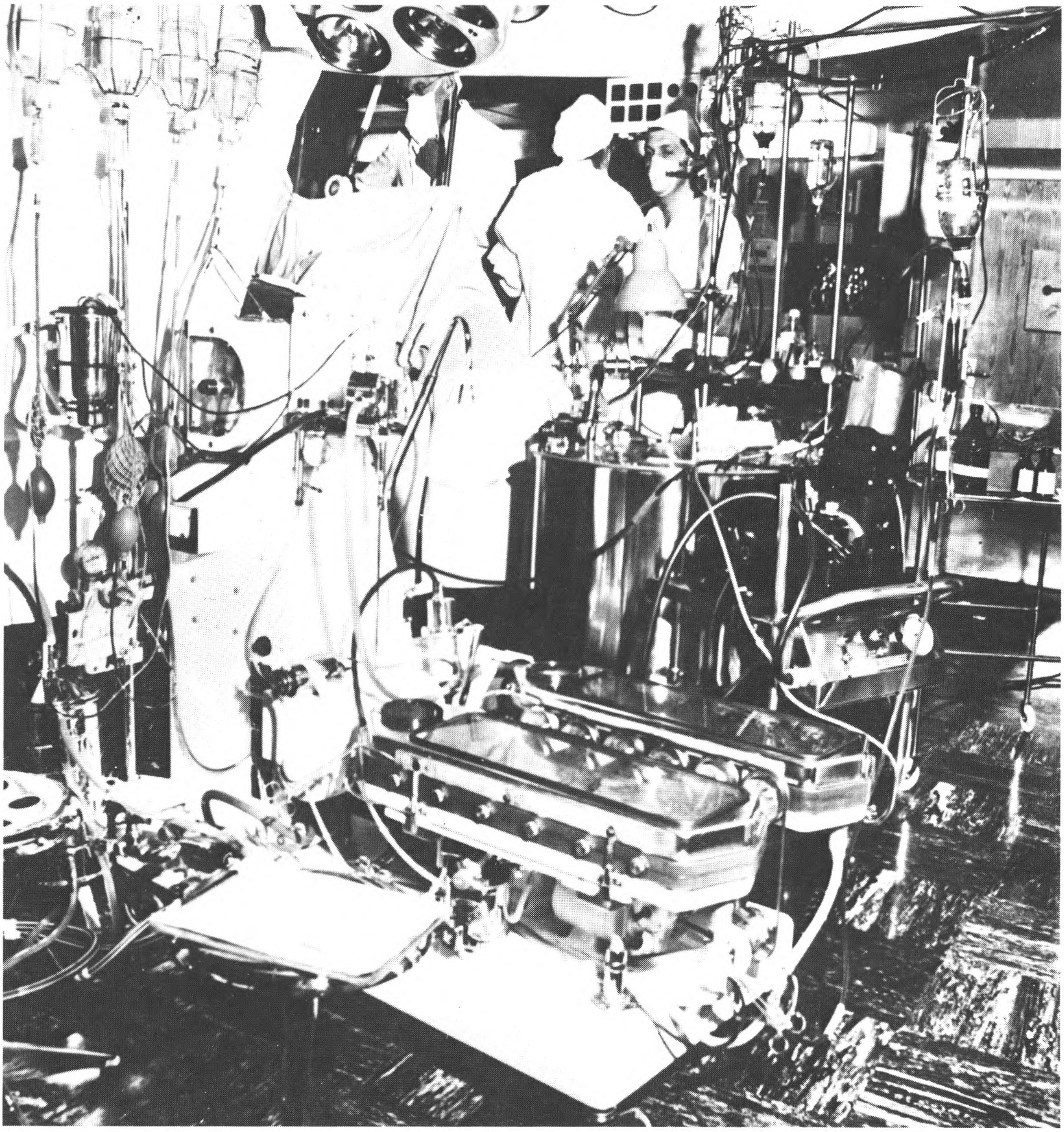


Fig. 9. *Emergency operation with aortic valvular replacement at the Thoracic Clinics in 1965. Professor Crafoord (left) is supervising the operation performed by Lennart Johansson (hidden) with Ingrid Nordén (centre) and Olof Norlander (right) as anaesthetist. Front, the Crafoord-Senning heart-lung machine connected to the artificial kidney.*

also protects the brain should periods of ischaemia occur. In the majority of open-heart cases, a mild alpha-blocade is instituted with chlorpromazine or droperidol prior to bypass. In patients with a tendency to hypertension, nitroprusside, nitroglycerine or trimthapan are given intravenously.

The urine output is constantly monitored during the bypass procedure. If, despite good blood-flow and pressure, urine output remains low, we give furosemide or mannitol. Intravenous potassium substitution is started as soon as a satisfactory urine flow is established.

We use calcium, dopamine, adrenaline and isoprenaline as heart stimulating drugs at the end of bypass. Dopamine in continuous infusion and a bolus injection of adrenaline directly into the heart are often used if the heart fails to respond to calcium and is too weak to take over the circulation. The lungs are normally not ventilated during bypass, but thoroughly cleaned and hyperinflated at the end of extracorporeal circulation.

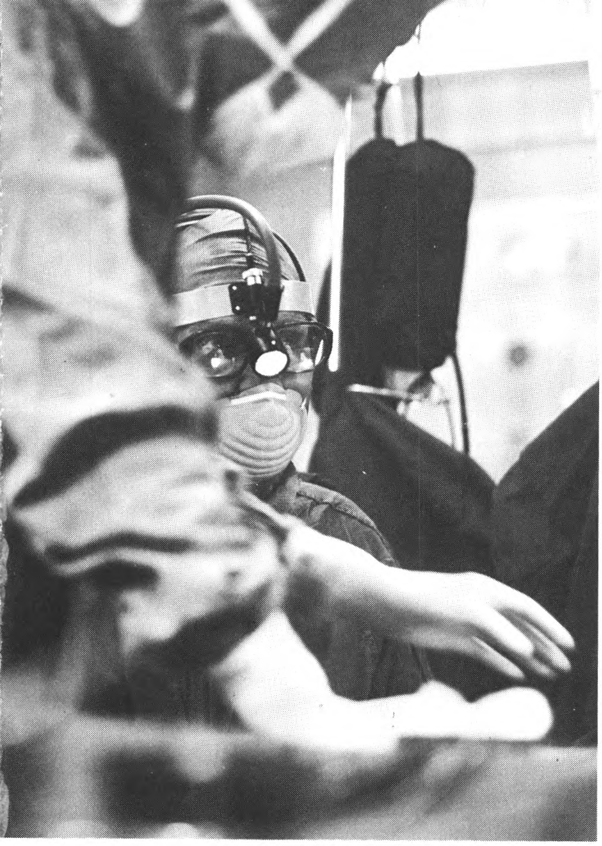
Monitoring during open-heart surgery. (Fig. 9) Arterial and central venous pressures, oesophageal and rectal temperature, standard ECG leads and urine flow are monitored. Percutaneous puncture and catheterization of the radial or femoral artery and the external or internal jugular vein are normally performed. If percutaneous puncture of the artery is not possible, a cut-down of the radial artery is carried out. The caval catheter is introduced by the surgeon after the sternal-split. In the majority of open-heart cases, catheters are also placed in the left atrium and sometimes in the pulmonary artery. This enables us to determine the filling pressure of the left heart and the AV-oxygen content difference and thus the adequacy of blood volume and cardiac output.

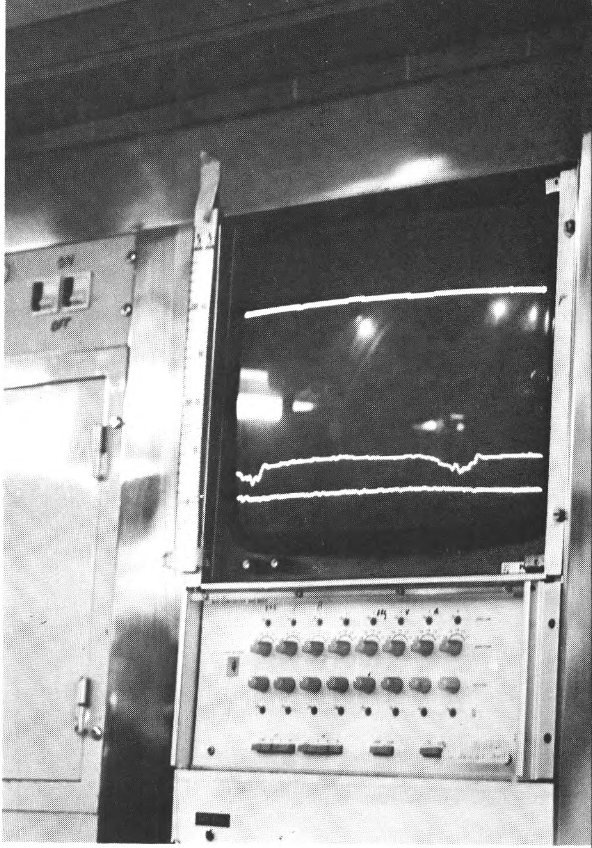
Deep hypothermia, surface cooling and circulatory arrest. In infants with complicated congenital heart lesions, we have during the last three years used deep hypothermia (20°C) with circulatory arrest. An initial fall in body temperature to 27—28°C is achieved by using surface cooling in ice-water prior to bypass for the following reasons:

1. Better protection against hypoxic damage if the heart should stop or fibrillate before perfusion.
2. A shorter perfusion time.
3. Possibly a more physiological and even cooling with the skin, muscles and fat being cooled before metabolically vital organs, such as the kidney and liver.

The disadvantage is that the method is somewhat time-consuming and prolongs total duration of anaesthesia.

Operation of a 1-month-old child with a ventricular septal defect during deep hypothermia and circulatory arrest.

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Intensive care illustrated by some current, clinical problems

The postoperative course of the great majority of our patients is uneventful. Normally the lung and vascular cases will stay in the intensive care unit over night and the open-heart cases another 24 hours; however, a few patients will need intensive care for several days. The reason for this may be found among the examples of current clinical problems given below:

Tissue oedema. In thoracic intensive care of today we are mainly concerned with postoperative complications caused by the surgical procedure per se. These include, i.e. bleeding problems, tamponade, low output syndrome, as well as cerebral, pulmonary and renal complications. Several of these well-known complications can be traced back to the same origin: the heavy fluid load imposed on the patient during bypass procedures. With our present bypass routine, large quantities of colloid-free solutions are often given both for priming the heart-lung machine and as cardioplegic solution to cool and stop the heart. The colloid osmotic pressure of plasma is in fact temporarily reduced during bypass to 50 % or less if no colloid is used in the priming solution, but there is seldom clear evidence of pulmonary oedema. This heavy fluid load favours the occurrence of oedema in all tissues, including the vital organs, such as the brain, heart, lung, liver and kidney. It is therefore vital to achieve a good urine output even when the patient is still on bypass and to maintain a brisk flow of urine during the first postoperative days. If, despite the use of diuretics, the urine output remains low, peritoneal dialysis should be started immediately after operation.

Since a higher volume of priming and cardioplegic solutions per kg body weight is often used in infants or children than in adults, tissue oedema is a special problem in young patients. By checking the weight of the child immediately before and after the open-heart surgery, we have often observed an 8—10 % increase of body weight as a result of the bypass procedure per se. Due to severe oedema in one particular case, it was not possible to close the wound with skin-sutures until aggressive diuretic therapy proved successful the next day.

In order to combat further tissue oedema, all open-heart cases have their fluid intake heavily restricted during the first postoperative days. We give sodium-free glucose solution, adding extra potassium and calcium as required.

Weaning from the ventilator. The majority of patients after bypass surgery is kept on a volume-cycled ventilator overnight and extubated early next morning. In infants and children, the oral tube which has a tight fit, is replaced by a half-size smaller nasal tube at the end of the operation. This tube is fixed with a modified Tunstall connector (Fig. 10). Provided that nursing and care are professional, this fixation makes it possible to maintain a patent nasal tube for more than two weeks if required. In a few children, spontaneous respiration against a fixed expiratory resistance is used as part of the weaning procedure.

The criteria for extubation are:

1. Stable haemodynamics without inotropic drugs.
2. Regained consciousness and ability to cooperate.
3. Normal O_2-tension in arterial blood without positive end-expiratory pressure and with an inspired fraction of oxygen lower than 35—40 %.

While on the ventilator, the patients are sedated with morphine and diazepam. Meticulous care is taken to keep the airways clean and wet and to avoid atelectasis. This is achieved by proper nebulizing of the inspiratory gas mixture and regular suction, preceded by administration of saline and manual hyperinflation of the lungs with oxygen.

Fig. 10. *Intubated girl eating ice cream.*

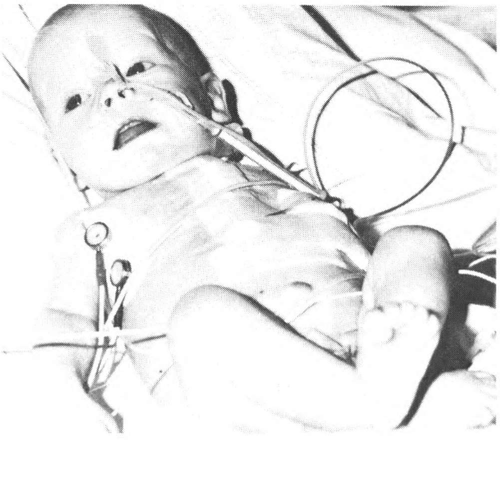


Fig. 11. *3-month-old baby 3 days after closure of ventricular septal defect.*

Haemolysis. We are still intrigued by the presence of haemolysis in a few patients, i.e. the occurrence of excessive amounts of free haemoglobin in serum, often observed first when the urine turns pink or even black. The origin of the haemolysis is certainly multifactorial: the reticulocytes may be congenitally fragile, prolonged or traumatic perfusion may destroy the erythrocytes, impurities on the artificial surfaces of the heart-lung machine may likewise destroy the erythrocytes, incompatible blood may cause blood destruction and finally continuous postoperative damage to the blood may be seen as a result of an artificial surface placed in the blood stream (a patch or an artificial valve).

We combat haemolysis with forced diureses alkalization of urine and, if necessary, dialysis and/or blood exchanged transfusion.

Cerebral complications. In common with other cardiac centres, we still have postoperative neurological disturbances after heart surgery. This may be related either to air or particle embolies, despite all precautions, or as a consequence of cerebral hypoxic damage caused by inadequate perfusion or oxygenation.

In order to reduce or eliminate any residual gas bubbles within the circulation as soon as possible, we always ventilate the patients with pure oxygen for the first hour after bypass. If there is clear evidence of air embolies, this oxygen ventilation will be prolonged. This is because the venous gas pressure of nitrogen will be almost zero when using oxygen ventilation, whereby absorption of any gas bubbles into the venous blood is favoured. For the same reason, nitrous oxide is not used at the end of bypass since this would have the opposite effect of increasing any air bubbles.

In the event of signs or suspicion of cerebral oedema, the postoperative regime includes fluid restriction, diuretics, moderate hyperventilation, cortisone and barbiturate.

If signs of damage to the central nervous system, such as epileptic seizures or delayed unconsciousness occur, we consider hyperventilation so important that extubation may be delayed for several days until the patient regains consciousness or no longer shows any regression in neurological symptoms.

It is of particular interest to know if damage to the brain occurs as a result of deep hypothermia and circulatory arrest. In a recent follow-up study, we could not, however, demonstrate any neurological, intellectual or emotional disturbances in 49 infants and children subjected to this procedure. In the majority of these patients the circulation was stopped for less than one hour. It would seem that this is close to the safe upper time limit, because a circulatory arrest of this duration was followed by a substantial reduction in the immediate postoperative cerebral blood flow, possibly as a result of cerebral oedema.

The absence of neurological disturbances after circulatory arrest in these infants and children with complicated heart lesions is possibly attributable to the dual protection of the brain by hypothermia and barbiturates.

Fig. 12. *"Ice cream time" at the Intensive Care Unit.*

SURGERY OF THE LUNGS

Luis Rodriguez and Kim Böök

Surgery of lung diseases was performed at the Sabbatsberg's Hospital, Stockholm in the late forties by Clarence Crafoord and his team, among whom Viking Björk and Ture Wiklund were active members. Tuberculosis was at that time a common disease in Sweden and presented a complexity of therapeutical problems, which became more and more amenable to surgical treatment. Many complications occurred from the disease per se and as a result of the different modes of treatment, which often called for surgical intervention, posing difficult problems, e.g. postpneumothorax empyema, cavernous perforation with concomitant tbc empyema etc. These problems fascinated Björk, who, in order to gain further experience, travelled to Rome to study with Monaldi at the Forlanini Institute and to learn the modern approaches to lung surgery. Björk also visited one of the other main centres for thoracic surgery in Europe at the time, the Brompton Hospital in London, where the face-down position during lung surgery was used. Björk later introduced this technique in Sweden.

On his return, Björk was appointed head of an independent surgical unit at the Sabbatsberg's Hospital, where he started to systematically develop new methods and techniques for tbc surgery. A crucial problem after major lung resection was the postoperative pleural cavities, which caused mediastinal shift and overexpansion of both the contralateral and the operated lungs. Remaining cavities also increased the risk of postoperative tuberculous empyema and bronchial fistula. In order to avoid these complications, Björk developed the so-called "Björk's osteoplastic roof thoracoplasty", which at the same time reduced the thoracic cavity and fixed the mediastinum in the midline (Fig. 15).

The development of modern ventilators, in which Carl Gunnar Engström, Paul Herzog and Björk took an active part, made it possible to treat and cure advanced tuberculous patients with reduced ventilatory function. Even patients with bilateral lesions could be operated upon on both sides simultaneously using the face-down position and postoperative respirator treatment through a

Fig. 13. *Viking Olov Björk, Professor of Thoracic and Cardiovascular Surgery at the Karolinska Institute since 1966.*

tracheostomy. The respirators were originally developed mainly for long-term treatment of poliomyelitis patients, but the temporary use of assisted ventilation after lung surgery led to the more widespread utilization of this method in patients with temporarily impaired respiratory function after surgical interventions or in otherwise critically ill patients.

Fig. 14. *Lung operation at the Sabbatsberg's Hospital. From left to right: Nurse Valborg, Fritz Lidström, Karl Boman, Arne Erlandson, Ture Wiklund and Nurse Inga.*

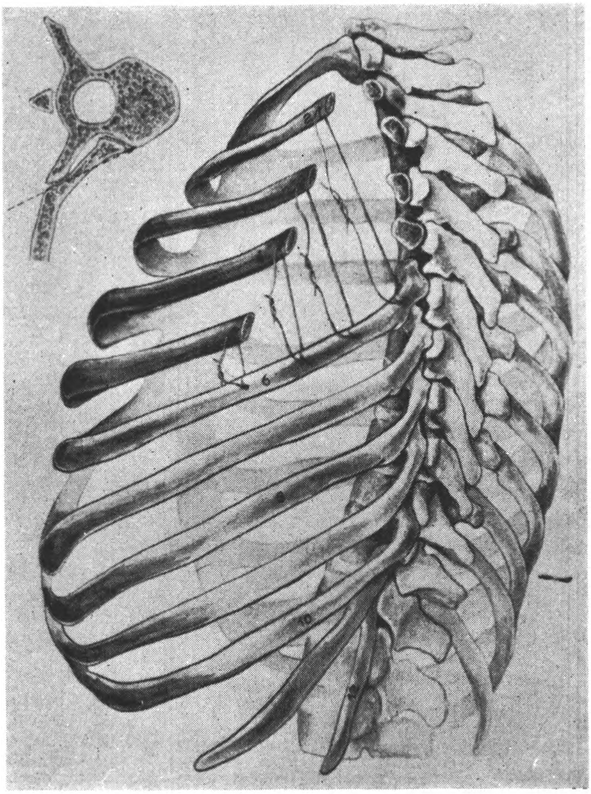
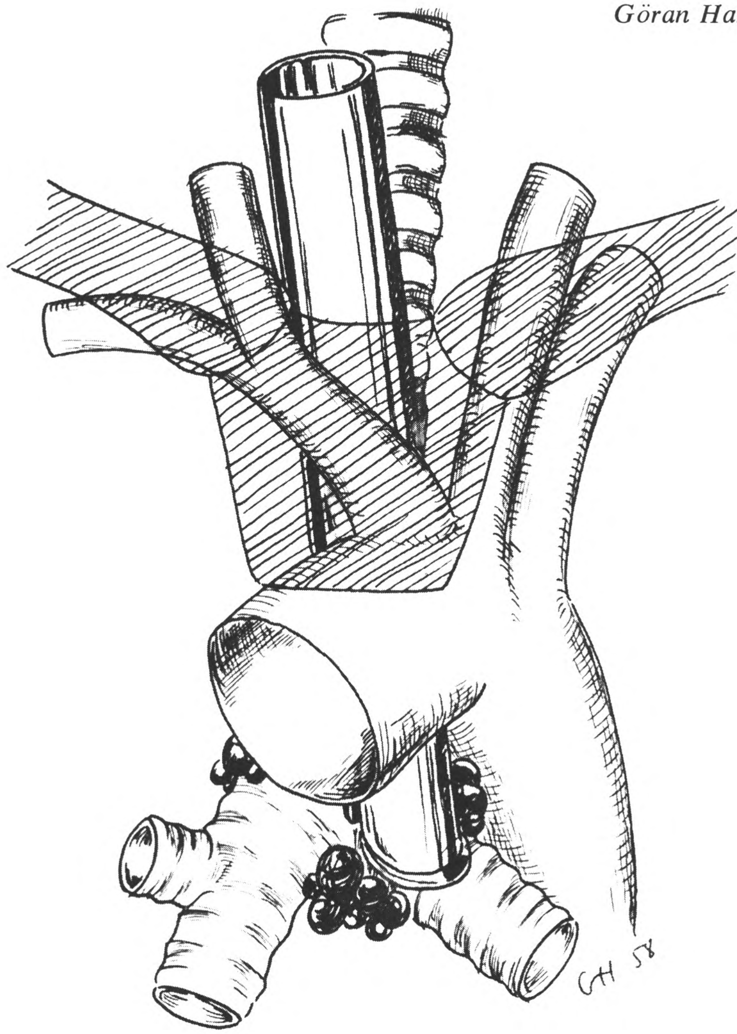


Fig. 15. *Diagram of Björk's osteoplastic roof thoracoplasty.*

The new Thoracic Surgical Clinic at the Karolinska Hospital was opened in 1957 and all thoracic surgery in the Greater Stockholm area was concentrated there. A large part of the Clinic was designed for surgical treatment of tbc patients, evidence of which can still be seen today in the large balconies for the open-air treatment of these patients. Thanks to the development of effective tuberculostatic drug therapy, it soon became evident that the need for surgical treatment of tbc decreased dramatically, but on the other hand the incidence of lung cancer showed marked increase, calling for intensified surgery on patients with lung tumours. New and more precise diagnostic methods made it possible to select operable lung tumour patients with greater accuracy. Erik Carlens introduced mediastinoscopy, providing access to the mediastinum and the regional lymph nodes of the lungs, and biopsies could be taken and analysed by this simple method, thus avoiding unnecessary explorative thoracotomies (Fig. 16). The method also proved useful as a diagnostic procedure in other diseases, e.g. sarcoidosis. Direct needle biopsy of lung tumours with the aid of biplane fluoroscopy was introduced at the Department of Diagnostic Radiology by Björn Nordenström and rendered possible more reliable diagnosis of uncharacteristic tumours not accessible through bronchoscopy.

Fig. 16. *Mediastinoscopy according to Carlens. Drawing made by Göran Hambraeus.*



Today the most predominant part of the lung surgery performed at this Clinic consists of patients with lung cancer. Surgery for tuberculosis is undertaken only in very special cases when chemotherapy for different reasons does not cure a patient. Only 5—10 tbc-patients are operated on per year, whereas the total number of yearly lung operations exceeds 200. 15—25 % of these patients have benign diseases, e.g. hamartoma, infection, pneumothorax, corpus alienum etc. and, in the remaining group, lobectomies, pneumonectomies or in some cases exploratory thoracotomies for cancer are performed. Pneumonectomies bear an operative and early mortality of 2—3 %, while the corresponding rate for lobectomies is less than 1 %.

SURGERY OF CONGENITAL HEART DISEASE

Christian Olin

First operation for coarctation of the aorta

Several surgeons affiliated to the Karolinska Institute in Stockholm have contributed to the development of new methods for repair of congenital heart malformations. The first event to arouse international attention was when Crafoord in 1944 operated on the first case of coarctation of the aorta. The operation was performed on October 19 at the Sabbatsberg's Hospital in Stockholm. The patient was an 11-year-old boy with high blood pressure, the only child to elderly parents. The parents were informed that the prognosis without operation was poor and that such an operation had never been performed before. After long consideration, the parents permitted an exploratory thoracotomy and gave Crafoord freedom to decide during the operation whether or not a resection and end-to-end anastomosis of the aorta would be feasible.

At the operation, the fifth rib was resected, providing excellent access to the aortic arch and the upper portion of the descending aorta. The mediastinal pleura was opened and a firm fibrous ligament was identified as the ductus ligament (Fig. 17). It was divided between ligatures. The impression was gained that the ligament had dislocated the aorta anteriorly and medially. The stenosis of the aorta distal to the origin of the left subclavian artery was located. Thereafter a wide collateral was divided and two others occluded with clamps. A pair of vascular clamps were applied above and below the stenosis. The aorta was then divided a few millimeters proximal to the first intercostal arteries at an angle of 30° to the longitudinal axis and at the same angle above the stenosis to enlarge the anastomotic lumen.

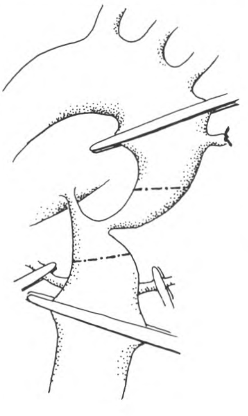


Fig. 17. *Schematic drawing of the operative technique used by Crafoord in his first operation of coarctation of the aorta in 1944.*

Vascular continuous suture with fine silk according to Carrel was performed, including the adventitia and media, but *leaving* the inner layer of the intima. The clamps were removed and only one extra stitch had to be applied. Strong pulsations were found distal to the anastomosis and, in contrast to the pre-resection condition, the proximal aorta was not a distended structure any longer.

Apart from some fever, the postoperative course was uneventful and the patient could be discharged two weeks after operation. The blood pressure was 130 in both arms and 140 in the legs one month after surgery.

The patient was recently admitted to the Thoracic Clinic for a late follow-up investigation. He is still free from symptoms and the anastomosis that was performed 32 years earlier was still functioning well (Fig. 18). The pressure in the ascending aorta was 136/87 and in the descending aorta below the anastomosis 136/84.

Fig. 18. *Aortography of the first operated patient with coarctation of the aorta made 32 years postoperatively. Only a slight narrowing at the site of the anastomosis is seen.*

Crafoord gained the idea of this daring operation a few years previously during a ductus operation when he had a severe bleeding from the aorta that could not be arrested unless he put clamps above and below the bleeding. The clamps had to be applied for 28 minutes and, in spite of this long interruption of the circulation to the lower part of the body, there were no problems afterwards. Crafoord reached the conclusion that a patient with a coarctation would stand an even longer period of the aortic cross-clamping as there were also collateral vessels present in this case.

Credit has been given in some American literature to Gross in Boston for performing the first operation for coarctation. He, however, performed his first operation in June the following year after having heard of three of Crafoord's successful cases from an American cardiologist, Walter Bauer, who had attended one of Crafoord's earliest operations.

Early operations for congenital heart disease

In 1945, Blalock and Taussig in Baltimore described a new method for operating on patients with severe cyanosis caused by congenital heart lesions with pulmonary stenosis. They were able to improve the oxygenation by taking one of the patient's subclavian arteries and anastomosing it to the pulmonary artery (Fig. 19). Their achievement led to an enormous interest in congenital heart disease and resulted in the development of several new methods for diagnosis and operation. This was particularly true at the Crown Princess Lovisa's Children's Hospital and at the Paediatric Clinic, Karolinska Hospital, Stockholm, where several new techniques for cardiac catheterization and angiocardiography were introduced among others by Sven Roland Kjellberg, John Lind, Edgar Mannheimer, Bengt Jonsson and Ulf Rudhe.

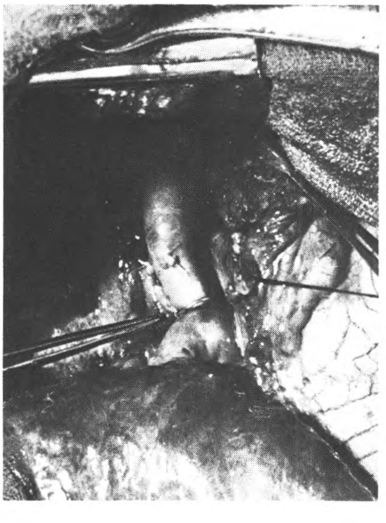


Fig. 19. *Operative photograph from one of the first Blalock-Taussig shunt operations performed at Sabbatsberg's Hospital. The right subclavian artery (coming from above) is anastomosed to the right pulmonary artery.*

In the beginning of the 1950's, methods for the correction of atrial septal defects, valvular pulmonary stenosis and valvular aortic stenosis were developed. The operations were initially carried out with the so-called closed technique, i.e. instruments were introduced into the beating heart. Atrial septal defects were operated on with the circumclusion technique, which involved closure of the *hole* between the atria by a suture that was tied around the atria from the outside. The method was developed and improved by Björk and Crafoord by introducing a finger through the right atrial appendix, thus guiding the precision of the occluding suture.

When hypothermia (see page 35) was introduced in the middle of the 1950's, the results of the operations improved. The atrial septal defects could be closed under *direct vision.* In Uppsala, 130 patients were thus operated on by Björk and his associates without mortality and without recurrence of the defects (Petersson, 1966).

The development and routine use of the heart-lung machine (see page 35) after 1955 meant a tremendous step forward in the repair of congenital heart defects. Even complex lesions, such as ventricular septal defects and Tetralogy of Fallot, could be repaired. The surgeons were able to work in an *empty and quiet* heart. The ventricular septal defects were initially closed with synthetic patches made of Ivalon sponge, a plastic material that later proved to be unsuitable for this purpose. Some of the defects re-opened due to resorption of the material and several patients had to be reoperated.

Experimental heart surgery and the first operation for transposition

When the Thoracic Surgical Clinic was opened in 1957, a laboratory for experimental thoracic surgery was equipped, partly through a generous donation by the Rockefeller Foundation. One of Crafoord's assistants, Åke Senning, was appointed Head of the Department. He developed and introduced into clinical practice several new adjuncts to cardiac surgery, such as an electrical fibrillator and defibrillator. He was also the first to implant a subcutaneous pacemaker. The latter was constructed in collaboration with Rune Elmqvist at the Elema-Schönander Company in Solna, Sweden (Fig. 20). The first patient to receive this pacemaker is still alive 20 years after this pioneering operation.

One of Senning's greatest achievements was his ingenious method for the correction of transposition of the great arteries. The technique was first tested in the laboratory and then successfully applied on man in June 10, 1958. The patient was a 9-year-old boy with severe cyanosis. The arterial oxygen saturation was 69 % before operation. At operation, the blood flow in the atria was switched with the aid of a plastic procedure which included the atrial wall

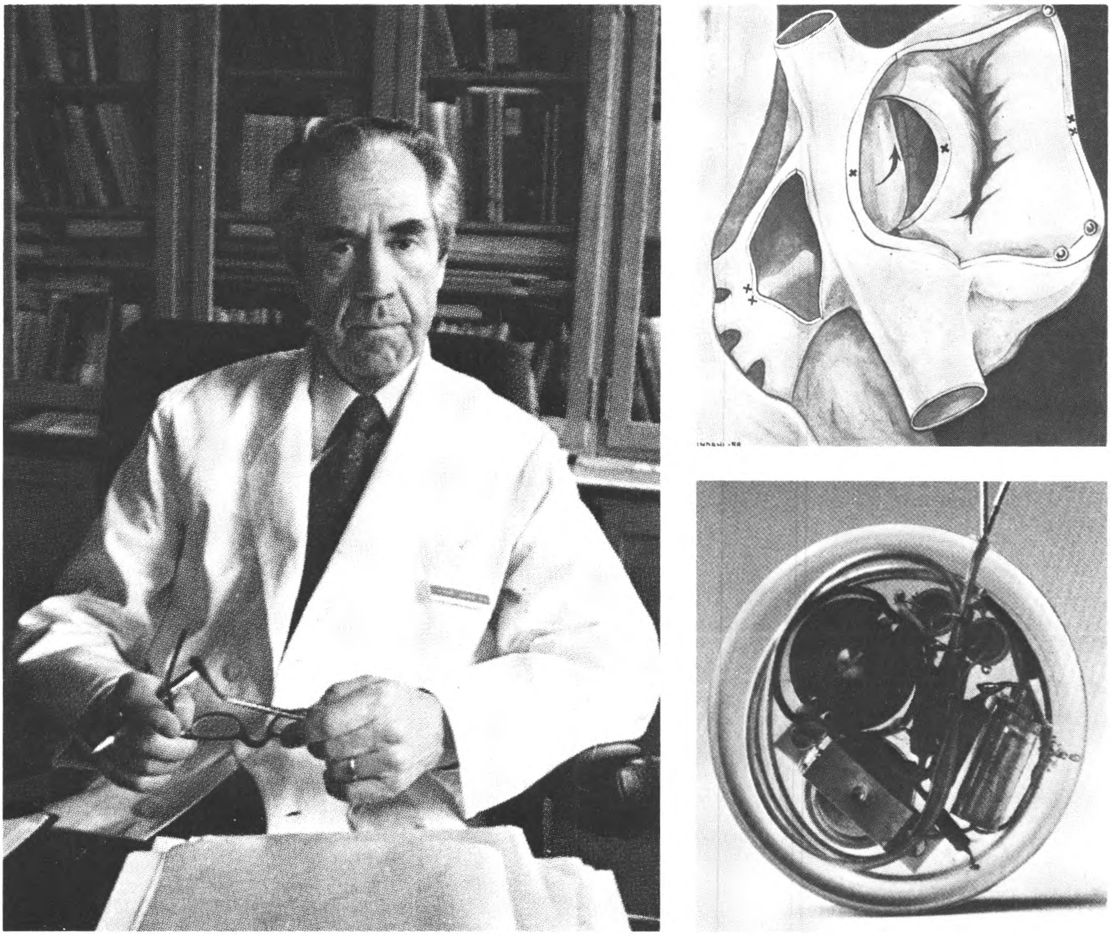


Fig. 20. *Professor Åke Senning, former Head of the Thoracic Surgery Research Laboratory, presently Head of the Department of Surgery, Kantonspital, Zürich. Sketch of Senning's method for the correction of transposition of the great arteries and the first implantable pacemaker, constructed by Rune Elmqvist and implanted by Senning.*

and the atrial septum (Fig. 20). The arterial oxygen saturation increased from 40—93 % during operation. The postoperative course was uneventful and a postoperative investigation one month later confirmed the successful repair (Jonsson, Ovenfors and Senning, 1959). The patient lived in perfect health in his home country, Poland, until 1978 when he developed severe tricuspid insufficiency after an acute bacterial endocarditis and died.

The development of congenital heart surgery during the last 15 years has been characterized by refinement and sophistication of the methods. A few new techniques have been added. Among those can be mentioned the use of artificial heart valves and conduits with heterograft valves. With these aids, complex lesions such as tricuspid atresia, pulmonary atresia and complex forms of transposition can be corrected with good results.

Current methods for repair of some congenital heart lesions at the Thoracic Surgical Clinic

During the last decade, the number of operations for congenital heart disease has increased. There has also been a marked tendency to operate at a younger age This trend has by necessity imposed a greater burden on intra- and postoperative care. The results have, however, been gratifying as will be shown in this survey of the last ten year's experience.

Ventricular septal defect (VSD)

The operations were performed with extracorporeal circulation and moderate hypothermia. In some smaller infants, deep hypothermia with circulatory arrest was used (see page 13). The transatrial approach has routinely been employed, i.e. the VSD has been exposed through an incision in the right atrium (Fig. 23). In about 20 cases the septal leaflet of the tricuspid valve was incised to facilitate the exposure of the defect. This technique was used without disadvantages and there have been no instances of tricuspid insufficiency. The VSD's were usually closed with a Teflon patch anchored to the septum by isolated mattress sutures of Ticron, buffered with Teflon pearls (Fig. 27).
Since 1966, altogether 135 patients have been operated upon. 6 patients died, resulting in a mortality of 4 % (Table 1, page 32).

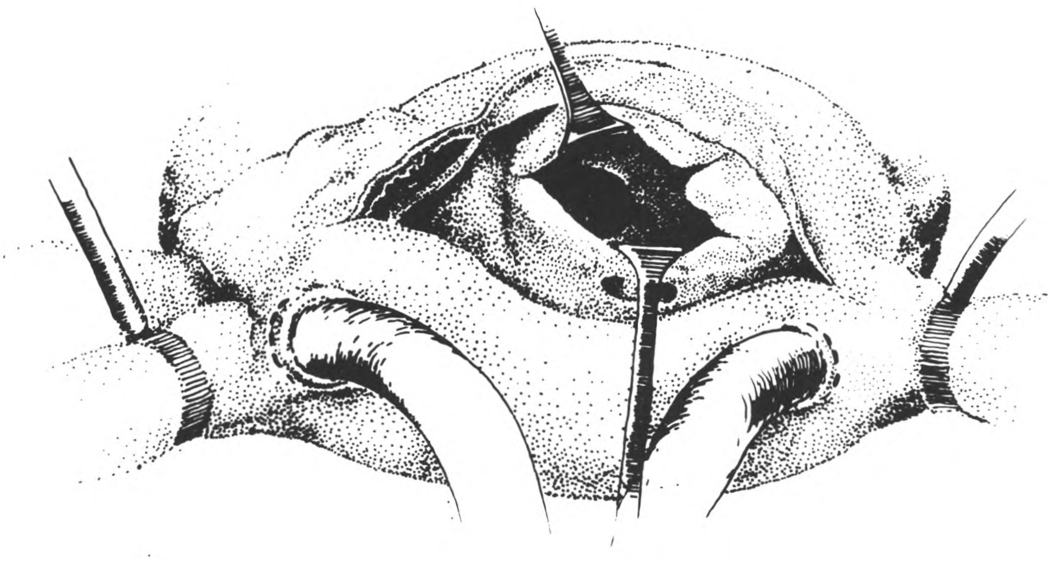


Fig. 23. *Transartrial approach for closure of a VSD which is visualized when the tricuspid valve is retracted.*

Fig. 24. *Angiographic visualization of Tetralogy of Fallot. Note the severe obstruction of the right ventricular outflow.*
Fig. 25—26. *Tetralogy of Fallot before and after correction. The infundibular stenosis is resected and the VSD closed with a patch.*
Fig. 27. *Closure of a VSD with a synthetic patch. Mattress sutures, buffered by small Teflon pearls, are placed near the margin of the VSD. Special care is taken to avoid the conduction system (interrupted line).*

Fig. 24

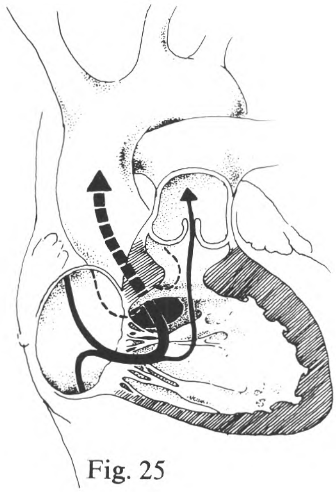


Fig. 25

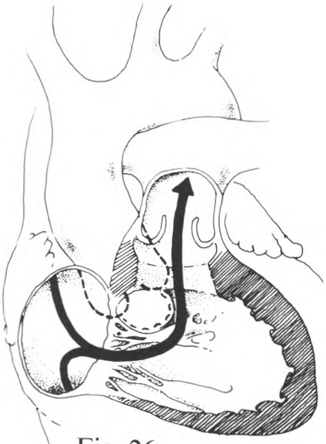


Fig. 26

Fig. 27

Tetralogy of Fallot

This anomaly consists of a VSD and a pulmonary stenosis. The pulmonary stenosis is infundibular and sometimes also valvular in type (Fig. 24—26). At correction, the infundibular stenosis was always resected first. Then the VSD was closed with a large Teflon patch. In about half of the cases, a right ventricular outflow patch was used. In some cases, the outflow patch was made on to the pulmonary artery.

Since 1966, 154 patients have been operated upon. The youngest patient was 3 months of age and the oldest 54 years. About 40 % of the patients had undergone a previous palliative shunt operation. 19 deaths gave a total mortality of 12 %. During the last 5 years, however, the mortality has fallen to less than 4 % (Table 1). 5 patients were re-operated upon, in 4 instances due to a residual right ventricular stenosis and in 1 to a residual VSD.

Table 1

Year	VSD	Deaths	Fallot	Deaths	Uncompl. TGA	Deaths
1966	2	0	7	2	—	—
1967	6	1	14	3	—	—
1968	7	1	22	7	2	0
1969	12	0	10	1	—	—
1970	5	1	10	0	2	1
1971	11	0	14	3	8	1
1972	9	0	8	0	—	—
1973	7	0	5	0	3	0
1974	11	0	12	1	8	1
1975	15	0	21	0	3	0
1976	23	3	16	1	4	0
1977	24	0	15	1	7	0
Total	132	6 (4 %)	154	19 (12 %)	37	3 (8 %)

Transposition of the great arteries (TGA)

In general, the technique described by Mustard was used. In recent years a few of Senning's procedures were carried out. In the Mustard correction, a piece of pericardium is fashioned like a pair of short trousers and sutured between the atria so that the venous inflow to the heart is switched.

64 patients were operated on since 1967. 27 of them were complicated by either a VSD or a pulmonary stenosis, or both. In these cases the mortality was considerably higher, approximately 35 %, which is explained by the fact that more complex corrections proved necessary.

In general, few late complications were encountered. There were no cases of pulmonary venous obstruction.

Atrial septal defect (ASD secundum)

During the last 10 years, approximately 250 patients with uncomplicated secundum defects were operated upon. More than 90 % of the defects were closed by direct suture. Only 2 patients were re-operated.

Endocardial cushion defects (ASD primum and AV-commune)

40 patients were operated on for a primum atrial septal defect. The cleft in the mitral valve was repaired in almost all instances and in all patients a patch was used to close the defect. The patch was routinely sutured to the base of the mitral valve so as to avoid heart block.

There was no mortality in this group of patients and only two patients were re-operated, in both cases due to late infection causing mitral insufficiency. No permanent heart block was encountered.

During the same period, 40 patients were operated on for complete AV-canal (Fig. 28—29). 4 patients died (10 %) and none was re-operated.

Congenital aortic stenosis

30 patients were operated on with commissurotomy. The mean pressure gradient before operation was 80 mm Hg. All except one survived operation.

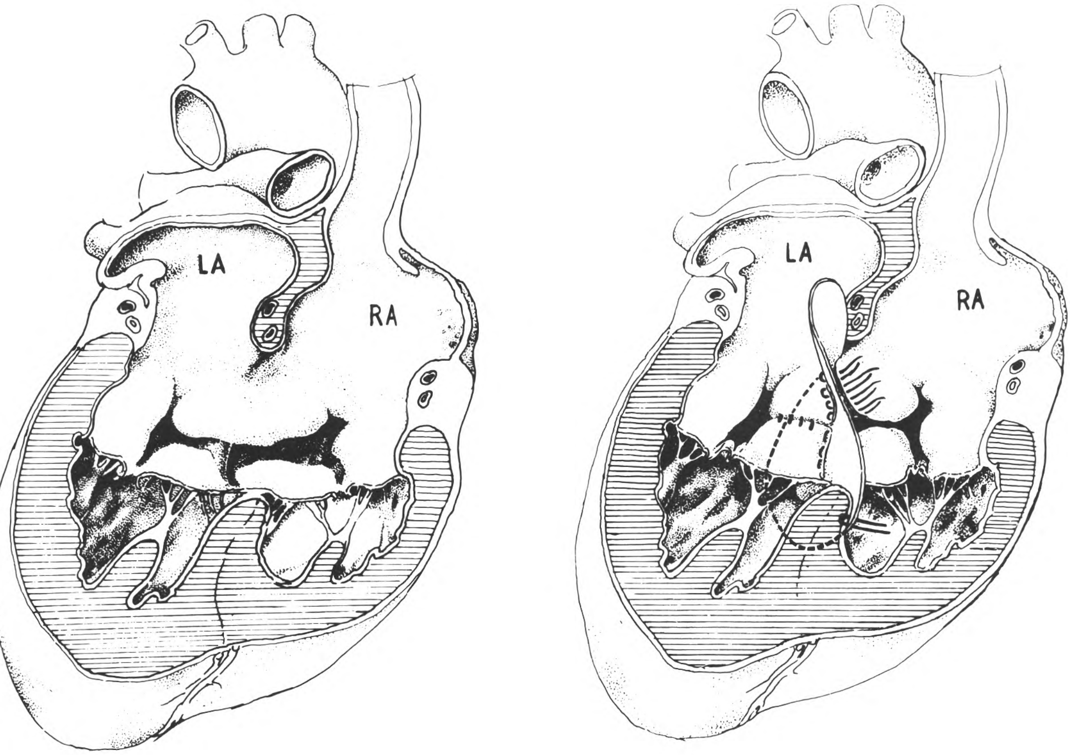


Fig. 28—29. *Repair of complete AV-canal. The common anterior leaflet is incised, the cleft in the mitral valve is closed, a new "septum" is inserted and finally the valve leaflets are sutured to the septum.*

Tricuspid atresia

A new method for correction of tricuspid atresia was developed at the Clinic. This includes an anastomosis between the right atrium and the right ventricle without using a conduit. 4 patients were operated upon, 3 of whom survived. The long-term results of these patients were most gratifying.

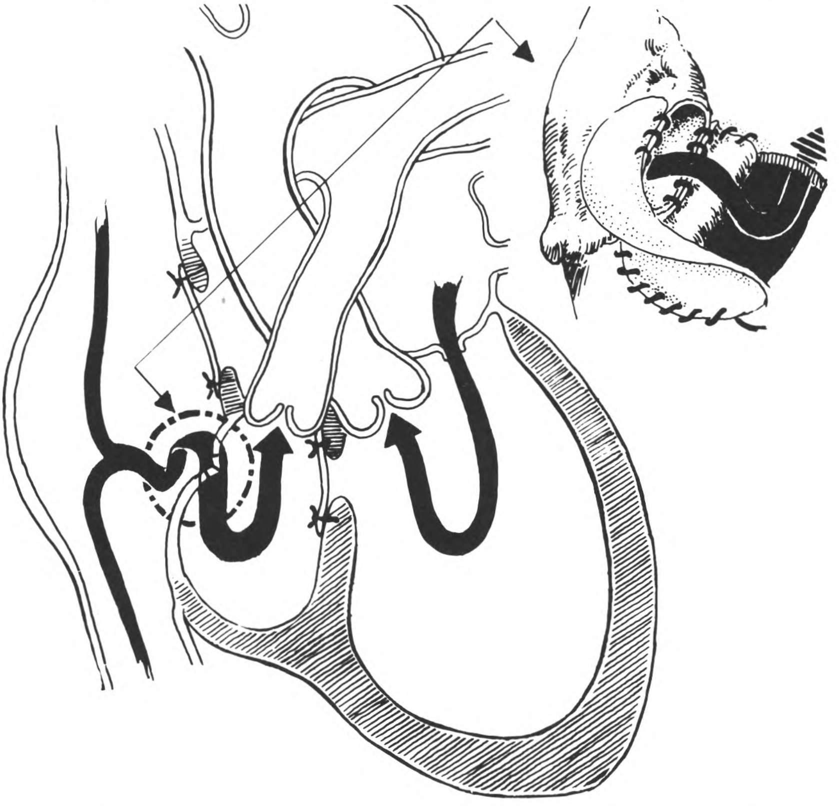


Fig. 30. *Correction of tricuspid atresia. The associated ASD and VSD are closed with patches and a communication between the right atrium and the hypoplastic right ventricle is made with the aid of a pericardial patch (inset).*

"Surgery for congenital heart disease is second to none in the necessity for technical perfection. It must be accomplished in the operating room by an alertness of mind, an intensity of effort, a steadiness of hand and a gentleness of touch."

DWIGHT C. McGOON (1968)

EXTRACORPOREAL CIRCULATION

Kjell Rådegran

Operation within the open-heart necessarily means that the function of the heart must be temporarily stopped. Unfortunately, the human body tolerates only a few minutes of circulatory arrest before irreversible brain damage ensues. Ever since the inception of cardiac surgery, there has been a continuous search for methods that would allow the surgeon to operate within the empty heart.

The first such method to be used in clinical practice was surface-induced hypothermia. The hypothermia was obtained by cooling the sleeping patient in a bath with cold water. At a body temperature of 29—30°C, the oxygen demands are reduced to approximately 50 % of normal. This prolongs the period that the brain can be without circulation to about 8 minutes. During that time the surgeon can close a simple atrial septal defect or open up a valvular pulmonary stenosis. Repair of more complicated cardiac defects, however, demand an appreciably longer time.

Already in 1937, an American surgeon, John Gibbon, had designed a machine that could replace the function of the heart and lungs in cats for periods of up to one hour. The capacity of this early heart-lung machine was, however, not sufficient for larger animals or human beings. Gibbon continued to develop his heart-lung machine and on May 6, 1953, he was successfully able to close an atrial septal defect with the aid of his apparatus.

Crafoord, who was Gibbon's good friend, had visited his laboratory several times. He realized at an early stage the importance of the heart-lung machine and had soon constructed one in collaboration with his assistants, Åke Senning and Viking Björk, and P. A. Åstradsson, engineer at the AGA Company. Crafoord was able to use successfully this machine in an operation in July 1954, when he removed a tumour (myxoma) from the left atrium. The operation was performed through a left thoracotomy and the perfusion altogether took 28 minutes. This was the second successful open-heart operation in the world.

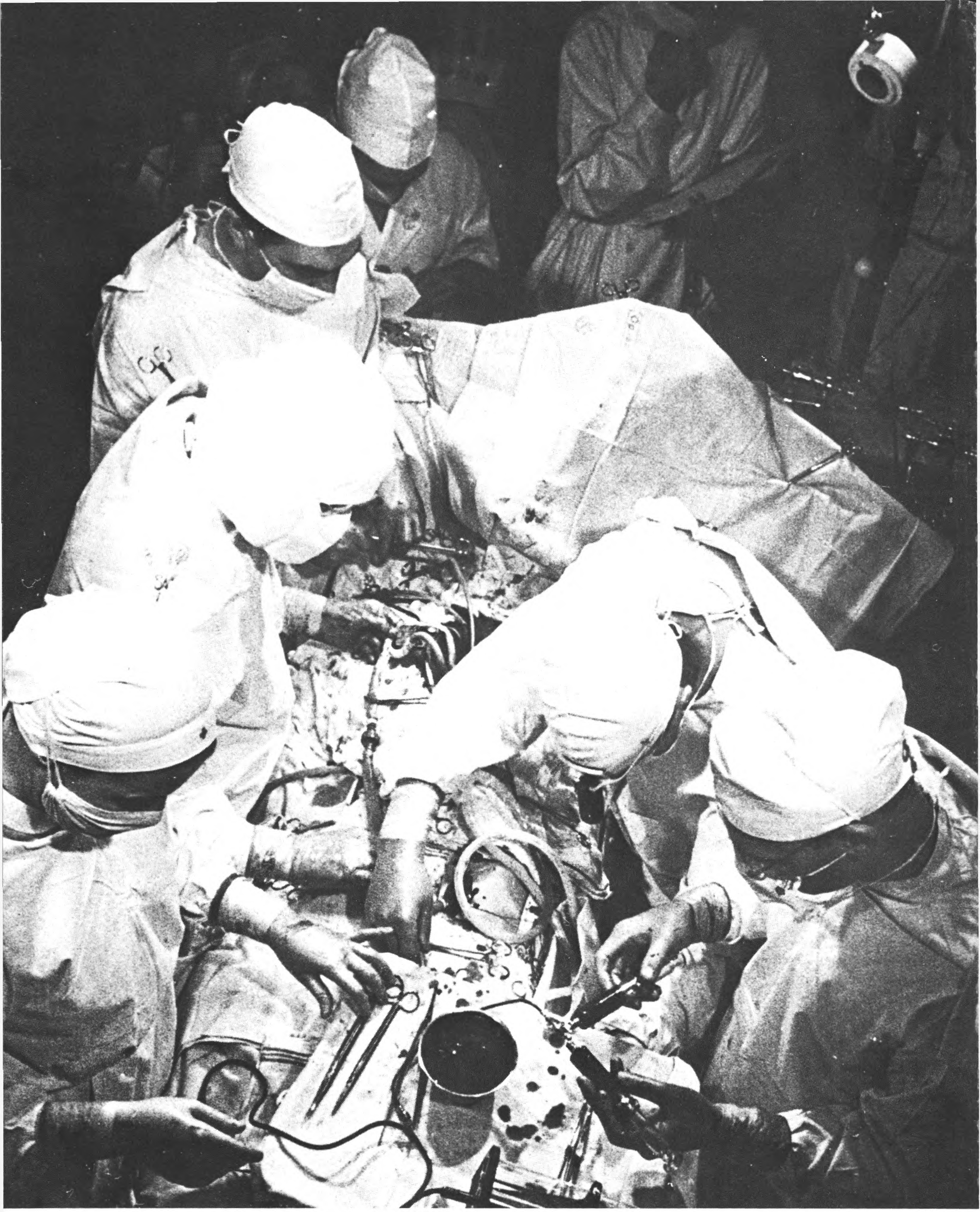


Fig. 31. *From one of the earliest heart-lung machine operations. From left to right: Nurse Inga, Crafoord, Hambraeus, Senning and Ekeström.*

Introduction of heparin

When using a heart-lung machine the blood must be prevented from clotting. A suitable anticoagulant was found by MacLean, Howell and Holt 1916—1918 and named *heparin*. This agent was purified and became clinically available in 1935 thanks to the work of Erik Jorpes at the Karolinska Institute. Crafoord energetically supported Jorpes and was subsequently one of the first to introduce heparin into clinical practice. The importance of heparin for extracorporeal circulation and the prevention of blood clotting cannot be overestimated and it is still the only anticoagulant used during extracorporeal circulation.

Construction of the heart-lung machine

The heart-lung machine consists of two main components, the pump (which replaces the heart) and the oxygenator (which replaces the lungs). The venous blood returning to the heart is drained from the right atrium or from the caval veins by gravity. This blood then enters the oxygenator where it is oxygenated and the carbon dioxide is removed. The blood is then pumped back into the patient's arterial system, usually through a cannula in the ascending aorta (Fig. 32).

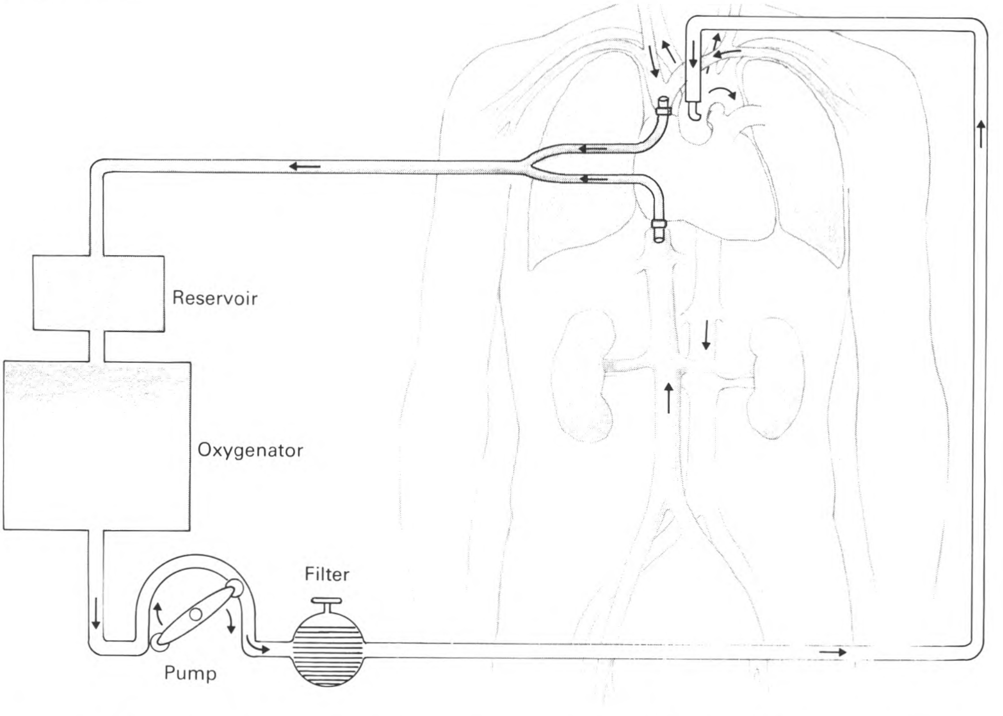


Fig. 32. *The principle for extracorporeal oxygenation. Venous blood is drained to a reservoir and then goes through the oxygenator where it is oxygenated. Finally it is pumped through an arterial filter back to the arterial system.*

The *pumps* used today in the heart-lung machine are generally of roller-pump type. Rotating rollers simply milk the blood forward in an elastic tube. Back flow is prevented by occlusion of the tube by the roller itself. Ordinarily roller pumps give only small pulsations in the flow of blood. So far, most studies indicate that a pulsatile flow is not necessary for limited periods, although there are indications that a pulsatile flow may have certain physiological advantages.

The *oxygenator* presented the greatest obstacle in the construction of the heart-lung machine. The gas exchange in the oxygenator consists of uptake of oxygen and removal of carbon dioxide from the blood. In the natural lung, blood passes through the capillaries of the lungs in a monocorpuscular layer with a diameter of 5—10 μ, while in an artificial oxygenator oxygen must diffuse through a blood layer often 20—30 times thicker. In order to achieve a sufficient gas exchange in an artificial lung, there must be a large contact surface between blood and gas. This contact surface can be obtained by dispersing oxygen in blood, i.e. introducing a large amount of oxygen bubbles in the blood (bubble oxygenator) or by letting a thin blood film come into contact with the oxygen gas (screen, disc or membrane oxygenator).

Screen oxygenators. In the heart-lung machine used in the first successful open-heart operation (Gibbon, 1953), the blood film was produced over a large area of vertical screens. The screen oxygenator was used extensively in the early era of open-heart surgery, but it was very sensitive to variations in the thickness of the blood film which necessitated a complicated design. It is expensive and difficult to make disposable and is therefore no longer used, although it is fairly atraumatic to the blood.

Disc oxygenators. Björk had constructed a disc oxygenator in 1947 which he was able to use in animal experiments (Fig. 33). It was originally designed for perfusing the brain with oxygenated blood. He was able to sustain life in dogs and, in one of the experiments, the heart was deprived of its circulation for 33 minutes. At that time, however, plastic materials were not available and therefore it was not possible to use it on human beings. The principle, however, was employed by Björk when he constructed the AGA-Björk heart-lung machine that is still in use at the Thoracic Surgical Clinic (Fig. 35).

Membrane oxygenators. In the natural lung there is no direct contact between blood in the capillaries and the air in the alveoli. It was therefore natural to try to design an oxygenator after the same principal, i.e. by putting a semipermeable membrane between the blood and the gas. Membrane oxygenators have been developed to a high degree of perfection, but they are more expensive and difficult to use than bubble oxygenators. They may give less trauma to the blood than other oxygenators and it should thus be possible to use them for longer perfusions. This has been reported by e.g. Hill's group in San Francisco, where perfusions have been extended over several days.

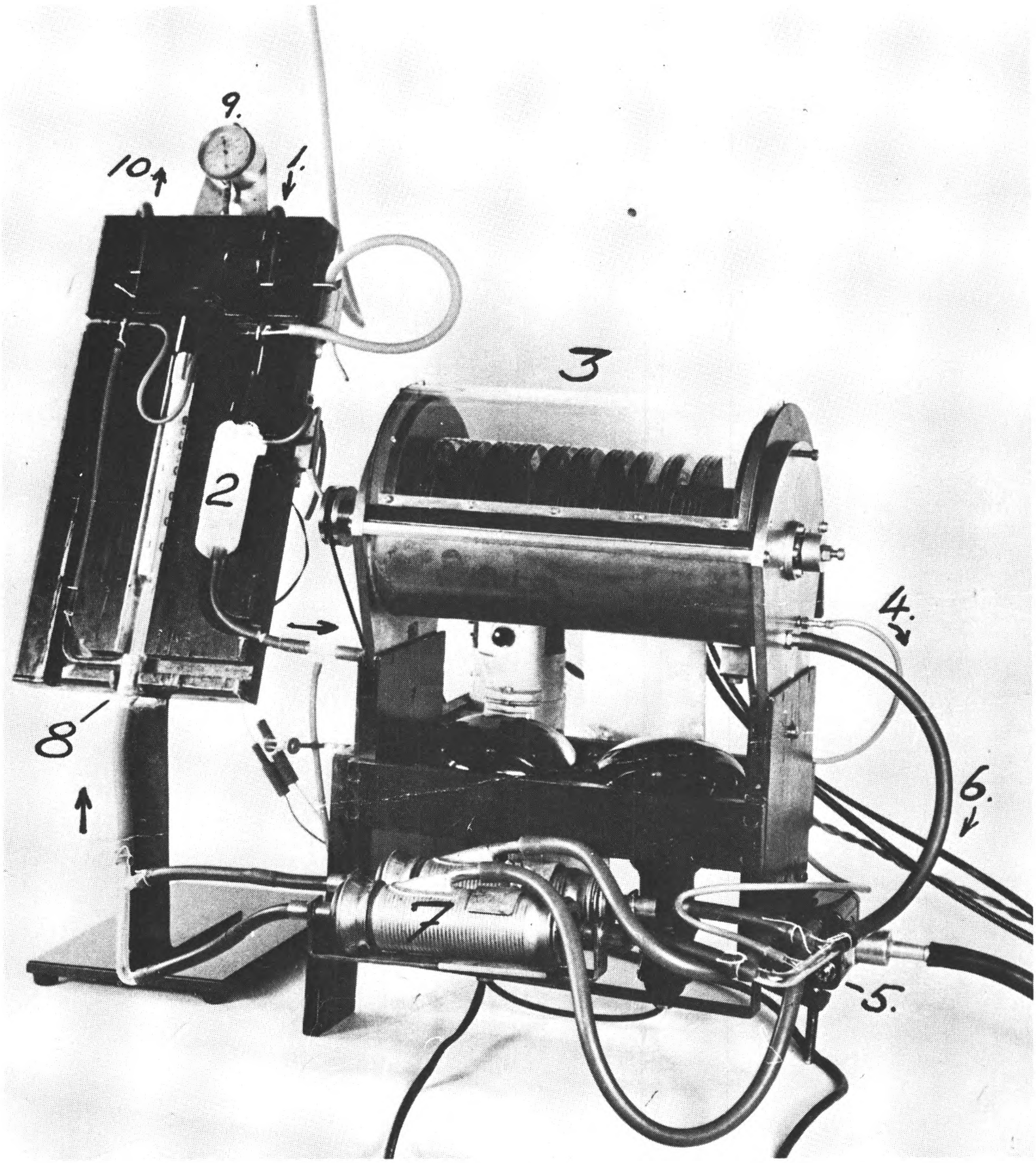


Fig. 33. *Disc oxygenator for experimental brain perfusion constructed by Björk in 1947.*

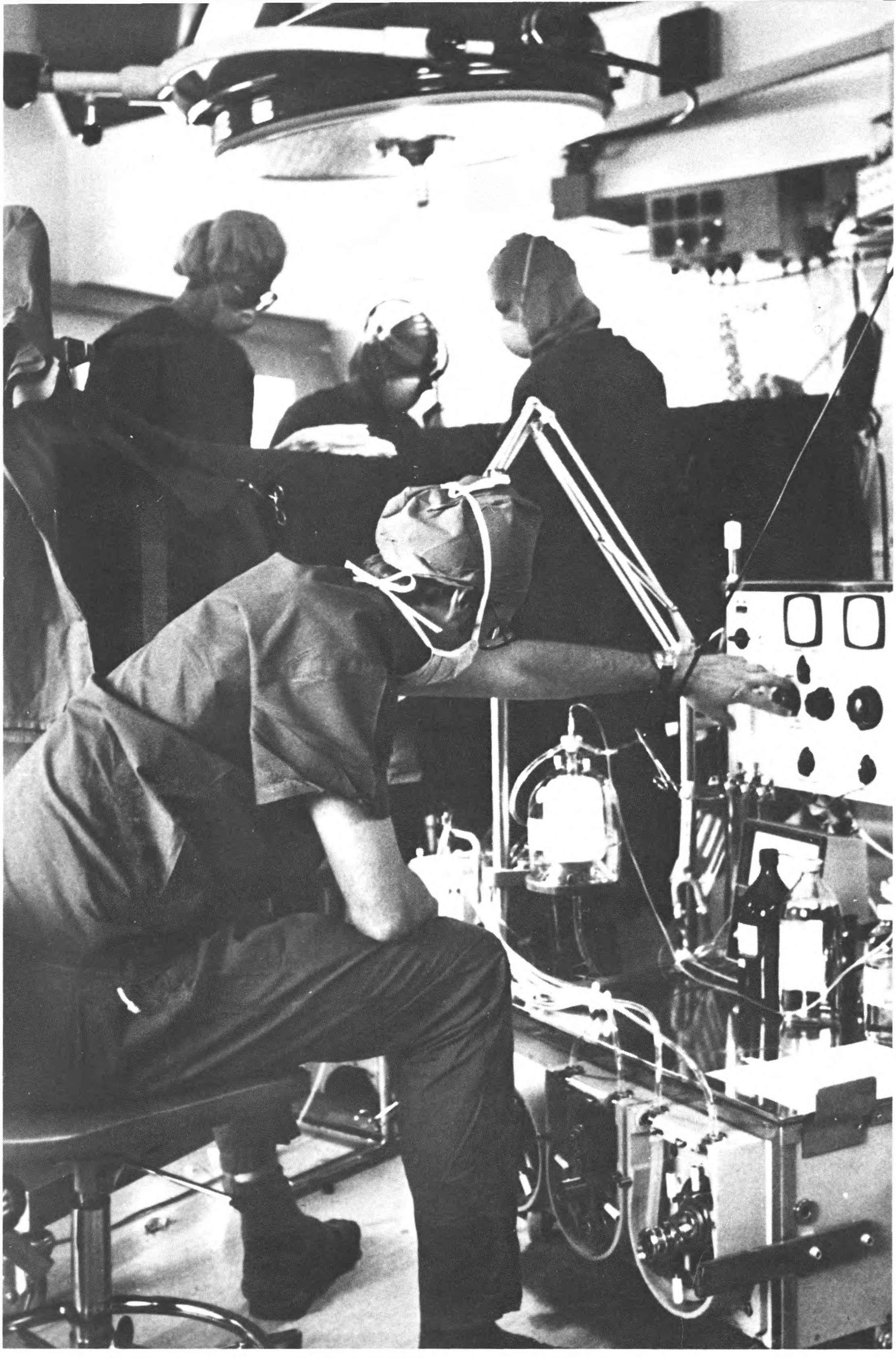


Fig. 34. *The perfusionist at work at the heart-lung machine.*

Present perfusion technique

At present, an AGA-Björk heart-lung machine equipped with a Shiley disposable bubble oxygenator is used for routine perfusions (Fig. 36). The bypass circuit is primed with 2,000 ml Ringer's acetate (Ringerdex, Pharmacia, Stockholm, Sweden) and 5,000 units of heparin are added. The lines are connected to the heart cannulae previously inserted by the surgeons. After all air has been evacuated, the perfusion is slowly started. Usually a flow of 2.5—3 $l/min/m^2$ is used. The temperature of the patient is routinely reduced to 25—30°C by letting cold water flow through the heat exchanger of the oxygenator. A special feature of the Shiley oxygenator is its low priming volume and small need of gas.

After the intracardiac repair has been carried out, the patient is slowly rewarmed. This is done by letting warm water (usually 10—12°C warmer than the blood) flow through the heat exchanger. When heart action is regained and the heart is able to support the circulation, a partial occlusion clamp is placed on the venous line and the perfusion is slowly terminated. Blood is then transfused from the heart-lung machine with the guidance of the left atrial pressure Remaining blood in the machine is pumped into plastic bags for later retransfusion into the patient.

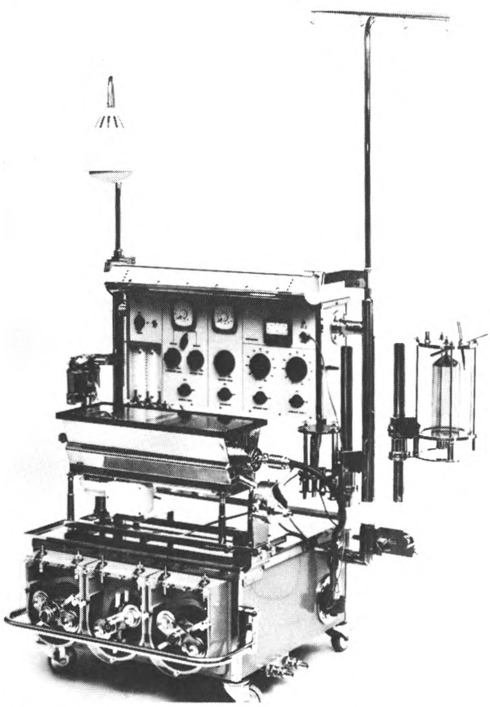


Fig. 35. *AGA-Björk heart-lung machine with a disc oxygenator.*

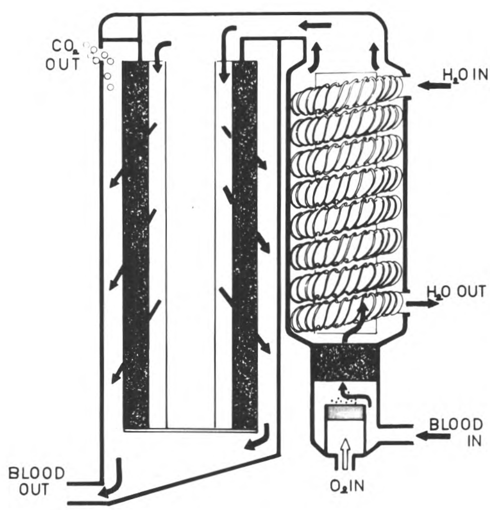


Fig. 36. *Principle for the Shiley disposable oxygenator.*

Myocardial protection

During the period when the heart is deprived of its circulation, the heart muscle must be protected from ischaemic injury. Otherwise microscopical myocardial infarcts may occur that will reduce postoperative heart function. At present, myocardial protection is achieved by the hypothermic cardioplegia technique. Cold Ringer's acetate with 16 mekv potassium added is infused into the aortic root after that the aorta has been cross-clamped. In this manner the heart muscle is cooled and arrested via the coronary circulation. Furthermore, the heart is cooled from the outside by iced Ringer's solution and then a specially designed piece of plastic foam keeps it isolated from its surroundings. With this technique, it is possible to operate on the cold and relaxed heart for several hours without causing clinically significant reduced cardiac output post-operatively.

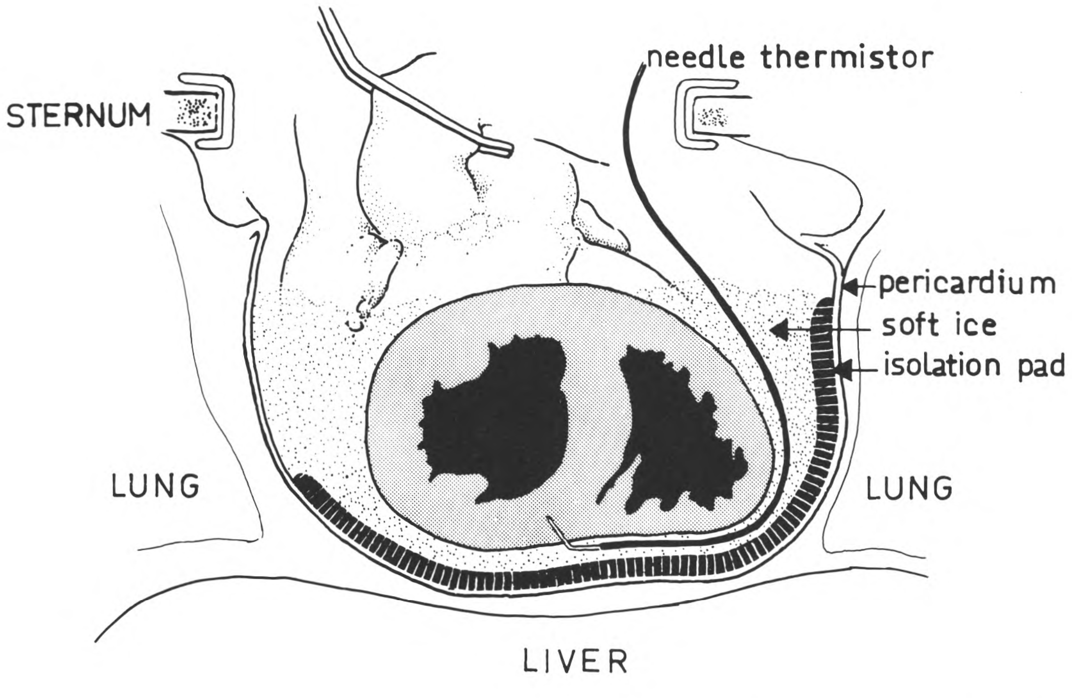


Fig. 37. *System for maintaining cold cardioplegia during aortic cross-clamping. The heart is surrounded by soft ice and isolated from the pericardium by a specially designed pad of compressed plastic foam.*

FROM COMMISSUROTOMY TO TILTING DISC

Axel Henze

Surgical interest in heart valve disease can be traced back for more than 100 years, to 1876, when Klebs reported experimental work on valvular surgery in dogs. At the turn of the century, Brunton made the farsighted suggestion that mitral stenosis would prove amenable to surgical correction. This dream of the future became reality 50 years later, when closed commissurotomy was employed in clinical practice for the relief of mitral, pulmonic and aortic valvular stenosis. When Gibbon performed the first open-heart operation with his heart-lung machine in 1953, it was the culmination of 20 years of work in the laboratory which made possible the subsequent development of direct-vision surgery on the heart. Many of the early local valvular procedures have been gradually abandoned and the entire problem of surgery for acquired heart valve disease has mainly assumed the radical approach of excising the valves and replacing them by either mechanical or biological heart valve prostheses.

Today, surgery for heart valve disease accounts for nearly half of the cardiac operations performed in Sweden, despite the persistent increase in coronary work. The greater part of these valvular procedures constitute prosthetic valve replacements and acquired aortic valvular disease remains the foremost cause for such an operation. Open valvulotomy or commissurotomy is reserved for the congenital pulmonic and aortic valvular stenoses and is usually performed in childhood. Closed commissurotomy remains the method of choice for classical mitral stenosis, although this type of lesion is nowadays so rare in this country that the young generation of cardiac surgeons is hardly familiar with this closed technique.

Closed commissurotomy

Tuffier (1913) made the first attempt to dilate a stenosed aortic valve in man. He invaginated the aortic wall with his finger in the hope of dilating the valve. We know now from the nature of aortic stenosis that Tuffier was hardly successful, although his patient survived surgery. The first instrumental approach to a pulmonic valve is also ascribed to Tuffier (1913). Unfortunately, the stenosis in this patient was not valvular but infundibular and therefore the attempt was unsuccessful.

Allen & Graham (1922) designed a valvulotome in which an optical system was incorporated to permit visual control of the valvular procedure. The instrument was employed without clinical success. Souttar's report in 1925 of a successful mitral valvulotomy by way of the left atrial appendage remains a remarkable document in light of further developments in this field. Cutler and Beck performed partial excision of the stenosed mitral valve in 5 patients and presented their final report in 1929. The only long-term survivor in this series, the first patient, lived for nearly 5 years. By 1950, thanks to the persistent efforts of Smithy, Harken, Brock, Baily and other pioneers, closed commissurotomy of mitral stenosis was brought into the circle of acceptable operations. Smithy was a victim of rheumatic heart disease and did not live to see the fulfilment of his important early work.

In common with Souttar (1925), modern cardiac surgeons also attempted to dilate the mitral valve by "finger fracture". The difficulties in achieving an adequate opening in many instances stimulated the supplementary use of dilators and cutting instruments and the final development of the valvulotome.

Good results with mitral stenosis

Few operations have gained the attention and respect accorded to commissurotomy for mitral stenosis. The success of this procedure is due to the fact that in the pure form of mitral stenosis the adhesions fusing the valve leaflets are more torn than the leaflets per se. Under these circumstances, if the chordae tendinae are not shortened and the leaflets are soft, mobile and competent, then good and lasting clinical results can be expected.

The principle procedure is an application of a bursting force to the stenotic mitral valve orifice that literally tears the leaflets from each other. This is perhaps most easily achieved by means of a mechanical dilator or valvulotome, which is inserted by the transventricular route and guided into the mitral opening by the palpating finger through the left auricle (Fig. 39). This operation can be performed with minimal requirements of transfusion and without circulatory support, since instrumentation of the valve extends only over a few heart beats. Certain definite drawbacks to this closed approach to mitral surgery should be mentioned. They are detachment of thrombotic deposits from either the atrial appendage or the valve; fragmentation of valvular calcifications

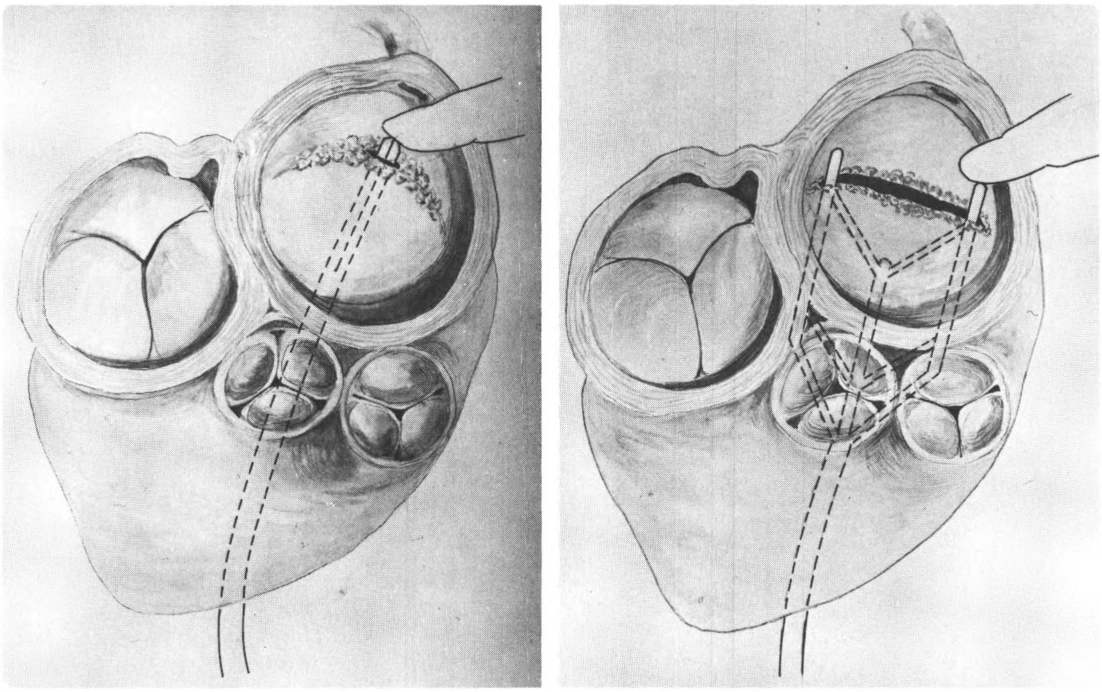


Fig. 38—39. *Closed mitral commissurotomy (by courtesy of Professor V. O. Björk).*

with subsequent embolization; accidental damage to the mitral leaflets and tendons with resultant regurgitation; insufficient opening of the valve orifice with residual mitral stenosis.

Nevertheless, the closed approach to mitral stenosis offers very satisfactory improvement to selected patients. Brock (1975) presented an analysis of his personal experience in 618 patients undergoing closed mitral valvulotomy over the 15 year period 1948—63. The mortality rate of 7.6 % was much higher than it is today, as it included the early pioneer days when many very sick patients were operated upon. There were only 5 early deaths among his most recent 400 cases, a mortality rate of 1.3 % that well corresponds to the achievements of modern surgical treatment. A detailed follow-up of at least 10 years showed that many patients were obviously cured of their mitral stenosis. Restenosis was diagnosed in 128 patients (22 %) and 93 of them underwent re-operation. 60 patients were alive and well with their own valves 20 years or longer after correction of mitral stenosis, a challenge to modern prosthetic devices.

The long-term results depend clearly upon the extent of the valvular damage by rheumatic disease or from subsequent relapses. Even under ideal circumstances, however, refusion of the mitral valve leaflets may occur and call for a second operation 10—20 years later. At the Karolinska Hospital we have re-operated on many patients 10—15 years after closed mitral commissurotomy. Some patients return earlier and 24 % of our open mitral cases today are repeat operations after previous mitral commissurotomy. These valves are always severely damaged by calcifications and fibrosis so that the decision to replace them by prosthetic valves is never difficult to make (Fig. 40).

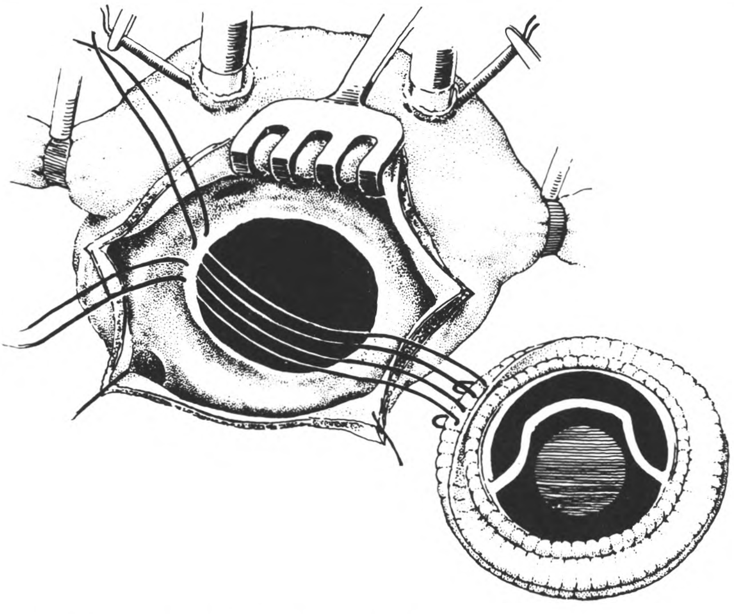


Fig. 40. *Mitral valve replacement.*

Open commissurotomy

The use of the heart-lung machine permits surgery under visual control and within reasonable time limits. It is very likely that open valvulotomy is more effective in pure mitral stenosis than poorly performed closed valvulotomy, but this is hardly sufficient reason to expose the patients to the risks of extra-corporeal circulation, hypothermia and massive blood transfusions. Cooley (1959), Gerbode (1960) and Björk (1960) and their associates discouraged the routine use of direct-vision commissurotomy on the grounds that the open procedure hardly facilitates identification of the lines of fusion or permits a more effective commissurotomy. Separation of the fused leaflets is the purpose of the operation and therefore, open mitral commissurotomy is never justified as the first operation unless an intracardiac thrombus is suspected.

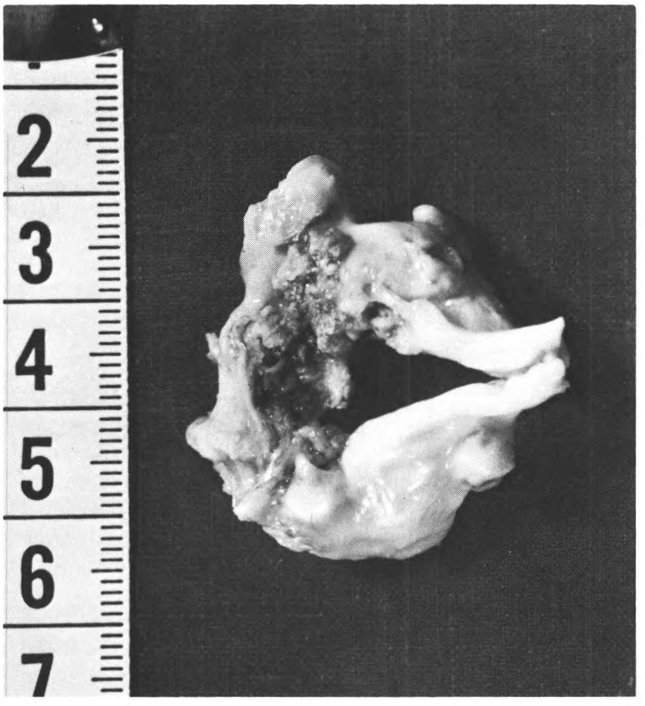


Fig. 41. *Severely calcified aortic stenosis.*

Calcific aortic stenosis generally displays an advanced pathology. In many instances the aortic cusps are completely changed into stonehard, clumsy and immobile structures lacking all resemblance to cardiac valves. The calcifications often extend into the aortic annulus and adjacent heart muscle or anterior mitral leaflet. Hence, the early experimental efforts by Smithy (1948) and Bailey (1950) with closed transventricular valvulotomy have not gained a permanent position in the management of acquired aortic stenosis. The basic flaws in closed aortic valve surgery are that this approach hardly provides significant relief of the stenosis itself, but subjects the patient to the dangers of calcific embolism and aortic regurgitation. Lewis (1956) and Swan (1956) and their associates therefore performed aortic valvulotomy under direct vision with the aid of hypothermia and circulatory arrest. Although the period of safe circulatory arrest was extended to 8 minutes with the use of hypothermia, it proved insufficient in the event of unexpected complications or when extensive reconstruction was required. The logical continuation of the early approach to open aortic valve surgery was the supplementary use of the heart-lung machine, as advocated by Lillehei and his group (1956), following the preliminary experimental work of Glowes and Neville (1954). The calcifications were carefully removed from the valve cusps in order to restore their flexibility and normal motility. However, this decalcification procedure was time-consuming, requiring about 30 minutes for each extensively calcified cusp, and the relief of symptoms in most cases was only temporary as the calcifications and the stenosis recurred within a few years.

Suitable procedure for congenital pulmonic and aortic valvular stenosis

Congenital aortic stenosis usually involves no calcifications, so that the danger of embolization during closed valvulotomy should be minimal. Nevertheless, the closed commissures must be opened by precise incision, as a safeguard against inadvertant laceration of the cusps and the production of disastrous aortic incompetence. In contrast, the low pressure in the pulmonary artery precludes serious valvular incompetence following free incision of the pulmonary valvular commissures.

The early results obtained with open valvulotomy in congenital aortic and pulmonary stenosis are satisfactory and may be permanent for many years. The operative mortality is nowadays lower with the open method than with the closed method and should be under 1 %. A further advantage in favour of a direct vision valvulotomy is that it permits simultaneous correction of concomitant cardiac anomalies.

The long-term results after open commissurotomy are hardly predictable merely on the basis of a successful operation. Stenotic valves, which have been opened are not entirely normal and may undergo degeneration and calcification with the passage of time, particularly under the influence of systemic pressures. Many adult patients come back with recurrences of their aortic stenosis displaying the advanced pathology so typical for acquired aortic valvular disease. A prosthetic heart valve is then the only alternative.

Valvular repair and annuloplastic procedures

The extensive development devoted to surgical correction of stenosing valvular lesions during the 1950's had received lasting success in many respects. During the same period, surgical interest for valvular incompetence was not less intense. Ingenuity was considerable regarding the reparative and reconstructive procedures on incompetent valves and the same can be said about the plastic procedures employed in order to restore dilated mitral and aortic rings to their normal size.

The first attempt to perform an annuloplasty was made by Cushing and Branch in 1908, who narrowed the mitral and tricuspid orifices in dogs by sutures encircling the leaflets or chordae tendinae. Many years later, in 1954, a similar technique was devised for clinical application by Davila and his group and by Borrie. "Plication" of the mitral annulus has later been used to narrow the valve orifice and improve approximation of the leaflets by Baily, Kay, Nichols, Merendino and many others. Attempts were also made to reduce the size of the aortic annulus by constricting ligatures placed externally, with temporary success in a few cases (Baily & Likoff, 1955; Taylor *et al.*, 1958).

Reconstructive valvular surgery started rather late. Two such procedures are worth mentioning. Garamella (1958), Baily (1959) and their associates introduced bicuspidalization by fusing two aortic cups in order to correct the incompetence. McGoon (1960) performed "plication" of the mitral leaflet for incompetence resulting from rupture of the chordae tendinae. Although the early results obtained with bicuspidalization and other valvuloplastic procedures were encouraging, recurrent insufficiency due to breakdown of the repair was evident in the majority of cases within a few years. Today, a heart valve prosthesis is the only alternative for the correction of aortic incompetence. There is, however, renewed interest in reconstructive procedures for pure mitral regurgitation.

Annuloplasty in functional tricuspid incompetence

Functional tricuspid incompetence is due to dilatation of the annulus secondary to enlargement of the right ventricle, while the leaflets per se are intact. Empirically, the relatively low right heart pressures create opportunities for lasting improvement following annuplastic procedures in functional tricuspid insufficiency. Kay (1963) narrowed the tricuspid orifice by obliterating whole or part of the posterior leaflet, thus converting the tricuspid valve into a bicuspid one. De Vega (1972) performed "plication" of the tricuspid annulus by sutures running along the anterior and posterior leaflets in a horseshoe-shaped fashion. Both these techniques avoid the conduction system which runs along the septal leaflet. Carpentier (1971) designed a special prosthetic "ring" which was fixed to the tricuspid annulus by multiple sutures in order to restore its normal size and configuration. The long-term benefits after the three above mentioned techniques have been reported in many publications.

Biological heart valves

The use of free tissue grafts in cardiac surgery can be traced back to 1930 when Wilson reported experiments in which strips of pericardium, fascia lata or tendon were placed across the mitral orifice. Murray et al. (1938), Templeton & Gibbon (1949) and Baily et al. (1954) reconstructed deficient valve leaflets by free tissue grafts of vein or pericardium. Prosthetic materials have also been used in many ingenious ways. Between 1956 and 1960, stimulated by the work of Hufnagel, the Canadian orthopaedic surgeon, Gordon Murray, inserted fresh aortic valve homografts into the descending aorta in a series of patients suffering from aortic incompetence. Angiography and autopsy evidence have been reported to confirm the essential normal state of these homografts, which had functioned for at least 12 years.

Biological valves can be prepared from autologous tissue taken from the patient, homologous tissue obtained under sterile conditions from deceased persons or heterologous tissue harvested from other species. These tissue grafts are further subdivided into viable and non-viable or preserved types. The pulmonary valve used as a replacement for the diseased aortic valve in the same patient is a perfect example of a potentially viable autograft (Ross, 1972). Fresh homografts must in fact be stored for some hours or days in nutritive and antibiotic solutions in which preservation of their viability is hardly complete. It has also been reported that the number of viable cells continues to decrease even after implantation of such grafts, probably as part of the rejection process. Recently, long-term storage of "viable" homografts has been accomplished in the vapor of liquid nitrogen. The maintenance of an adequate supply of "viable" homografts is obviously a major undertaking. Furthermore, different fixatives are required to destroy the antigenic properties. Irradiation or freeze-drying has been used for the same purpose. Glutaraldehyde is now recommended as a fixative as it preserves the collagen structures. Encouraging clinical results have been reported with Hancock's glutaraldehyde-preserved porcine heterograft.

Transplantation of the pulmonary autograft to the aortic orifice presupposes that the pulmonic valve is capable of withstanding systemic pressures. The mortality associated with this advanced technique is relatively higher than that of an ordinary aortic valve replacement, so that transplantation of the pulmonic valve is reserved for selected patients in the younger age groups (Ross, 1972). Tricuspid bioprostheses for aortic valve replacement have been prepared with the aid of autologous fascia lata mounted on a frame of synthetic material (Senning, 1967). Autologous pericardium has been used in the same way and, more recently, biological heart valves have been prepared from heterologous pericardium (Ionescu, 1974) and homologous dura mater.

The "natural" heart valve can be inserted either on free hand or after previous mounting on a frame. The "free-hand technique" places heavy demands on the surgeon, but preserves the natural flexibility and elasticity of the valve and obviously entails favourable late results. The homografts inserted in the descending aorta by Murray (1956—1960) have demonstrated an essentially normal function for 10—15 years.

Fig. 42. *Professor Björk operating with Henze, Böök and Nurse Yvonne assisting and Dr. Geoffrey Smith from Great Britain watching.*

Long-term results

A low incidence of thrombo-embolic complications has been reported, although anticoagulation therapy was generally avoided (Angell, 1975; Ionescu, 1975; Jacoub, 1975). The biological heart valves which have been studied in vivo also simulated the haemodynamic performance of the normal natural valves. Unfortunately, they also simulate its tendency towards degeneration, fibrosis and calcification resulting in irreversible valvular damage. By 1970, Senning's method with autologous fascia lata grafts for aortic valve replacement appeared to be the most promising alternative to mechanical heart valves. The function of the fascia lata valves was most satisfactory and, even without the use of anticoagulants, there were no instances of thrombo-embolism. However, the long-term follow-up revealed late deterioration of valve function in 60 % of the patients after an average observation period of 5 years. Morphological studies of the valves removed 1—7 years after insertion revealed slowly proceeding degenerative and proliferative changes of the fascia tissue, which were responsible for the late deterioration. Moreover, late bacterial endocarditis tended to increase in frequency the longer the fascia lata grafts were in place. In view of the unfavourable record of durability of the autologous fascia lata aortic valve, Senning in 1975, after 13 years of experience, discouraged the further use of this method.

Other recently developed biological heart valves have received much attention and enjoyed success, although the observation periods are still less than the follow-up in Senning's series. There is today considerable optimism regarding the Hancock glutaraldehyde preserved porcine heterograft.

Mechanical heart valves

The modern era of prosthetic valve replacement began with the partial correction of aortic incompetence. In 1953, Charles Hufnagel succeeded in inserting a mechanical ball-valve, housed in acrylic, into the descending aorta distally to the origin of the left subclavian artery. Physiological evidence has been reported that this mechanical heart valve controlled about 75 % of the regurgitation through the aortic valve. Many patients, perhaps several hundred, were operated upon in that manner until the direct approach to aortic valve surgery became possible. Murray, meanwhile, inspired by the work of Hufnagel, placed aortic valve homografts instead of mechanical valves in the descending aorta. By 1960, Harken had designed a caged ball-valve which he inserted in the aortic orifice below the coronary ostia after previous excision of the diseased cusps. With the further development of caged ball-valves, including the incorporation

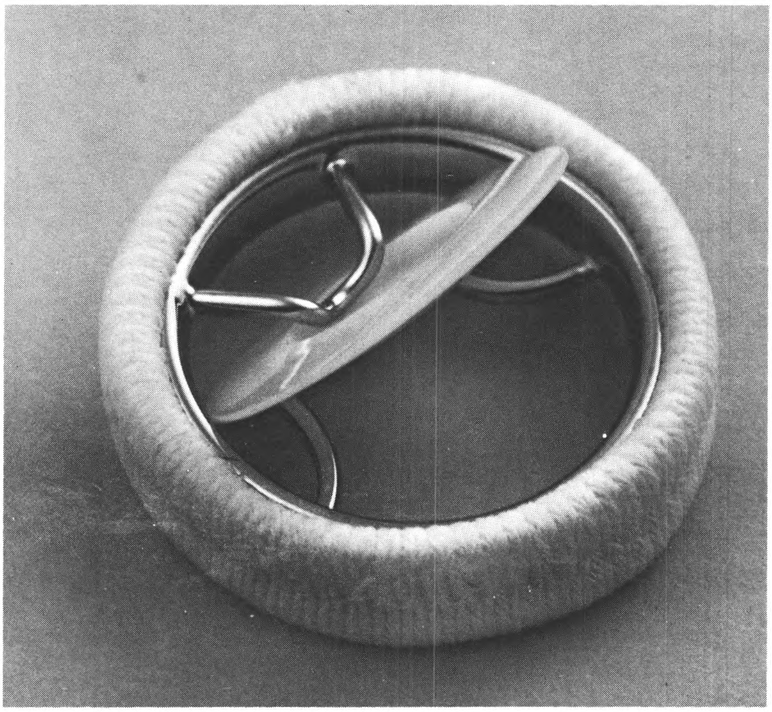


Fig. 43. *The original Delrin disc model of the Björk-Shiley prosthesis.*

of a sewing ring. Starr (1963) reported a series of patients undergoing total aortic valve replacement. The encouraging results obtained by Starr and his group initiated the more common use of mechanical valves in cardiac surgery.

Mechanical heart valves have been designed in many ingenious ways. The numerous attempts to construct prosthetic valves with the normal aortic valve configuration in mind have lacked one important quality—the long-term durability that has been obtained in mechanical valves of "unnatural design".

The general design of all currently available mechanical heart valves can be separated into three components. These are 1) a moving member, the so-called occluder, which opens and closes against 2) a ring-shaped seat functioning as the orifice and 3) a sewing ring encircling the seat. Highly durable materials have been developed for the manufacture of prosthetic valves. These include elastomeric materials, rigid materials and fabrics. Silicone rubber is the only elastomer that has been employed satisfactorily for valve occluders. Pyrolytic carbon, a rigid material with a glasslike appearance, has had widespread use in the occluders of disc valves. Stellite 21 and Titanium are widely used metals for the production of valve seats and Teflon is a suitable material for the sewing ring.

There are three types of mechanical heart valves for current clinical practice. The first type uses a ball-occluder within a cage. The Starr-Edwards, Smeloff-Cutter, Braunwald-Cutter and DeBakey ball-valves belong to this category. The second type is a caged disc valve with a disc instead of a ball-occluder. The Beall, Starr-Edwards and Kay-Shiley disc valves are of this type. The third type has a pivoting or tilting disc which opens at a level roughly parallel to the blood stream. The Wada-Cutter, Lillehei-Kaster and Björk-Shiley valves belong to this third group.

The tilting disc valve

Viking Olov Björk, Professor of Thoracic and Cardiovascular Surgery at the Karolinska Institute, Stockholm, Sweden, has himself, during his more than 30-year-long activity in this field of surgery, tested the many different possibilities of correcting heart valve lesions. He gained fundamental experience of the Starr-Edwards ball-valve which he personally inserted in a series of 120 patients with aortic valvular disease. The patients were followed up carefully and 46 of them underwent recatheterization. Undoubtedly, the ball valve prostheses functioned well except in cases with narrow aortic roots, where the smallest prostheses had been inserted with remaining obstruction as consequence. Björk made similar observations among 88 patients operated upon with the Kay-Shiley disc valve. The caged ball and disc valves caused obstruction of the central blood stream which resulted in critical gradients or transprosthetic pressure differences in cases with narrow aortic roots (Fig. 44). It was therefore

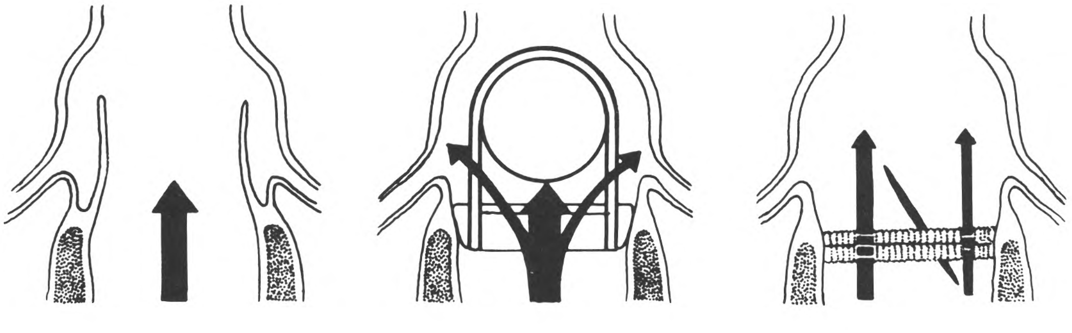


Fig. 44. *Central forward flow through a normal aortic valve (left), obstruction of this flow by a central occluder in a caged ball-valve (centre) and possibility of central flow through a tilting disc valve (right).*

considered a great step forward when Juro Wada, the Japanese surgeon, in 1964 implanted his original tilting disc valve in a dog and in 1965 inserted it in man. The Teflon disc in these prostheses tilted open in a hinge-like mechanism, which obviously diminished the central obstruction of the blood flow (Fig. 44). In practice, the gradient was only half of that caused by the central type of occluder. However, the original model of Wada's prosthesis showed certain wear disturbances of the Teflon disc. It happened on occasions that the disc got stuck in a half open position or escaped out of the valve seat and embolized to the aortic bifurcation. The wear was more pronounced in the larger valves inserted in Swedish patients than in the smaller ones in Japanese patients. Björk was the first to draw the attention to the wear problem, which he initially observed in Sweden, and he anticipated that it must occur sooner or later in all cases. Hence, all Wada's early valves were exchanged by re-operation.

It became evident that the tilting disc was the answer to the problem posed by mechanical heart valves in narrow aortic roots. However, the satisfactory haemodynamic properties of the tilting disc had to be combined with security. Donald P. Shiley (Shiley Laboratories, Irvine, California, USA) had an experimental model under development which was modified in consultation with Björk. An ingenious opening mechanism allowed the disc to open to an angle of 60° and rotate freely so as to ensure an even distribution of the wear. Shiley guaranteed the durability with Delrin for the disc, a material 7 times more resistant to wear than Teflon. Accelerated experimental wear tests confirmed a durability corresponding to at least 100 years. After comparative pulse duplicator studies with other prosthetic valves, Björk accepted the Delrin tilting disc prosthesis for the first human implantation in January 1969 (Fig. 43).

The original Delrin disc model of the Björk-Shiley tilting disc valve has been modified in several respects. In 1971, pyrolytic carbon was introduced as disc material instead of Delrin, mainly because of its longer durability. The opening angle in the mitral valve model was increased from 50° to 60° and its sewing ring designed with 2 flanges. Since 1975, the disc is equipped with a ring-shaped radiopaque marker, permitting noninvasive function control. The tilting motion of the disc can be visualized by cineradiography and fluoroscopy so that an easy method is now available to follow the prosthetic valve function in patients (Fig. 45).

A total of 140 of Björk's initial aortic (90) and mitral (50) cases underwent recatheterization at rest and during exercise. The beneficial haemodynamic results from these postoperative studies are widely known today. None of the currently employed mechanical heart valves has such a low resistance to blood

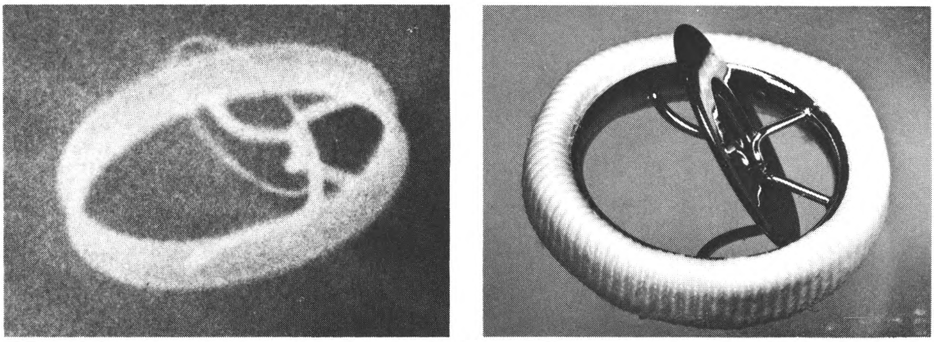


Fig. 45. *The Björk-Shiley tilting disc valve with a pyrolytic carbon disc and a radiopaque marker for function control.*

flow as the Björk-Shiley prosthesis. The merits are due to the construction itself, which uses a non-overlapping disc occluder. Thereby 2 additional mm of orifice diameter are gained for a given external diameter which provides the highest possible orifice-to-tissue diameter ratio for each prosthetic size. A further advantage is that this non-overlapping closing mechanism avoids mechanical crushing of the red blood cells. Haemolysis is therefore mild and without clinical significance.

Anticoagulation necessary

Patients with mechanical heart valves, in contrast to those with biological heart valve prostheses, must undergo life-long anticoagulation treatment. The advocates of biological prostheses generally refer to anticoagulation as a burden, binding the patients to regular blood chemistry control. Moreover, anticoagulation involves a certain risk of serious bleeding complications, particularly in the older age groups. The risk is low as long as anticoagulation is carefully managed. It has been calculated to be less than 0.5 per 100 patient years on the basis of nearly 400 anticoagulated cases in Björk's series with observation times of 3—5 years.

The present situation at the Karolinska Hospital, Stockholm

The Björk-Shiley tilting disc valve has been used in clinical practice for nearly 10 years. A total of 1,700 such valves have hitherto been inserted at this hospital with the development shown in Figs. 46 and 47. The mean observation time today is almost 4 years and not a single case of genuine mechanical valve failure has been encountered in the entire series. The incidence of thrombo-embolic complications is perhaps the most interesting parameter of the late results obtained with the Björk-Shiley prosthesis.

Systemic emboli had an incidence of 0.7 per 100 patient years after aortic valve replacement, 7.6 per 100 patient years after mitral valve replacement and 3.6 per 100 patient years after combined aortic and mitral valve replacement. After mitral commissurotomy, an incidence of 11 late embolic episodes per 100 patient years has been reported and should serve as comparison. Thrombotic obstruction was encountered with an incidence of 0.3 per 100 years for aortic prostheses, 1.9 per 100 years for mitral prostheses and 2.3 per 100 years for tricuspid prostheses. This complication was frequently associated with poor anticoagulation and most of the patients involved were re-operated upon without mortality.

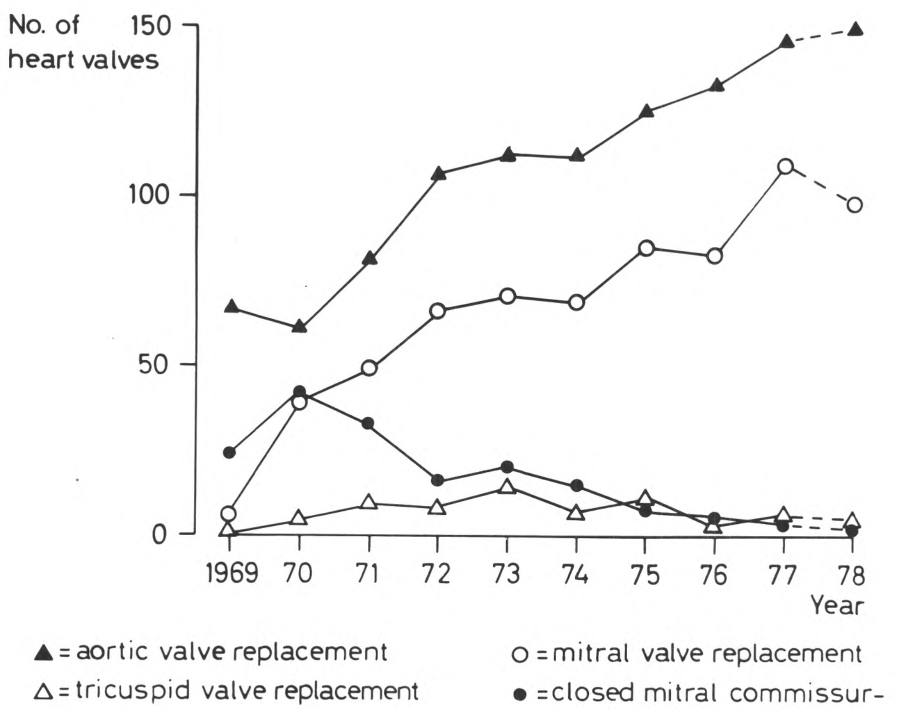


Fig. 46. *Development of heart valve surgery at the Karolinska Hospital, Stockholm, Sweden, during the 10-year period 1969—78.*

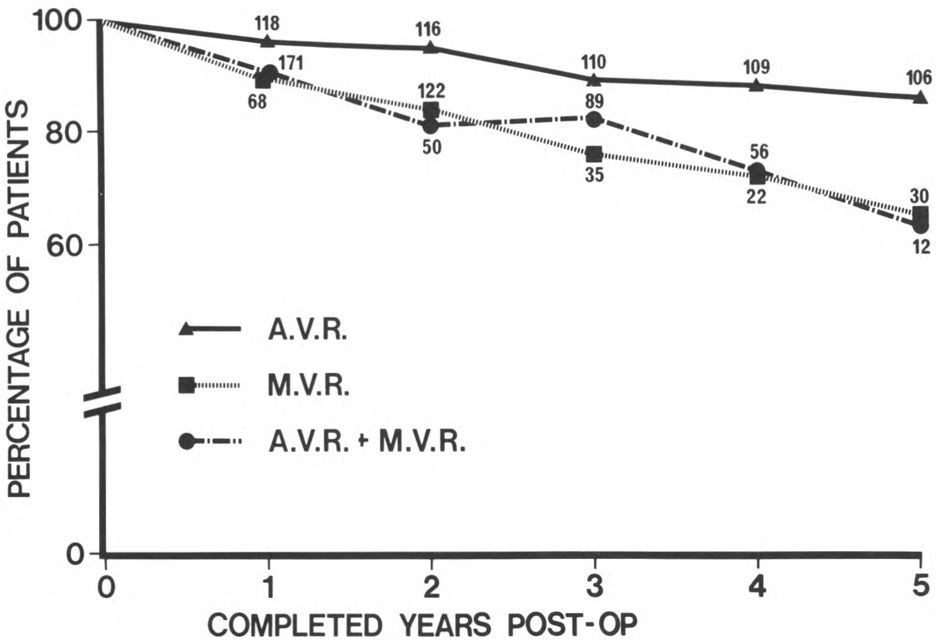


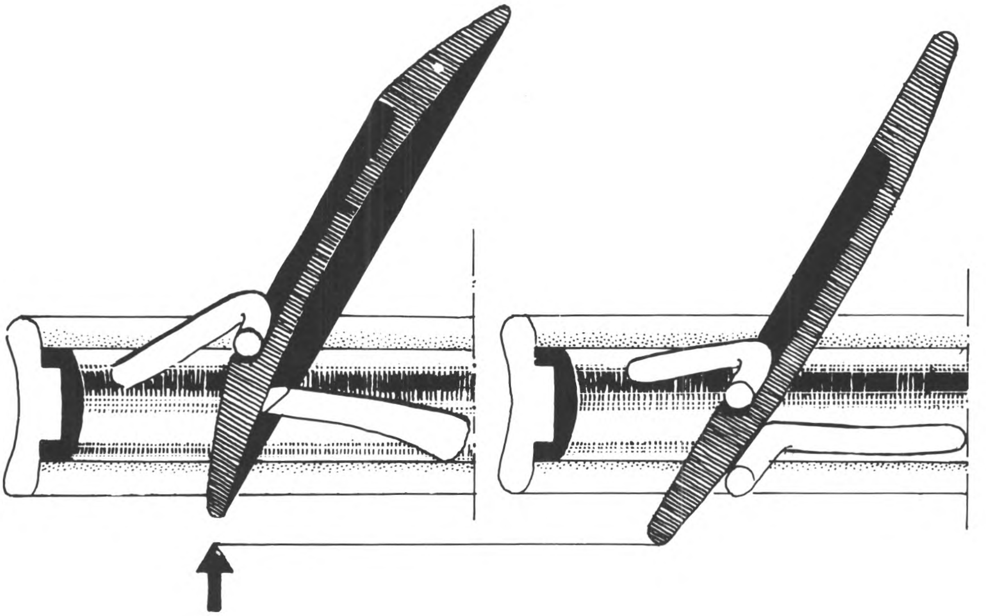
Fig. 47. *Actuarial survival following valve replacement with the Björk-Shiley prosthesis. The figures on the curves denote the number of patients at risk in the three groups at the beginning of each year of observation (AVR=aortic valve replacement, MVR=mitral valve replacement) (from the author's archives).*

Further development

Viking Olov Björk is never content to rest on his laurels. His future goal is a mechanical heart valve which can be implanted without the protection of anticoagulation, at least in the aortic position. We know today that a prosthetic thrombus probably starts generating at the pivot point between the disc and valve ring, where the flow pattern should be turbulent. Björk, in collaboration with the Shiley Laboratories, tackles this problem by means of his new convexo-concave version of the tilting disc valve. The opening mechanism is designed to add a sliding-off-the-valve-ring-motion when the disc tilts open and, simultaneously, the smaller opening of the prosthesis is somewhat increased at the expense of the larger one (Figs. 48 and 49).

This design permits effective washing at the pivot point. In experimental studies, the resistance to flow is lower for the convexo-concave model than for the standard model Björk-Shiley prosthesis. The convexo-concave disc prosthesis has been inserted to date in about 100 patients at the Karolinska Hospital and recatheterization in 12 cases with narrow aortic roots shows promising haemodynamic results. Anticoagulation is maintained while awaiting the longterm results in a larger series of patients.

Fig. 48. *The opening mechanism of the new convexo-concave model of the Björk-Shiley prosthesis (left) is designed to add a sliding-off-the-valve-ring-motion when the disc tilts open (by courtesy of Professor V. O. Björk).*



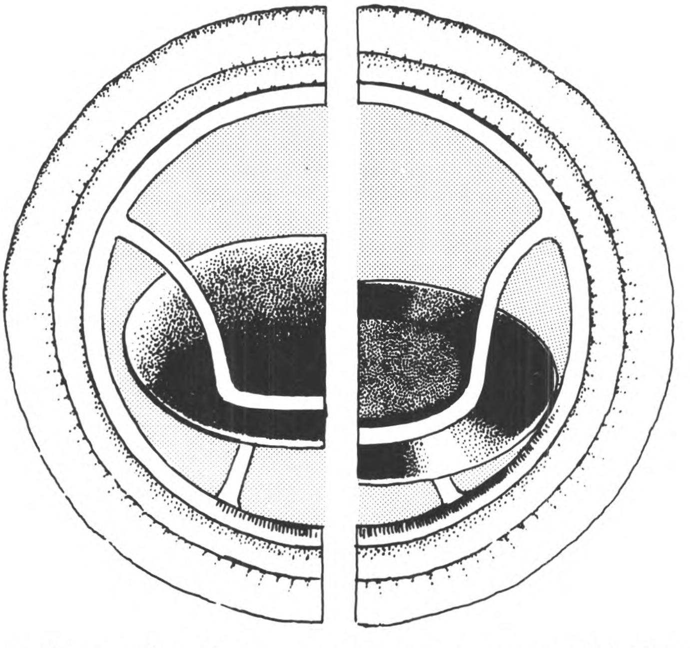


Fig. 49. *The smaller opening of the new convexo-concave model of the Björk-Shiley prosthesis (left) is somewhat increased at the expense of the large one (by courtesy of Professor V. O. Björk).*

ON WATCHING A HEART OPERATION

This is the heart, but not as poets dreamed it,
Rich fountain of a thousand different flows,
This is the heart as Harvey's genius schemed it,
Four-chambered pump with petals like a rose.
This is the heart, but not as poets see it,
Insurgent centre of tumultuous joy,
This is the heart as surgeon's scalpels free it
And scientific stratagems employ.
This is the heart torn from its tender sac,
Denied its pulses, cheated of its blood,
Until the moment, rhythm given back,
It manages its own triumphant flood.
And looking in the theatre I view
A love as keen as any Venus knew.

HELEN FORSYTH

VASCULAR AND CORONARY ARTERY SURGERY

Stig Ekeström

The vascular surgical technique is nowadays well established and used for arterial reconstruction in a large number of vascular regions and under various conditions.

The technique of thrombendarterectomy, with or without widening of the artery with a patch graft, is the principal method for reconstruction of the artery in many areas, such as the carotid or subclavian regions. Another common technique, arterial bypass with autologous vein transplant, is often the method of choice in cases of coronary or peripheral artery reconstructions. The two above mentioned methods are those of choice at our Clinic. Synthetic grafts have been strictly avoided, except for reconstruction of aneurysm of the aorta or the large arteries.

Indications for vascular surgery: The principle indication for arterial reconstruction is the presence of a regional ischaemia due to an obstructive or obliterative arterial disease. This applies, for instance, to the coronary, mesenteric and iliac-femoral regions. There are, however, vascular areas where the ischaemia is not caused by a chronic obliterative arterial disease, but by a sudden and often transitory occlusion of the smaller arteries. This is the case in many of the patients with carotid artery stenosis. The transitory occlusions are, to a great extent, due to the peripheral micro-embolization from an arteriosclerotic, ulcerated intimal plaque at the carotid bifurcation.

A renal artery stenosis, on the other hand, is not necessarily the cause of ischaemia of the kidney tissue and therefore has only slight influence on the excretory renal function. The renovascular hypertension, which is the true indication for renal artery reconstruction, is a result of an increased release of renin from the juxtaglomerular apparatus in the renal parenchyma. The overproduction of renin may depend on a stenosis of the renal artery and, if this is the case, it will be normalized when the stenosis is eliminated.

The risk for arterial rupture is the true indication in case of aneurysms of the aorta or any of its branches.

Selection of patients for vascular surgery: A correct selection of patients with vascular disease for arterial surgery is of the utmost importance for good long-term results. This holds good for all the arterial regions, but is perhaps most obvious in cases of renal artery stenosis. The presence of a combination of a renal artery stenosis and a renovascular hypertension does not at all imply an indication for arterial reconstruction. On the contrary, there are several additional criteria that must be present before surgery is indicated. Such criteria are, for instance, a short duration of the hypertension in a young patient, a high renin content in the renal vein on the stenosed side and a fibromuscular, hyperplastic type of arterial obliteration.

The selection of patients for peripheral vascular surgery is facilitated by a large number of pre-operative physiological investigations, such as oscillometry, venous occlusion and digital plethysmography, ultrasound Doppler scanning of pulse or pulse pressures at different levels of the arteries and studies of walking tests on a treadmill. On the other hand, the degree and importance of a carotid artery stenosis cannot yet be ascertained to any great extent by pre-operative physiological investigations. In such cases, the selection of patients for carotid artery reconstruction should be based on clinical data and on aortocervical arteriography.

Long-term results of vascular surgery: The follow-up of the patients operated on for obliterative arterial disease is equally as important as that in any other kind of surgery. Vascular surgery, however, offers the surgeon a possibility of immediate control of his reconstructive work. Intra-operative pressure and flow measurements before and after arterial reconstructions provide him with information of the utmost importance and may convince him whether or not he has done a sufficiently extensive reconstruction. The pressure measurements and the flow determinations with electromagnetic flowmetry are indeed essential for all kinds of vascular surgery and should be routinely used. For more than 15 years, this has been the practice at the Thoracic Surgical Clinic.

Characteristics of vascular surgery at the Thoracic Surgical Clinic

The Thoracic Surgical Clinic at Karolinska Sjukhuset was opened for thoracic and cardiovascular surgery in April 1957. Since then, more than 1,000 patients suffering from vascular diseases in all regions of the body have been treated at the Clinic. 500 patients with coronary artery disease and 420 with carotid artery stenosis have undergone surgical treatment. Over 100 patients had renal artery stenosis. The largest group, over 800 patients, had obliterative diseases of the peripheral arteries. However, peripheral arterial disease is now mainly treated at the General Surgical Clinic due to the increase of patients for coronary artery reconstruction at the Thoracic Surgical Clinic.

98 patients with occlusive disease of the subclavian and innominate arteries, many of them with a steal syndrome, were operated on. Only few patients with mesenteric artery disease have been referred to this clinic, a large number of patients with aneurysms of the thoracic or abdominal aorta are included in our series of vascular operations.

Some special features of the vascular surgery at this Clinic may be of interest:

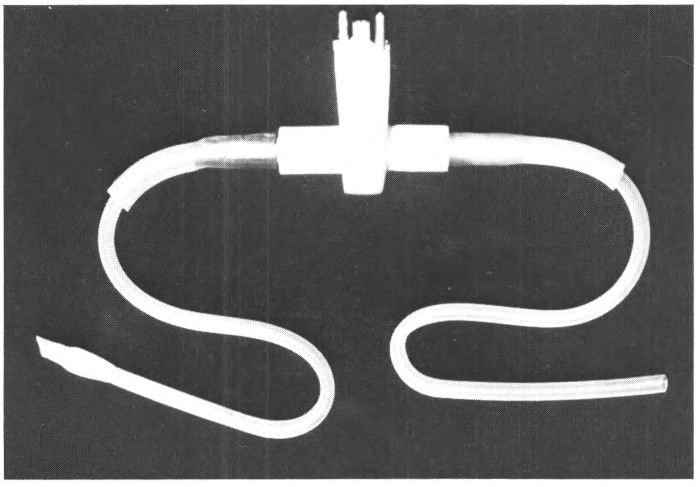


Fig. 50. *Carotid thrombendarterectomies are always performed under brain protection with the aid of an omega-formed partly extra-luminal shunt. The shunt blood passes an electromagnetic flowmeter continuously measuring blood flow during the surgical procedure.*

Carotid artery surgery: The transient ischaemic attacks, which are the typical indication for carotid surgery, may be caused by a haemodynamically important carotid stenosis or by peripheral embolization. In many patients, a sufficient collateral circulation, mainly through the circle of Willis, compensates for the decrease of blood flow, which is the result of a necessary occlusion of the carotid artery during surgery on the side of the reconstruction. The volume of the flow decrease is, however, in most of the cases, not known before the reconstruction. Hence, the most physiological way of protecting the brain during surgery is the use of a shunt. An omega-formed shunt (Fig. 50) with a built-in electromagnetic flowmeter is routinely used at the Clinic. Although not always needed, it is not an extra burden on the surgeon in the more complicated cases if he is accustomed to the shunt technique in which a shunt during carotid reconstruction does not constitute an extra risk to patients who do not need it.

Subclavian artery: From the follow-up of 85 patients operated on for obliterative disease of the subclavian or innominate arteries, it is evident that a direct approach to the subclavian arteries with the technique of thrombendarterectomy, with or without a vein patch in order to widen the diseased artery, does not involve an extra risk to the patient. The mortality with the above method is equal to that reported in large series of extrathoracic cross-over bypasses with synthetic grafts between the extracranial vessels. There is, however, a demand for a particularly skillful surgical technique when thrombendarterectomy is performed at the area of the origin of the subclavian and innominate arteries from the aortic arch.

The preoperative flowmetry at reconstruction of subclavian and innominate artery occlusions in the present series of subclavian steal syndrome (Fig. 51) showed an average retrograde vertebral flow of approximately 100 ml/min. After reconstruction it augmented to over 110 ml/min in anterograde direction (Fig. 52).

The long-term results, not yet available in a sufficiently large number of patients, will guide the selection of the proper technique for arterial reconstruction in this area. However, it seems somewhat illogical to use a method that implies exchange of a long and often modest connection for a short and large one in cases of the subclavian steal syndrome.

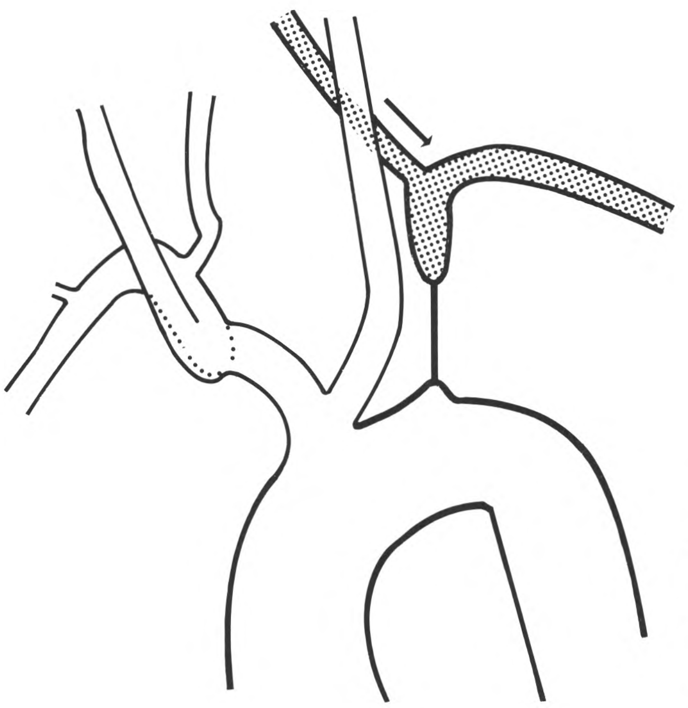


Fig. 51. *The dotted artery in the drawing represents the subclavian steal with retrograde flow downwards from the vertebral artery to the left arm.*

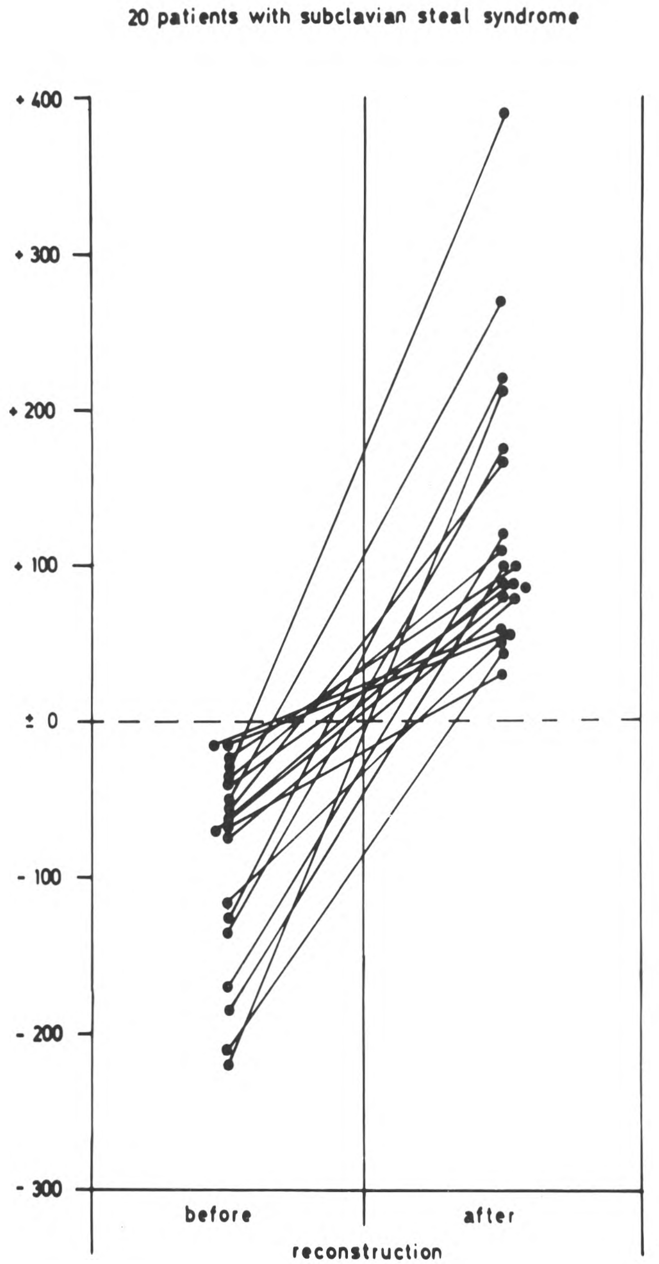


Fig. 52. *Before reconstruction, the vertebral flow was approximately 100 ml/min. in the retrograde direction and afterwards 120 ml/min. in the antegrade direction.*

Renal artery reconstruction: The characteristic feature of the routine at the Thoracic Clinics in cases of renal artery reconstruction is the approach to the renal artery. In the majority of the cases the thoraco-retroperitoneal approach with division of the diaphragm, including the crura medialis of the aortic hiatus, was used. This approach gives a wide exposure of 10—12 cm of the abdominal aorta from the thoracic border downwards. It allows not only access to the entire renal artery and vein, but also to a large part of the aorta and to the entire kidney. With this approach, a vein bypass reconstruction can be made with 45° down-stream angle, which gives favourable haemodynamic conditions.

Intraoperative pressure and flow measurements, which are easy to perform with the thoraco-retroperitoneal approach to the renal artery, have made it possible to calculate the flow resistance over the renal stenosis and compare it with that over the renal parenchyma. Postoperative follow-up of patients with renovascular hypertension and renal artery stenosis has demonstrated the importance of a careful selection of patients for this kind of surgery. A young patient with short duration of the hypertension, a high renin content in the renal vein on the stenosed side and a fibromuscular hyperplastic type of stenosis represents the strict limitation of patients accepted for surgery. The percentage of normalization of the blood pressure in this group of patients, however, is rather high, 70—80 %, as shown in a follow-up of 52 patients (Table 2).

Table 2. *The best predictable criteria for long-term normotension*

Predictable criteria	Normotensive $n = 22$	Improved $n = 20$	Failures $n = 10$
Mean age, years	35	42	47
Duration of known hypertension, months	16	59	43
Arteriosclerosis	3	9	5
Fibromuscular hyperplasia	19	11	5
Renin ratio >1.5	12	5	1

Peripheral artery surgery: The pre-operative flow studies on patients with peripheral vascular disease have given important information concerning the selection of patients and the immediate postoperative care. The arterial reconstruction was shown to be successful mainly in cases with good run-off in our series. However, the peripheral vasculature is well supplied with a collateral system with a great potential of compensation for deteriorated circulation.

The largest collateral system existing in the human body includes the profunda femoris artery, which is primarily responsible for nourishing the leg below the knee. In case of occlusion of the superficial femoral artery, an open profunda femoris and good distal vessels compensate the diseased artery to a great extent and will make vascular surgery unnecessary. This fact has restricted our indications for reconstructive vascular surgery in this region. It was evident from postoperative flow studies with implanted flow probes at the Thoracic Clinics that early mobilization of the patient after peripheral artery reconstructions improves the blood flow through the new reconstructed area immensely (Fig. 53). It was also clearly demonstrated that an adequate minute blood volume is of the utmost importance for a high regional blood flow for prevention of early acute arterial thromboses (Fig. 54).

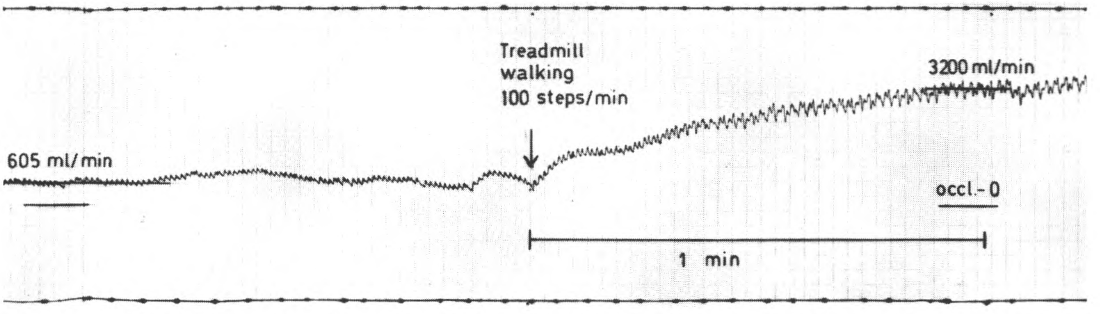


Fig. 53. *With the aid of an implanted electromagnetic flow probe, it is possible to demonstrate the pronounced flow increase during exercise during the immediate postoperative period in the common iliac artery.*

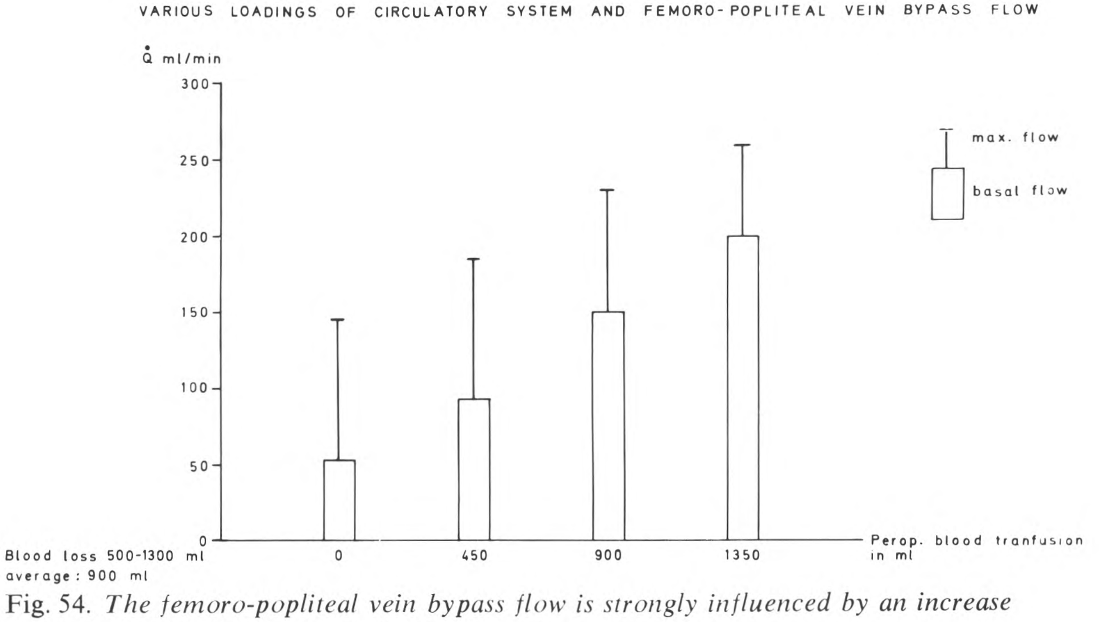


Fig. 54. *The femoro-popliteal vein bypass flow is strongly influenced by an increase of minute volume (Cronestrand, 1970).*

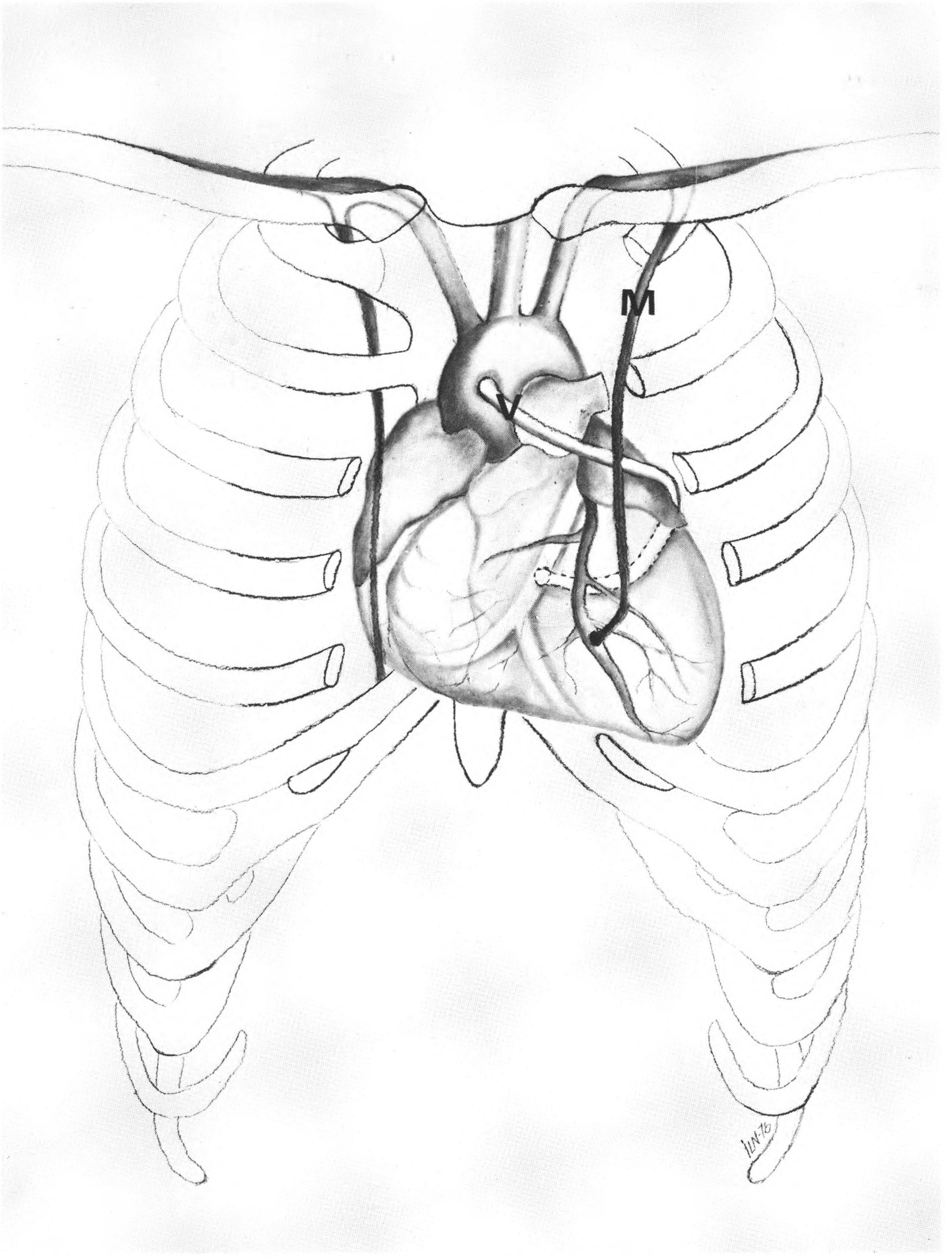


Fig. 55. *The coronary artery reconstruction is made either with the aid of the left internal mammary artery (M) or with autologous vein transplant from distal part of saphenous vein (V).*

Coronary artery: The aorto-coronary bypass technique has been used on 500 patients during the last eight years at the Thoracic Clinics (Fig. 55). The overall graft patency rate, as well as elimination or improvement of angina pectoris, is as high as in other reported series. The total mortality is within an acceptable range, i.e. 2.5 %.

Various methods for coronary bypass technique and myocardial protection have been in use simultaneously at the Clinics. The experience gained is not yet fully analyzed.

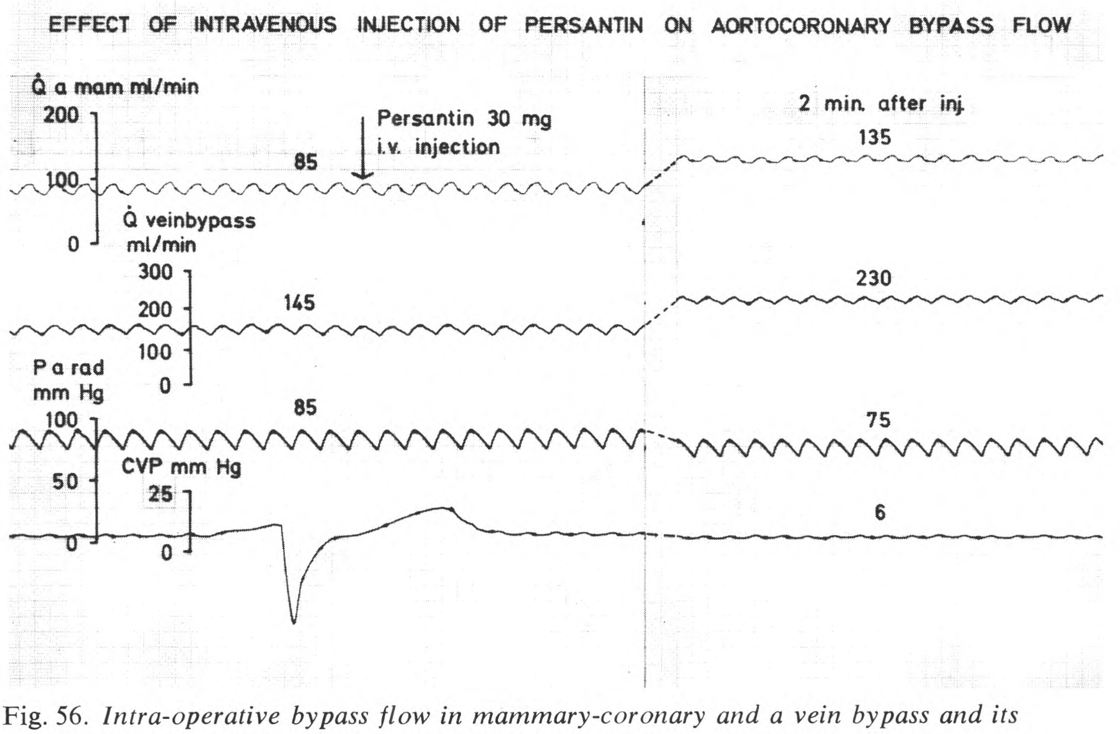
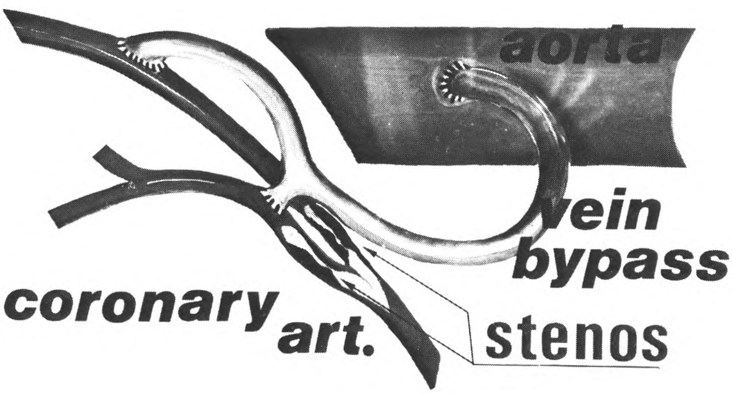


Fig. 56. *Intra-operative bypass flow in mammary-coronary and a vein bypass and its reaction on vasodilating drug (Dipyridamol) injected intravenously.*

As in all kinds of vascular surgery, the results of aorto-coronary bypass were also controlled intra-operatively with electromagnetic flowmetry. The bypass flow was also studied in most cases under various myocardial conditions or with the aid of specific coronary vasodilators (Fig. 56). It is evident from these investigations that both bypass flow and flow reaction to vasodilators may vary with age, duration of angina pectoris and the number of pre-operative myocardial infarctions. These observations may in the future influence the selection of the patients for coronary bypass surgery.

A special feature at the Thoracic Clinics is the extensive use of the internal mammary artery as bypass to the left anterior descending coronary artery. More than 250 mammary-coronary bypasses were performed. The patency rate of this bypass was high, 94 % after one year, compared with an 80 % patency for the aorto-coronary vein bypasses. However, as shown in Fig. 56, the flow through the mammary arteries is in average no more than half of that obtained with a vein bypass. This fact limits the use of the mammary artery to cases with a small peripheral left anterior descending artery and to patients with a severe stenosis of this artery. It is obvious from our results of coronary artery surgery, as well as from other series of coronary reconstructions, that the operation to a great extent eliminates or improves the angina pectoris and that the results from the clinical point of view correlate well with the intra-operative studies of the bypass flow and the patency rate.



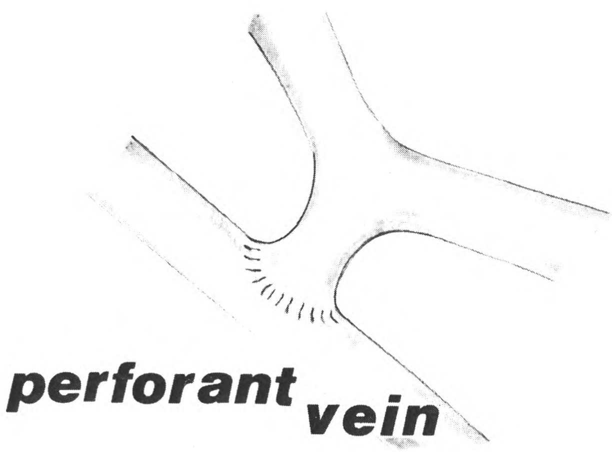


Fig. 57. *The saphenous vein transplant may be used as jumpgraft supporting LAD and a branch of the LAD.*

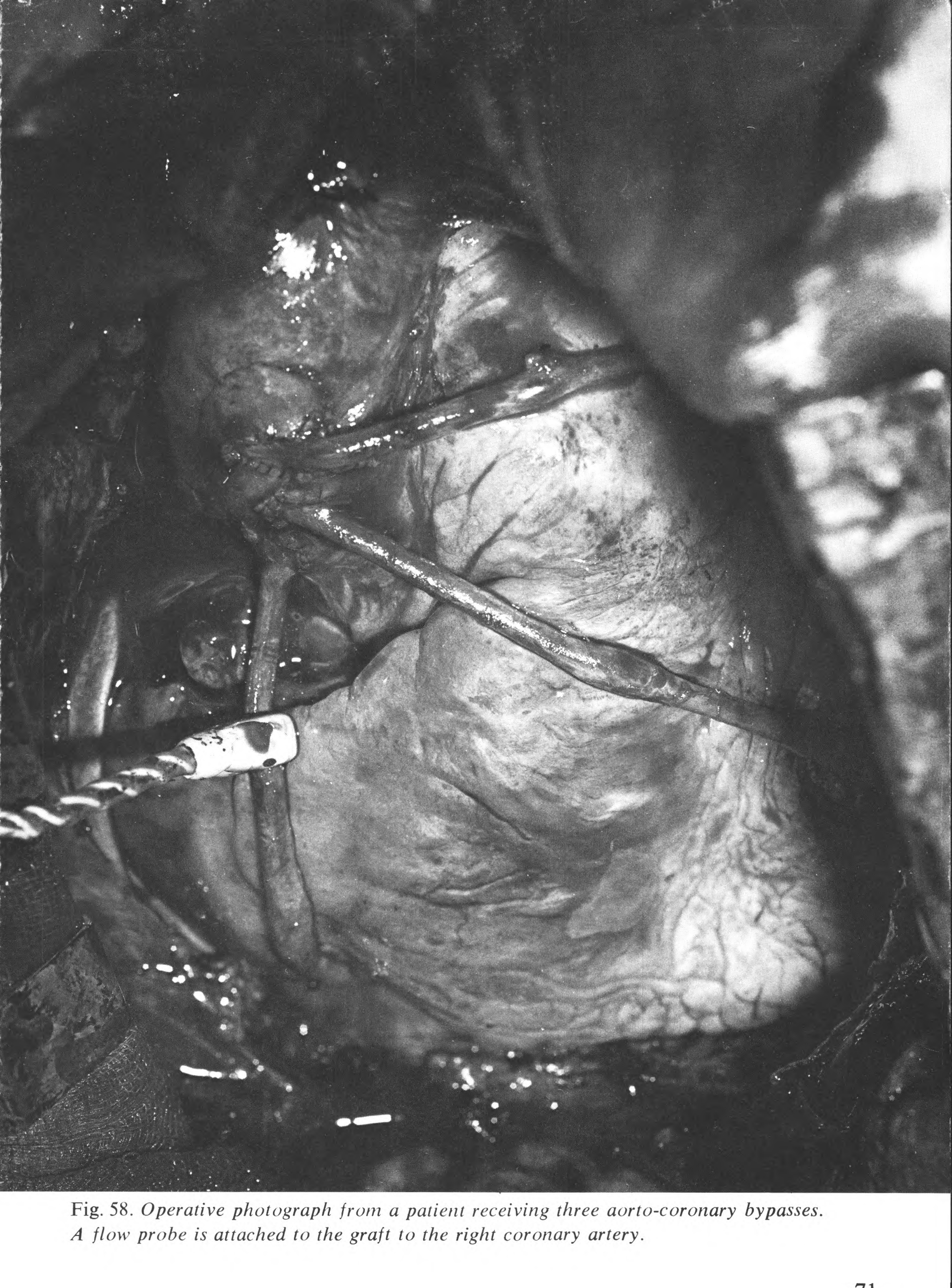
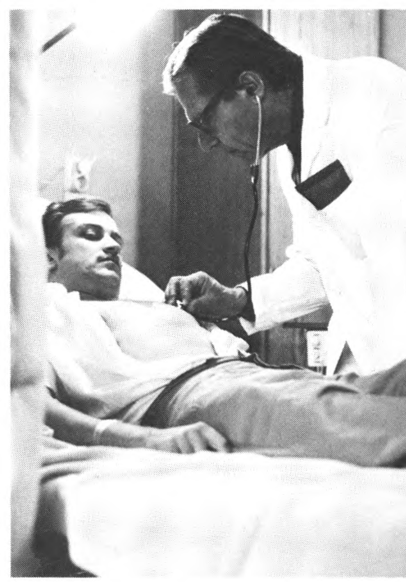


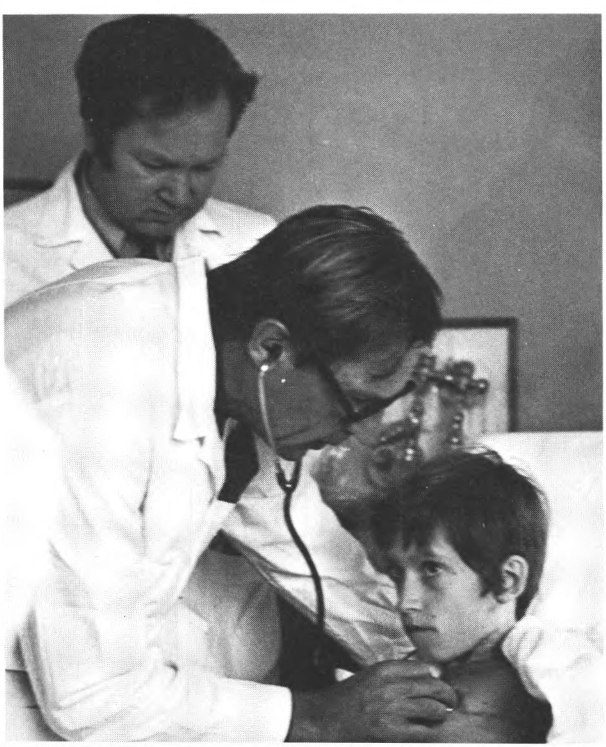
Fig. 58. *Operative photograph from a patient receiving three aorto-coronary bypasses. A flow probe is attached to the graft to the right coronary artery.*

X-ray demonstration in the morning. In the front row: Alf Holmgren, Bengt Jonsson, Viking Björk, Prof Lajos Soltész from Hungary. Second row: Axel Henze and Christian Olin.

Rounds in the wards. From left to right: Viking Björk, Christian Olin (partly concealed), Prof Lajos Soltész, Wollmer Bomfim and Leif Bergdahl.



Prof Viking Björk examining patients before and after surgery.



PRESENT SURGICAL ACTIVITIES

Christian Olin

Patients with pure mitral stenosis due to rheumatic fever have diminished considerably, but apart from that we have not noticed any decrease in the number of operations for acquired valvular disease (Tables 3 and 4). Operations for calcified aortic stenosis have been performed at a higher age. This means that the total number of patients with acquired valve disease has increased somewhat during the years and will probably continue to do so.

Table 3. *Surgical activity at the Thoracic Surgical Clinic*

	1969	1971	1973	1975	1977
Heart op.					
With ECC	158	174	294	370	494
"Closed"	40	60	46	35	34
Total	198	234	340	405	528
Below 15 years	37	53	60	75	110
Lungs	148	146	147	160	216
Oesophagus + diaphragma	31	30	32	30	10
Pacemakers	437	440	386	363	304

Table 4.

	1975	1976	1977
ECC			
Valvular heart disease	192	195	238
Coronary artery disease	65	81	115
Congenital heart disease	95	131	140

As has been pointed out earlier, operations for congenital heart disease will be undertaken at an earlier age in the future. In this way, palliative procedures are avoided and the operation can be performed at an age before secondary, unfavourable changes appear in the lungs and other organs.

Fig. 59. *Discussion after the x-ray round. From left to right: Björk, Pluth (Mayo Clinic), Smith (Sheffield), Koivistu (X-ray Dept.), Törnell (Head of X-ray Dept.) and Holmgren (Head of Clinical Physiology).*

Table 5. *Some statistical data from 1977*

Diagnostic group*	Total number of hospital days	Admissions	Mean hospitalization
Pulmonary tuberculosis	222	14	15.9
Malignant pulmonary tumours	2,882	166	17.4
Chronic rheum. heart disease	2,093	130	16.1
Ischaemic heart disease	1,567	89	17.6
Cerebrovascular disease	650	33	19.4
Digestive tract disease	284	20	14.2
Congenital malformations	2,247	176	12.8
Postoperative control	108	25	4.3
Total for 1977	16,585	1,102	15.0
for 1976	14,834	851	17.4

* All diagnostic groups are not listed.

The number of operations for tuberculosis has steadily diminished. In recent years only about ten operations have been performed each year. The same is true for bronchiectasis, where only a few procedures have been carried out. Lung cancer, on the other hand, has slowly increased and will constitute a significant part of future thoracic surgery.

"The heart is the chief mansion of the soul,
the organ of the vital faculty
and the beginning of life,
the fountain of the vital spirits
and so consequently the nourisher of the vital heart,
the first to live and the last to die."

AMBROSE PARÉ (1691)