Cardiothoracic Surgery at The Mount Sinai Hospital

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Abstract

Beginning in the early years of the twentieth century, there has been a continuing record of significant contributions made by Mount Sinai physicians to the surgical management of thoracic and cardiovascular pathology. The availability of intratracheal anesthesia, a method developed at this institution, was the *sine qua non* which made it possible for surgeons to perform thoracic, and later cardiac procedures. Of great importance to medicine in general, and surgery in particular, were the investigations of two Mount Sinai physicians that made the transfusion of blood safe, and the modern blood bank a reality. The later contributions of Mount Sinai staff members to the effective employment of open-heart surgery without the use of donor blood, mechanical support of the failing heart, cardiac transplantation, and complex aortic surgery are described.

Key Words: History of cardiothoracic surgery, cardiac surgery, pacemaker implantation, hypothermia, intratracheal anesthesia, blood transfusion, Jehovah's Witness.

Over the years, the contributions of a number of Mount Sinai physicians have been of key importance in the development of thoracic and cardiac surgery. A towering figure was Howard Lilienthal, who began his service here as a junior house staff physician (1886), rose to the distinguished level of consulting surgeon (1922), and went on to become an internationally acclaimed authority on thoracic surgery.

Lilienthal's interest and involvement in developing not only thoracic but also cardiac surgery was apparent from his early years at Mount Sinai. His classic two volume text, *Thoracic Surgery*, was published in 1926 (1). In addition to comprehensive discussions of pulmonary, esophageal and related pathology, Lilienthal devoted four chapters to the management of cardiac and great vessel problems. He described his experience with pericardiostomy (1889), limited excision of pericardial constriction (1923) and management of life-threatening aortic aneurysms (1907, 1914). An extensive section of the book was devoted to the management of pulmonary embolism and described an attempted pulmonary embolectomy performed by Harold Neuhof on a patient who was in profound shock, having recently undergone an abdominal operation (date not stated). The book further reveals Lilienthal's insight in anticipating the role of surgery in the management of cardiac valvular pathology (2):

> The most important heart lesions which may some day come regularly to the surgeon are the aortic stenoses, the mitral stenoses, and possibly stenoses of the pulmonary arteries. Perhaps also some tricuspid contractions may be added to the list of surgical conditions.

Lilienthal described in considerable detail the first successful use of transventricular valvulotomy in the relief of mitral stenosis, which had been performed in 1923 by the distinguished Harvard surgeon, Elliot Cutler. It was clear that Lilienthal also appreciated the potential role of surgery in congenital cardiac and great vessel problems such as patent ductus arteriosus. Lilienthal observed (3), "The anomaly in which surgery promises some hope is that of [ligating a] persistent ductus arteriosus."

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Accepted for publication January 2002.

Other members of Mount Sinai's staff also made contributions of enormous importance to the developing fields of thoracic and cardiac surgery. One of these trailblazers, Charles Elsberg, was responsible for the first clinical application of a method which would effectively deal with the one overriding deficiency which, above all others, had delayed any substantive progress in the field — the lack of a simple and predictable method of establishing and maintaining adequate pulmonary ventilation when the thorax was open and the lung exposed. Elsberg was impressed with the 1909 report of two Rockefeller Institute physiologists, Meltzer and Auer, who experimentally demonstrated the efficacy of a simple apparatus which could maintain expansion of the lungs while administering anesthesia employing a method of intratracheal insufflation, thereby permitting safe transpleural exposure (4). In February of the following year, Elsberg (who later would distinguish himself as Mount Sinai's chief of Neurosurgery) utilized the Meltzer and Auer concept for the first time in a clinical open-chest procedure. Employing an apparatus he himself had constructed, Elsberg administered intratracheal anesthesia to a patient being operated on by Lilienthal for a lung abscess (5). In the next two years more than 400 operations were performed employing the Elsberg system, and within five years the method was employed throughout the world. Almost a half-century later, the distinguished thoracic surgeon, Evarts A. Graham, observed (6):

> There is no doubt that this simple device has been one of the most important foundation stones upon which the structure of modern chest surgery has been erected. [However] in spite of the great importance of this simple method of avoiding the collapse of the lung it was used very little before the First World War largely because there were very few surgeons prepared to undertake intrathoracic operations, in addition to the fact that the diagnosis of intrathoracic disease was far from accurate [since] the Coolidge tube which made the X-ray examination of the thorax feasible was not invented until 1917.

One can hardly conceive of a patient undergoing major thoracic or cardiac surgery today without the immediate availability of carefully typed, cross-matched blood. Two distinguished members of Mount Sinai's staff helped make the modern blood bank a reality. Reuben Ottenberg (who later would be recognized as one of this institution's outstanding physician investigators) not only performed the first blood transfusions in New York City (1907 and 1908) but also — utilizing Landsteiner's description of blood groups — was the first to employ the practice of typing and cross-matching of blood donors and recipients (7). Another Mount Sinai physician, Richard Lewisohn (who rose from adjunct to attending surgeon), introduced the use of citrate as an anticoagulant in donor blood, thereby making it possible for blood to be stored. Thus was born the basis for the modern blood bank (8, 9).

Early Experience with Extracardiac Surgery at Mount Sinai

In 1940, after the seminal report of Robert E. Gross of the first successful ductal ligation (10) and two years after John Strieder's report of an unsuccessful attempt to obliterate a ductus complicated by bacterial endarteritis (11), Arthur Touroff, a member of the Mount Sinai surgical staff, reported the first survivals of two of four patients who underwent ductal obliteration in the presence of active *Streptococcus viridans* infection (12, 13). In that preantibiotic era, it is of importance that the blood cultures of one of the survivors immediately became and remained sterile following ductal division. In the second survivor, bacteremia was reported as being significantly reduced. A paper published by Mount Sinai's Cardiovascular Research Group revealed that it was also Touroff who, following the monumental report of Blalock and Taussig (14) describing the efficacy of systemic pulmonary artery shunts in the management of cyanotic heart disease — successfully performed the first shunt procedure at this institution, on a five-year-old child with complex cyanotic congenital heart disease, in April of 1949 (15).

Cardiac Surgery after the Second World War

Closed Intracardiac and Extracardiac Surgery at Mount Sinai: The Early Years

The end of the Second World War coincided with an enormous burst of interest throughout the surgical world in developing operative approaches to congenital and acquired cardiac and great vessel pathology. Undoubtedly, the stimuli for this heightened interest were (a) the success of Gross and Blalock in the United States and Crafoord (Sweden) in the management of an increasing number of extracardiac congenital cardiovascular lesions, and (b) the brilliant success achieved during World War II by Lt. Col. Dwight E. Harken, who had performed 134 operations in which foreign bodies were removed from the heart and great vessels without any mortality (16). Harken had demonstrated that well planned and skillfully executed cardiac and thoracic operative procedures could be accomplished with a high degree of success. The multiple elements underlying that achievement — so long in coming — were at last at hand: well-controlled endotracheal anesthesia, the ability to replace blood loss with whole blood, a skilled surgical team, meticulous postoperative care by experienced nurses and physicians in areas which would now be identified as intensive care units, and finally, the newly available antibiotic penicillin. Only three years after the end of the war (1948), Harken in Boston, Charles Bailey in Philadelphia and Russell Brock in London — each unaware of the others' efforts — independently and convincingly demonstrated the efficacy of surgical relief of severe mitral stenosis. Predictable intracardiac surgery having become a reality, Robert Nabatoff of the Mount Sinai surgical staff initiated a highly successful series of surgical enlargements of the stenotic mitral orifice (commissurotomy) in 1951, employing the techniques recently described by Bailey, Harken and Brock. During this same period, two other members of the Mount Sinai surgical staff, Irving Sarot and Mark Ravitch (the latter having been recruited from Johns Hopkins as Mount Sinai's first full-time director of Surgery), also performed mitral valve operations as well as correction of congenital cardiovascular lesions, including ligation of the patent ductus and resection of a localized, severely narrowed area (coarctation) of the thoracic aorta.

Open-Heart Surgery at Mount Sinai: Early Experience

The first open-heart surgery (OHS) effort at The Mount Sinai Hospital was initiated by Ivan Baronofsky, who had been recruited as director of Surgery (in 1957) from the University of Minnesota (UM), one of the two institutions in the world which were actively involved in clinical OHS at that time (the other being the Mayo Clinic). Having witnessed the clinical success of C. Walton Lillehei and his UM colleagues, who employed a pump and oxygenating unit which was relatively simple, inexpensive and disposable, Baronofsky — upon his arrival at Mount Sinai — promptly initiated an aggressive canine experimental laboratory effort with the UM system, the goal being to begin clinical work as soon as both a reliable pump-oxygenating system and support staff could be established. To accomplish this, he assigned three Mount Sinai surgical residents to various laboratory tasks: Isadore Kreel would perform the surgery, Lawrence Zaroff would run the pump-oxygenator, and David Kavee would be responsible for performing a myriad of other technical chores. After five months of intensive effort involving approximately 200 canine OHS operations employing the Lillehei UM system, two of the residents, Kreel and Zaroff, spent one week at the UM, where they observed all OHS cases performed during that week and were updated on the entire UM experience. Upon their return to New York, Mount Sinai's clinical OHS program was initiated by Baronofsky in January of 1958, with the successful repair of an atrial septal defect in a ten-year-old boy. Following this first successful case, approximately 100 open cardiac operations were performed with an operative procedure scheduled for each Tuesday. Most of the cases involved repair of atrial septal defects, with a smaller number undergoing repair of ventricular septal defects. According to Kreel (who supplied the writer with all of the details of that period), each case was a "logistical nightmare," since the protocol at that time required 20 units of fresh heparinized blood to be drawn on the morning of operation. The patient did not enter the operating room until the required number of blood units were confirmed to be immediately available. Since a cardiac surgical recovery room did not exist at that time, a small area adjacent to the old Guggenheim operating rooms (currently a reception area for patients scheduled for ambulatory surgical procedures) was utilized for immediate postoperative care with surgical residents in constant attendance throughout the night on each case.

Upon Baronofsky's departure from Mount Sinai in March of 1960, an administrative decision was made to discontinue all OHS efforts until a new surgical director and staff could be recruited.

The Division of Cardiothoracic Surgery: The Early Years

In 1961, one of the important early tasks of the newly appointed full-time director of

Surgery, Allan Kark, was the establishment of a Division of Cardiothoracic Surgery (CTS), with an experienced staff which would re-establish the OHS effort and develop strong teaching and research programs. Within months of Kark's arrival, Robert Litwak was appointed director of the newly established Division of Cardiothoracic Surgery. He and his talented colleague, Howard Gadboys, began their work at Mount Sinai in July of 1962. Litwak undertook development of a strong clinical program which sought to integrate both the cardiac and the well-established general thoracic surgical efforts, thereby providing the basis for a formal CTS residency teaching program. Both Litwak and Gadboys shared clinical cardiac surgical responsibilities, and the latter also undertook primary responsibility for development of a research program that would initially focus on study of pathophysiologic events associated with bypass of the heart and lungs (cardiopulmonary bypass) with a mechanical pump-oxygenator exchange device (17, 18).

After a hiatus of two and a half years, open-heart surgery (OHS) began again on August 15, 1962, with the performance of a pulmonary valvotomy in a six-year-old child. In the first twelve months following re-establishment of the OHS program, an average of two open cardiac procedures were performed each week, predominantly on adult patients with acquired mitral and aortic valvular heart disease and on children with various congenital cardiac and vascular malformations.

A number of administrative decisions made by the hospital were of key importance in the re-establishment of an OHS effort at Mount Sinai. A dedicated operating room fully equipped for the conduct of open-heart surgery was established, with six experienced nurses assigned full time to the program. Immediately adjacent to the operating room there was space for both a biochemical laboratory and a "pump room" (where the heart-lung machine would be assembled and disassembled). Two experienced perfusionists (Bennett Mitchell and Phillip King) were recruited to run the heart-lung machine. Additionally, two physiological-biochemical technicians were recruited and assigned on a full-time basis to the cardiac operating room and recovery areas. Of great importance was establishment of a well-equipped, two-bed CTS Intensive Care Unit (CTSICU) with state-of-the-art monitoring equipment and staffed with six experienced nurses who delivered excellent around-the-clock care to fresh postoperative OHS patients.

Cardiothoracic Surgery Residency Program

With re-establishment of an active cardiac surgical effort and the presence of a substantial volume of patients requiring a variety of non-cardiac thoracic surgical procedures, a two-year CTS residency program was immediately established. B. George Wisoff, a brilliant young surgeon (who would later distinguish himself as chief of Cardiac Surgery at the Long Island Jewish Medical Center) was the first CTS resident. Once the CTS residency program was operational, a site visit was made by a group representing both the American Medical Association's Accreditation Committee for Graduate Medical Education (ACGME) and the American Board of Thoracic Surgery (ABTS). As a result, a two-year training program was given formal approval. The initial approval stipulated that only one CTS house officer could be trained in each two-year period. Fortunately, second- and third-year general surgical residents augmented the house staff with three-month CTS rotations.

The progressive increase in patient volume and the necessarily limited exposure of a single CTS resident to a broad spectrum of both pediatric and adult thoracic and cardiac cases requiring surgery prompted a second request to and subsequent approval by the ACGME and ABTS (in 1975) for augmentation of the CTS resident staff to two house officers. The additional resident position permitted the first-year resident to focus primarily on general thoracic surgical problems and the second-year resident, as the CTS Chief Resident, to focus on management of patients requiring cardiac surgery. In reality, however, the ever-expanding cardiac surgical volume often resulted in the first-year thoracic resident suddenly being spirited away to scrub in as an assistant on a complicated cardiac surgical case. Thus, the goal of a predictable and continuing experience in non-cardiothoracic surgery still was not being met. Once again, the ACGME and ABTS were approached (in 1983) with a request to lengthen the CTS residency from two to three years. While the request was approved, we were to learn later that it had been done with considerable ambivalence since a number of committee members had pointedly indicated that no other institution had expressed the need to lengthen its CTS residency because of perceived limitation of general thoracic surgical resident experience. However, it was gratifying to note that within the next five years a substantial number of institutions with approved CTS residencies had elected to extend their programs to three years.

Beginning in the early 1970s and continuing for a number of years, CTS residents rotated through the Bronx Veterans' Administration Hospital to augment their experience in a wide variety of thoracic problems, particularly pulmonary and esophageal disease. Under the knowledgeable guidance of the chief of Thoracic Surgery, Hideki Sakurai, and the chief of Surgery, A.J. McElhinney, the experience was a consistently rewarding one.

Nursing and Support Staff

Nurse Clinicians

The steadily increasing patient volume soon made it apparent that CTS residents, who were frequently in the operating room for many hours, needed help in providing and coordinating perioperative patient care. It was for this reason that a CTS nurse clinician program was established in 1964. These individuals were highly qualified nurses who almost invariably had prior CTSICU experience. Their responsibilities included making daily rounds with the CTS staff and communicating any concerns or decisions made at rounds with cardiologists and consultants, making certain that the necessary myriad of management "paperwork" had been completed, and taking the time to discuss at length with both patient and family any concerns that might have arisen concerning projected care plans. The program proved to be highly successful and remains an important CTS operational component.

Physician Assistants

In addition to nurse clinicians, certified physician assistants (PAs) have played a significant role in patient management at Mount Sinai since 1978. The PA support concept was originally established at Duke University in the 1960s because of the sharp limitation of approved surgical resident positions by accrediting agencies. With college backgrounds supplemented by two years of formal lectures and supervised medical and surgical patient care experience in accredited programs, PAs are approved to assist CTS surgeons in the operating room and carry out many of the time-consuming tasks previously assigned to residents. Since recruitment of the first PA more than 20 years ago, there has been a gradual increase in the number of CTS PAs (currently 14), a reflection of the importance and effectiveness of these professionals in providing thoughtful patient care.

Bioengineers

The frequent need to develop new instrumentation for research or clinical purposes made it essential that there be close collaboration of CTS staff with bioengineers. In 1966, informal discussions between CTS staff and members of the Artificial Organs Research Laboratory (AORL) of Columbia University concerning investigative areas of mutual interest led to the establishment of a formal relationship, which was recognized with appointment of the AORL director, Edward F. Leonard, Ph.D. (professor of chemical engineering at Columbia University) as lecturer in surgery. This relationship led to the establishment of a fruitful collaborative laboratory research effort (see later discussion).

In 1971, having learned that studies employing on-line computerized analysis of cardiac and pulmonary variables being conducted by John J. Osborne (director, Institute of Medical Sciences at the Presbyterian Medical Center, San Francisco) facilitated postoperative management of critically ill cardiac surgical patients, Roy Jurado (associate professor of Surgery) spent a year working with Osborn and colleagues on this project. Impressed with the efficacy of the system, Jurado and three CTS bioengineers (Richard A. deAsla, Hillard Fitzkee, and Byong Min) constructed a bedside sensing and data acquisition unit at the Institute of Medical Sciences (IMS). The unit was then carefully moved to the CTSICU at Mount Sinai and connected via leased long-distance telephone lines to an IBM 1800 digital computer located in the IMS. On-line real-time computerized surveillance studies of cardiac, hemodynamic and pulmonary variables and parameters carried out by Jurado and colleagues documented for the first time that computerized surveillance could significantly reduce sudden, unexpected life-threatening events in postoperative cardiac surgical patients (19). The data were sufficiently impressive to Mount Sinai administrative staff that they approved funds which permitted full computerization of the newly constructed eight beds located in the old Guggenheim Pavilion.

Two bioengineers, Anthony Benis and Robert M. Koffsky (whose initial involvement with CTS was as members of the AORL conducting collaborative research at Mount Sinai), later became full-time members of CTS and made a number of major contributions over the years. After collaborating with CTS staff for several years Benis, with more than ten years of bioengineering background, elected to seek a degree in medicine and graduated from the Mount Sinai School of Medicine in 1976. His medical career blossomed and he currently is director of the CTS Intensive Care Unit. Koffsky, having left the AORL for a relatively brief but productive experience in the research division of a West Coast pharmaceutical firm, was persuaded to return to CTS in 1976 to coordinate instrumentation development for the research laboratory, the CTS operating rooms and the new twelve-bed CTSICU in the Lucy Moses Cardiothoracic Center in the recently completed Annenberg Building.

Growth of the Cardiac Surgical Program: 1962–1985

As a consequence of collaboration of pediatric cardiology and adult cardiology colleagues, the volume of cardiac operations steadily expanded over the years. All patients referred for surgery underwent diagnostic hemodynamic studies by the cardiac catheterization team (directed by Alvin Gordon). There was also excellent angiographic input by Murray Baron of the Department of Radiology. The pediatric cardiology effort was directed by Leonard Steinfeld, who was later joined by Rica Arnon. Both physicians performed diagnostic catheterization studies in children. The adult cardiology group was directed by the distinguished Charles Friedberg, whose conservatism was legendary when considering patients for cardiac surgery. Nonetheless, many members of the Department of Medicine and the Division of Cardiology regularly referred patients for cardiac surgery.

Surgery for Congenital Cardiac and Great Vessel Problems

In the 1960s and 1970s, OHS for severe congenital cardiac cases in the first year of life was still in the development stage. Neonates and infants with severe cyanotic heart disease (such as tetralogy of Fallot) — rather than undergoing open cardiac correction at that young age — underwent palliative surgery (Blalock-Taussig operations) which increased pulmonary blood flow, with reduction of cyanosis, and improved the general condition of the child. Similarly, infants with life-threatening large ventricular septal defects underwent pulmonary artery banding (partial occlusion), which reduced excessively high blood flow to the lungs and thereby improved the child's stability. Only a decade later would open-heart corrections of the above lesions be performed in the first year of life.

Valve Repair and Replacement

The availability of OHS methodology permitted Mount Sinai surgeons the option of performing closed mitral commissurotomy in patients with favorable (non-calcific, non- regurgitant) rheumatic mitral stenosis. At operation, if necessary, the surgeon could immediately switch to the open-heart approach. One of the early reports of the method was published by Mount Sinai CTS staff in 1965 (20).

With the development of caged ball valve prostheses by Albert Starr and engineer Lowell Edwards in the early 1960s (21) patients with otherwise uncorrectable, far-advanced mitral and/or aortic valve pathology could now undergo replacement of one or more valves. The first patient at The Mount Sinai Hospital to undergo implantation of a Starr-Edwards mitral valve was operated upon in May of 1963. In August of that year the first Starr-Edwards aortic valve prosthesis was implanted. The first combined mitral and aortic valve replacement performed with these prostheses was also carried out in August 1963.

While improvements continued to be made in mechanical prosthetic valves over the years, the disturbing frequency of thromboembolic complications required that all patients be maintained permanently on warfarin, an effective anticoagulant. While capable of reducing the potential of thromboembolism, warfarin imposed the equally threatening possibility of intracerebral or other vital organ bleeding.

A welcome addition to the surgical armamentarium was the development (in the mid-1960s by Carpentier and colleagues in Paris) of stent-mounted, aldehyde-treated aortic porcine xenografts, which offered the hopeful possibility of avoiding the need for indeterminate anticoagulation (22). The first commercially available, formalin-fixed stented porcine xenograft (Hancock Laboratories) was implanted in the mitral position at The Mount Sinai Hospital in November 1968. Over the next two years, 59 patients underwent single or multiple-valve replacements with these bioprostheses. Unfortunately, initial enthusiasm for the porcine xenografts was tempered by early leaflet failure. Within thirty-six months, every one of the implanted, formalin-fixed bioprostheses had developed evidence of significant incompetence which required their replacement with a mechanical (Starr-Edwards) prosthesis. Fortunately, all patients who had undergone initial bioprosthetic implantation survived their subsequent removal and replacement with a mechanical prosthesis. In recent years, as a result of improved methods of leaflet preservation, bioprosthetic valve replacement is again being performed in appropriately selected patients. Women of childbearing age in regular cardiac (normal sinus) rhythm and elderly patients with aortic valve pathology are candidates for bioprosthetic valve replacement, since anticoagulation can be discontinued several months after operation with minimal risk of thromboembolism and the implanted valves can be expected to remain competent for approximately a decade.

Coronary Artery Bypass

Following demonstration by Favaloro and colleagues at the Cleveland Clinic (1968) (23) of the efficacy of coronary artery bypass grafting (CABG) utilizing reversed saphenous vein segments in the management of severe coronary artery disease, many institutions throughout the world promptly began aggressive CABG programs. Unfortunately, referral of patients for CABG surgery at Mount Sinai was quite slow for a number of years following Favaloro's report, presumably because persuasive information which clearly documented improved longevity, reduced potential of future myocardial infarctions, etc. had not yet been published. Indeed, the first CABG procedure at this institution was performed in 1971, but the volume still remained small. Only after documentation of the efficacy and improved long-term patency of internal mammary artery grafts by George Green (24) did the CABG volume significantly increase. It is pertinent that Green demonstrated the clinical efficacy of anastomosis of the internal mammary artery to the left anterior descending coronary artery, employing an operating microscope, originally developed by a young surgical investigator, Julius Jacobson II (25), who would later become Mount Sinai's distinguished director of Vascular Surgery. Characterized by the late physiologist and historian, Julius Comroe (26), as "one of the great cardiovascular advances . . . ," the microvascular surgical methods and principles established by Jacobson have become the bedrock underlying successful performance of a wide variety of cardiovascular and other surgical procedures performed today.

From its inception, the CTS CABG program was superbly directed by Salvador Lukban and, later, by Manuel Estioko and Bruce Mindich. Estioko's employment of a "no blood" approach in the management of Jehovah's Witnesses (whose religion absolutely forbids use of donor blood or blood products) referred for CABG or other cardiac surgery quickly led to Mount Sinai being designated as a regional referral cardiac surgical center for this religious group (27).

Permanent Pacemaker Implantation

The development of permanent implantable cardiac pacemakers in the early 1960s sharply improved the dismal outlook of patients with complete heart block. The first permanent pacemaker was implanted by Howard Gadboys and CTS resident, George Wisoff, in an elderly patient in September 1962. In the early years (prior to the development of permanent transvenous pacing methods), permanent pacemaker implantation required a formal thoracotomy. There was close collaboration with members of the cardiology catheterization team (directed by Alvin Gordon) who would insert a preliminary temporary transvenous catheter electrode into the patient's right ventricle to attain immediate cardiac pacing. With the patient anesthetized, the CTS team would open the chest, expose the heart and insert permanent pacing electrodes directly into the left ventricle. The pacing electrodes would then be connected to a generator to begin the pacing. Although the early pacing methods unquestionably improved the outlook for patients, accumulating experimental and clinical evidence clearly suggested significant physiologic advantages if atrioventricular synchrony could be maintained. The fortunate development of a fully implantable permanent synchronous pacing unit in 1963 permitted CTS staff to begin implantation of such units that same year. While clearly advantageous from the physiologic standpoint, the surgical approach was somewhat more extensive, because both the left atrium and left ventricle required exposure for electrode implantation. This could only be accomplished by employing a large thoracic incision in an anesthetized patient.

A major advance which eliminated the need of thoracotomy for pacemaker implantation was the development by several investigators of permanent transvenous endocardial pacemaker catheter lead and generator systems. Implantation required only local infiltration anesthesia in an awake patient. The first procedure of this type was performed at Mount Sinai by CTS in 1966. As in the early pacemaker experience, Gadboys continued to direct the program in collaboration with Salvador Lukban, a gifted resident who would later become a member of the CTS attending staff. Over subsequent years, the program was directed by Estioko and, later, by Jorge Camunas. In recent years, Jan Galla of CTS has joined Camunas in managing the steadily increasing volume and spectrum of pacemaker implantations. Over the years, the program has been fortunate to have magnificent nursing collaborators, initially Yael Duvduvani, R.N. and, in recent years, Unsoon Shagong, R.N.

Progress in the management of heart block and other electrophysiologic distortions in the three decades since the early pacemaker implantations has been extraordinary. The pacemaker program has grown steadily, with the annual implant volume averaging 200–230 patients. Each patient requires arrhythmia analysis and implantation of a pacemaker which deals with the specific conduction problem. The pacemaker group also has substantial experience in the effective management of several types of life-threatening ventricular arrhythmias, employing an implantable cardiac defibrillator (ICD) device which, having detected the problem, immediately shocks the heart to reestablish normal cardiac rhythm. The effort has been a collaborative one involving CTS surgeons and the Division of Cardiology's excellent electrophysiology group (directed by J. Anthony Gomes) in both arrhythmia diagnosis and operative management. Each year more than 75 patients receive these literally life-saving ICD units.

Mechanical Support of the Failing Heart

The urgent need for pump assistance for the failing heart had been appreciated since the early days of OHS. The first system employed by many cardiac surgical groups was the intra-aortic balloon pump (IABP). The IABP operational concept is based on the arterial counterpulsation principle developed in the early 1960s (28). The pump utilizes a rapidly inflatable and deflatable balloon which is positioned in the aorta just beyond the origin of the carotid arteries (which supply blood to the brain). Utilizing the electrocardiogram, the balloon is timed to deflate immediately preceding onset of left ventricular (LV) contraction, thereby reducing the energy-consuming work that the LV must perform in ejecting blood into the aorta. During the succeeding cardiac diastolic phase (when the LV is being refilled from the left atrium with oxygenated blood coming from the lungs), the IABP suddenly inflates, causing the arterial pressure to rise. The overall result is an improvement in hemodynamic stability and reduced work stress on the heart.

First utilized at Mount Sinai in 1972, the IABP was deployed in a patient with advanced cardiac dysfunction undergoing OHS whose post-repair low cardiac output did not permit discontinuance of the heart-lung machine. The IABP successfully stabilized the hemodynamic state of the patient so that the heart-lung machine could then be discontinued. The patient recovered satisfactorily and was subsequently discharged.

In later years, development of a percutaneous method of IABP insertion proved to be of great importance in the cardiac catheterization laboratory and coronary care unit when patients suddenly manifested cardiac ischemia as indicated by altered electrocardiogram or by angina. In these patients, the IABP was effective in promptly alleviating the ischemic episode and restoring hemodynamic stability. In the early years of IABP use at Mount Sinai, Roy Jurado (associate attending surgeon) and Richard DeAsla (senior CTS bioengineer) had been responsible for the direction and supervision of the highly effective IABP support program.

In the 27 years since the IABP was first employed at this institution, it is estimated that the system has been employed in approximately 2,500 patients and continues to represent the first line of defense in managing severe cardiac dysfunction.

A second circulatory support system, the Left Heart Assist Device (LHAD), was developed at Mount Sinai by CTS investigators and subsequently utilized by many cardiac surgical groups. The LHAD was first utilized at Mount Sinai in 1973 in a critically ill patient with low cardiac output following cardiac repair. Despite prior use of the IABP, this patient still could not be separated from the heart-lung machine (29). The system consisted of special biocompatible silicone elastomer cannulae which were connected to a pump. The first LHAD cannulae which were employed clinically were designed at Mount Sinai and fabricated by Robert Koffsky, an extraordinarily talented bioengineer who was a member of the CTS staff. One cannula was sutured to the left atrium (LA), the chamber which receives oxygenated blood from the lungs and delivers it to the LV. The other cannula was sutured to the aorta (beyond the LV).

In operation, the LHAD offered the dual advantages of (a) decompressing and unloading the failing LV of blood which it was unable to eject and (b) significantly augmenting systemic arterial blood flow and pressure, to restore and sustain adequate performance of all organ systems until the heart had recovered sufficiently to permit discontinuance of mechanical support. An additional advantage of the support system was that after discontinuance of the LHAD, the highly biocompatible cannulae could be occluded by precisely fitting obturators, without the necessity of reentering the chest. Results in the desperately ill patient group requiring LHAD support revealed that approximately one in three recovered sufficient cardiac function to permit LHAD separation, subsequent hospital discharge and long-term survival. Although other mechanical systems have replaced the LHAD in recent years, it is pertinent that the latter was one of the earliest cardiac support systems to be described and utilized clinically throughout the world.

The Cardiothoracic Surgical Research Laboratory: 1962–1985

With establishment of the Division of Cardiothoracic Surgery in July of 1962, an immediate effort was made to develop a vigorous research program. A CTS animal research facility was provided by the institution, on the seventh floor of the Atran research building. The laboratory was directed by Gadboys with support staff consisting of an experienced veterinarian, Howard Shiang, Wiltrud Berger (who later would marry Gadboys), and a research fellow, Junichi ("John") Ishiguro. The focus of the investigations centered upon exploration of problems accompanying the use of the heart-lung machine which were believed to contribute to both mortality and morbidity.

A major concern of the laboratory was to better understand factors underlying the frequently observed, isotopically measured hypovolemia after cardiopulmonary bypass (CPB), a volumetric distortion commonly observed in the early days of open-heart surgery, when gravimetrically measured blood loss was replaced volume for volume in an attempt to rigidly maintain blood balance (normovolemia) during the course of CPB. On clinical grounds, it was apparent that attempts to maintain normovolemic conditions were accompanied by hypotension. When the extent of the hypovolemia, measured isotopically, was reversed by the administration of additional blood, the patients did far better. What was the basis of the hypovolemia? Gadboys and colleagues hypothesized that as with canines which were suspected of developing severe, frequently lethal reactions when mixed units of homologous blood were utilized to prime the CPB machine, humans might be experiencing a similar, albeit less severe, reaction manifested by sequestration of a portion of both the formed components of the blood (red, white cells and platelets) as well as plasma.

Supported by a grant from the National Heart Institute, a large number of canine investigations were carried out, which clearly incriminated homologous blood as the etiologic factor in producing these reactions (17). Subsequent studies in humans proved to be similar to those observed experimentally and were the basis for important changes in the conduct of clinical OHS: redesign of the heart-lung machine to permit reduction of the priming volume and use of electrolyte solutions to replace and dilute the homologous blood needed to prime the heart-lung machine (18). Application of these two principles made it possible for OHS to be performed without use of homologous blood. This approach was brilliantly employed by Denton Cooley (Texas Heart Institute) when he, for the first time, successfully performed OHS on a Jehovah's Witness, whose religious tenets forbid the use of homologous donor blood for blood products (30).

Another major area of study evolved from this discovery that thromboembolism was a problem when any type of extracorporeal circulatory support system was employed. The thrombotic buildup (with ultimate embolization) was believed to be the result of a number of critical factors, one of the most important being the foreign plastic and metallic surfaces of the devices which were in constant contact with the circulating blood of the patient. Although the patient's blood was anticoagulated with heparin, thromboembolic complications still occurred. Beginning in 1966, CTS investigators, in collaboration with engineering faculty from the Columbia University Artificial Organs Research Laboratory, initiated a series of National Institutes of Health (NIH)-supported investigations which sought to identify factors provoking the thrombotic process. It was hoped that comprehensive understanding of these factors would provide a basis for subsequent investigation of pharmacological agents and new polymeric and other thromboresistant materials which offered promise of effectively blunting thrombus generation. Over the course of a decade of exhaustive study, no clear determination of factors which were operative in initiating the clotting process on foreign surfaces could be identified. Rather, the evidence was persuasive that thromboresistance probably was determined by an environment. It was concluded that while the physical properties of the blood-contacting surface of a test material did play a significant role in determining the potential for thrombus generation, at least four other factors were involved: the hematologic variables present in a given patient, flow geometry, flow rate and the amount of time which the patient's blood was exposed to a test material (31). These studies and those conducted in many other centers, while providing much useful information, failed to find a single "magic bullet" which would effectively solve the thromboembolism problem. In the 30 years which have elapsed since initiation of the investigation, many advances have been made in heart-lung machine design and mechanical circulatory support systems. While the incidence of thrombus buildup and embolization has been reduced, actual elimination of the problem still eludes us.

Division to Department: 1985 and Beyond

Randall Griepp became chief of the Division of CTS in August 1985. The circumstances relating to his recruitment are of some historical interest. In the preceding year a multi-departmental conference group of faculty convened by James Glenn (dean of the medical school and CEO of the medical center), had recommended that the institution undertake a broad transplantation effort, one of a number of areas being cardiac transplantation. Circumstance — that mother of opportunity — immediately brought to Litwak's mind the name of Griepp. Litwak had no clinical experience with the many challenges of cardiac transplantation, whereas Griepp had years of transplantation experience, having been both student (cardiac resident) and, thereafter, colleague of the veritable "father" of cardiac transplantation, Norman Shumway, at Stanford University Medical Center. Having been chief of the Division of CTS for 23 years, Litwak viewed the opportunity to recruit Griepp as a propitious time for a change of leadership.

Griepp's arrival at Mount Sinai opened a new era in cardiac surgery. He was able to persuade his former trainee and subsequent colleague, M. Arisan Ergin, to join him. As Griepp's trusted "right hand," Ergin quickly demonstrated his brilliance as surgeon, investigator, scholar and teacher, the totality of personal qualities which epitomize a superb surgical scientist. The steadily increasing cardiac surgical volume necessitated recruitment of additional CTS faculty over the next few years. Each physician was given primary oversight responsibility for a specific program. With rare exception, these young surgeons who had trained under Griepp were outstanding.

Division to Department

Within several years after Griepp had assumed leadership of the division, and in recognition of the progressive clinical growth and academic impact of the CTS effort, the recommendation by the chairman of the Department of Surgery (Arthur Aufses) that CTS be elevated to departmental status was approved by the Board of Trustees. The excellent general thoracic surgical effort was given full divisional status and continued to be directed initially by Paul Kirschner, later by Steven Keller, and more recently by Paul Waters, all of whom were distinguished in different areas of thoracic surgery.

Expanded Clinical Program

From the outset, it was apparent that Griepp intended to develop a multifaceted CTS program which included not only a cardiac transplantation effort, but the complete spectrum of cardiovascular surgery: the management of life-threatening aortic aneurysms and dissections, complicated valvular and coronary artery problems (which frequently coexist) as well as the broad range of pediatric cardiovascular lesions, particularly in neonates, in whom open cardiac corrections had become feasible and were being performed with increasing frequency.

In all of these endeavors Griepp planned on utilizing a method — hypothermia — which he had employed for almost two decades. His seminal investigative efforts had provided much of the solid basis which permitted its clinical use in complex open-heart surgery.

Hypothermia and Total Circulatory Arrest

Experiments initially reported a half century ago that hypothermia potentially would permit direct vision intracardiac surgery. The reduction of body temperature and metabolic activity of the brain and other vital organs has been extensively investigated and utilized clinically by Griepp and colleagues. They were the first to describe the use of hypothermia to protect the heart to permit a safe period during which the heart could be arrested (by cross-clamping the ascending aorta) to permit repair of complex congenital cardiac defects in infants and children (32). Griepp subsequently utilized the same principle to facilitate correction of complex cardiac and aortic lesions in adults. He utilized the heart-lung machine with a heat-exchanging device to precisely cool the patient's blood to sufficiently low temperature levels, thereby permitting the entire circulation to be totally arrested for approximately 45 minutes without overt damage to the brain and other vital organs. Griepp's successful experience with hypothermia and total circulatory arrest (HCA) in infants and children was most encouraging. He than adapted the method to resection and replacement of aneurysms and dissections of the aortic arch (33). His impressive results with the procedure represented a major contribution, since prior to publication of the Griepp HCA technique, the results of resection of the aortic arch had been dismal. The relative ease of the approach to lesions of the aortic arch led to adoption of the Griepp HCA method by other surgeons, with prompt improvement in their survival figures.

With broadening experience, all groups employing HCA found it occasionally necessary to exceed the generally agreed upon safety limit of 45 minutes. Although significant and prolonged brain damage in these cases fortunately was relatively uncommon at Mount Sinai, the experience provided the impetus for exploration of methods which hopefully would protect the brain during necessarily more prolonged periods of HCA. Funded by a multi-year grant from the National Heart, Lung and Blood Institute of the NIH, Griepp and colleagues developed experimental and clinical data which indicated that considerable residual metabolic activity of the brain could be demonstrated at temperatures previously considered to be sufficiently low to safely permit establishment of a period of circulatory arrest. They concluded that the previously considered "safe period" of HCA (45 minutes) was dangerously too lengthy. Moreover, they demonstrated that significantly better cerebral protection could be maintained, particularly during longer periods of HCA (beyond 45 minutes), with substantially lower blood temperatures (34 – 37). These and a number of other important technical details developed in the laboratory and subsequently utilized clinically by the Mount Sinai CTS group have been widely accepted and are now employed by cardiovascular surgeons throughout the world.

Aortic Aneurysms and Dissections

The number of patients with life-threatening aortic aneurysms or dissections referred to CTS as possible surgical candidates has resulted in the program being one of the largest in the United States. This program, currently approximately 2,500 patients, has included those requiring emergency surgery because of aneurysm rupture and those undergoing elective operation who, on periodic examination, had been found to have either rapid aneurysmal enlargement or a number of other significant risk factors (chest pain, chronic obstructive pulmonary disease, older age, and poorly controlled hypertension) highly suggestive of impending rupture.

In view of the increased operative risk in the presence of rupture, a prospective study of the natural history of patients with thoracic aneurysms was initiated in 1988 to provide a more rational basis upon which appropriate timing of surgery (i.e., pre-rupture) could be made. Conducted by Griepp, Ergin, Galla and colleagues, the study involved all aneurysm patients whose clinical condition had not prompted immediate surgery when first seen (38 – 41). By comparison of sequential aortic changes in computer-generated, three-dimensional reconstructions of serial computed tomographic (CT) scans (a method developed by CTS bioengineer, Richard deAsla), the pattern of aneurysmal enlargement could be precisely evaluated over time. While quite obviously, surgery was advised for all patients with rapid aneurysm enlargement, a key aspect of the study was the fact that the investigators also were able to derive an equation which could estimate a patient's annualized probability of rupture based upon both the rapidity of aneurysmal enlargement and the non-dimensional risk factors described above. Thus, these sequential studies made it possible to delay surgery with relative safety until such time as the data clearly documented a pre-rupture state. Following publication of the investigation, this equation was widely accepted by cardiovascular surgeons as a rational means of operative timing in all patients presenting with thoracic aneurysms.

The respect for the many contributions made by CTS faculty in the management of thoracic aneurysm is reflected in the consistent attendance of more than 1,000 surgeons at each of the sponsored Aortic Surgery Symposia held every other year since 1988 at the Mount Sinai Medical Center.

Growth of the Pediatric Cardiac Surgical Effort

The past decade and a half has witnessed a sharply increased volume of cardiac operations performed on infants and children. Currently, the department consistently has a pediatric operative volume of four to five open-heart cases each week. In view of the high mortality of many neonates and infants with complex congenital cardiac lesions diagnosed in the first year of life, shortly after Griepp's arrival, the department initiated an open-heart surgical program which specifically focused on this high-risk group. Directed by Griepp, many of the operative procedures were performed on patients who had conditions of deep HCA. Impressive results have been obtained in the correction of defects in deeply cyanotic, high-risk infants with a wide variety of severe lesions, such as pulmonary atresia with ventricular septal defect, various types of transposition of the great arteries and hypoplastic left heart pathology.

Of key importance in the success of this effort was the development of a close-knit CTS-Pediatric Cardiology team. The Pediatric Cardiology group (directed initially by Richard Golinko and later by Ira Parness) was augmented by a number of highly qualified individuals whose experience yielded consistently superb preoperative diagnostic information employing the latest echocardiographic, cardiac hemodynamic and angiographic methods. A pediatric cardiac surgical ICU was staffed on a full-time, twenty-four hour basis by highly experienced pediatric cardiologists, nurses and physician assistants whose specific forte was the management of post-cardiac surgical infants and children. As a key component of the team, over the next few years, Griepp augmented the CTS staff with surgeons of excellent technical competence and specific interest in pediatric cardiac surgery. Ali Sadeghi, a highly qualified surgeon (who had trained under one of this country's finest pediatric cardiac surgeons) was the first to join the Griepp team. In due course, two outstanding young men, both having completed the Mount Sinai CTS residency and subsequently having joined the attending staff, worked closely with Griepp in the cardiac surgical management of the pediatric cases. The first of these colleagues, Cid Quintana, remained on the staff for several years until he was successfully recruited for a leadership position at another institution. Upon his departure, another of Griepp's former CTS residents, Khanh Nguyen (who had spent a fruitful post-residency year as senior registrar on the cardiac surgical service at London's world-renowned Hospital for Sick Children) rejoined Griepp and continues to share responsibility for the pediatric cardiac surgical load.

The collaborative CTS-Pediatric Cardiology team effort has justifiably earned the admiration of other pediatric cardiac surgical programs in the United States and abroad. Indeed, a reflection of the high regard in which the combined team is held has been a number of invitational visits to Russia, Romania and China to perform open-heart procedures on critically ill infants and children.

Coronary Artery Bypass and Valvular Surgery in a Changing Patient Population

In the past decade a broadened spectrum of patients undergoing surgery for either intrinsic coronary artery or valvular heart disease (or both) has become clearly apparent. Patients who in earlier years would never have been considered surgical candidates are now accepted for surgery. Commonly, not only are they older (occasionally in their eighth and ninth decades of life), but they also manifest evidence of diffuse atherosclerotic involvement (coronary, carotid and peripheral arterial obstructive disease, and systemic arterial hypertension which was frequently accompanied by renal dysfunction) and sharply compromised ventricular function, often with coexisting mitral or aortic valvular pathology. Additionally, patients who in earlier years had undergone coronary artery bypass grafting (CABG) primarily with saphenous vein grafts are being accepted for reoperation because of graft occlusion, as are those patients in whom previous direct coronary artery catheter interventions (percutaneous transluminal coronary angioplasty or the more recently introduced atherectomy or stent procedures) have been unsuccessful. Despite frequently severe and multiple preoperative risk factors, the surgical results in these cases are being accomplished with surprisingly low mortality and long-term improvement (42). The higher long-term patency and consistent use of internal mammary arterial bypass grafts more than the less satisfactory saphenous vein grafts is a key component in the impressively effective surgical procedures performed at this institution.

Patients having surgery for either single or multiple valve pathology who are shown to have coexisting coronary artery disease consistently undergo both valvular and CABG surgery. Whenever possible, valvular repair rather than replacement is elected since it offers the major advantage of not requiring the patient to be placed on a permanent anticoagulant regimen, with the attendant drug-related complications.

Cardiopulmonary Transplantation and the Circulatory Support Effort

The institutional decision to establish a multi-organ transplantation program was one of the important factors which attracted Griepp to Mount Sinai. Having been an important participant in the extraordinary cardiac transplantation program at Stanford University, Griepp, upon his arrival at Mount Sinai, immediately established a cardiac transplantation team. He, in collaboration with Valentin Fuster (chief of the Division of Cardiology) and Gail Weissman (vice president, Nursing), quickly organized an effective multi-departmental transplant group. Steven Lansman, who previously had trained under Griepp and who recently had joined the CTS faculty, was selected to direct the program. Assigned to coordinate the myriad medical details so essential to the success of any transplantation effort were Marc Cohen (Division of Cardiology) and Deborah Matza (Department of Nursing). Months of intense planning preceded Mount Sinai's first clinical cardiac transplantation, which was successfully performed on August 28, 1986. Fourteen years later, the patient was in excellent health with no evidence of cardiac rejection. At this writing, Mount Sinai has one of only two approved cardiac transplantation programs in the New York City area.

A major and continuing problem experienced by all transplantation programs has been the relative dearth of suitable donor organs for the many desperately ill patients awaiting life-saving transplantation. For a rapidly deteriorating cardiac patient whose probable survival could be projected to a period of only days, the deployment of a ventricular assist device (VAD) as a "bridge-to-transplant" has been shown to be a life-saving measure until a suitable donor heart becomes available. Three types of support devices have been employed, but the majority of patients have been supported with the Novacor® device, a superbly designed left ventricular assist device (LVAD), which was first utilized at Mount Sinai in 1996. At this writing, the unit has been employed for periods of up to 272 days in 38 patients awaiting cardiac transplantation. The Novacor® LVAD is sufficiently compact to permit patients to be ambulatory in the hospital, and on occasion, to be discharged from Mount Sinai to their homes while awaiting the news that a suitable donor heart is available.

Pulmonary transplantation became a potential with the recruitment of Ali Sadeghi, an experienced transplant surgeon who joined the CTS faculty in 1990. Sadeghi directed the first combined transplantation effort in which the heart and one lung obtained from a single donor were separately implanted in two critically ill patients. He also performed the first combined heart and lung transplant on a sixteen-year-old patient with advanced congenital cardiopulmonary disease (1992). There also have been three important recent additions to the surgical component of the transplantation group. In April 1999, Paul Waters was appointed professor of CTS, chief of the Division of General Thoracic Surgery and surgical director of the Lung Transplantation Program in the Recanati/Miller Transplantation Institute. Waters is one of the world's most experienced surgeons in lung transplantation. Two other surgeons who had recently joined the CTS faculty were assigned to collaborate with Waters in the lung transplantation effort. Both surgeons had received their CTS tutelage at Mount Sinai under Griepp and both, upon completion of their training, had been accepted for postgraduate study in institutions with world-renowned transplantation reputations. Jock McCullough spent many months working with the highly experienced heart and lung transplantation team at the University of Pittsburgh and David Spielvogel spent a year at the Harefield Hospital (England) working with Sir Magdi Yacoub, the internationally renowned transplant surgeon and unit director.

The passage of time has inevitably been accompanied by a number of personnel changes in the CTS transplant group. In recent years, Alan Gass (division of Cardiology) has assumed directorship of the medical and cardiologic aspects of the transplantation program and collaborates closely with Lansman, his surgical colleagues, and two extraordinary nurses, Mary Courtney, R.N. and Rhodora Correa, R.N. This trio conducts intensive preoperative screening of potential transplantation candidates, carefully follows each patient in the hospital immediately after transplantation, and also maintains careful surveillance of each patient following discharge, with continuing concern for the early detection and management of any evidence of organ rejection.

The fifteen years which have elapsed since Mount Sinai's first cardiac transplantation have witnessed progressive growth of the entire transplantation effort. At this writing, 279 cardiac transplants and 8 combined heart and lung transplants have been performed. The expanding scope of the transplantation program is further reflected by the fact that 15 lung (single and double) transplants have been carried out. Despite the difficult donor organ supply problem, cardiac and pulmonary transplantation at Mount Sinai is a program which justifiably is well respected nationally.

The Research Laboratory (1985 to Present)

Guided by Griepp's continued input over the past decade and a half, day-to-day planning and direction of all laboratory activities was assigned to Ali Sadeghi in the early 1990s, then to Jock McCullough, and, more recently, to David Spielvogel. Over the years, improved understanding and development of possible management approaches to a number of important and unresolved clinical issues have been the central focus of all of the studies. The consistent use of HCA by Griepp and colleagues in the conduct of cardiac and aortic operations, and appreciation that the incidence and severity of neurologic dysfunction correlated directly with the duration of HCA, provided the impetus over the past 15 years for a continuing series of laboratory studies (funded by the NIH). It had two goals: to enlarge our understanding of cerebral pathophysiologic derangements associated with HCA, and to develop management strategies which would utilize methods developed in the experimental laboratory to permit consistently safe use of HCA for 60 minutes or longer.

Utilizing two reliable canine and porcine experimental models developed over a period of years, researchers determined cerebral hemodynamic and metabolic variables and parameters as well as brain stem and spinal cord activity before, during and after HCA. There was excellent correlation between cortical electrophysiologic recovery, clinical behavior of the animals and histopathologic changes (34–37). Thus, the models provided a means of rigorously comparing a variety of management techniques with respect to both physiology and outcome.

A number of important laboratory observations which were made over the years have directly influenced changes in clinical management. The experimental studies demonstrated unequivocally that the protective effect of hypothermia could be enhanced by using more profoundly hypothermic temperatures than those which had been widely employed clinically previously. Of importance was the fact that even under laboratory conditions in which sharply lower blood temperatures were employed, there was evidence that some degree of residual, albeit reduced, cerebral metabolic activity persisted. The implications of the studies were that both the perfusion temperature and the permissibly safe period of HCA had to be lowered, conclusions which have been applied clinically by Griepp and colleagues (43, 44). Currently, investigations are in progress which seek to better understand events and cellular pathologic alterations which are discernible when a cerebral ischemic insult has occurred. The possibility of preventing or mitigating the process of cell damage by utilizing pharmacologic inhibitors of adverse enzymatic activity which play a central role in cell death is under investigation (45–47).

Another important laboratory study sought to understand factors underlying paraplegia, a devastating complication occasionally seen following resection and replacement of segments of the descending thoracic aorta. The clinical procedure requires proximal (upstream) clamping of the aorta for varying periods of time, which necessarily interrupts critical blood flow to the spinal cord, with the resulting potential for paraplegia. An experimental porcine model was developed which precisely simulated varying anatomic and operative conditions encountered when descending thoracic aortic aneurysms and dissections are operated upon (48). The studies revealed that a prolonged period of aortic cross-clamping, with failure to provide blood flow to both intercostal and lumbar arteries (which was shown to be critical to maintenance of spinal cord integrity), is the single most important factor determining the probability of paraplegia. Further, it was determined that it is vital that those arteries providing essential blood flow to the spinal cord be reimplanted into the polyester graft utilized to replace the diseased aortic segment. The results of the experimental study have prompted significant modifications in the operative approach to these cases (49, 50).

The laboratory also studied two specific problems relating to pulmonary transplantation. The possibility that single lung transplantation might be an acceptable therapeutic option for children with specific types of complex congenital heart disease with accompanying poorly developed or absent connections to the lungs prompted an experimental study in which a single lung was successfully transplanted under conditions which simulated that found in severely cyanotic infants and children suffering from the cardiopulmonary lesion described above. The possibility of transplantation of a living related adult donor lobe into a child suffering life-threatening pulmonary disease prompted a second successful laboratory study in which conditions were established in which the animal was entirely dependent on the transplanted lobe or lung. Both types of transplantation studies have the potential for clinical application in the immediate future.

Precise conduct of the research protocols described above required the presence of competent staff with a keen interest in research and the surgical expertise required to establish complex experimental models. A two-year competitive research fellowship was established by Griepp some years ago in which interested surgical investigators were recruited from both the Mount Sinai residency programs (Peter Midulla and Dale Levy) and abroad. Investigators from abroad included Alejandro Gandsas (Argentina), Otto Dapunt and Marek Ehrlich (Austria), Tatu Juvonen (Finland), Christian Hagl (Germany), N. Zhang (People's Republic of China) and M.E. Yerliogl (Turkey). Special mention must be made of a remarkably gifted Mount Sinai School of Medicine student, Craig K. Mezrow, who found himself unexpectedly assuming the role of senior investigator while in the midst of his medical studies. Granted permission for a "sabbatical" absence, which lengthened to a period of five years before he returned to complete his medical studies, young Mezrow played a key role in both the design and conduct of all of the demanding investigations carried out during those years.

The effectiveness and productivity of the laboratory was immeasurably augmented by collaboration with a number of faculty members from other departments: Donald Weisz and Rosario Zapulla (Neurosurgery), David Wolfe (Pathology), Carol A. Bodian (Biomathematics), Nadine A. Tatton (Neurology), and Ian Holzman (Pediatrics).

Conclusion

It has been ninety years since thoracic surgery began at Mount Sinai with Howard Lilienthal's first open chest procedure employing a ventilator designed and constructed by Charles Elsberg. The years that followed have seen incredible advances in both general thoracic and cardiovascular surgery, many of the seminal contributions having been made by Mount Sinai staff members. Notwithstanding all that has been done, the new millennium offers promise that in the fullness of time, all that has been accomplished will pale beside what is yet to be.

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

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