The farther backward you can look, the farther forward you are likely to see."

—Sir Winston Churchill

It is a high privilege to have served as President of the North American Chapter of the International Society for Cardiovascular Surgery for the past year, quite an eventful one in our specialty. Please permit me to begin by expressing a few words of appreciation to persons who have been important to my professional career over the past 40 years: to my mentors during residency at the Columbia-Presbyterian Medical Center, especially the late Arthur B. Voorhees, Jr.; to my senior colleague at Emory for many years, Garland Perdue; to other faculty associates in the Division of Vascular Surgery at Emory; to our 34 vascular surgery trainees, many of whom are present here today; and, finally, to my own family, especially my wife, Flo, without whose support and forbearance it would not have been possible, and certainly not as much fun. Indeed, I am also indebted to every colleague in this room for your enrichment of the discipline of vascular surgery, our chosen life’s work.

Now, to the subject at hand, the foundations of modern aortic surgery. As some of you know, the history of vascular surgery has been one of my interests for a number of years, sparked, I am sure, by friendship during training and in subsequent years with Arthur Voorhees, one of the true innovators of surgery. I have been fortunate that my own professional career has spanned almost the entire modern period of our specialty, since I graduated from medical school exactly 40 years ago this month. For some time I have felt that the current generation of young vascular surgeons should have a better knowledge of the birth and early maturation of modern vascular surgery to appreciate more fully the contributions of our pioneers. Standard infrarenal aortic aneurysm repair has become almost routine to vascular trainees of the 1990s. With expert anesthesia, superior instruments, reliable prostheses, autotransfusion devices, and critical care units, most aortic operations are performed expeditiously, and the patients recover uneventfully and are discharged on the appropriate day as defined by their clinical pathway. Believe me, the early days of aortic surgery were not so routine or predictable. Some colleagues here today, maybe even a few senior to me in years of practice, can well remember the courage, perseverance, and self-sacrifice necessary for both the surgeon and the patient to undertake aortic surgery in those early days. It is exactly that period in our history to which I wish to focus your attention this morning.

In preparation for this talk, I have consulted the literature, of course, but I have also been privileged to interview a number of senior surgeons who were important contributors in the decades of the 1950s and 1960s. In addition, I have been able to visit the headquarters of several of the largest graft fabricators in the industry. Finally, through the generosity of
Art Voorhees’ widow, Margaret, I have received trusteeship of his slide collection and other memorabilia of his career. For all of these various opportunities, I am deeply grateful. Before proceeding, I must pause to commend to you two recently published books on the history of vascular surgery: Band of Brothers, conceived and started by Andrew Dale before his death and finished by his associates, George Johnson and James DeWeese, and Clio: The Arteries, an encyclopedic work compiled by Wiley Barker.\(^5,\(^3\) I must also express one proviso. There is always the possibility in a presentation of this type that the speaker will fail to include an important contributor or to ascribe sufficient primacy to his work—for any such failings, I apologize in advance. Finally, I would be remiss if I did not acknowledge the invaluable assistance of Jesse Thompson in the quest for historical accuracy.

Before we jump directly to the middle of this century, allow me to back up long enough to describe some of the earlier foundations of our discipline. Those of you who have visited the ancient cities of Jerusalem or Luxor know that many modern sites are built on foundations of previous civilizations (Figs. 1 and 2). Such is the case with modern vascular surgery, as well. It is safe to assume that among the foundations of vascular surgery one must include the seminal work of Carrel and Guthrie, early in this century at the University of Chicago, and later at the Rockefeller Institute, where Carrel performed homograft aortic replacements and other vascular procedures on experimental animals.\(^4\)\(^-\)\(^6\) For his pioneering achievements in vascular surgery and organ transplantation, Alexis Carrel was awarded the Nobel Prize for Physiology and Medicine in 1912. Jose Goyanes\(^7\) of Madrid had performed the first successful replacement of a human artery in 1906, and later at the Rockefeller Institute, where Carrel banded the aorta for control of a painful aneurysm. Rigid tubes made from a variety of materials had been used for years in an effort to preserve vascular continuity, with uniformly poor results. Arthur Blakemore of the Columbia Presbyterian Medical Center in New York resurrected a previously described method for the introduction of wire and application of an electrical current to induce thrombosis of the aortic aneurysm sac.\(^12\)\(^-\)\(^14\) In 1938, he reported wire insertion in 11 patients who had thoracic or abdominal aortic aneurysms; most eventually died of aneurysm rupture, but one patient survived for 2 years.\(^15\) In the same period, other surgeons used a variety of materials to wrap aneurysms in an effort to retard expansion or to induce periarterial fibrosis, which might secondarily serve to arrest enlargement. Cellophane wrapping was investigated by Pearse,\(^16\) Harrison and Chandy,\(^17\) and Abbott.\(^18\) Other materials, including fascia lata, skin, and polyvinyl sponge, were also used, but largely to no avail because the aneurysms grew relentlessly despite circumferential wrapping.\(^19\)\(^-\)\(^21\) Even after prosthetic graft materials later became available, we found at Emory that the wrapping method was no match for the lateral pressure exerted by an expanding aneurysm.\(^22\)

But to drop back to other so-called alternative techniques, some surgeons had chosen the more direct approaches of ligation or banding of the aorta or the tangential excision of suitable saccular aneurysms. Halsted was an advocate of banding. He banded the aorta for control of a painful aneurysm in 1910, only to have the patient die 6 weeks later when the band eroded the aorta.\(^3\) As early as 1936, Leriche advocated terminal aortectomy and bilateral lumbar sympathectomy for treatment of aortic occlusive disease, in the belief that thrombus in the aortic lumen tended to migrate and also that thrombus incited an inflammatory response with peripheral vasoconstriction.\(^11\) Dan Elkin and Fred Cooper of Atlanta described a limited experience with this treatment.\(^23\) Geza de Takats of Chicago summarized the cases of 37 patients who had undergone total aortic ligation over the preceding century, only eight of whom had survived for 6 months or longer.\(^20\) In general, the prevailing attitude concerning aortic surgery was quite pessimistic, as reflected in I. A. Bigger’s address to the American Surgical
Association in 1940: “Judging from the literature, only a small number of surgeons have felt that direct surgical attack on aneurysms of the abdominal aorta was justifiable, and it must be admitted that the results obtained by surgical intervention have been discouraging.”

The experiences of World War II did little to advance the cause of aortic surgery, but enthusiasm increased somewhat in 1944 when Alexander and Byron of Ann Arbor reported the first successful proximal and distal ligation of the thoracic aorta for removal of a fusiform aneurysm. In the same year, Clarence Crafoord of Sweden successfully resected and performed an end-to-end reanastomosis for coarctation of the thoracic aorta, another important foundation stone in the edifice of vascular surgery.

Crafoord’s feat was repeated in this country the following year by Robert Gross of Boston. Harris Shumacker, then of New Haven, Conn., performed a similar successful resection and reanastomosis in 1947, after his release from military duty. It should be noted that Charles Hufnagel of Washington, D.C., experimented with permanent intubation of the thoracic aorta with rigid tubes of methacrylate, but results were marred by frequent erosion of the vessel.

Denton Cooley and Michael DeBakey of Houston successfully performed lateral aortorrhaphy of a saccular aneurysm of the thoracic aorta, and Henry Bahnson of Baltimore affirmed the efficacy of that approach in highly selected patients. At that juncture, it was obvious that further progress would not be possible without a suitable flexible conduit to replace resected segments of the thoracic or abdominal aorta. Once again, Robert Gross deserves credit as a major innovator, because he was the first to use harvested, preserved homografts for treatment of coarctation of the aorta and to establish an aorta-to-pulmonary artery shunt for alleviation of tetralogy of Fallot. By his contributions, the modern era of vascular grafting began.

Two years later, in 1950, Jacques Oudot of Paris performed the first resection and homograft replacement of a thrombosed aortic bifurcation, fulfilling the prophecy of his fellow countryman Leriche 27 years earlier. The following year, Charles Dubost and associates, also of France, treated an infrarenal abdominal aortic aneurysm by insertion of a thoracic aortic homograft that had been preserved for 3 weeks: “Three months after the operation the patient was in perfect health.” DeBakey and Cooley performed the first similar case in this country 1 year later, only days after Brock’s first repair in Britain. Soon thereafter, Brock described the arduous state of aortic surgery: “These cases are long, anxious, tiring, one might even say exhausting....” It should also be noted that during that period Charles Rob and Felix Eastcott were actively involved in developing the first frozen human artery bank at St. Mary’s Hospital in London.

Ormand Julian and associates of Chicago successfully operated on an occluded aorta with homograft insertion in 1952. Henry Bahnson is credited with the first successful repair of a ruptured aortic aneurysm in 1953. Thereafter, enthusiasm for homografts swelled over the next decade but then waned because of frequent degeneration of the grafts, as well as difficulty with the harvesting and banking of the grafts. Gross had acknowledged in a preliminary report that the short-term results of human homograft implantation, up to 3 years, had been gratifying but that “no final conclusion should be made until these patients have been followed for several decades.” In a summary report of extensive experience with arterial homografts, Szilagyi and colleagues observed serious deterioration of structural integrity over time and predicted their failure as a vascular substitute.

It was exactly in this period that Arthur Voorhees made his momentous contribution to the foundation being laid in our specialty. Art had completed a straight internship in surgery at Presbyterian Hospital in 1947 and remained an additional year to work in the research laboratory of Arthur Blakemore while awaiting an assignment at the Brooke Army Medical Center to begin the following year. Under Blakemore’s direction, Art was assigned the difficult task of developing a mitral valve replacement in a canine model. In the absence of cardiopulmonary bypass, the procedure was technically demanding,
requiring blind placement of silk support sutures to function as “chordae tendinae” for the homograft valve. In the spring of 1948, while performing an autopsy on one of the animals several months after valve implantation, Art noticed that a silk suture bridging the ventricular cavity was coated with a glistening layer of what appeared to be endocardium. In a moment of inspiration, he speculated that “a piece of cloth might react in a similar way.”

Later, he wrote: “As an outgrowth of this observation it was conceived that if arterial defects were bridged by prostheses constructed of a fine mesh cloth, leakage of blood through the walls of the prosthesis would be terminated by the formation of fibrin plugs and would thus allow the cloth tube to conduct arterial flow.” Art acknowledged that he was not aware at that time of Guthrie’s suggestion 30 years earlier that an implant need serve only as scaffolding for ingrowth of host tissue. Evidently, he was also unaware of the earlier reports by Dorfler in Germany and Carson in the United States that silk sutures in the lumen of an artery sometimes became encapsulated by a fine veil coating. Of course, none of these earlier observers had made the epochal leap from an interesting experimental observation to the concept of a fabric tube, as proposed by Voorhees. His first effort in the animal laboratory using a conduit fashioned from his wife’s silk handkerchief was only partially successful. Then during his 2-year tour at the Surgical Research Unit in San Antonio, Tex., Art performed a limited number of experiments using nylon parachute cloth as an aortic prosthesis. From that experience he concluded: “The cloth had to be strong, inert, stable, of the right porosity, supple, and yet easily traversed by a fine needle.”

Upon returning to Presbyterian Hospital in 1950 to begin his surgical residency, Art resumed his work on vascular grafts in Blakemore’s laboratory. Following advice from an orthopaedic resident, Wallace Blunt, Art secured a bolt of Vinyon-N fabric from the Union Carbon and Carbide Corporation. The plastic material, Vinyon-N, had been designed to be used as sail cloth but had proved too inert to hold a dye and thus had no commercial value. Art found it quite suitable for his experiments, however, in which he prepared a variety of straight tube grafts on Margaret’s sewing machine and then sutured them into the abdominal aortas of mongrel dogs. Early implantations were demanding and tedious: “We were often hard pressed to separate our technical ineptitude, the perversity of our handcrafted materials, and the variations of host response, in analyzing our end results.” By the end of 1950, implants had been performed in 30 dogs, three quarters of which survived the operative procedure. Animals were killed according to a predetermined schedule ranging from hours to months, and eventually up to 8 years, to provide a portrayal of graft healing. By the middle of 1951 there were sufficient data to prepare an optimistic preliminary report that was published in the Annals of Surgery in March 1952: “The use of tubes constructed from Vinyon “N” cloth in bridging arterial defects,” coauthored by Voorhees, Jaretzki, and Blakemore. Later that year, when Art was a senior resident, the first synthetic graft implantation was performed in a patient with a ruptured abdominal aortic aneurysm. Blakemore had planned to use an aortic homograft, but because none was available Art prepared a bifurcated graft of Vinyon cloth. Although the patient died of coagulopathy, the graft was intact and patent at autopsy, providing sufficient encouragement to implant a graft in a second patient electively a few weeks later; the patient survived. Over the following year, 16 additional aneurysms were similarly treated, with an impressive 56% survival rate. At about the same time, Harris Shumacker successfully repaired a ruptured abdominal aortic aneurysm with a conduit prepared from a sheet of nylon. To fully appreciate the achievements of that era, one must understand that hemostasis was a constant challenge both because of the variability of fabrics and because of the misconception that aneurysms had to be completely excised to avoid contamination. The early grafts frequently leaked from their home-sewn seams or frayed at the cut ends, which prompted Voorhees and others to heat-seal the ends or to

Fig. 2. An Islamic mosque has been constructed on the ruins of the ancient temple at Luxor, Egypt.
turn back the grafts, French-cuff style, to facilitate suturing.

In March 1954 Art reviewed the Presbyterian data at a Symposium on Vascular Transplants sponsored by the National Research Council. Panelists included Robert Gross, Charles Hufnagel, Harris Shumacker, and Michael DeBakey. It was evident that a new era had indeed begun in vascular surgery. One month later, Blakemore and Voorhees presented both animal and human data at the American Surgical Association meeting, which were published later that same year in the *Annals of Surgery*. The new field of vascular prostheses had been opened, and it expanded rapidly under sponsorship of a number of influential American surgeons. Other prosthetic materials were introduced by the industry, and surgical meetings and journals during that time focused on textile lexicon, debating the relative merits of porosity, denier, taffeta, crimp, and other elements of fiber fabrication. Vinyon-N rapidly gave way to competitive fibers with more favorable physical properties, including Orlon, Teflon, nylon, and Dacron. Although vascular surgeons were key to these developments, we must acknowledge that industrial entrepreneurs and textile engineers were important collaborators. In the early days of vascular graft insertion, the materials were not custom-made for use as medical devices; the yarns used and most of the early conduits were, in fact, “borrowed” from commercial textile applications. Voorhees lamented the absence of industrial support for development in the initial phase: “Materials were procured wherever they could be found; tubes were cut and sewn in scrub rooms...unsophisticated, often cranky, prototypes...” (Fig. 3).

Michael DeBakey and associates in Houston rapidly became the leading advocates of Dacron, a fabric well established in the garment industry. In cooperation with Professor Thomas Edman of the Philadelphia College of Textiles and Science, DeBakey sponsored the development of a knitting machine capable of producing seamless knitted Dacron tubes in various sizes and in the form of bifurcations. Within less than 4 years, he and his colleagues at Baylor had implanted more than 1000 synthetic grafts with a 90% success rate. One must remember that progress could be made quickly in those days in the development of new devices because the pioneers were not handicapped by Food and Drug Administration oversight or by the threat of legal entanglements at every turn. In 1960 the U.S. Catheter and Instrument Company began production of DeBakey grafts; eventually, C.R. Bard, Inc., took over the manufacture and distribution of DeBakey grafts worldwide. Twelve years later, Bard also introduced the first version of a filamentous velour prosthesis, designed by Lester Sauvage of Seattle.

Sterling Edwards, another name synonymous with early vascular graft innovations, heard Voorhees’ paper at the American Surgical Association meeting and, back in Alabama, developed a relationship with James Tapp, a physical chemist at the Chemstrand Corporation. It was Tapp who introduced the concept of crimping cylindrical grafts to allow greater flexibility without kinking and to provide better handling characteristics. The Edwards-Tapp braided nylon graft was fabricated by U.S. Catheter and Instrument Corp., headed by Norman Jeckel. Eventually, Edwards switched his preference from nylon to Teflon, because the latter had shown superior tensile strength in studies reported by Harold Harrison of Atlanta; Teflon prostheses remained commercially available until 1979. Edwards in more recent years told Andrew Dale: “You and I may have been tremen-
dously fortunate to have lived through the most exciting era in surgery that there has ever been.”

Ormond Julian of Chicago and Ralph Deterling of New York collaborated with William von Liebig, the general manager of Meadox von Liebig, an upholstery and drapery fabric manufacturer in New Jersey, to design and produce fabric grafts. Of that period, Deterling somewhat irreverently declared: “It seemed almost heretical that the introduction of cloth as a vascular replacement allowed people with practically no background in the field to go to Macy’s and ask a clerk, ‘What’s the best thing for an aorta?’” He also astutely observed: “The aggressiveness of the vascular surgeon is a tremendously important thing. The willingness at the end of a hard day to go back and repair a graft if it shows early failure is something that separates the men from the boys.” From their beginnings in 1954, the first woven grafts manufactured by Meadox were distributed by the Ethicon Division of Johnson & Johnson. By 1961, William von Liebig emerged as the new owner, and Meadox Medical, Inc., was launched, later to team also with Denton Cooley in production of the graft line that carries his name. Liebig credited erstwhile associate Walter Golaski of Philadelphia for a number of important technical developments during the startup phase of Meadox grafts. Emerick Szilagyi, working first with John Sidebotham of Philadelphia, and later with Meadox, produced a woven Dacron graft of specially elasticized yarn that proved to be highly porous but quite efficacious, providing 97% patency at 3 to 5 years after implantation of 286 aortoiliac grafts.

A variety of other prosthetic materials and fabrications were tried in those early years. Norman Shumway et al. of Minneapolis experimented with rolled sheets of polyvinyl sponge (Ivalon), and Shumacker and colleagues of Indianapolis used layered nylon, incorporating a thin polyethylene film to provide hemostasis. Allan Callow of Boston called attention to the need for better control of the manufacturing process of vascular grafts, while Sterling Edwards warned that it was not feasible to continue to tailor-make grafts—the industry had to develop adequately tested, prefabricated tubes in a variety of shapes and sizes. Deterling and Bhonslay of New York summarized physical and chemical data as well as in vivo experiments on a wide range of fabrics in 1955, concluding that “...Dacron appeared to have the most desirable qualities in the overall evaluation.” Dacron, a polyester polymer developed about 1939, had been introduced in the United States by E. I. DuPont de Nemours and Company, Inc., in 1946 and was adapted to vascular applications 8 years later. It consisted of a basic 70-denier yarn, 54 filaments to the strand, texturized to provide bulk and elasticity. In a report to the Society for Vascular Surgery meeting in 1956, Oscar Creech, Chairman of a Committee for the Study of Vascular Prostheses, concluded that Dacron and Teflon were the most satisfactory materials for use at that time, because Vinyon-N was no longer commercially available and because both nylon and Orlon exhibited significant loss of tensile strength over time. Soon thereafter, Sigmund Wesolowski of New York and coworkers drew attention to the importance of porosity of synthetic grafts, describing a method still in use today to quantitate that characteristic by the volume of water filtered per minute, per square centimeter of fabric, at a pressure of 120 mm Hg. There have been still other modifications of textile grafts over the succeeding decades: alignment marks in the grafts, internal and external velours, exterior reinforcement, tapered configuration, impregnation with blood-tight barriers, antibiotic bonding, and efforts to achieve antithrombogenic surfaces. Henry Haimovici of New York may have put these modifications into proper perspective, however, when he emphasized that host factors ultimately may be more difficult to overcome than to achieve an ideal vascular graft. He predicted: “Expanded use of vascular replacements will take place and will depend on three major factors: (1) improvement in grafting material; (2) proper selection of patients for surgery; and (3) adjuvant prophylactic treatment of atherosclerosis.”

Art Voorhees, also, had recognized the limitations of the outflow system of the host and challenged us to address the issue of angiogenesis:

“I believe that our focus in vascular research should now center on improving the flow of blood to the arterioles and the capillary bed; not only as we do presently by increasing pressure in the distributing artery, but also by increasing the volume of the outflow tract. Why can’t we unlock the secret of the blood-vessel proliferation of a capillary hemangioma, the rapid collateralization of arteries in the child, or the succulent plethora of blood vessels where portal and systemic blood meet in a patient with portal hypertension? Our thrust for research and development should not be arrested by the quest for an ideal replacement for the arterial delivery system alone.”

Looking back over the phenomenal accomplishments of the first decade of modern vascular surgery, Hufnagel observed: “Only the few is given the
great gift of perception which permits them to introduce and demonstrate the feasibility of new ideas. 92

In closing, allow me to mention one cautionary note. Just when vascular surgeons had become comfortable with the durability and availability of Dacron prostheses, we were shocked to hear that the future supply of the raw material is threatened. Dupont, the solitary source of Dacron for 50 years, has withdrawn the textile from medical use as a result of product liability issues. Although the graft applications of Dacron appear to have constituted only a small fraction of Dupont’s total market, inordinate business expenses for legal defense of the material were cited as the rationale for withdrawing the product. It is said that the major graft makers presently have only a 3-year stockpile of Dacron yarn with which to continue to manufacture grafts. At that point, they will have to switch to alternate sources of polyester. We have been assured by the industry, however, that other raw material sources have been identified and that surgeons will not discern any difference in the quality of the new grafts. One can only hope that their predictions are true. Meanwhile, an agency called The Alliance of Patients, Physicians, and Industry for Access to Medical Devices has urged Congress to address biomaterials shortages and other related tort reform issues. As you know, biomaterials legislation was incorporated into a broader product liability bill that was passed by Congress last year but vetoed by the President. With the current Congress, the Biomaterials Access Assurance Act has been redrafted by Representative George W. Gekas (R-Pa.). The President. With the current Congress, the Biomaterials Access Assurance Act has been redrafted by Representative George W. Gekas (R-Pa.). The

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REFERENCES


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The foundations of vascular surgery include the seminal work of Carrel and Guthrie early in the 20th century at the University of Chicago and later at Rockefeller Institute. Alexis Carrel performed homograft aortic replacements and other vascular procedures on experimental animals. For this work as well as his experiments in organ transplantation, he was awarded the Nobel Prize for Physiology and Medicine in 1912. The first successful replacement of a human artery was performed by Jose Gioyanes of Madrid in 1906. He used a venous autograft to bridge an excised popliteal aneurysm. Address John Jones Surgical Society Department of Surgery, MHB-7SK 177 Fort Washington Avenue. New York, NY 10032 Tel: 212.305.2735 Fax: 212.305.3236. Visit the Department of Surgery. This shareable PDF can be hosted on any platform or network and is fully compliant with publisher copyright. Presidential address: The foundations of modern aortic surgery. Robert B. Smith III. Journal of Vascular Surgery, January 1998, Elsevier. DOI: 10.1016/s0741-5214(98)70286-1. The authors haven't yet claimed this publication. Presidential address: the foundations of modern aortic surgery. J Vasc Surg 27:7-15, 1998. Warren R. Surgery. Van Damme, the modern student of abdominal vascular anatomy, states the following about the celiac axis in his beautiful paper Behavioral Anatomy of the Abdominal Artery. The celiac trunk does not trifurcate into its three main branches as is usually depicted, but it bifurcates into the splenic and the (common) hepatic artery. From the International Society for Cardiovascular Surgery, North American Chapter. Presidential address: The foundations of modern aortic surgery. Robert B. Smith III, MD, Atlanta, Ga. The farther backward you can look, the farther forward you are likely to see. Sir Winston Churchill. It is a high privilege to have served as President of the North American Chapter of the International Society for Cardiovascular Surgery for the past year, quite an eventful one in our specialty. Please permit me to begin