Historical review

The evolution of cardiac surgery in the United Kingdom

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Unlike pulmonary and oesophageal surgery, most of the important advances in cardiac surgery have occurred during my professional lifetime and that of my colleagues. Progress has been dramatic and sometimes explosive, and much of it has been of great interest to the press and broadcasting media, as witnessed during the "hole in the heart" era and more recently with heart transplantation. Such attention from the news vendors has not always been healthy for the profession or the public but it is difficult to counteract this tendency.

As a result of the rapid evolution of cardiac surgery there are inevitably claims for priority in the performance of certain procedures or the publication of results. I have endeavoured to record these wherever appropriate and have attempted to verify the claims either by personal communication, by consulting publications, or by browsing through clinical and operating records. Wherever possible I have recorded the relevant published papers.

Much of what follows is directly concerned with the surgery of the heart, but progress would have been difficult without the help of cardiologists, radiologists, biochemists, and haematologists. Even more important has been the contribution of the perfusionist and anaesthetist and it is impossible to do them justice in an article of this nature.

The beginnings

Billroth's much quoted comment that "Any surgeon who would attempt an operation on the heart should lose the respect of his colleagues"¹ was upheld by the profession generally for many years, until it gradually lost credibility in the decades after the end of the second world war. Even now there are still doubters. Despite this negative attitude to cardiac surgery the specialty in the United Kingdom has provided one life peer, three knights, and three presidents of royal colleges as well as many administrative and other officials.

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Most histories of cardiac surgery refer to the quite fortuitous procedure of Henry Souttar,² who on 6 May 1925 carried out the first operation for mitral valve disease with survival and whose approach, as it turned out, was to become the accepted one 30 years later. He explored the mitral valve with a finger inserted through the left atrial appendage and found both stenosis and regurgitation. With the finger he broke down the adhesions between the leaflets. By good fortune the patient recovered, but the disciples of Billroth were still active and Souttar was never given the chance to repeat his operation. Perhaps this was just as well for disaster would surely have ensued, as with other attempts to attack the mitral valve in the 1920s. There were no blood transfusion service and no antibiotics and, perhaps most important, anaesthesia suitable for open chest surgery had not been developed.

On 26 August 1938 Robert Gross³ performed the first successful ligation of a patent ductus arteriosus. Oswald Tubbs⁴ at St Bartholemew's Hospital was presented with a patient with an infected patent ductus which was successfully ligated on 5 December 1939. This cured the infection and he thus became the first surgeon in Britain to attempt closure of a duct, albeit an infected one. In his Hunterian lecture in April 1943 Tubbs⁵ reported a series of nine infected ducts which had been closed surgically, with six survivors.

At the start of the second world war Dwight Harken was RSO to Tudor Edwards at the Brompton Hospital but was recalled to the United States shortly after the declaration of war. Eventually in 1944 he returned to Britain to be in charge of the first American surgical chest centre, located with the 160th General Hospital of the US Army in Cirencester. Harken had already had more than a passing interest in the heart and became fascinated by the problem of cardiac wounds and foreign bodies in the heart. His success in removing foreign bodies from the cavities of the heart was soon well known and his unit received a steady flow of patients with cardiac wounds. In all Harken carried out 134 operations

for the removal of cardiovascular foreign bodies⁶—78 were within or related to the great vessels and 56 within or related to the heart. Of these, 13 were actually within the cavity of the heart or great vessels. The remarkable feature of Harken's series was that not one of his patients died. Harken was to return to Boston with his appetite for cardiac surgery thoroughly aroused and he was soon concerned with the surgery of the mitral and aortic valves.

On the 19 October 1944 Clarence Crafoord⁷ in Stockholm performed the first coarctation resection with end to end anastomosis. Price Thomas was a great personal friend of Crafoord and persuaded him to demonstrate his operation in London. This was done at the Westminster Hospital on 26 January 1946. The operation and postoperative course were uneventful and the patient regained good femoral pulses. When seen in December 1952 he was fit and well without symptoms and was playing football; he was a powerful swimmer and had won a medal for boxing. In 1963 he passed the rigorous Australian immigration medical examination and left for Australia.

On 29 October 1944 Alfred Blalock⁸ performed the first subclavian and pulmonary artery anastomosis (Blalock–Taussig operation) on a patient with Fallot's tetralogy. This procedure and two others performed at the same time were outstandingly successful and were reported in 1945: cardiac surgery was launched. On the 16 and 17 September 1947 he demonstrated the new procedure at Guy's Hospital. The demonstrations coincided with the first meeting of the International Society of Surgeons, which was being held in London. As one who was privileged to witness some of these operations, I was impressed by the technical brilliance of the surgeon and the remarkable smoothness of the procedure.

With this pioneering work of Gross in 1938 and of Crafoord and Blalock in 1944 the stage was set for the explosive development of cardiac surgery that occurred in the next two decades.

Closed intracardiac surgery

So far "cardiac surgery" had been entirely extracardiac and the pericardial cavity had not been violated. But in June 1948, after much preparatory study and experimentation, Bailey in Philadelphia and Harken in Boston successfully operated on the stenotic mitral valve and Brock and Sellors in London performed the first closed pulmonary valvotomies.

According to Harken, the credit for suggesting surgery for congenital pulmonary stenosis should go

to O'Shaugnessy.⁹ The suggestion appears in the text of a Hunterian lecture he was prevented from giving by his untimely and unfortunate death during the evacuation of the British Army from Dunkirk in 1940. In the unpublished text there was a drawing of the stenotic valve and another depicting its incision with a valvulotome inserted through the right ventricle. Sellors¹⁰ was the first to apply O'Shaugnessy's technique in an operation carried out on a 20 year old boy with Fallot's tetralogy on 4 December 1947.

Two weeks before Sellor's report appeared Brock¹¹ reported three successful pulmonary valvotomies performed through the right ventricle, the first having been done on 16 February 1948. His first success followed three failed attempts at valvotomy through the pulmonary artery. Brock was to develop the technique using graded valvulotomes, sleeve punch forceps, and expanding dilators in the treatment of Fallot's tetralogy. This was an alternative to the Blalock and Potts procedures and was considered by Brock to be a better alternative where it could be applied, as it led to better development of the often hypoplastic pulmonary vasculature. The combined procedure of pulmonary valvotomy and infundibular resection became known as the "Brock operation" and enjoyed a measure of popularity, especially in Britain (there was less enthusiasm in the United States), until it was superseded by total one stage correction of the tetralogy.

There were many exasperating problems with mitral valve surgery,¹² including torn atria, atrial thrombus and systemic embolism, dysrhythmias, and the production of serious mitral regurgitation. In addition, there were mechanical problems to be solved and various cutting valvulotomes were devised. In July 1954 Logan of Edinburgh attempted dilatation of the mitral valve with a Brock aortic dilator inserted through a small incision near the apex of the left ventricle. Tubbs developed this idea and produced a dilator which had a maximum expansion of 4.5 cm, whereas Brock's instrument could expand only to 3.3 cm. Moreover, the expansion of Tubbs's instrument could be accurately controlled by a screw. In 1962 he reported a series of 124 patients which he had treated.¹³ Both he and Logan used the method enthusiastically, as did almost all the surgeons in Britain—so much so that most of the valvulotomes and other dilators designed for the mitral valve became obsolete.

Ten years later, closed mitral valvotomy was a well established procedure with a low mortality rate (5%) and good short and long term results. But there was a feeling that better results would be achieved if the operation could be done under direct vision. Moreover, it seemed certain that the management of mitral regurgitation required direct vis-

ion surgery as the use of baffles, pericardial tube grafts and the like had proved disappointing.

The aortic valve proved to be a more formidable problem and in fact it was never very satisfactorily dealt with by closed techniques. The approach was either from the left ventricle with an expanding dilator (Bailey and Brock) or from the aorta with an operating tunnel stitched to an aortotomy incision in the ascending aorta (Harken). There were some spectacular successes but many failures and the surgery of the aortic valve had to await the advent of open heart surgery and a reliable valve prosthesis.

Towards direct vision intracardiac surgery

It had been known for some time that reduction of the body temperature had an anaesthetising effect on the body and also reduced the metabolic requirements of the tissues. Bigelow in Toronto carried out the basic early experiments in 1950.¹⁴ He showed that a reduction of body temperature to 30°C prolonged the period during which the brain could be rendered anoxic from three to 10 minutes. This was time enough for rapid intracardiac surgery. Lewis in Minneapolis was the first to use the procedure clinically to close an atrial septal defect using rubber blankets;¹⁵ but it was Henry Swan in Denver, using an iced water bath,¹⁶ who developed the technique which was found to be most acceptable.

In London Sellors, working at the Middlesex Hospital, was one of the first to adopt Swan's technique and he reported a series of over 200 cases of closure of atrial septal defects in 1960.¹⁷ Swan's hypothermic bath technique, however, was cumbersome and messy and the rewarming process was slow. Brock therefore developed a technique of venovenous cooling whereby blood was removed from the venae cavae, passed through a cooling coil, and then returned to the heart. The procedure was more controllable and more "surgical." Rewarming was easier, quicker, and more reliable but the patient had to be heparinised. The technique was never widely used and both Brock's and Swan's methods were eventually superseded by the development and perfection of an extracorporeal circulation.

Ten minutes of circulatory arrest was sufficient only for a few intracardiac procedures, such as the closure of atrial septal defects and the relief of pulmonary and aortic stenosis, and surgeons longed for the ideal operating conditions of a still and bloodless heart and no time limit. A device to take over the essential functions of the heart and lungs was needed. Gibbon¹⁸ in Philadelphia, Björk in Stockholm, and Melrose in London were all simultaneously working in their laboratories with heart lung

machines. Gibbon had been engaged for years in such research and on 6 May 1953 carried out his first and only successful open heart operation.¹⁹ Two others were done later but both patients died. Gibbon did not proceed with clinical work but his device (the stationary vertical screen oxygenator) was adopted and adapted for use in the Mayo Clinic by Kirklin and later by Sellors at the Middlesex Hospital. Björk in the meantime had devised an apparatus consisting of stainless steel discs rotating in a bath of blood. Melrose, having seen Björk's machine, made improvements which increased efficiency by rotating an inclined drum through which blood flowed slowly by gravity across a series of shallow trough like discs, so that the blood was passed from one disc to the next and was thus able to take up a greater proportion of oxygen.^{20 21} The machine was manufactured by New Electronic Products (NEP), which was later taken over by Honeywell.

Animal experimental work was carried out in London at the Royal Veterinary College and by 1953 Melrose and the Hammersmith Hospital team were ready for clinical trials. It was decided initially to use the machine as a supportive bypass for very sick patients with aortic stenosis. The operation would still be a closed procedure but the extracorporeal circulation, it was hoped, would support the heart during the surgical manoeuvre. On 9 December 1953 Rose Pilgrim, a woman with severe aortic and mitral valve disease, survived a double closed valvotomy with supportive bypass using the Melrose machine.²² Six other patients were operated on but only the first survived and further clinical work was halted.

Further experimental work and sporadic clinical trials followed but little progress was made. Eventually, in 1956 Melrose and Cleland paid a lengthy visit to Kirklin at the Mayo Clinic and to Lillehei in Minneapolis. Returning with a much clearer understanding of the physiological problems of extracorporeal circulation and the vital importance of monitoring all physiological functions and especially the fluid and blood balance, the Hammersmith team on 17 April 1957 put their experience to the test. The patient was a 30 year old woman with a secundum atrial septal defect and pulmonary hypertension (which was the reason for choosing extracorporeal circulation rather than hypothermia). The postoperative course was stormy and a tracheostomy was required, partly as a result of a bilateral transverse thoracotomy.⁹ The patient survived, however, and was subsequently discussed by Beard.²³ In 1982 she was alive and well from the cardiac point of view but was having some psychiatric troubles.

The initial successes with extracorporeal circula-

tion were with operations which could have been done with hypothermia alone and it became clear that to convince the septic team would have to perform operations for more complex conditions. Richard Bonham Carter, paediatric cardiologist at the Hospital for Sick Children in Great Ormond Street, came to the rescue and promised to refer 50 children with ventricular septal defects from his vast list to the Hammersmith team with "no questions asked" until the 50 operations had been completed. The series was resoundingly successful, with an overall mortality rate of 20% but only 4% in cases of uncomplicated defect (that is, without pulmonary hypertension or anatomical complications).

These early operations used potassium citrate to arrest the heart.²⁴ Two millilitres of a 25% solution of potassium citrate in 50 ml of heparinised blood from the patient were injected into the aortic root, with the ascending aorta clamped. Ideal operating conditions ensued—a flaccid, bloodless heart—with rapid return to normal beating on release of the aortic clamp. Over 100 patients were dealt with by this technique without any apparent ill effect. Reports from North America, however, where the technique was widely adopted, suggested that the potassium solution resulted in myocardial damage and it was reluctantly abandoned in favour of hypothermia, hypoxia, and electrical fibrillation, with later coronary artery cannulation and perfusion.

In July 1957 the second unit using the Melrose-NEP heart lung machine started at Leeds under the direction of Wooler. His first patient had mixed mitral valve disease. He became interested in the problem of mitral incompetence and after studying the pathology of the condition developed a form of annuloplasty that proved effective over a long period and was the forerunner of other techniques of annular plication. These were reported in 1962;²⁵ of the 38 patients treated, 21 were alive, the longest survivor for four and a half years. Five years later Logan and colleagues²⁶ recorded a series of 51 patients treated in this way, with seven early and two late deaths.

These early efforts with extracorporeal circulation attempted to stimulate the normal cardiac output of 2.4 litres/min/m². Anthony Andreasen, however, working at Downe House in Kent on a Royal College of Surgeons grant, demonstrated in 1950 that he was able to keep vital organs, especially the brain, alive with a blood flow about one tenth of the normal.²⁷ Few people, apart from Lillehei, paid much attention to this work; but the latter fully realised its implications and from this evolved first his cross circulation techniques, which were used 45 times, and later his bubble oxygenator with a low flow output. By 1956 the two basic techniques were

being used regularly in the United States within 60 miles of each other. In Rochester Kirklin was using the modified Gibbon machine with a high flow technique while in Minneapolis Lillehei and Varco were using the low flow principle with a bubble oxygenator. The visitor was thus able to gravitate with ease from one centre to the other and pick up the best of both.

The technique of potassium citrate cardioplegia developed by Melrose fell into disrepute with the appearance of reports of adverse myocardial reaction to the solution. In retrospect it seems likely that too long a period of ischaemia was being permitted and that the hearts were failing to function because of hypoxia as much as the potassium. Braimbridge at St Thomas's Hospital was one of the first to study the ultrastructure and enzyme changes of the myocardial cell under varying conditions of myocardial preservation.^{28,29} On the basis of his studies carried out in association with Hearse³⁰ he was largely instrumental in launching a revival of chemical cardioplegia in the early 1970s. This was ultimately recognised in the designation of "St Thomas's cardioplegic solution," which was—and still is—widely used in Britain.³¹

There were, however, others working in this field who held contrary views. One of the problems with total cardiopulmonary bypass was that the lungs were often subjected to a very foreign set of circumstances when deprived of blood and not ventilated and sometimes reacted by developing widespread consolidation. Moreover, doubts were cast on the efficiency of the artificial lung and there was concern about the amount of damage that this could do to the blood. Drew at the Westminster Hospital aimed to keep the patient's lungs as the oxygenator by having a two pump system to replace the right and the left sides of the heart respectively.^{32,33} Once this was established it was easy to add a cooling coil and Drew explored the territory of deep hypothermia with body temperatures as low as 8–10°C. On 15 January 1958 he carried out his first clinical operation on a 1 year old with Down's syndrome and a complete A–V canal. Unfortunately the child developed heart block some hours after operation and died. The first successful operation was on 29 January 1959 and was on a 4 year old with ventricular and atrial septal defects.

Few followed Drew's lead but Belsey and colleagues in 1968 reported a series of 304 patients having open heart surgery with profound hypothermia,³⁴ the high mortality rate of 18% being attributed to the complexity and severity of the congenital lesions being treated. There was, however, one important spinoff from Drew's work. Variations in the method were developed by Barrett-Boyes in

New Zealand and applied to infants requiring open heart surgery.³⁵ In 1976 he reported his experience with profound hypothermia in 57 infants and young children, all aged from 21 days to 21 months and all under 10 kg in weight. Surface cooling was used until the infant's temperature was about 22°C. Further cooling to 10–12°C was carried out with a short period of bypass, and bypass was used for the greater part of the rewarming process. This technique, with or without refinements, has been generally used for cardiac surgery in the younger age group with remarkable success. Meanwhile Drew persisted with his methods and at the time of writing he has operated on 2500–3000 cases of all types.

Modifications and refinements of the heart lung machine continued during the 1960s and 1970s but the next major step was the development of the membrane oxygenator. Although it was essentially developed and produced in the United States much fundamental work with the membrane was carried out by Melrose and Norah Welbourne at Hammersmith Hospital. The definitive membrane oxygenator was produced in the United States and Ghadiali at the Brompton Hospital supervised its introduction to clinical practice in Britain on behalf of the Department of Health and Social Security.

Valve surgery

With more efficient cardiopulmonary bypass techniques attention switched from congenital to acquired heart disease. Mitral valvotomy with closed techniques was well established for mitral stenosis but there were no satisfactory procedures for treating regurgitation. With open heart methods varying reparative procedures were attempted (annuloplasty by Wooler,²⁵ pericardial inserts by Ross³⁶ and Cleland³⁷), but there was clearly a demand for a prosthesis.

Hufnagel had already designed and used a caged ball valve prosthesis for insertion in the descending thoracic aorta in cases of severe aortic regurgitation. Development along similar lines by Starr, Harken, and Magovern led to a satisfactory caged ball prosthesis for insertion in the subcoronary position. A similar prosthesis used in the mitral area, however, posed problems as the cage of the prosthesis projected into the outflow tract of the left ventricle, where it could cause serious obstruction unless the ventricle was dilated. Despite this, in 1962 Starr and Edwards³⁸ reported a series of 16 patients who had mitral valve replacement with a ball valve prosthesis, of whom 10 survived.

In 1964 Melrose and his colleagues³⁹ reported the experimental and clinical use of a tilting disc valve made of polypropylene, which overcame some of

the disadvantages of the caged ball prosthesis. These valves were subsequently manufactured and marketed by Portland Plastics and were used clinically by Wooler in Leeds and Logan in Edinburgh as well as at Hammersmith Hospital. Although haemodynamically sound and initially highly successful, as time went on more and more patients returned with extensive thrombus formation around the prosthesis; and in the form in which it had been designed it had to be abandoned. Unfortunately the drive and finance to carry out further research with this promising prosthesis was not available and no further development occurred. In the meantime Björk had designed a similar tilting disc valve, which was eventually taken up and developed by the Shiley Company and used clinically almost as frequently as the Starr valve developed by the Edwards Laboratories.

Some surgeons had serious reservations about placing a totally foreign body either within the heart or in the great vessels. Brock was among the principal doubters. He was convinced that natural tissues from the cadaver ought to be used to replace diseased ones in the patient and was the first in Britain to use an aortic homograft for the repair of a coarctation of the aorta. In 1952 Conrad Lam and his coworkers⁴⁰ reported experiments with aortic valve homografts and in 1956 Gordon Murray⁴¹ in Toronto reported the use of homograft aortic valves placed in the descending aorta for the management of severe aortic incompetence; but it was Donald Ross, a pupil of Brock's, who on 24 July 1962 inserted the first aortic valve homograft in the subcoronary position.⁴² Both he and Barret-Boyes in Auckland worked enthusiastically with homograft replacement, refining the techniques and the methods of collection, preparation, and preservation. Later Ross varied the technique by transferring the pulmonary valve to the aortic area and replacing the pulmonary valve with a homograft. So far some 200 patients have had this "autograft switch."

Meanwhile Senning⁴³ in Zurich was replacing the aortic valve with the patient's own fascia lata. Early results were excellent and the technique was used fairly widely. At Hammersmith Hospital about 40 patients had fascia lata valves inserted, but the procedure was eventually abandoned because the fascia gradually became shrunken and calcified and the prosthesis became either obstructed or regurgitant.

Many surgeons found homograft valve replacement tedious and difficult to carry out with sufficient accuracy to ensure a competent valve. To overcome these drawbacks attempts were made to mount homograft aortic valves to a metal frame to which a sewing ring was attached.^{44 45} In addition to homografts, fascia lata, pericardium, and dura mater were

all tried. Ghadiali at the Brompton Hospital was particularly active here. Later heterografts (from pig or calf) were used, especially after Carpentier⁴⁶ in Paris had shown that glutaraldehyde preparation removed most of the antigenic properties of the heterograft.

The construction of an artificial prosthesis—either mechanical or tissue—depended very considerably on studies of the normal valves in action and of artificial valves in simulated clinical conditions. McMillan and his colleagues⁴⁷ at St Thomas's Hospital developed high speed photography to study aortic cadaver valves, and later this technique was used and extended in Oxford by Bellhouse,⁴⁸ who became the most experienced valve tester and developer in Britain.

As a result of Carpentier's work on the effects of glutaraldehyde on the antigenic properties of foreign proteins there was a burst of activity in various centres with aortic valves constructed from different tissues. At Guy's Hospital *dura mater* was used but eventually abandoned owing to the high incidence of calcification. The only success so far has been achieved by Ionescu in Leeds, who after a decade or more of painstaking and dedicated research and experimentation produced a prosthesis prepared from pericardium,⁴⁹ which is now marketed as the Ionescu-Shiley valve and has had very considerable and satisfactory clinical use.

Acquired heart disease

O'Shaugnessy was surgeon to the Lambeth cardiovascular unit (London County Council) and thoracic surgeon to Preston Hall Hospital near Maidstone. Before his death at Dunkirk he was far ahead of most of his colleagues in his vision about cardiac surgery. Revascularisation of the ischaemic myocardium by omentopexy had been established by him and in 1937 he reported his experiences in the Carey Coombs memorial lecture.⁵⁰ Reference has already been made to his views on pulmonary stenosis, and in 1939 he was experimenting with methods of preserving brain function during operations on a bloodless and non-beating heart. What might not have happened had he lived? The work on omentopexy was carried on by George Mason, O'Shaugnessy's successor at Preston Hall. Omentopexy, pneumopexy, partial coronary sinus ligation, pericardial abrasion, and chemical destruction were all tried and on the whole found to be wanting, although there were some clinical successes which encouraged the committed.

It was Vineberg,⁵¹ working in Montreal on internal mammary implantation into the myocardium, who provided a more promising line of attack. He

had shown that an open ended artery buried in the myocardial sinusoids could establish vascular connections and thus supply additional blood to the ischaemic myocardium. The medical world was sceptical but Effler and Favaloro in the Cleveland Clinic adopted his technique and were soon writing enthusiastically about it.⁵² They were aided and abetted by Mason Sones, who had developed a technique of coronary arteriography that for the first time enabled the clinician to visualise the coronary circulation and determine its deficiencies.⁵³ Despite the enthusiasm emanating from the Cleveland Clinic, the Vineberg operation was never very widely carried out in Britain and it was overtaken by Favaloro's important success when he bypassed the obstructed coronary artery using autogenous saphenous vein.⁵⁴ Once again the procedure was greeted in Britain with much scepticism and doubt by the cardiologists. From 1969 to 1973 only small series were reported, but from then on increasing numbers were recorded, so that now over 80% of all cardiac operations are for coronary artery disease. In 1981 over 6000 coronary artery bypass grafts were performed, compared with a mere 300 operations 10 years earlier.

Initially it was clear that successful coronary artery bypass was an effective way of relieving angina but many doubts were expressed about its ability to prolong life and protect against further myocardial infarction. From 1973 to 1978 several British centres took part in a European multicentre randomised trial to compare the long term results of bypass with those of medical management. Up to three years there was little difference between the two groups but from then on the surgical group showed a convincingly better outlook.⁵⁵ The results of this trial convinced many of the value of the bypass procedure and resulted in a vast increase in its popularity throughout the country.

One of the most challenging conditions presented to the cardiac surgeon was aneurysmal dilation, with or without dissection, of the ascending aorta, affecting the sinuses of Valsalva and often the aortic valve ring as well. Bentall and de Bono⁵⁶ in 1968 described a technique for complete replacement of the affected aorta, the sinuses of Valsalva, and the aortic valve by a Dacron conduit containing a mechanical valve prosthesis, the coronary arteries being carefully sutured to a small opening in the Dacron tube. Although alterations of detail have been suggested by other surgeons, the basis of this "Bentall operation" remains sound.

Surgery for congenital heart disease

It was inevitable that the earlier efforts in open heart

surgery were reserved for older children and directed against the anatomically simpler and clinically less severe conditions such as atrial and ventricular septal defects, pulmonary valve stenosis, and Fallot's tetralogy. But quite rapidly the more complex lesions were coming to be tackled and the age for operation was steadily lowered. McMillan⁵⁷ in 1965 reported a series of 14 children below the age of 5 years who had a total correction of Fallot's tetralogy with only three deaths, the combination of bypass and deep hypothermia being used. This undoubtedly set a trend, although it was almost 10 years before operation in the first year of life became a practicable and safe procedure generally.

Edwards at the Liverpool Children's Hospital made a special study of congenital aortic valve disease and in 1962 reported a study of 120 children with aortic valve stenosis.⁵⁸ Thirty two of this group were surgically treated. The article contains a full description of the morbid and surgical anatomy of the condition. His unit developed into one of the leading centres in Britain and since his retirement the work has been carried on with great success by Hamilton. Meanwhile at the other main paediatric hospital (Great Ormond Street) cardiopulmonary bypass was established slowly. Waterston, Aberdeen, and Stark had a special interest in transposition of the great arteries and soon had an unrivalled experience and a worldwide reputation. They had the good fortune to have a well staffed unit, which enabled them to maintain their statistics in an up to date form and to contribute to conferences with excellent results.

The most recent developments in surgery for congenital heart disease have been breathtaking. They are based on the excellent anatomical and embryological contributions of Anderson and Allwork, together with improved methods of perfusing the neonate and intricate intensive care both before and after surgery. Surgical advances in the form of external and internal conduits with or without valves enabled the surgeon to deal with such lesions as tricuspid stenosis, double outlet ventricle, and persistent truncus arteriosus. Magdi Yacoub at Harefield Hospital and Chris Lincoln at the Brompton Hospital in addition to the surgeons at Great Ormond Street were leaders here. On the medical side echocardiography became so effective as a diagnostic tool that it often made the risk of angiography unnecessary.

Cardiomyopathy

In 1957 Brock, when operating on a patient with aortic stenosis by dilatation through the left ventricle, encountered a normal aortic valve and obstruc-

tion of the outflow tract of the left ventricle by a mass of muscle.⁵⁹ He labelled the condition "functional obstruction of the left ventricle." A year later Teare, a pathologist, reported on several young patients who had died suddenly and were found to have massive hypertrophy of the ventricular septum, a condition he referred to as asymmetrical hypertrophy.⁶⁰ Later that year Cleland and Bentall were operating on a young man with supposed aortic stenosis. The patient was crippled by angina, which prevented him from working and leading a normal life. Exploration of the valve with cardiopulmonary bypass revealed an aortic valve but massive hypertrophy of the septum below it. A limited incision and excision of the muscle mass resulted in a dramatic relief of symptoms, which was maintained for many years.

Goodwin and his colleague Celia Oakley put these three isolated observations together and began a study of the condition they called "hypertrophic obstructive cardiomyopathy."⁶¹ Some patients who met the required criteria underwent surgery, and the results were encouraging. Glen Morrow in Bethesda and Barrett Boyes in Auckland became even more enthusiastic about surgery than the Hammersmith group. Twenty years later enthusiasm for surgery has waned as more effective drug treatment has become available but there are still a few patients who can be helped surgically. Interestingly, about half the cardiac transplantations done at Papworth Hospital are for cardiomyopathy.

Cardiac transplantation

In December 1967 Barnard⁶² astonished the world by performing the first clinical human cardiac transplant, based on the pioneer work of Shumway at Stanford. His patient lived for 18 days and died from acute rejection according to Dempster at Hammersmith, who was shown the slides from Cape Town. A second patient lived for about 18 months but died from severe atheroma of the coronary vessels of the transplanted heart. A wave of enthusiasm swept the surgical world and transplants were carried out widely.

In Britain the only team to carry out transplants was at the National Heart Hospital, led by Donald Ross and Donald Longmore. Three patients were transplanted by Ross, two at the National Heart Hospital and one at Guy's Hospital. The longest survivor lived for 43 days. Unhappily, the handling of the problem of donors led to a public outcry and further transplants were discouraged by the Department of Health and Social Security. A transplant advisory panel was then set up by the health departments to supervise transplant activities. A

definition of brain death evolved,⁶³ which was designed to convince the public and the profession that an individual would be accepted as a donor only after it had been ensured that independent life would never be possible.

Shumway at Stanford continued with his transplant programme when most others had given up in disillusionment. As his results improved⁶⁴ and it appeared that clinical transplants in the United Kingdom might be resumed, the Transplant Advisory Panel outlined a series of guidelines which would have to be met before permission would be given to proceed. Thus in January 1979, at Papworth Hospital, Terence English performed his first cardiac transplant. He was followed by Yacoub at Harefield Hospital and each unit has continued a steady programme of about 10–12 transplants a year. Although the results do not yet compare with Shumway's they are good enough to encourage further endeavour and are improving. By December 1981 English was able to report a series of 27 patients, half of whom had ischaemic heart disease and the remainder cardiomyopathies.⁶⁵ Seventeen of the 27 patients were alive at the time of reporting. Yacoub had similar numbers and results at Harefield. One year later English had performed 43 transplants, with 23 survivors.

Education

The United Kingdom was one of the first European countries to establish flourishing centres for open heart surgery, each performing at least 100 open heart procedures a year. Inevitably it has played a major part in education and training, especially in Europe and the old Commonwealth. Overseas surgeons came to Britain for all varieties of training and British surgeons or teams went on educational tours supported by the British Council, the health departments, or the universities, though often they were financed by the host country.

In 1957 in Turin Melrose and the manufacturers (New Electronic Products) demonstrated the heart lung machine that was being used at Hammersmith Hospital. In Moscow the Russians had recently completed a new cardiothoracic hospital headed by Academician Bakulev. Bakulev ordered a Melrose-NEP pump oxygenator for the new hospital but his staff were unable to operate it. In 1959 the Russians appealed to NEP for help and as a result were offered a replacement with a more modern machine. The Russians were grateful but asked if they could have help in putting it into action. Eventually it was arranged that Hammersmith Hospital should send a team to set up the heart lung machine and demonstrate it both experimentally and clinically.

In April 1959 the team, consisting of Melrose (physiologist), Bentall and Cleland (surgeons), Beard (anaesthetist), Hollman (cardiologist), Robson (technician), and Bowtle (theatre sister) set out by sea with over 5000 kg of equipment for Moscow. The clinical members performed several closed heart operations while the scientists were working in the laboratories. Hollman and Cleland were presented with 40 or so young patients with exceptionally severe congenital cardiac anomalies. Four of the most favourable cases were selected for surgery. They included two patients with Fallot's tetralogy, one with pure pulmonary valve stenosis with a right ventricular pressure of 200 mm Hg and one with a hypertensive ventricular septal defect. All were successfully operated on and all survived long term except the child with pulmonary stenosis, who later developed an aneurysm at the site of the ventriculotomy and died after a subsequent operation. The two children with Fallot's tetralogy were the first such patients that the Hammersmith team had operated on.

Thereafter teams from British centres were in constant demand both in the United Kingdom and abroad to help emergent units. All responded generously and often received helpful support from the British Council. Visits to Finland, Munich, Greece, Turkey, Iraq, Egypt, Syria, Libya, India, Sri Lanka, Malaysia, Singapore, and Australia followed, and in most cases successful units were established, although there were many disappointments en route.

In 1957 the British Council, realising the demand for education emanating from a Europe starved by the recent war, arranged a two week course in cardiac surgery based on the Brompton Hospital but with additional sessions at Oxford, Birmingham, Liverpool, or Leeds. Initially some 50 surgeons attended the course, which because of the demand and initial success was repeated every three to four years. Some of the highlights of these courses were the clinical teaching sessions which Paul Wood and Russell Brock gave in the outpatients department. Rarely have I experienced such superb clinical teaching and it was a sad loss when Paul Wood died in 1963. Paul Wood was one of the first cardiologists to realise the full potential of surgery in the management of heart disease and it was largely due to his enthusiasm and drive that the surgical centres at the National Heart Hospital and the Brompton Hospital were established.

By 1969 these courses had become so popular that they were made available to trainees in the United Kingdom and they were now organised by the British Postgraduate Medical Federation with the British Council holding a watching brief. The course

lasted a week and was run by the three institutes in the federation that were concerned with cardiac surgery—the Institute of Child Health (Great Ormond St Hospital), the Cardiothoracic Institute (Brompton, National Heart, and London Chest Hospitals), and the Royal Postgraduate Medical School (Hammersmith Hospital). Since 1969 the course has been run annually with attendances of 100–150 and 1983 sees the 14th such course.

Goodwin at Hammersmith soon saw the value of close consultation between the cardiologist and cardiac surgeon and was to develop the joint consultative clinic, which became a regular feature of the teaching scene at Hammersmith Hospital and was adopted by many other units.

Conclusion

There seems little doubt that in the realms of cardiac surgery the United Kingdom has been a follower rather than a leader and it has been the United States that has made most of the running. Undoubtedly this is largely due to the greater efforts and money poured into research and development. The system is geared to it and it has paid handsomely. Britain not only has been short of dedicated research workers but has had few well equipped laboratories and inadequate funding, so that the occasional breakthrough originating in Britain has been difficult to exploit.

Our forte has been in the clinical field, in the application of techniques worked out elsewhere, and in carrying out carefully controlled studies with thorough follow up. Perhaps our greatest contribution has been educational. Our busy centres attract many trainees from abroad and our surgeons have spent considerable time and energy helping emerging cardiac surgical units in other countries.

References

- ¹ Billroth TH, Winiwarter A. *Die allgemeine chirurgische Pathologies und Therapie in einundfunzig Vorlesungen. Ein Handbuch fur Studierende und Aertze*, Berlin: G Reimer, 1893:15.
- ² Souttar HS. The surgical treatment of mitral stenosis. *Br Med J* 1925;ii:603–6.
- ³ Gross RE, Hubbard JP. Surgical ligation of patent ductus arteriosus: report of first successful case. *JAMA* 1939;112:729–31.
- ⁴ Bourne G, Keele KD, Tubbs OS, Swain RHA. Ligation and chemotherapy for infection of patent ductus arteriosus, with note on bacteriology. *Lancet* 1941;ii:444–6.
- ⁵ Tubbs OS. The effect of ligation on infection of the patent ductus arteriosus. *Br J Surg* 1944;32:1–12.
- ⁶ Harken DE. Foreign bodies in, and in relation to, thoracic blood vessels and heart. I—Techniques for approaching and removing foreign bodies from chambers of heart. *Surg Gynecol Obstet* 1946; 83:117–25.
- ⁷ Crafoord C, Nylin G. Congenital coarctation of the aorta and its surgical treatment. *J Thoracic Surg* 1945;14:347–61.
- ⁸ Blalock A, Taussig HB. Surgical treatment of malformations of heart in which there is pulmonary stenosis or pulmonary atresia. *JAMA* 1945;128:189–202.
- ⁹ Harken DE. Quoted in: Wertebaker L. *To mend the heart*. New York: Viking Press, 1980:30–1.
- ¹⁰ Sellors TH. Surgery of pulmonary stenosis. *Lancet* 1948;i:988–9.
- ¹¹ Brock RC. Pulmonary valvotomy for the relief of congenital pulmonary stenosis. Report of three cases. *Br Med J* 1948;i:1121–6.
- ¹² Harken DE, Ellis LB, Ware PF, Norman LR. Surgical treatment of mitral stenosis: valvuloplasty. *N Engl J Med* 1948;239:801–9.
- ¹³ Tubbs OS. Transventricular mitral valvotomy. *Ned Tidschr Geneesk* 1962;106:335.
- ¹⁴ Bigelow WG, Lindsay WK, Greenwood WF. Hypothermia: its possible role in cardiac surgery. An investigation of factors governing survival in dogs at low body temperatures. *Ann Surg* 1950;132:849–66.
- ¹⁵ Lewis FJ, Taufic M. Closure of atrial septal defects with the aid of hypothermia: experimental accomplishments and the report of one successful case. *Surgery* 1953;33:52–9.
- ¹⁶ Swan H, Zeavin I, Holmes JH, Montgomery V. Cessation of circulation in general hypothermia: physiologic changes and their control. *Ann Surg* 1953;138:360–76.
- ¹⁷ Sellors TH. Atrial septal defects. *Minerva Cardioangiol Eur* 1960;8:172–83.
- ¹⁸ Gibbon JH jun. Artificial maintenance of circulation during experimental occlusion of the pulmonary artery. *Arch Surg* 1937;34:1105–31.
- ¹⁹ Gibbon JH jun. Application of mechanical heart and lung apparatus to cardiac surgery. *Minn Med* 1954;37:171–80.
- ²⁰ Melrose DG. A mechanical heart-lung for use in man. *Br Med J* 1953;ii:57–62.
- ²¹ Melrose DG, Bassett JW, Beaconsfield P, Graber IG, Shackman R. Experimental physiology of a heart-lung machine in parallel with normal circulation. *Br Med J* 1953;ii:62–6.
- ²² Aird I, Melrose DG, Cleland WP, Lynn RB. Assisted circulation by pump-oxygenator during operative dilatation of the aortic valve in man. *Br Med J* 1954;i:1284–7.
- ²³ Beard AJW. The anaesthetic management of patients for extracorporeal circulation. *Proc R Soc Med* 1958;51:589–91.
- ²⁴ Melrose DG, Dreyer B, Bentall HH, Baker JBE. “Electric cardiac arrest.” *Lancet* 1955;ii:21–2.
- ²⁵ Wooler GH, Nixon PGF, Grimshaw VA, Watson DA. Experiences with the repair of the mitral valve in mitral incompetence. *Thorax* 1962;17:49–57.
- ²⁶ Logan A, Turner RWD, Kitchin AA. Surgical treatment of mitral incompetence. *Br Heart J* 1967;29:1–21.
- ²⁷ Andreasen AT, Watson F. Experimental cardiovascular surgery. *Br J Surg* 1952;39:548–51.
- ²⁸ Braimbridge MV, Darracott S, Clement AJ, Bitensky L, Chayen J. Myocardial deterioration during aortic valve replacement assessed by cellular biological tests. *J Thorac Cardiovasc Surg* 1973;66:241–6.

- ²⁹ Niles NR, Bitensky L, Chayen J, Cunningham GJ, Braimbridge MV. The value of histochemistry in the analysis of myocardial dysfunction. *Lancet* 1964;**1**:963-5.
- ³⁰ Hearse DJ, Stewart DA, Braimbridge MV. Cellular protection during myocardial ischemia. The development and characterization of a procedure for the induction of reversible ischemic arrest. *Circulation* 1976;**54**:193-202.
- ³¹ Braimbridge MV, Chayen J, Bitensky L, Hearse DJ, Jynge P, Cankovic-Darracott S. Cold cardioplegia or continuous coronary perfusion. *J Thorac Cardiovasc Surg* 1977;**74**:900-6.
- ³² Drew CE, Keen G, Benazon DB. Profound hypothermia (experimental background). *Lancet* 1959;**ii**:745-7.
- ³³ Drew CE, Anderson IM. Profound hypothermia in cardiac surgery. *Lancet* 1959;**ii**:748-50.
- ³⁴ Belsey RHR, Dowlatsahi K, Keen G, Skinner DB. Profound hypothermia in cardiac surgery. *J Thorac Cardiovasc Surg* 1968;**56**:497-509.
- ³⁵ Barrett-Boyes BG, Neutze JM, Clarkson PM, Shardy GC, Brandt PWT. Repair of ventricular septal defect in the first two years of life using profound hypothermia—circulatory arrest techniques. *Ann Surg* 1976;**184**:376-90.
- ³⁶ Ross JK, Olsen EGI. Mitral valve reconstruction by posterior cusp advancement using a pericardial graft. *Thorax* 1976;**31**:324-1.
- ³⁷ Cleland WP. Pericardial repair of the mitral valve. In: Ionescu MI, Ross DN, Wooler GH, eds. *Biological tissue in heart valve replacement*. London: Butterworth, 1972:703-7.
- ³⁸ Starr A, Edwards ML. Mitral replacement: late results with a ball valve prosthesis. *J Cardiovasc Surg* 1963;**4**:435-47.
- ³⁹ Melrose DG, Bentall HH, McMillan IKR, et al. The evolution of a mitral-valve prosthesis. *Lancet* 1964;**iii**:623-4.
- ⁴⁰ Lam CR, Aram HH, Munnell ER. Experimental study of aortic valve homografts. *Surg Gynec Obstet* 1952;**94**:129-35.
- ⁴¹ Murray G. Homologous aortic-valve-segment transplants as surgical treatment for aortic and mitral insufficiency. *Angiology* 1956;**7**:466-71.
- ⁴² Ross DN. Homograft replacement of the aortic valve. *Lancet* 1962;**ii**:487.
- ⁴³ Senning A. Fascia lata replacement of aortic valves. *J Thorac Cardiovasc Surg* 1967;**54**:465-70.
- ⁴⁴ Cleland WP, Ghadiali PE, Lennox SC. Mounted mitral homografts. In: Ionescu MI, Ross DN, Wooler GH, eds. *Biological tissue in heart valve replacement*. London: Butterworth, 1972:399-406.
- ⁴⁵ Lennox SC, Blesovsky A, Chang VP, Cleland WP, Ghadiali PE, Aparico SGR. Frame mounted homografts for mitral valve replacement. *J Thorac Cardiovasc Surg* 1971;**62**:337-44.
- ⁴⁶ Carpentier A. Biological factors affecting long term results of valvular heterografts. *J Thorac Cardiovasc Surg* 1969;**58**:467-83.
- ⁴⁷ McMillan IKR, Daley R, Mathews MB. The movement of aortic and pulmonary valves studied post mortem by colour cinematography. *Br Heart J* 1952;**14**:42-6.
- ⁴⁸ Bellhouse BJ. Fluid mechanics of model mitral valve and left ventricle. *Cardiovasc Res* 1972;**6**:199-210.
- ⁴⁹ Ionescu MI, Tandon AP. The Ionescu-Shiley pericardial xenograft heart valve. In: Ionescu MI, ed. *Tissue heart valves*. London, Butterworth: 1979:201-52.
- ⁵⁰ O'Shaughnessy L. Carey Coombs memorial lecture: pathology and surgical treatment of cardiac ischaemia. *Bristol Med-Chir J* 1937;**54**:109-26.
- ⁵¹ Vineberg A. Treatment of coronary artery insufficiency by implantation of the internal mammary artery into the left ventricular myocardium. *J Thorac Surg* 1952;**23**:42-54.
- ⁵² Favalaro RG. Bilateral internal mammary artery implants. Operative technic—a preliminary report. *Cleveland Clinical Quarterly* 1967;**34**:61-6.
- ⁵³ Sones FM jun, Shirey EK. Cine coronary arteriography. *Mod Conc Cardiovasc Dis* 1962;**31**:735-8.
- ⁵⁴ Favalaro RG. Saphenous vein autograft replacement of severe segmental coronary artery occlusion. *Ann Thorac Surg* 1968;**5**:334-9.
- ⁵⁵ European Coronary Surgery Study Group. Prospective randomised study of coronary artery bypass surgery in stable angina pectoris. Second interim report. *Lancet* 1980;**ii**:491-5.
- ⁵⁶ Bentall HH, De Bono A. A technique for complete replacement of the ascending aorta. *Thorax* 1968;**23**:338-9.
- ⁵⁷ McMillan IKR, Johnson AM, Machell ES. Total correction of tetralogy of Fallot in young children. *Br Med J* 1965;**ii**:348-50.
- ⁵⁸ Edwards FR, Jones RS. Congenital aortic stenosis. *Thorax* 1962;**17**:218-29.
- ⁵⁹ Brock RG. Functional obstruction of the left ventricle: acquired aortic subvalvar stenosis. *Guy's Hospital Reports* 1957;**106**:221-38.
- ⁶⁰ Teare RD. Asymmetrical hypertrophy of the heart in young adults. *Br Heart J* 1958;**20**:1-8.
- ⁶¹ Goodwin JF, Steiner RE, Teare RD, Cleland WP. Discussion on obstructive cardiomyopathy. *Proc R Soc Med* 1964;**57**:443-8.
- ⁶² Barnard CN. The operation. A human cardiac transplant: an interim report of a successful operation performed at Groote Schuur Hospital, Cape Town. *S Afr Med J* 1967;**41**:1271-4.
- ⁶³ Conference of the Medical Royal Colleges and their faculties in the United Kingdom. *Br Med J* 1976;**iii**:1187-8.
- ⁶⁴ Jamieson SW, Reitz BA, Oyer PE, Biever CP, Stinson EB, Shumway NE. Current management of cardiac transplant recipients. *Br Heart J* 1979;**42**:703-8.
- ⁶⁵ English TAH. Cardiac transplantation. *Hospital Update* 1982;**8**:1447-54.