The Past 50 Years of Cardiovascular Surgery

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Cardiovascular surgery has developed so rapidly that it is hard to believe that this specialty is little more than a half-century old. In fact, had it not been for World War II, the emergence of modern cardiac surgery may have been delayed further. In 1943 and 1944, Dwight Harken, then a captain in the medical corps, successfully removed foreign bodies from in and around the hearts of >100 soldiers who had been injured in battle. Harken’s work helped overcome the notion that the heart could not be surgically manipulated and, not only did it pave the way for the incredible progress of the last 50 years, it was a catalyst for the event that would mark the dawn of this era: the creation of the first Blalock-Taussig shunt for treating tetralogy of Fallot in 1944. The striking results from this procedure, which increased the circulation through the pulmonary arterial system, caused much excitement in the surgical community.

In those early days at the midpoint of the 20th century, many warned about operating on children, particularly those with cardiovascular disease, severe cyanosis, and hypoxia. There was great concern that it would not be possible to anesthetize these young patients safely and to see them through an operation. Helen Taussig believed that one should not try to operate on a child younger than 4 years with tetralogy of Fallot or a child younger than 8 years with an aortic coarctation. Many pediatricians heeded these warnings, and it was with enormous trepidation that the anesthesia staff undertook the first congenital heart operations in very young patients. (In the earliest days of heart surgery, nurse-anesthetists usually administered anesthesia.) However, this did not deter those who believed that successful cardiac surgery could be undertaken in younger patients. By 1959, those at Texas Children’s Hospital had successfully operated on 120 infants with congenital defects.

Advent of Open Heart Surgery

Until the mid-1950s, most pediatric operations were “palliative” extracardiac procedures performed on the closed heart. The challenge was to operate inside the heart safely and to perform a definitive intracardiac repair. A number of ingenious techniques were proposed for this purpose. For instance, Elton Watkins, a medical student at Harvard, suggested a procedure to Robert Goss that became known as the Gross atrial wall. They showed that it was possible to operate inside of the beating heart, through a rubber funnel sutured to an incision in the atrial wall, as long as the patient was heparinized. This technique, however, was rather traumatic to the surgeon’s index finger: the only way a surgeon knew when the suture was properly placed was to impale his finger with the needle. That resulted in many painful fingers.

What was definitely needed was a method for interrupting blood flow during an intracardiac operation. Hypothermia was one of the early methods tried, either by placing patients in a tub of ice water or by cooling them with ice packs. Once the patient’s temperature was lowered to ~26°F, blood flow to the heart could be interrupted rather easily by placing a snare on the inferior and superior vena cava. If the repair could be accomplished within 8 or 10 minutes, the patient was spared cerebral complications. Unfortunately, this technique had some serious drawbacks, including the possibility of air embolism, which was one of the greatest problems encountered by the developers of open heart techniques. In addition, the more complicated lesions, such as atrioventricular canal and large ventricular septal defects, could not be repaired at all. Thus, it became increasingly obvious that more dependable methods were needed.

For over a decade, John Gibbon worked to design a device that would provide for the oxygenation and circulation of blood in an extracorporeal circuit. Finally, in 1953, his open heart technique with total cardiopulmonary bypass was tested in 4 patients with congenital heart disease, only one of whom survived. Although Gibbon called a personal halt to the clinical use of his technique, his efforts were a strong stimulus to other investigators.

The first truly successful open heart operations were performed by C. Walton Lillehei using a cross-circulation technique; this method had been performed as a physiological experiment for ~50 years before the first trial in a child. This approach worked very well. One of the parents, usually the mother, served as the oxygenator. By cross-circulating the parent’s arterial blood into the recipient and controlling the amount of venous blood being returned, the surgeon had up to an hour in which to perform an intracardiac repair. Proponents of this technique soon determined that the patient could survive if less than full cardiac output was used and, therefore, only moderate stress was placed on the donor. Lillehei said that it was the only operation he knew of with a potential 200% mortality rate, because both the donor and the recipient could be lost. (In Lillehei’s experience, only 1 donor...
ever suffered a serious complication—a stroke that probably resulted from an air embolism.) With this approach, Lillehei and his team were able to correct ventricular septal defects and even tetralogy of Fallot. With the success of this method, he became convinced that open heart surgery with temporary cardiopulmonary bypass was feasible.

Among the different types of oxygenators being investigated, the one devised by one of Lillehei’s younger colleagues, Richard DeWall, proved the most practical (Figure 1). DeWall and his colleagues devised a simple bubble diffusion system, with a helical coil for defoaming the blood by means of a silicone antifoam substance. With this mechanical oxygenator and a pump in the circuit, open heart surgery finally became a reality. Many more complicated defects, such as tetralogy of Fallot, ventricular and atrial septal defects, and other intricate lesions, became amenable to surgical correction. Using the more complex Gibbon-type apparatus (Figure 2), John Kirklin at the Mayo Clinic also demonstrated that open repair of complicated defects could be accomplished with low risk. Soon thereafter, our team at the Texas Heart Institute also adopted the DeWall-Lillehei device, which allowed us to establish an open heart program in 1955. We modified the DeWall device, however, by building a vertical stainless steel model that was easier to assemble and use (Figure 3). By the end of 1956, using this device and a roller pump (Figures 4 and 5), we had performed >100 open heart procedures, more than any other group in the world, including the first repair of a postinfarction ventricular septal defect (Figure 6).

One of the major problems associated with those early procedures was the need to prime the extracorporeal system with blood. Depending on the complexity of the system, up to 14 U of blood had to be collected on the morning of surgery, and the blood had to be freshly heparinized and kept at body temperature (Figure 7). With some of the larger extracorporeal systems, the operation could not be performed until 8 or 10 o’clock at night because it was difficult to collect so much blood. Eventually, we showed that blood could be stored overnight and that it could be citrated. Nonetheless, cardiac surgeons had become slaves of the blood bank with respect to the scheduling of open heart operations.

A major breakthrough came when Nazih Zudhi and colleagues demonstrated that priming the extracorporeal circuit with blood was not only unnecessary, but potentially hazard-
ous. Our team next promoted and popularized the concept of
tromilution with 5% dextrose solution\textsuperscript{12} and, although we
had many critics, the critics were proved wrong. In this
technique, which is used almost universally today, a dispos-
able oxygenator primed with 5% dextrose was used with
normothermia. For the first time, open heart surgery became
practical. It also became safer because, when 6 or 8 U of
blood are mixed together in an extracorporeal circuit, patients
end the procedure with more transfused blood than their
original volume. Also, because each unit of blood had some
basic incompatibility with the others, some patients devel-
oped homologous blood syndrome, which contributed to
various postoperative complications. With the introduction of
a non–blood-priming technique, these concerns became rel-
atively unimportant.

With these simplified techniques, surgeons were quickly
able to extend their use of open heart surgery and to repair
almost every type of intracardiac abnormality.

Valvular Repair and Replacement
The earliest intracardiac operations had been performed for
rheumatic heart disease and mitral stenosis. Several surgeons,
including Lord Brock,\textsuperscript{13} Charles Bailey,\textsuperscript{14} and Dwight Harken
and colleagues,\textsuperscript{15} had shown that the stenotic mitral valve
could be manipulated in a technique called “finger-fracture”
valvuloplasty. However, those who performed such proce-
dures realized that, in many instances, they were not really
accomplishing much. Even with a knife on the fingertip, this
technique was not very effective. In 1954, the treatment of
mitral valve stenosis was revolutionized with the advent of
the mechanical dilator, a relatively simple device that was
designed and first used by Charles Dubost.\textsuperscript{16} The dilator had
2 parallel blades that could be passed into the atrium and into
the valve (Figure 8). Dilating the valve mechanically proved
more effective than pulling it open manually. Today, cardi-
ologists are using balloons, introduced through catheters in
leg veins, for the same purpose. The approach seems to work
well as a palliative measure.

Heart valve repair gave rise to a whole new field of
possibilities, as well as a number of ingenious devices and
techniques. In 1952, Hufnagel and Harvey\textsuperscript{17} introduced a
valve that they had placed in a patient’s descending aorta to
treat aortic regurgitation. Unfortunately, the silicone-type ball
(methacrylate) was very resonant; if the patient opened his or
her mouth, the clicking of the ball could be heard across a
large room. Nevertheless, this valve did partially relieve
aortic regurgitation by reducing left ventricular load by about
one-third to one-half.

The real breakthrough was total valve replacement, which
was introduced almost simultaneously by 2 surgeons: Dwight
Harken,\textsuperscript{18} who used a double-caged, ball-and-seat prosthesis,
and Albert Starr,\textsuperscript{19} who used a caged ball-and-seat valve.
Both models incorporated a silastic ball within a metal cage.
With the introduction of the ball-and-seat valve, surgeons
could finally definitively treat aortic valve and mitral valve
disease. Years of trial and error, however, were necessary
before consistently durable, reliable valves would become available. Many of the pioneers of cardiac surgery worked to
develop reliable prostheses, and they gave their names to the products that they developed: Smeloff, Magovern, Cromie, Braunwald, DeBakey, Barnard, Beall, Cross, Jones, Conrad, Kay, Starr, Taber, Cooley, Lillehei, Wada, Stuckey, Pierce, Behrendt, Morrow, Williams, Bjork, Gott, Emery, and Nicoloff, among others (Figure 9).

Even in cardiac surgery, techniques and procedures lose and gain fashion. For example, today’s surgeons are now using homograft valves in an increasing number of cases. In earlier years, homografts never had the popularity that their mechanical counterparts did, in part because of the problems of supply and demand and of storage and preservation. Some, however, continued to use homografts, especially Donald Ross 20 and Brian Barratt-Boyes, 21 who were largely responsible for their development.

Even before valve prostheses became available, Ross 22 conceived the idea of implanting a patient’s own pulmonary valve as an autograft into the aortic annulus; he then replaced the pulmonary valve with a homograft or some other kind of valve. Today, there is renewed interest in the Ross procedure, and surgeons are even considering the use of mitral homografts to mimic normal function and eliminate the need for anticoagulation. Nevertheless, the natural valve should be retained whenever possible.

Coronary Revascularization

Patients with coronary artery disease comprise another group that challenged early cardiac surgeons. Originally, the only option was to modify or palliate this condition. Early operations were designed to stimulate intercoronary anastomoses by producing a granulomatous response in the pericardium and epicardium. To achieve this goal, powdered asbestos, talc, silica, or phenol was insufflated into the pericardial space. Other approaches included abrading the epicardium, ligating the internal mammary artery or coronary vein,
arterializing the coronary sinus, or grafting vascular tissue into the epicardium.

A major breakthrough occurred with the advent of coronary arteriography, which allowed surgeons to visualize the coronary lesion for the first time. This breakthrough was brought about fortuitously in 1958 by Sones and Shirey, who were attempting to perform a left ventriculogram in a patient and inadvertently injected a contrast agent into the patient’s coronary circulation. Sones was terrified that the patient would not survive because, at that time, coronary injection was mistakenly considered dangerous. Sones subsequently designed and successfully used a specialized coronary catheter for selective coronary angiography.

Once surgeons could see where a coronary blockage was located, they could proceed with revascularization by means of a bypass graft technique. With cardiopulmonary bypass and cardioplegic arrest, surgeons were able to construct coronary bypass grafts in a quiet, bloodless field, originally by using saphenous vein grafts and later by including the internal mammary artery. The first coronary bypass was performed by Edward Garrett and colleagues in 1964, when they encountered difficulties while performing an endarterectomy and were forced to bypass the left anterior descending artery. Much of the pioneering work in the area of coronary bypass was done by René Favaloro and Donald Effler and colleagues, who were the first to report the procedure, and by Dudley Johnson and Derward Lepley and colleagues, beginning in late 1968. The procedure soon became the world’s most frequently performed cardiac operation.

After the introduction of percutaneous transluminal coronary angioplasty by Andreas Gruentzig and colleagues, the use of interventional techniques increased, and the number of surgical revascularization procedures began to decline. At the Texas Heart Institute and at most other heart centers, patients with coronary artery disease now undergo more interventional procedures than direct surgical operations. However, the pendulum may swing the other way again. The results of simple beating-heart surgery are so satisfactory that surgeons can almost offer patients the same degree of comfort, and perhaps a better life expectancy, by performing an internal mammary artery bypass in a minimally invasive procedure rather than by an interventional procedure.

Many surgeons today are reverting to operating on the beating heart. Because coronary artery bypass grafting is done on the surface of the heart, cardiopulmonary bypass is not absolutely essential. Moreover, the extracorporeal circuit (particularly the oxygenators and suction devices) can induce a whole-body inflammatory response and other postoperative complications, which are eliminated by beating-heart surgery. One of the most difficult problems in developing this technique has been in finding methods to stabilize the arteries during grafting. New devices are being developed, however, to make such procedures safer and more reliable (Figure 10).

Despite the success of conventional myocardial revascularization techniques, some patients are not suitable candidates for these therapies, so researchers have continued to look for new options. Surgeons have begun to use lasers to perform a procedure called transmyocardial laser revascularization. The laser creates new channels through which oxygenated blood can enter the myocardium from the intracavitary region. Controversy exists, however, regarding the mechanism of transmyocardial laser revascularization and the likelihood of the channels’ remaining patent. Whatever its mechanism, this technique may stimulate angiogenesis, thereby revascularizing the ischemic myocardium. Thus far, it remains unclear whether the promising results are related to subjective factors or to actual myocardial revascularization.

Aneurysm Repair
Aneurysm surgery has evolved in a fashion similar to coronary surgery, in that various indirect methods were used for some years until excision was undertaken and, later, repair became standard. In 1951, at the annual meeting of the Southern Surgical Society, Cooley and DeBakey became the first to recommend direct surgical removal of aortic aneurysms. Synthetic vascular grafts were not yet available, so the early operations were performed mainly on sacciform aneurysms, many of which of were luetic in origin. After fabric vascular grafts became available in the late 1950s, the goal became to restore circulation without excision of the lesion.

Cardiac Support and Replacement
Probably the most exciting event in heart surgery occurred in 1967, when a South African surgeon named Christiaan Barnard performed the first human heart transplant. The operation was only temporarily successful, but it was an important historic event. Although Barnard was roundly criticized at the time by ethicists and religious groups, both of whom opposed the very concept of heart transplantation, many surgeons around the world were searching for the means to perform a heart transplant. It was Barnard, however, who defined for the rest of the world the concept of brain
death and who deserves credit for making heart transplantation a reality.

Soon after Barnard’s transplant, the Texas Heart Institute became actively involved in cardiac transplantation. Within a year, surgeons here had performed 20 transplant operations, which put the Institute in the forefront of cardiac transplantation in the world.30 Unfortunately, none of those 20 patients lived more than 18 months: they all succumbed to rejection and infection. We, and others, became discouraged, and a moratorium was called on any further cardiac transplant procedures. In 1980, however, Barry Kahan31 introduced the new immunosuppressant cyclosporine, which he used to prevent rejection in renal transplant patients. With his permission and encouragement, we began using cyclosporine to prevent rejection in heart transplant patients. The introduction of cyclosporine gave surgeons the tool they needed to re-enter the field of cardiac transplantation.

During this time, investigators were developing a mechanical means of supporting the failing heart. One possibility, a total artificial heart, was being developed by Domingo Liotta in our laboratory. In 1969, we33 used this heart in the first bridge-to-transplant operation (Figure 11) for a patient who could not be weaned from cardiopulmonary bypass after an extensive ventricular reduction procedure (what would be called the Batista34 procedure today). Three days after the artificial heart was implanted (the first implantation of its kind in the world), a donor was found, and a heart transplant operation was performed. Today, the bridge-to-transplant operation has become a routine procedure, with a variety of circulatory support devices available for use as a bridge.

The left ventricular assist device is most commonly used today as a bridge to transplant. In a 1980 request for a proposal, the National Heart, Lung, and Blood Institute changed its focus from the total artificial heart program to support development of left ventricular assist devices. A number of devices resulted from that development program. One such device, the HeartMate left ventricular assist device (Thermo CardioSystems, Woburn, MA), was the first fully implantable device to receive approval from the US Food and Drug Administration for implantation in humans as a bridge to transplant (Figure 12). The HeartMate connects the left ventricle to the ascending aorta. By unloading the left ventricle, the pump allows the heart to rest and is proven to help in the recovery of at least some left ventricular function in most patients.35 Because of the possibility of recovery and its track record for reliability, the HeartMate device is now being tested in a controlled trial for long-term use.

Newer still are much smaller, continuous-flow pumps. One of several under investigation is the Jarvik 2000, which is being developed at the Texas Heart Institute with Robert Jarvik.36 The device is implanted into the apex of the left ventricle and rests in an intracavitary position, which makes it very different from earlier left ventricular assist devices (Figure 13). The Jarvik 2000 shows promise as a bridge to transplant and as long-term support for the heart; however, in the United States, the Food and Drug Administration currently restricts its use to a bridge. The device has been implanted in 7 patients. Two of these patients have recently undergone transplant operations and are doing well. In
Dr Cooley, who began practicing transplant operations. These statistics are astonishing to both thousands of open heart procedures are performed each year. Many operations that were once considered experimental are now routine, and hundreds of open heart procedures are performed each year. In 1997, in the United States alone, surgeons performed 197,000 cardiovascular procedures, including 2300 heart transplant operations. These statistics are astonishing to both Dr Cooley, who began practicing >50 years ago, and Dr Frazier, who began practicing 30 years ago. Even with this increased practice, cardiac surgery remains what it has always been: a profession where art and science mix and where skill and decisiveness rule; these qualities are unlikely to change anytime soon. The use of robotics for minimally invasive procedures and the minimally invasive procedures themselves can challenge even the deftest of hands and may subject the patient to added risk. Technology has certainly not forget that we should be building on our past. In our haste to embrace the future, however, we must Summary

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References


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Figure 13. Jarvik 2000 continuous-flow left ventricular assist device. Reprinted with the permission of the Texas Heart Institute.
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