CARDIAC SURGERY: from a stabbing in the chest to the artificial heart

Robert S. Litwak, MD

Professor Emeritus - Department of Cardiothoracic Surgery - Mount Sinai Medical Center - New York - NY - USA

The tree of cardiac surgery emerged from seeds that were sown a mere century ago when effective means to manage cardiac trauma and the advent of reliable methods of pulmonary ventilation permitted open-chest operations. Initial successes led to early surgical attempts to correct or palliate "approachable" lesions such as mitral stenosis and patent ductus arteriosus with the heart still beating. The need to stop the heart in order to do more elaborate repairs stimulated seminal work on hypothermia and the landmark development of cardiopulmonary bypass, the two golden keys that opened the door to the remarkable accomplishments of contemporary cardiac surgery, epitomized by cardiac transplantation—severely restricted due to the continued shortage of donor hearts—and intensive efforts to develop a reliable permanent total artificial heart.

Keywords: cardiac surgical heritage; cardiac surgical vignettes; cardiac surgical growth; cardiac surgical history

Address for correspondence:
Robert S. Litwak, MD, Professor Emeritus, Department of Cardiothoracic Surgery, Mount Sinai Medical Center, 1190 Fifth Avenue, Box 1028, New York, NY 10029, USA
(e-mail: litwak@optonline.net)

Dialogues Cardiovasc Med. 2006;11:141-147

Applying the "tree metaphor" to the topic of cardiac surgery perhaps first conjures up a vision of the tools needed for "invasive" tree husbandry: axe, saw, pruning knife, secateur, and others. One way this topic might have been approached is therefore from the technological side, describing the increasing sophistication of techniques and procedures and implements. Instead, I have chosen a somewhat (though not entirely) different approach that is more attuned to the clinical point of view that characterizes *Dialogues:* I have attempted to show how the various pathological situations themselves influenced surgical technique, and how surgery was above all a matter of urgency. There is indeed a logical progression from the immediate seminal threats posed by trauma and valvular disorders (the latter having triggered the transition from closed-chest surgery to open-heart surgery), before surgical technique branched out—and continues branching out—toward the entire range of pathological situations in which it has a vital role to play.

THE ROOTS

Trauma

It is ironic that trauma should have contributed so much to the development of cardiac surgery. The latter had its halting beginning in 1896 when Ludwig Rehn of Frankfort successfully repaired a right ventricular stab wound. Although Rehn's operation was not the first attempt, it was his landmark report of success that moved cardiac surgery into the realm of the possible.[1]

Ventilatory control

The primary problem that delayed progress in thoracic and cardiac surgery was the lack of an effective means of avoiding the adverse consequences of pneumothorax. The development of intratracheal insufflation by Meltzer and Auer in 1909[2] therefore permitted future cardiothoracic operations by maintaining ventilatory exchange and expansion of the lungs.

Internists and surgeons

Following Rehn's report, several internists suggested that mitral stenosis might be relieved by surgery. One of them, Sir Thomas Lauder Brunton *(Figure 1, next page)*, sparked a storm of controversy with his 1902 *Preliminary note on the possibility of treating mitral stenosis by surgical methods,* published in *The Lancet.*[3] Though the time was wrong, Sir Thomas' suggestion was right and ultimately would come to fruition. Two decades would pass until the surgical relief of mitral stenosis again would be considered. At Boston's Peter Bent Brigham Hospital, the

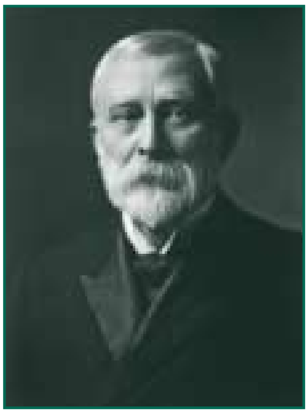

Figure 1. *Sir Thomas Lauder Brunton (1844-1916) who had the temerity to propose surgery for mitral stenosis. © The National Library of Medicine.*

distinguished physician Samuel A. Levine, defying Sir James Mackenzie's view that it was the myocardium and not the narrowed valve that was the dominant problem, collaborated with Elliot C. Cutler, the Peter Bent Brigham Hospital surgical chief, who, in May 1923, successfully operated on a 12-year-old child with mitral stenosis. Utilizing a knife inserted via the left ventricle, Cutler incised the mitral valve with the intent of creating an acceptable degree of mitral regurgitation. Despite its apparent success, Sir James caustically wrote Dr Levine:

> What a foolish thing you have done. It doesn't matter that the patient lived. You, of all physicians, should know that patients with mitral stenosis are in trouble primarily because of their sick myocardium and not because of the narrowed valve orifice.

Cutler subsequently performed six additional operations; all six patients succumbed. In retrospect, a dominant factor in the deaths was the misguided hypothesis that mitral regurgitation was a more readily tolerated lesion than mitral stenosis. Only two years after Cutler and Levine's report, the principles upon which contemporary mitral stenosis surgery are based were established by Henry S. Souttar, in London, in a landmark operation he performed in May of 1925 on a 19-year-old girl. Of importance, endotracheal intubation was employed, which permitted transpleural exposure and facile left atrial entrance so that digital dilatation of the mitral stenosis could be performed. Although the patient recovered, Souttar never was referred another patient. He later wrote, "…the physicians declared that it was all nonsense and…the operation was unjustifiable." However, in the light of history, Souttar's operation was instrumental in orienting the future direction of valvular surgery.

THE TRUNK AND BRANCHES

Early congenital cardiovascular disease surgery

In the 1930s, as a consequence of increased use of endotracheal intubation, convenient access to the mediastinum and pleural spaces made surgery of congenital cardiovascular disease possible. Patent ductus arteriosus ligation was first suggested by the Boston surgeon John C. Munro in 1907, but he was unable "to inspire the pediatric specialist with my views." Three decades later, in 1938, at Boston's Children's Hospital, Robert E. Gross successfully ligated the patent ductus arteriosis in a 7-year-old girl.[4] He also developed a method of coarctation excision with aortic reanastomosis, which was reported in 1945, as was an identical operation independently developed in Sweden by Clarence Crafoord. Experiments that "failed" were seminal in the development of the shunt operation to palliate tetralogy of Fallot. In 1938, Alfred Blalock, in Nashville, Tennessee, conducted experiments in which he was unable to produce an experimental model of pulmonary hypertension in dogs by increasing pulmonary blood flow through a subclavian artery–to–pulmonary artery shunt. After Blalock had been appointed chairman of surgery at Johns Hopkins, his colleague, the renowned pediatric cardiologist Helen B. Taussig, suggested that the "failed" shunt would be "all that [was] necessary for the cyanotic child." History was made! In November 1944, Blalock successfully performed his first "blue baby" operation on a severely cyanotic infant.[5]

World War II: impact on cardiac surgery

In 1944, Lieutenant Colonel Dwight E. Harken, and colleagues, began a series of 134 operations in which foreign bodies were removed from the heart and great vessels. Remarkably, there were no deaths. Carried out before the era of cardiopulmonary bypass, Harken's experience was a landmark. Precise operative management, endotracheal anesthesia, use of whole blood, the recently available penicillin, and skilled postoperative management constituted the elements of success. Moreover, Harken anticipated that these methods could be utilized in a postwar surgical attack on heart disease.

Closed cardiac surgery after World War II

The end of World War II coincided with resurgent attempts to attack mitral stenosis surgically. In 1948, within the space of 13 weeks, Charles Bailey, Philadelphia; Dwight Harken, Boston; and Russell Brock, London—each operating without knowledge of the others' activities—had independently replicated Souttar's operation and made modern intracardiac surgery a reality.[6,7] By establishing an operation for mitral stenosis, in which a finger inserted through the left atrial appendage of the beating heart was used to dilate the valve, these pioneers opened the door to progress in the management of other stenotic and regurgitant valvular lesions. Performed largely with digital guidance, these early operations often were more ingenious than effective. In September 1952, Charles Hufnagel successfully implanted a self-contained ball valve *(Figure 2)* in a patient with

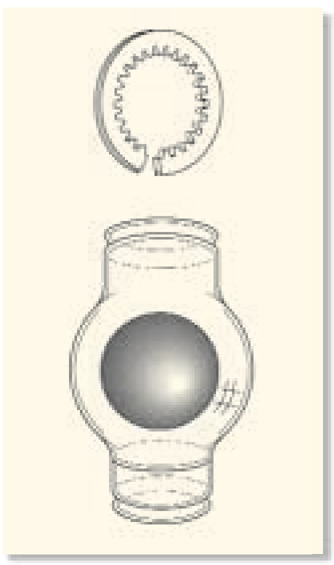

Figure 2. *The Hufnagel ball-valve prosthesis, which was implanted in the descending thoracic aorta. Nylon rings secured the valve to the aorta.*

severe aortic regurgitation. Since cardiopulmonary bypass was not yet available, Hufnagel inserted the valve in the descending thoracic aorta. While the hemodynamic result was suboptimal, the operation was the first instance of complete prosthetic valve implantation in man.[8] The ball-valve prototype became the design for valves employed in the open-heart era.

The open-heart surgery era

Hypothermia

Despite the ingenuity of closed cardiac operations, management of more complicated lesions clearly

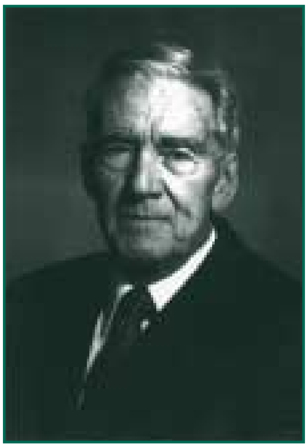

Figure 3. *Wilfred G. Bigelow (born 1913), whose work on hypothermia was fundamental in advancing the entire spectrum of cardiac surgery. From the Canadian Medical Hall of Fame. All rights reserved.*

required direct vision of the interior of the heart. Because only brief intracardiac exposure (2 to 3 minutes) would be possible with normothermic vena caval occlusion, the use of hypothermia to prolong this period was explored in the late 1940s by Wilfred Bigelow and his colleagues in Toronto *(Figure 3)*. They documented in animals that hypothermia reduced total body oxygen consumption pari passu with temperature drop,[9] seminal data that made possible the first direct vision repair of pulmonary valve stenosis and atrial septal defects, in1952.

Cardiopulmonary bypass

On May 6, 1953, a groundbreaking event in cardiac surgery occurred when John H. Gibbon, utilizing cardiopulmonary bypass successfully closed an atrial septal defect in an 18-year-old girl *(Figure 4)*. The idea for this technique had its origin in 1931 when, as a research fellow at the Massachusetts General Hospital, Gibbon saw the futility of an unsuccessful pulmonary embolectomy. Nineteen years of research preceded Gibbon's success, much of the effort having been conducted with his wife, Mary. Her memories of the development of the heart-lung machine have been recorded by Schumacker[10] and Eloesser.[11] As noted by Eloesser:

> Gibbon's idea and its elaboration take their place among the boldest and most successful feats of man's mind… Not a *Deus ex machina,* but a *machina a Deo…*

Heparin, which was the sine qua non in Gibbon's research, had been discovered in 1915 by Jay McLean, a student awaiting entrance to Johns Hopkins Medical School. In 1933, Charles Best and his colleagues, in Toronto, succeeded in purifying heparin. It was Best who generously shared their heparin with Gibbon so that he could proceed with his research.[12] After visiting Gibbon, John W. Kirklin and his colleagues constructed an improved version of the Gibbon pump-oxygenator and on March 23rd, 1955, successfully performed their first intracardiac operation, the beginning of what would become one of the two pre-

Figure 4. *John H. Gibbon (1903-1973), who was the first to successfully perform an open-heart operation, on May 6, 1953, with his heart-lung machine that made the procedure possible after two decades of research. © The National Library of Medicine.*

eminent programs in open heart surgery—both in Minnesota. Beginning in August of 1954, C. Walton Lillehei and colleagues performed their first open-heart operation with parabiotic use of a parent as an oxygenator, thereby making possible intracardiac operations in children. The method was highly successful, but the possibility of donor complication and limitation of the method to pediatric cases impelled Lillehei to assign a research fellow, Richard DeWall, to the development of a pump-oxygenator. DeWall's success was aided by the earlier work of Leland Clark and colleagues who had developed a bubble oxygenator in 1950 with effective debubbling capability. Beginning on May 13, 1955, it was DeWall's bubble oxygenator that made possible Lillehei's extraordinary cardiac surgical program. In 1944, Willem Kolff and T. J. Berk reported on their experience with a hemodialysis unit, which they had constructed from a washing machine. They noted that venous blood entering the dialyzing tubes emerged arterialized, an observation that was to have long-ranging implications for it presaged the future development of the membrane lung by Kolff and others. The findings of William Lee and colleagues, in 1961, were an impetus for membrane lung development. They documented the adverse effect of denaturation of plasma proteins and release of fat emboli by bubble oxygenators.[13] Today's low-prime, efficient, and disposable membrane lung plays a dominant role in clinical cardiopulmonary bypass.

Perfusion hypothermia

The combined use of hypothermia and cardiopulmonary bypass—perfusion hypothermia—is routinely employed in the performance of complex intracardiac and aortic operations. Perfusion hypothermia was made possible by the contributions

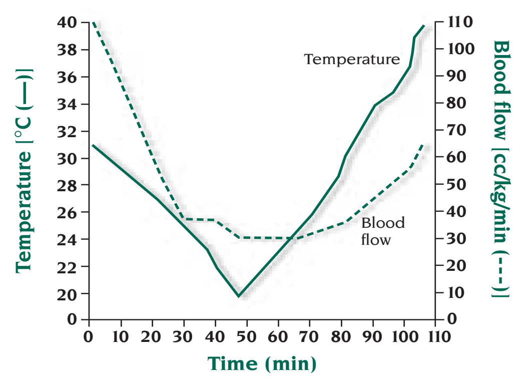

***Figure 5.** Frank Gollan's data on experimental cooling and rewarming, utilizing a pump-oxygenator with a heat exchanger as a component of the extracorporeal circulatory system.*

***Reprinted from reference 14:** Gollan F et al. Studies on hypothermia by means of a pump-oxygenator.* Am J Physiol. *1952;171:331-340. Copyright © 1954, American Physiological Society.*

of Bigelow and two others. Unaware of the Bigelow studies in the late 40s, which were then unpublished, Ite Boerema and colleagues, in Amsterdam, carried out cooling and rewarming studies in dogs through an arteriovenous shunt utilizing an extracorporeal heat exchanger. In the 1950s, Frank Gollan and colleagues, utilizing a blood oxygenator that incorporated a heat exchanger, documented that profound perfusion cooling and rewarming could be accomplished with survival of the animal *(Figure 5)*.[14] Gollan utilized Ringer's solution to prime the cardiopulmonary bypass unit, a hemodilution concept that had made survival possible in dogs cooled as low as 1.5°C[15] and provided the basis for the protocol employed today in which perfusion hypothermia permits a safe period of circulatory arrest and a bloodless surgical field.

THE LEAVES AND FRUITS: CONTEMPORARY CARDIAC SURGERY

Myocardial protection

Two requirements during intracardiac surgery are maintenance of myocardial integrity and a bloodless operative field. Efforts to accomplish these goals have been comprehensively reviewed by Hearse, Braimbridge, and Jynge.[16] In 1955, Dennis Melrose and colleagues made a vital contribution in approaching the goal of direct vision cardiac surgery when they arrested the heart with potassium citrate. Elective cardiac arrest was soon abandoned because of myocardial damage, and it would be years until it would again be explored. In the interim, the earlier work of Bigelow et al (1950) provided the basis for cooling the heart by perfusion of the aortic root (Gott, Cross, 1957) and topical cardiac cooling (Shumway, 1959). In the 1960s, chemical cardioplegia was reexamined by a number of German investigators: Hölscher, Bretschneider, and Kirsch and colleagues, each group having developed different formulations that were utilized clinically as early as 1964. In London, at the Rayne Institute at St Thomas' Hospital, studies involving David Hearse, a laboratory scientist and one of the two coeditors of this Journal, initiated a series of studies, in association with a cardiac surgeon, Mark Braimbridge, which resulted in a chemical cardioplegia formulation that retained an essentially extracellular ionic character. Introduced clinically in 1975, the cold (4°C) chemical cardioplegia formulation has been widely adopted. A number of significant contributions were also made by Gerald

Buckberg and colleagues in Los Angeles, including the use of blood as the vehicle for infusing the chemical cardioplegia, thereby improving buffering and oxygenating capacities.

Open cardiac correction in infants

In the early years of cardiopulmonary bypass, mortality was high in infants undergoing open intracardiac surgery. An essential contribution was made in 1963 by Horiuchi et al when they reported excellent survival in infants less than 1 year of age utilizing only 25°C surface cooling with the procedure performed under total circulatory arrest. With improved heat exchangers, cardiopulmonary bypass played an increasingly prominent role (Hikasa, 1967; Barratt-Boyes, 1970). Current methods employ only cardiopulmonary bypass for both cooling and rewarming and permit both neonates and infants to undergo intracardiac operations with remarkably high survival rates.

Direct vision valve replacement

In 1960, using a valve design based on Hufnagel's ball valve concept, Dwight Harken was the first to succeed in performing aortic valve replacement with subcoronary implantation of a caged ball valve prosthesis designed by an engineer, W. Clifford Birtwell. In the same year, utilizing Hufnagel's concept, Albert Starr successfully performed mitral valve replacement with a caged ball valve prosthesis designed by another engineer, Lowell Edwards. Within several years, the latter valve was widely utilized. By the end of the 60s, other prostheses (leaflet, tilting disc, etc) had been utilized clinically, but serious design flaws frequently required urgent prosthesis removal and replacement. Whatever the design, the "bête noire" of all mechanical prostheses has been thromboembolism, even despite the use of warfarin. In 1955, D. W. Gordon Murray, Canada, inserted an aortic homograft in the descending thoracic aorta of a patient with aortic regurgitation, a procedure that presaged later homograft use in subcoronary aortic valve replacement.

While remarkably effective, the availability of homograft aortic valves was a problem that quickly led to the exploration of xenografts. In 1964, Carlos Duran and Alfred Gunning, in Oxford, performed the first clinical aortic valve replacement with a stent-mounted freeze-dried xenograft porcine valve bioprosthesis. A year later, Jean Claude Binet, Duran, and Alain Carpentier, in Paris, reported their early experience with formalin-preserved frame-mounted porcine xenograft valve bioprostheses. However, within a few years, the formalin-preserved xenograft valve bioprostheses failed and had to be replaced. It was only when Carpentier found that gluteraldehyde fixation and preservation would provide long-term durability, that the use of stent-mounted xenograft valve bioprostheses rapidly spread.

Direct vision repair

Whenever possible, valve repair is always preferable to replacement. Although others had described repair methods, it was not until Carpentier's operative descriptions involving leaflet and chordal restructuring and annular stabilization with prosthetic annuloplasty rings that predictable valve repair became a reality.[17]

Myocardial revascularization

In 1910, Alexis Carrel suggested the possibility of coronary artery bypass in patients with angina. Fifty years would pass before Carrel's suggestion would become a reality. It was only when coronary arteriography was discovered by accident at the Cleveland Clinic by F. Mason Sones in 1958 that a rational basis for coronary artery bypass was established and initiated by Donald Effler and Rene Favoloro at that institution.

Sequelae of myocardial infarction

Surgery has played a selective role in managing acute sequelae of myocardial infarction (ventricular septal and papillary muscle rupture). Excision of a left ventricular aneurysm—a more chronic complication of myocardial infarction—was first performed before cardiopulmonary bypass by Bailey in 1955 and 3 years later by Denton Cooley, in Houston, employing cardiopulmonary bypass. An important contribution was reported in 1985 by Adib Jatene, in Brazil, when he combined left ventricular aneurysm excision with reconstruction of the ventricular cavity to reduce volume overload.

Pacemakers

During their hypothermia studies, Bigelow, Callaghan, and Hopps devised a pacemaker with electrodes positioned either transvenously or by direct suture to the heart. Their effort was shared with Paul Zoll and colleagues, in Boston, who developed and clinically utilized a unit with externally applied electrodes (1952). Development of transistors (1950s) permitted totally implantable pacemakers (Senning, Sweden, and Chardack, USA). A major advance was the successful transvenous positioning of pacing electrodes by Furman and Robinson (1958). Continued progress has resulted in a spectrum of physiologically based atrioventricular pacing devices.

Arrhythmia surgery

In 1967, Dirk Durrer and colleagues, Amsterdam, made a major contribution to the understanding and management of arrhythmias when they documented by intraoperative mapping in patients with Wolff-Parkinson-White syndrome that atrioventricular conduction occurred over an accessory pathway. Employment of Durrer's mapping approach permitted operative management of Wolff-Parkinson-White (Dwight McGoon, Will Sealy; USA). In 1982, James Cox, USA, performed the first cryoablation for reentrant arrhythmias, which evolved into the maze operation to control atrial fibrillation or flutter.

Thoracic aortic aneurysms, dissections, and vascular grafts

The idea of a surgical approach to aortic aneurysms was first implemented in 1902 by Rudolph Matas, in New Orleans, when he sutured an aneurysmal sac from within. Eight years later, Alexis Carrel hypothesized that aortic aneurysms could be excised and replaced "by a vascular [graft] transplantation…" It was not until 1948 that Carrel's concept would become a reality, when Robert Gross and colleagues replaced resected aortic segments with homografts. Contemporary management of aortic aneurysms and dissections (resection and replacement) began in 1953 when Michael DeBakey and Denton Cooley, in Houston, reported successful resection and homograft replacement of a descending thoracic aortic aneurysm. Homograft supply problems made the search for a synthetic vascular graft essential. An important advance was made in 1952 by Arthur Voorhees and colleagues, in New York, when—by accident—they found that cloth could be utilized to fabricate vascular grafts.[18] The availability of both synthetic vascular grafts and profound perfusion hypothermia has made possible excision and replacement of ascending, transverse arch, and thoracoabdominal aortic aneurysms and dissections (Borst et al, 1964; Griepp et al, 1975).

Heart, heart-lung transplantation

Cardiac transplantation has been established as an effective method in managing patients with end-stage cardiac failure. Research began with the seminal experiments of Alexis Carrel and Charles Guthrie in 1905 when they attempted heterotransplantation of the heart and heart and lung in animals. In 1933, Frank Mann and colleagues, at the Mayo Clinic, performed heterotopic cardiac transplantation and concluded that rejection was "due to some biological factor…" It would be a decade (1944) until Peter Medawar proved that rejection was due to an immunological reaction. Shumacker[19] has emphasized the many contributions made by the remarkable Soviet investigator, Vladimir Demikhov, who first carried out heterotopic transplantation of the heart in 1940, and heart and lung in 1946, but his prodigious efforts became widely known only when his 1960 monograph, *Experimental Transplantation of Vital Organs,* was translated into English (1962). The cardiac transplantation method employed today was developed at Stanford by Richard Lower and Norman Shumway in 1960. According to Shumway, the idea evolved from their myocardial protection (topical cooling) experiments. After one hour of aortic cross-clamping on cardiopulmonary bypass, they decided to remove the heart and then resuture it into position. Subsequently, they utilized the hearts of donor dogs and performed allotransplants, a remarkable feat that was carried out before chemical immune suppression was available.[20] Clinical cardiac transplantation began almost four decades ago (Barnard, Shumway). Although early mortality was high because of rejection, efforts—principally by Shumway's group and Keith Reemtsma, at Tulane—improved the ability to diagnose (endomyocardial biopsy) and immunologically manage this devastating complication. The first successful clinical heart-lung transplant was performed by Bruce Reitz and the Stanford team in 1981, thirty-five years after the first experimental heterotopic heart-lung transplant by Demikhov.

Left ventricular assist devices, artificial heart

In 1954, Clarence Dennis' group, in Brooklyn, first employed a pump-oxygenator to support a nonsurgical patient in severe cardiac failure.[21] In 1961, the concept of afterload reduction utilizing "arterial counterpulsation" was described by Harken et al and further developed into the intra-aortic balloon pump by Moulopoulos et al in Cleveland. In the early 60s, Spencer and DeBakey and colleagues reported on the use of a left ventricular assist device in post-cardiac surgical patients. In recent years, left ventricular assist devices have been utilized as bridges to cardiac transplantation. Because of continued shortage of donor hearts, left ventricular assist devices are now being utilized for long-term mechanical support. The development of the artificial heart was first explored by the remarkable Vladimir Demikhov (1937). Two decades later (1958) Willem Kolff and his colleague, Tetsuzo Akutsu, reported on their first total artificial heart implantation in an animal.[22] The first clinical implantation of a total artificial heart was carried out in 1982 by Kolff's group in Utah. Total artificial hearts also have been employed as bridges to cardiac transplantation (Cooley, Pierce, Copeland), but a reliable permanent total artificial heart is a goal that has yet to be accomplished.

RETROSPECT AND PROSPECT

The cardiac surgical tree has grown remarkably! It has been eight decades since the first mitral valve operations were performed by Elliott Cutler and Henry Souttar, and five decades since the first successful open-heart operation by John Gibbon employing a heart-lung machine. Advances since those days have been breathtaking, but the past surely is prologue to another era, which, in time, will bring unimaginable approaches to the management of cardiovascular disease.

So many worlds,
so much to do,
so little done,
such things to be.
Alfred Lord Tennyson

REFERENCES

1. Rehn L.
Über penetrierend Herzwunden und Herznaht [Penetrating heart wounds and suture of the heart].
Arch Klin Chir. 1897;55:315-327.

2. Meltzer SJ, Auer J.
Continuous respiration without respiratory movement.
J Exp Med. 1909;11:622-625.

3. Brunton L.
Preliminary note on the possibility of treating mitral stenosis by surgical methods.
Lancet. 1902;1:352.

4. Gross RE, Hubbard JP.
Surgical ligation of a patent ductus arteriosus. Report of first successful case.
JAMA. 1939;112:729-731.

5. Blalock A, Taussig HB.
The surgical treatment of malformations of the heart in which there is pulmonary stenosis or atresia.
JAMA. 1945;128:189-202.

6. Johnson SL.
The History of Cardiac Surgery 1896-1955. Baltimore, Md: The Johns Hopkins Press 1970: 87-99.

7. Westaby S, Bosher C.
Landmarks in Cardiac Surgery. Oxford, UK: Isis Medical Media; 1997:139-148.

8. Hufnagel CA, Harvey WP.
The surgical correction of aortic insufficiency. A preliminary report.
Bull Georgetown Univ Med Ctr. 1952;6:60-61.

9. Bigelow WG, Lindsay WK, Harrison RC, Gordon RA, Greenwood WF.
Oxygen transport and utilization in dogs at low temperatures.
Am J Physiol. 1950;160:125-127.

10. Shumacker HB Jr.
The Evolution of Cardiac Surgery. Bloomington, Ind: Indiana University Press; 1992:243-255.

11. Eloesser L.
Milestones in chest surgery.
J Thorac Cardiovasc Surg. 1970;60: 157-165.

12. Comroe JH Jr.
Retrospectroscope: Insights Into Medical Discovery. Menlo Park, Cal: Von Gehr Press; 1977:13-14.

13. Lee WH Jr, Krumhaar D, Fonkalsrud EW, Schjeide OA, Maloney JV Jr.
Denaturation of plasma proteins as a cause of morbidity and death after intracardiac operations.
Surgery. 1961;50:29-39.

14. Gollan F et al.
Studies on hypothermia by means of a pump-oxygenator.
Am J Physiol. 1952;171:331-340.

15. Gollan F, Tysinger DS Jr, Grace JT, Kory RC, Meneely GR.
Hypothermia of 1.5°C in dogs followed by survival.
Am J Physiol. 1955;181:297-303.

16. Hearse DJ, Braimbridge MV, Jynge P.
Protection of the Ischemic Myocardium. New York, NY: Raven Press; 1981.

17. Carpentier A.
Cardiac valve surgery: the French correction.
J Thorac Cardiovasc Surg. 1983;86: 323-337.

18. Voorhees AB Jr, Jeretzki A, Blakemore AH.
The use of tubes constructed from Vinyon "N" cloth in bridging arterial defects. A preliminary report.
Ann Surg. 1952;135:332-336.

19. Shumacker HB Jr.
The Evolution of Cardiac Surgery. Bloomington, Ind: Indiana University Press; 1992:316-336.

20. Spencer FC.
Intellectual creativity in thoracic surgeons.
J Thorac Cardiovasc Surg. 1983;86: 164-179.

21. Newman MM, Stuckey JH, Levowitz BS, et al.
Complete and partial perfusion of animal and human subjects with the pump-oxygenator.
Surgery. 1955;38:30-37.

22. Akutsu T, Kolff WJ.
Permanent substitutes for valves and hearts.
Trans Am Soc Artif Int Organs. 1958;4:230-235.

See also:
Preconditioning.
Dialogues Cardiovasc Med. 1997;2(No. 4): 177-236 (entire issue).