VASCULAR SURGERY
PRINCIPLES & TECHNIQUES

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PREFACE

Almost three decades have now elapsed since the new field of vascular surgery started to assert its individuality. This specialty evolved as a result of significant developments in diagnostic methods and new surgical techniques. Through its often spectacular achievements the modern surgery of blood vessels, along with that of the heart, today occupies a select place in contemporary Medicine. Its increasing role in the treatment of vascular diseases is reflected by the fact that at least 73,000 reconstructions of major arteries are performed in the United States every year, as was recently reported by the Inter-Society Commission for Optimal Resources for Vascular Surgery. These figures illustrate the magnitude of only some of the main problems in vascular surgery.

Recognition of a new field of endeavor, notwithstanding its significance, is always achieved slowly. The history of surgical specialties is replete with such evidence, and vascular surgery is no exception. Within the past few years, however, the leading Vascular Societies, recognizing the need for better education and training of those entering this field, have evolved guidelines for the achievement of standards of excellence. As a result of this concerted effort there is a crescendo movement at present toward fulfilling this goal by establishing a specialty certification board.

Before the advent of the present era, the few surgical approaches available for managing vascular diseases were carried out within the framework of general surgery. But with the introduction of arterial reconstructive procedures progressively encompassing all vessels of the body, it became obvious that the new vascular techniques, though most often achieving spectacular results, do sometimes carry great risks to limb and life. The critical nature of these techniques is abundantly dramatized by the existence of only a narrow margin of error between success and failure when compared to most areas of general surgery. Proficiency in carrying out these exacting procedures requires a broad clinical background and superior technical skill.

While the training programs in other surgical specialties are well standardized today, those in vascular surgery are still far from having received similar implementation. The present-day often fragmentary and limited training in vascular surgery through a rotating general surgical residency does not provide the desired program for acquiring a comprehensive knowledge of this specialty. As in other surgical fields, postgraduate and postresidency vascular fellowship training often represents the main avenue for achieving competency in this discipline.

In his search for more knowledge of a particular aspect of vascular surgical techniques it is often hard for the general surgeon or the surgical resident to know where to begin to look up the most pertinent source of information. To some extent the above considerations prompted this book, which was conceived to provide a comprehensive presentation of all aspects related to vascular diseases and their surgical management.

In the preparation of guidelines for this multiauthored book, one of the major goals was to achieve uniformity in the presentation of the various chapters. Such goals were perhaps best expressed by Joseph Pulitzer, who advised his journalist profession how to present successfully their stories to the public. He said, "Put it before them *briefly* so that they will read it, *clearly* so that they will appreciate it, *picturesquely* so they will remember it and, above all, *accurately* so they will be guided by its light."

The *approach* for achieving an all-inclusive textbook on this ever-expanding specialty required a large up-to-date survey of all aspects of this field. To do justice to the diversity of the topics and to offer a spectrum of the best available knowledge, it was desirable to entrust some parts of this book to a number of contributors distinguished for their pioneering work and expertise in some specific areas. A multiauthored but well-integrated book should thus offer great advantage to the reader by providing him with the various authoritative options available for a given problem, whether common or uncommon.

The *scope* and the *level* of the contents of this book are designed not only for the experienced vascular and general surgeon, but also for the surgical residents in need of an all-inclusive text and atlas of vascular procedures.

The *contents* of this book are divided into eight parts, some of which include information not usually found in similar textbooks. Besides dealing in detailed fashion with all vascular techniques, it also devotes sizable sections to the basic subjects of the various surgical and biological problems as related to vascular disorders.

Part One on basic considerations includes ten chapters dealing with various aspects ranging from the history of vascular surgery and methods of evaluation of the patient and his vascular disorders to the anesthetic management for the various types of operation. Thus, it reviews the principles of angiography, the biologic behavior of arterial replacements, principles of hemodynamics, thrombogenesis and anticoagulation as related to arterial reconstruction, and many other basic considerations underlying vascular techniques.

Part Two deals with the surgical anatomy of the arteries and the methods for their exposure. This section is designed to fill a serious gap, since most surgical residents and general surgeons, as stated by Daniel Elkin, are "Woefully lacking in anatomic knowledge, particularly as it relates to blood vessels, peripheral nerves and even the musculature of the extremities" (JAMA *132*:421, 1946). This situation was true in 1946 and it is even more pertinent at present, as a result of today's more limited curriculum in all medical schools.

Part Three deals with the significant aspects of the biology of atherosclerosis and the angiographic patterns of this process in various arterial locations of the lower extremity. This knowledge is essential to the understanding of the atherosclerotic process, the number one problem in vascular diseases, and to the interpretation of the radiologic patterns.

Part Four deals extensively with the surgical procedures for the various aortic and peripheral arterial lesions (embolism, arteriosclerotic occlusive

disease, aneurysms, etc.). The clinical background, indications and contraindications to surgical management, are the object of 23 chapters with an in-depth review of these arterial entities and related complications with specific emphasis on operative procedures.

Part Five deals with the surgery of visceral vessels, including the extracranial arteries and the celiac, mesenteric, and renal arteries. It contains, as well, chapters on kidney transplantation and portal decompression.

Part Six deals with the thoracic outlet compression syndromes, thoracic and lumbar sympathectomy, and sensory nerve crushing in the leg.

Part Seven offers several chapters on the most important aspects of venous disease, including pulmonary embolectomy and the management of lymphedema.

Part Eight presents two comprehensive and practical chapters on the various levels of amputation of the lower extremity and the methods of early rehabilitation of the patient.

In the descriptions of the techniques, great emphasis has been placed not only on the "standard procedures" but also on: *(a)* the variants with their specific indications, *(b)* the pitfalls and their avoidance, and *(c)* the complications and their treatment. These details, so often neglected in textbooks, will add, it is hoped, immeasurably to the practical value of this book. While the accent is placed on the "method of choice," one has to bear in mind that "ideal" methods for reconstruction are not always applicable or feasible in a given case. Variation is often the rule because of the innumerable patterns of occlusive or aneurysmal arterial lesions. In each individual case the method to be preferred must be selected on the basis of clinical and arteriographic data, operative findings, and a surgeon's personal experience. Although the techniques described in this book are mostly those which have stood the test of time, in the years ahead changes, improvements, revisions and variations are to be anticipated.

With few exceptions, statistical data concerning operative results were deliberately omitted, such information being considered outside this book's primary scope. However, should the reader be interested in this aspect, numerous references are available in all chapters.

A particular effort was made to integrate the different chapters by using cross references. Thus repetition or duplication, which is often unavoidable in a textbook so structured, has been kept to a minimum or largely eliminated.

The book is profusely illustrated not only with line drawings for the step-by-step surgical techniques but also with angiograms and operative pictures or pathology specimens. The wide variety of the illustrative material should greatly enhance the value of the text.

Many of the early contributions, basic to the development of the new era of vascular surgery, were revolutionary in their concepts. They introduced innovative procedures which have radically altered our knowledge in vascular replacements and which have long-term implications that we do not yet fully apprehend. What the future holds in terms of further progress is difficult to foresee. But what is certain is that the past three decades have

witnessed a phenomenal change in our concepts of vascular diseases and their surgical treatment. The present book has endeavored to record this progress. And so, it is hoped that the scope, contents, and presentation of this book will enhance the knowledge of those interested in the craft of vascular surgery and will provide them with a broad level of information for the optimal performance of this specialty.

HENRY HAIMOVICI

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The production of VASCULAR SURGERY, Principles and Techniques, from its inception to the final stages, required concerted multiphasic efforts from all the individuals involved in this project. It is a distinct pleasure to take this opportunity of expressing to all the participants my indebtedness and gratitude.

I am especially deeply grateful to the many contributors to VASCULAR SURGERY for their gracious cooperation in providing their expert knowledge based on their personal experience as well as their critical appraisal of the most pertinent recent literature.

A book of this nature, dealing with the various clinicopathologic aspects of vascular diseases and the surgical techniques for their management, necessitated the inclusion of a great variety of illustrations. The line drawings depicting the step-by-step techniques required special attention to the accuracy of the anatomical details. In this respect, I am particularly appreciative of the excellent artwork provided by Mrs. Joanne Bosomworth and Paul J. Singh-Roy whose contributions represent a major share of the illustrative material of this book. I am equally pleased to acknowledge my thanks to the many illustrators cooperating with all the contributors to this project.

To the staff of McGraw-Hill Book Company, Blakiston Publications Division, I wish to express my appreciation for their interest in and support for this undertaking. I am especially indebted to Frances A. Neal, who shared with me my constant concern for achieving in this multiauthored book a well-integrated presentation of the various chapters.

HENRY HAIMOVICI

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PART I
BASIC CONSIDERATIONS

CHAPTER 1
HISTORY OF VASCULAR SURGERY

HENRY HAIMOVICI, M.D.

The history of modern vascular surgery with its present-day achievements unfolded at a rapid and spectacular pace in less than three decades. Prior to this period, however, beginning at the turn of the century, many of the basic principles of vascular techniques had already been worked out and thus paved the way for the renaissance of this surgical discipline. But its current golden era could not have been accomplished without new and brilliant contributions shortly after the 1940s.

The debt owed some of the pathfinders in this field was sometimes forgotten or inadequately appraised. Not infrequently their pioneering achievements remained buried in the pages of the past literature, only to be rediscovered decades later after painstaking repetitions.

To gain a proper perspective of the present state of the field of vascular surgery, it may be useful to look back over the fundamental contributions from both laboratory and clinical investigations. The objectives of this chapter will be limited to only the major landmarks with their enduring contributions.

The history of vascular surgery may be conveniently divided into three sections: (1) arterial, (2) venous, and (3) lymphatic.

ARTERIAL SURGERY

BASIC LABORATORY CONTRIBUTIONS

The progress which led to successful vascular surgery went through several preliminary stages, the main ones being the establishment of techniques for suturing vascular wounds and for anastomosing divided vessels.

Suture of vascular wounds

Hallowell [1] is credited with successfully closing a brachial artery in 1759 by uniting the edges of the wound with a peg, around which he twisted a thread. However, it was not until the latter part of the nineteenth century that successful repair of arterial wounds could be systematically or more frequently accomplished either by small ivory clamps (Gluck, 1881) [2] or by sutures (Jassinowsky, 1889) [3]. The technique used by the latter investigator was a stitch which avoided penetrating the intima.

A further step in improvement of the vascular suture was published by Dörfler in 1899 [4]. The essential features of his method consisted of the use of fine, round needles and fine silk. His suture was continuous, embracing all the coats of the vessel. From his experience, he concluded that aseptic silk thread in the lumen of the vessel does not necessarily lead to thrombosis and, therefore, the penetration of the intima was not contraindicated. He recommended the same method for repairing veins.

Anastomosis and grafting of vessels

Direct union of two blood vessels was accomplished in 1879 by Von Eck (Child [5]) and reported sporadically by other investigators (Hirsch [6], Jaboulay and Briau [7], Clermont [8], etc.).

However, the most notable contributions in this field, at the beginning of this century, were those of Carrel. In 1902 he published a paper Surgical Technique of Vessel Anastomosis and Transplantation of Organs [9] (Fig. 1.1). This brief article written by Carrel only 2 years after he received his medical degree marks the beginning of his vast contributions. His technique brought several improvements, one of which was the use of three-stay sutures. The triangulation of the opposed ends of the vessels did, indeed, greatly facilitate the anastomosis. In his early work, Carrel, like Jassinowsky before him, did not include the intima in the suture. However, in his subsequent experiments he included all layers, using a continuous over-and-over suture approximating intima-to-intima. After coming to the United States in 1905, Carrel continued his work for two short but productive periods with Guthrie [10] in 1905 and 1906. The highlights of the technique established by them for vascular anastomoses may be summed up as follows:

gentle, temporary hemostasis; peeling off of the adventitia at the site of the suture; avoidance of dehydration of the tissues; three-stay sutures; fine suture material; and approximation of wide intimal surfaces by everting sutures through all layers of the vessel.

Carrel, either alone or with Guthrie, carried out all basic investigations concerning blood vessel surgery. Among other contributions, Carrel was the first to study the functional and histologic results of the use of preserved homografts [11]. In 1910 he reported his extensive efforts to preserve arterial grafts in a viable state. To achieve this goal, he used various electrolyte solutions, serum, defibrinated blood, and refrigeration at −3°C. Although Carrel reached the conclusion that blood vessels could be preserved in a condition of "latent life," later evidence presented by subsequent investigators showed that these grafts underwent degenerative changes, as did all homografts, fresh or preserved [12,13].

The significance of the basic principles established by Carrel and Guthrie emerged only much later and fully justified their laboratory efforts in more than one way. It can be truly said that the principles and techniques of all modern vascular grafting stem from the exhaustive investigations of these two pioneers.

Establishment of the above techniques for vascular anastomosis enabled many others to apply them to vascular transplants, both experimentally and clinically. The most commonly used transplants of blood vessels were autogenous and homologous grafts in contrast to the heterologous ones which were rarely successful and, therefore, had little application.

EARLY SURGICAL CONTRIBUTIONS

Modern history of vascular surgery was preceded by the epoch-making contributions of Matas who in 1888 described endoaneurysmorrhaphy for the management of aneurysms, thus relegating ligation of the arteries to the category of obsolete methods [14]. The main feature of this technique consists of suturing the arterial openings in the aneurysmal sac. Matas devised three types of operations: restorative endoaneurysmorrhaphy used for saccular aneurysms; reconstructive endoaneurysmorrhaphy in which a new vessel is made out of the old one, and obliterative endoaneurysmorrhaphy for fusiform aneurysms [15] (Fig. 1.2).

As important as Matas' pioneering contribution

LA TECHNIQUE OPÉRATOIRE DES ANASTOMOSES VASCULAIRES ET LA TRANSPLANTATION DES VISCÈRES.

Par le Dr CARREL, prosecteur à la Faculté.

Pendant les derniers mois de l'année 1901, j'ai commencé des recherches sur le manuel opératoire des anastomoses vasculaires, dans le but de réaliser la transplantation de certains organes.

Cette transplantation consiste à prendre une glande, corps thyroïde ou rein, par exemple, à l'enlever avec son artère et sa veine, puis à greffer ces vaisseaux sur un autre point de l'appareil circulatoire. Simple curiosité opératoire aujourd'hui, la transplantation d'une glande pourra peut-être un jour avoir un certain intérêt pratique.

Nous n'étudierons ici que la technique employée pour obtenir une bonne réunion de vaisseaux souvent très petits.

La méthode, que je vais décrire, est très simple. Elle convient également aux artères et aux veines, aux vaisseaux de gros ou de petit calibre. Elle respecte l'intégrité de la tunique endothéliale. L'anastomose présente une étanchéité absolue, et ne provoque aucune diminution du calibre du vaisseau. Elle permet de réaliser aussi facilement une réunion termino-latérale, qu'une réunion termino-terminale. Son exécution est facile.

FIGURE 1.1
First page of Carrel's original article which appeared in *Lyon Medical*, 1902 [9].

was in the early phase of vascular surgery, grafting of vessels was to have a much greater impact on its development. In 1906 Goyanes [16] reported the use of the popliteal vein in situ to restore the continuity of the popliteal artery after excision of an aneurysm. The next year Lexer [17] used successfully a free vein graft in a similar operation. He bridged an 8-cm-long defect in the axillary artery with an autogenous segment of the great saphenous vein. He applied this method with equal success to replacing an iliac artery after removal of an aneurysm of this vessel. Pringle reported in 1913 two cases of vein grafting for the maintenance of a direct arterial circulation [18]. In this country Bernheim [19] published in 1916 a report of the first successful case of a free venous transplant for bridging a defect in the popliteal artery following excision of an aneurysm. During World War I several German surgeons reported excellent results in the treatment of traumatic aneurysms, using vein grafts [20]. However, the treatment of choice for acute

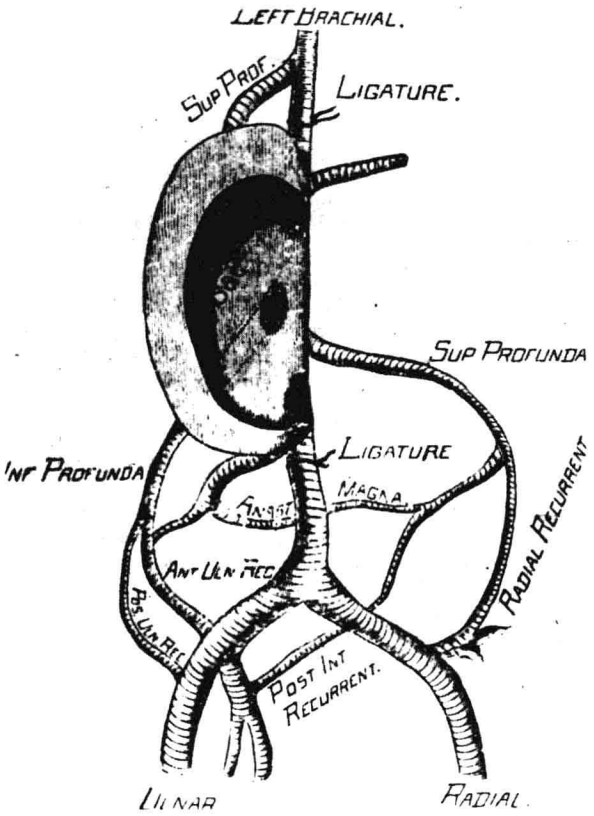

FIGURE 1.2
Drawing of the first endoaneurysmorrhaphy performed by Matas in 1888 for a large traumatic aneurysm of the brachial artery. Note the large collateral circulation [14].

arterial injuries in World War I still remained arterial ligation. This was also true for similar cases of World War II in the American Army, as reviewed by DeBakey and Simeone [21]. This practice of ligation for arterial injuries had remained in use also in the Korean War, when in April of 1952 the recent advances in civilian blood vessel surgery were applied to traumatic vascular surgery [22]. A new era in this field of traumatic vascular lesions was then established.

ROLE OF PROGRESS IN OTHER MEDICAL FIELDS

Although the techniques for arterial surgery had been well established at the beginning of this century, it was not until the 1940s that the modern era of vascular surgery could develop, expand, and flourish. This gap of several decades was due primarily to the lack of availability of important developments in many other medical disciplines, such as radiologic, hematologic, and antibiotic, and other areas as well. Once available, they made it possible for vascular surgery to fulfill its great potential.

Arteriography

Arteriography, an essential diagnostic procedure, had its slow beginnings shortly after Röntgen's discovery in 1895. Indeed, it was not until 1927 that Egaz Moniz of Lisbon devised carotid arteriography [23]. Two years later Reynaldo Dos Santos, also of Lisbon, developed the technique of translumbar aortography [24]. Although this diagnostic method was adopted by a few surgeons, more time elapsed before it gained greater acceptance. The delay was due primarily to lack of refinements of the radiologic techniques and of safety of the radiopaque substances. A further step in the progress of angiography was achieved when the technique of percutaneous arterial catheterization was introduced by Seldinger [25]. This allowed a more precise and selective visualization, especially of the visceral vessels.

Anticoagulants

Heparin, discovered in 1916 [26,27], became available clinically only in 1936 [28,29]. During the same year another important development had taken place in this field, namely, the discovery of Dicumarol [30]. The use of these anticoagulants in vascular surgery enabled the handling of blood vessels with relative safety, preventing intraoperative or postoperative thrombosis.

Antibiotics

Discovered at about the same time, antibiotics, by controlling infection, which was a major cause of graft failure, had an important beneficial impact on vascular surgery.

Other advances

Blood transfusions and substitutes, along with better knowledge of surgery-related metabolic disturbances, were indispensable factors in the successful

management of patients undergoing vascular surgery.

New instrumentation and suture materials have greatly contributed to improvement of vascular techniques. In addition, increasing physiologic orientation has occasioned a great demand for accurate monitoring equipment. Simultaneously, the field of bioengineering has come into its own, providing the technical know-how to adapt principles, techniques, and instruments to the needs of today's cardiovascular problems.

From the brief review of these ancillary developments it is quite apparent that vascular surgery could not have reached its present state without the backup offered by various medical and scientific achievements since the 1940s.

RECENT SURGICAL CONTRIBUTIONS

The current revival of vascular surgery was ushered in in 1938 by the successful ligation of a patent ductus arteriosus by Gross [31]. That was followed by another milestone in this field when Blalock performed his first operation for tetralogy of Fallot in 1944 in which he anastomosed the left subclavian to the left pulmonary artery by an end-to-side technique [32].

The same year, Crafoord of Stockholm succeeded in correcting a coarctation of the aorta and published his report in 1945 [33]. On July 6, 1945, Gross, independently, was likewise successful in correcting the coarctation of the aorta and reported his first two cases the same year [34]. These brilliant clinical results were preceded by careful laboratory experiments carried out by Blalock and Park in 1944 [35] and by Gross and Hufnagel in 1945 [36].

These early successes in the management of congenital vascular abnormalities stimulated a great deal of activity throughout the world. A true explosion of various new methods of investigating cardiac and vascular diseases was in the making. New and bold techniques were devised for the treatment of congenital and acquired heart disorders as well as for vascular diseases.

Two major developments, which made possible cardiac and aortic surgery, took place at about this time. One was the use of *hypothermia*, and the other was the introduction of *heart-lung machines* for extracorporeal circulation. Although these two advances, especially the latter, were essential for the current progress in heart surgery, their application was equally basic in handling aortic lesions, more particularly those of the thoracic and thoracoabdominal segments.

Bigelow in 1950 published his experimental results of the effects of hypothermia on the lowering of oxygen consumption and its impact on blood flow through the heart [37]. After refinement of this technique, hypothermia was applied shortly thereafter in the surgical management of a variety of cardiac lesions. In 1954 DeBakey and associates published their results of the use of hypothermia to prevent paraplegia following temporary aortic occlusion [38].

Although hypothermia represented a significant advance for the performance of cardiac and aortic surgery, the development of the extracorporeal circulation technique superseded it and offered one of the most dramatic and lasting achievements in the whole field of surgery. Gibbon [39] devised in 1937 the heart-lung apparatus that he used in animals, and he applied it in 1953 to close an atrial septal defect in a young woman [40]. This pioneering effort was followed by numerous contributions that modified, improved, and simplified this technique. In the end it had completely revolutionized the surgery for cardiac as well as for aortic lesions and pulmonary artery embolism.

Aortic grafts

Vascular grafting was in a way connected with the early phase of surgical correction of congenital cardiac and vascular abnormalities. They are mentioned only as a background to what is to follow. Indeed the first arterial transplantation of homografts was carried out for congenital vascular abnormalities by Gross and associates [41]. After extensive laboratory investigations of methods for the preservation and transplantation of arterial grafts, Gross et al. [42] published in 1948 and 1949 the first observations on the use of human arterial grafts in the treatment of coarctation of the aorta and the use of a shunt between the left pulmonary artery and the proximal end of the subclavian artery for tetralogy of Fallot (Figs. 1.3 and 1.4).

The modern phase of vascular grafting truly began with the successful implantation of arterial homografts as reported by Gross and his associates. The impetus provided by these successful applications of grafting procedures led to other similar innovative uses in other parts of the vascular system. Thus

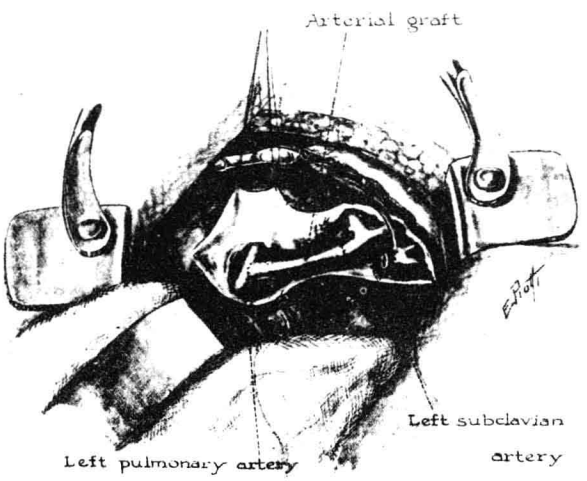

FIGURE 1.3
This is Fig. 7 from the original article by Gross et al. [42], depicting the insertion of a human arterial graft between the left pulmonary artery and the proximal end of the left subclavian artery in a patient (Case 2) with tetralogy of Fallot. [*From R. E. Gross et al., Surg. Gynecol. Obstet., 88:689 (1949).*]

FIGURE 1.4
This is Fig. 8 from the original article by Gross et al. [42], depicting insertion of a human aortic graft following removal of a narrowed segment of the aorta for the treatment of coarctation of the aorta (Case 9). [*From R. E. Gross et al., Surg. Gynecol. Obstet., 88:689 (1949).*]

Oudot reported in 1951 the first successful resection of the aortic bifurcation and its replacement with a homograft [43] (Fig. 1.5). Shortly after that, Dubost and his associates reported the first successful resection of an abdominal aortic aneurysm with insertion of a homograft [44] (Fig. 1.6).

In short succession, after this publication, DeBakey and Cooley [45], Szilagyi et al. [46], Shumacker and King [47], Julian et al. [48], and many others reported similar successful results.

The principle of excisional therapy used in 1951 for abdominal aortic aneurysms was also soon to be applied to thoracic aneurysms. Before the use of excisional treatment with graft replacement, a few cases of resection of thoracic aneurysms with or without anastomosis were reported. These cases consisted of simple saccular aneurysms [49] or were associated with coarctation of the aorta [50,51]. In 1953, Debakey and Cooley [52] reported the first successful resection of a fusiform thoracic aneurysm with graft replacement. Thereafter all segments of the thoracic aorta, including the arch, were treated by excision with replacement of homografts. In all these instances, some form of bypass or controlled extracorporeal circulation or hypothermia was used.

Bypass graft principle

In 1948 Kunlin of Paris introduced the bypass principle for the management of occlusive arterial disease of the femoral-popliteal segment [53] (Fig. 1.7). This report had a lasting impact on the management of occlusive disease as we know it today. The technique described by Kunlin consisted of a parallel shunt with the occluded artery, using end-to-side anastomoses. This method endeavors to preserve the collateral branches as well as the main arterial channels above and below the occlusion. The wide acceptance of this technique lay in a rationale of transporting arterial blood around the occluded segment while avoiding operative trauma and interference with collaterals or damage to concomitant veins. This technique was rapidly and universally adopted. Currently the same technique is being applied to the aortocoronary bypass with the known wide acceptance by cardiovascular centers the world over.

Dissecting aneurysms

Dissecting aneurysms of the aorta deserve special consideration. Various reports have shown that they