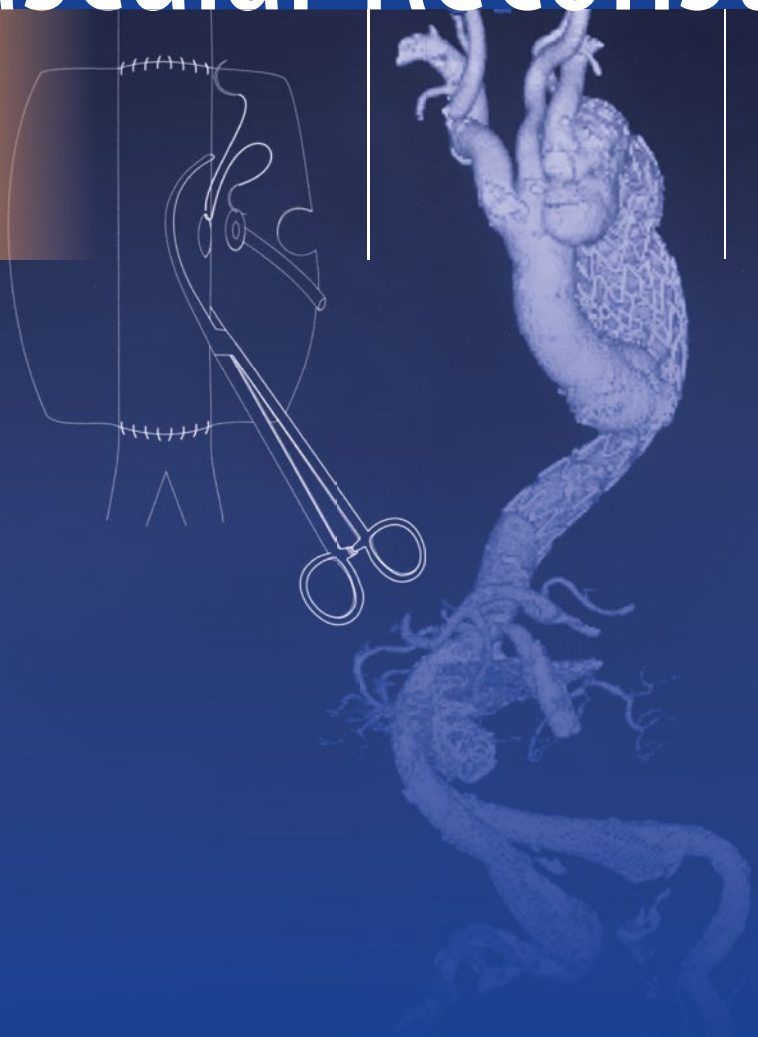
Jamal J. Hoballah
Carlos F. Bechara
Editors

Vascular Reconstructions



Anatomy, Exposures and Techniques

Second Edition

Springer

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This book is dedicated to my mother and father, with love and appreciation. (JJH)

This book is dedicated to my mother and father who taught me humility, honesty, and hard work. (CFB)

Preface

"Practice makes perfect," and time spent in the operating room should be used most efficiently. In an attempt to comply with these two principles, JJH designed a vascular anastomoses workshop for our surgical residents at the University of Iowa. The workshop introduced the basic steps of constructing various vascular anastomoses in a relaxed environment outside the operating room. During the workshop, the residents expressed the need for a manual that outlines and describes the various vascular reconstructions in a step-by-step manner from beginning to end. Most textbooks usually include a picture of a vascular anastomosis during or after the completion of the reconstruction without detailing the beginning and conduct of the procedure. The usefulness of including parts that address commonly asked or unasked questions was also apparent. These questions pertain to vascular instruments, grafts, and sutures, as well as vascular anatomy and exposures. It is with these thoughts in mind that the first edition of this book was conceived. This book was not intended to be a substitute for traditional atlases of specific vascular procedures, rather it was written to focus on the technical aspects of vascular reconstructions and to better prepare the surgical residents before they start their vascular rotation. When this book was first published almost 20 years ago, endovascular surgery was still in its infancy. The changes in the management of vascular pathology that ensued during the following two decades have been remarkable. Endovascular approaches became the preferred initial intervention for many vascular pathologies resulting in a major decrease in open vascular surgical procedures. Vascular trainees became more concerned about their open surgical experience rather than their endovascular training. The importance of maintaining the focus on open surgical techniques while advancing endovascular skills was obvious. As such, an additional part focusing on endovascular techniques was deemed essential and was included in this second edition.

This book in its second edition is divided into five parts. The first part starts with a review of commonly used vascular instruments and an overview of grafts and sutures used in vascular reconstructions. A detailed chapter on vascular anatomy and exposures is provided to serve as a quick reference before starting a vascular procedure. The remaining chapters in the first part of this book review the basic steps usually performed before and after constructing a vascular anastomosis in addition to thrombectomy and endarterectomy. The second part of this book focuses on the various methods used to conduct a vascular reconstruction, which include primary closure, closure with a patch angioplasty, end-to-end, end-to-side, and side- to-side anastomoses. The various possible modifications used are outlined. The third part of this book reviews the various adjunctive methods used when constructing the proximal or distal anastomoses of an infrainguinal bypass. The fourth part of the book reviews the various modifications that are carried out when constructing the proximal and distal anastomoses of an aortic occlusive or aneurysmal pathology. The vascular anastomoses workshop that inspired the conception of this book is included as an appendix. The fifth part focuses on endovascular therapy and imaging.

We certainly hope that this book will help make the vascular rotation a pleasant experience for both the surgical residents and the vascular faculty. We believe this book can also be very useful to recent graduates embarking on conducting vascular reconstructions independently as

well as healthcare providers who wish to be familiar with the various steps involved in conducting a vascular procedure.

We hope you enjoy this book as much as we enjoyed putting it together. We are eager for your comments, feedback, and suggestions for future editions. You may write directly to the Medical Editorial Department at Springer-Verlag New York, Inc., 175 Fifth Avenue, New York, New York 10010. Send your comments to the attention of the Editor, General Surgery Book Program.

Beirut, Lebanon — Jamal J. Hoballah
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Acknowledgments

I am indebted to many for the completion of this book. I am grateful to Dr. Frank C. Spencer and the Faculty in the Department of Surgery at New York University for my training in General Surgery and for igniting my interest in Vascular Surgery. I am thankful to Dr. John D. Corson, Dr. Steve G. Friedman, Dr. Anthony M. Imparato, Dr. Gary Giangola, Dr. Ismael M. Khalil, Dr. Timothy F. Kresowik, Dr. Patrick J. Lamparello, Dr. Thomas S. Riles, and Dr. William J. Sharp for their contribution to my training in Vascular Surgery. I remain indebted to Dr. Carol Scott-Conner for her encouragement and support to produce the first edition. I am also very grateful to the remarkable efforts of the illustrator Sheri Pressler. I am thankful to the surgical residents and fellows who were the impetus for the conception of this work. Special thanks to Dr. Bechara for his efforts in co-editing this second edition. I am also very grateful to all those who helped and were not recognized in this section. Finally, this book could not have been completed without the support of my wife Leila and my sons Jawad and Nader (*JJH*).

I was fortunate to be trained in an era when endovascular therapy was on the rise but open surgery was still common practice; it was the best of both worlds. More importantly, this training was in the largest medical center in the world (Houston, TX) at the hands of the leaders in cardiovascular surgery. Their mentorship inspires me to continue their legacy of education. When I met Dr. Debakey in his office for a picture, I asked him what advice do you have for a young surgeon? He simply replied, repetition. I want to thank all the trainees and medical students who challenge me with their inquisitive minds. As I always say, "Ask why." If you do, and research the topic, you will never forget it. I would like to thank Dr. Hoballah for his mentorship and friendship. Finally, I want to thank my wife Marwa, daughter Nai, and my two sons, Jude and Zane, for their endless support (*CFB*).

We thank all the authors for their valuable contribution to the second edition of this book. We are greatly appreciative of the assistance and thoroughness of the staff at Springer (Lee Klein and Richard Hruska) (*JJH, CFB*)

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Part V Endovascular Surgery

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Part I

Basic Principles in Vascular Reconstructions

1

Vascular Instruments

Jamal J. Hoballah

Vascular surgery can be performed with the addition of only a few instruments to the standard surgical tray. This chapter provides an overview of commonly used instruments during vascular reconstructions. Following is a list of commonly used instruments, with suggestions for possible sites of application.

Instrument	Common use
Scalpel blades	
Number 10; 20	Skin incision
Number 15	Dissection in scarred tissue
Number 11; microknife	Incision of blood vessels
Number …Ophthalmic blade	Incision of tibial vessels
Scissors	
Metzenbaum scissors	All-purpose dissection
Church scissors (Fig. 1.1)	Dissection of medium vessels (popliteal)
Stevens tenotomy scissors (Fig. 1.2) (sharp tip; curved blades)	Dissection of small vessels (tibial)
Potts scissors (Fig. 1.3)	Extension of incisions in medium vessels
Castroviejo scissors (Fig. 1.4)	Extension of incisions in small vessels
Tissue forceps	
Russian tissue forceps Ferris Smith tissue forceps	Removal of aortic plaque, holding fascia, and grasping fascia
Debakey tissue forceps (Fig. 1.5) (tip 1; 1.5; 2 mm)	Medium and large blood vessels

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Debakey–Diethrich	Medium and large blood vessels
Microsuture ring-tip forceps (Fig. 1.6)	Small blood vessels
Microsuture-tying forceps	Small blood vessels
Bishop–Harmon serrated iris forceps (Fig. 1.7)	Removal of fine fibers from an endarterectomized surface
Jeweler's forceps (fine tip)	Removal of fine fibers from an endarterectomized surface
Hemostatic forceps	
Right-angle forceps	Passing silastic loops around vessels
Right-angle forceps (Fig. 1.8) (fine tip)	Passing silk ties around small vessels (venae comitantes)
Needle holders	
Mayo Hegar needle holder (Fig. 1.9)	<4-0 sutures
Ryder needle holder (Fig. 1.10)	5-0; 6-0 sutures
Castroviejo needle holder (Fig. 1.11) (with or without locking handle)	5-0; 6-0; 7-0 sutures
Totally occluding vascular clamps	
Debakey aortic aneurysm clamp (Fig. 1.12) (side-to-side apposition of aortic wall)	Supraceliac and infrarenal aorta
Debakey-Bahnson aortic aneurysm clamp (Fig. 1.13a)	Infrarenal aorta
Howard-Debakey aortic aneurysm clamp with reverse curve shafts (Fig. 1.13b) (side-to-side apposition of aortic wall)	
Fogarty aortic clamp (Fig. 1.14) (side-to-side apposition of aortic wall)	Infrarenal aorta; aortic grafts, calcified aorta
Debakey aortic aneurysm clamp) (Fig. 1.15) (apposition of anterior and posterior walls together)	Infrarenal aorta
Lambert–Kay aortic clamp (Fig. 1.16a) (apposition of anterior and posterior walls together)	Infrarenal aorta
A rubber tube is inserted along the lower jaw of the Lambart–Kay clamp (Fig. 1.16b)	
A curved clamp is passed around the aorta to retrieve the free end of the rubber tube	
Gentle traction on the rubber tube will guide the application of the Lambart–Kay clamp (Fig. 1.16c)	
Wylie hypogastric clamp (Fig. 1.17)	Iliac arteries, especially hypogastric arteries
Debakey peripheral vascular clamp (angled handle)	Iliac arteries
Debakey peripheral vascular clamp (angled jaw, 45°) (Fig. 1.18)	Iliac and common carotid arteries
Henly subclavian clamp (Fig. 1.19)	Subclavian and common femoral arteries

Partially occluding (side-biting) vascular clamps	
Lemole-Strong aortic clamp (Fig. 1.20)	Aorta and aortic grafts
Satinsky clamp (Fig. 1.21)	Aorta and vena cava
Cooley anastomosis clamp	Aorta and aortic grafts
Cooley-Derra clamp	Graft limbs
Cooley pediatric clamp (Fig. 1.22)	Common femoral artery and saphenofemoral junction
Self-compressing vascular clamps: do not require an applicator	
Gregory carotid "soft" bulldog (Fig. 1.23)	Small vessels
Potts bulldog, straight, and angled jaw (Fig. 1.23)	Small vessels
Debakey bulldog (Fig. 1.23)	Small vessels
Diethrich bulldog (Fig. 1.23)	Small vessels
Self-compressing vascular clamps: require an applicator	
Yasargil aneurysm clips (Fig. 1.24)	Small vessels and branches
Heifetz clips	Small vessels and branches
Kleinert-Kutz clips-straight, angled, curved	Microvascular anastomoses
Louisville microvessel approximator	Microvascular anastomoses
Retractors (self-retaining)	
Balfour abdominal retractors	Abdominal exposures
Poly-tract full abdominal retractor	Abdominal exposures
Omni-tract retractor (Fig. 1.25)	Abdominal exposures
Beckman retractor (swing arm)	Deep soft tissue exposures
Gelpi retractor (sharp prongs)	Medium-depth soft tissue exposures
Weitlaner retractor (Fig. 1.26)	Superficial soft tissue exposures
Spring retractor (Fig. 1.27)	Superficial soft tissue exposures
Adson retractor	Superficial soft tissue exposures
Retractors (handheld)	
Deaver retractor	Deep abdominal exposure
Harrington retractor	Liver retraction
Brewster retractor	Superficial soft tissue
Vein retractor	Renal vein
Miscellaneous	
Freer double-ended elevator (Fig. 1.28)	Starting an endarterectomy
Internal occluders (Fig. 1.29)	Small arteries

VASCULAR CLAMPS

The most commonly used jaw design is a single row of serrated teeth opposing a double row of serrated teeth. This design allows for occluding the vessel with minimal damage to the vessel walls. In one variation, a double row of serrated teeth is opposing a triple row. In another variation, a special soft insert is applied

to the clamp jaws (Fogarty clamps). These variations are specially designed for use with calcified diseased arteries. Vascular clamps with straight jaws are usually used to completely interrupt the blood flow (Diagram 1). Vascular clamps with curved jaws can be used to provide total or partial interruption of blood flow (Diagram 2). In the latter situation, they are used as side-biting clamps, providing control of a segment of the vessel wall, and yet maintaining distal perfusion.

VALVULOTOMES

Several instruments have been designed to produce effective valve destruction of venous conduits. These valvulotomes include the Mills, Hall, Lemaitre (Tru-incise and Expandable), and Insitucat (B Braun) valvulotomes. The retrograde Mills valvulotome has the shape of a nerve hook (Fig. 1.30a, b). It is made of a rigid thin metallic wire with the tip bent at a 90° angle. The tip has a cutting edge to incise the valves. The instrument can be a retrograde or an antegrade valvulotome, depending on the location of the cutting edge. The retrograde Mills valvulotome has the cutting edge along the inner aspect of the tip. In the antegrade variety, the cutting edge is along the outer aspect of the tip. The retrograde valvulotome is 24 cm long and is usually introduced in the vein lumen through the distal end of the vein or through a side branch; this facilitates its use in small-diameter veins. However, the use of this valvulotome usually requires exposure of the entire vein. Valve cutting is achieved by withdrawing the valvulotome in the arterialized vein from proximal to distal (Diagram 3). The valvulotome is first advanced proximal to the valve to be disrupted. It is then withdrawn until the valve is engaged. The engaged valve leaflet is incised by pulling the valvulotome. The valvulotome is then readvanced and rotated 180° to engage the remaining opposite valve leaflet. The Mills retrograde valvulotome is one of the safest valvulotomes because of the limited contact area between the instrument and the endothelium [1]. Nevertheless, injury to the vein can occur, especially if the valvulotome engages a side branch inadvertently. In the remaining valvulotomes, a valve disrupter-cutter is introduced through the distal end of the vein and then withdrawn through the valves. Hall valve stripper consists of two metal cylinders, which are attached to a wire. The head cylinder has the negative imprint of a venous valve. The second metal cylinder is located 5 mm below the head cylinder and serves to stretch the vein. As the instrument is retracted, the lower end of the head cylinder engages the valve and rips it apart. The Hall valve stripper has been criticized for lacking a cutting edge, which could inflict significant injury to the endothelium when the valve is being disrupted and is rarely used nowadays. The Lemaitre Tru-Incise Valvulotome has interchangeable cutting heads to allow appropriate sizing for varying vessel diameters. The Expandable LeMaitre Valvulotome has a self-centering head with four blades, one at each quadrant. The head is mounted on a 110-cm-long catheter and is self-expandable, allowing it to self-size and adapt to the changes in the vein size, as it is withdrawn from proximal to distal vein. The blade ranges from 1.5 mm to 6 mm. In one new variation, the valvulotome comes with an over-the-wire technology that allows for safe repetitive passage over the wire.

The Insitucat vein valve cutter (B Braun) consists of a polyfilament, plastic-coated guide wire to which two conical plastic olives can be attached at one end. The upper olive represents the negative imprint of the venous valve sinus and has a sharp plastic cutting edge, which incises the valve when retracted. Valvulotomy can also be performed under angioscopic guidance. However,

angioscopy can result in fluid overload, potential endothelial injury from the angioscope, and added cost and is very rarely used nowadays.

CAROTID SHUNTS

Several carotid shunts are available to maintain cerebral perfusion during carotid endarterectomy. The proximal end of the shunt is placed in the common carotid artery and the distal end in the internal carotid artery. Shunts can be either inlying or outlying. The inlying shunt is straight and lies entirely in the lumen of the common and internal carotid arteries (Diagram 4). The outlying shunt is longer than the inlying shunt. It is inserted with only the ends lying in the vessel lumen, while the remainder of the shunt extrudes as a loop outside the vessel (Diagram 5a). Performing the endarterectomy is usually easier with an outlying shunt (Diagram 5b). However, the limbs of the shunts extruding from the lumen can make closure of the arteriotomy more demanding than with an inlying shunt. Surgeons should be familiar with the various shunts available and should use the one with which they feel most comfortable.

The shunts most commonly used include the Javid, the Sundt, and the Pruitt-Inahara shunts (Fig. 1.31). The Javid shunt has two ends of different calibers with small bulges on either end of the shunt. These bulges serve to stabilize the shunt and prevent bleeding around it; this is achieved by applying special clamps on the common and internal carotid arteries at the level of the bulges. The Javid shunt is an outlying shunt. It is simple to use, but it is relatively rigid. The Sundt shunt is made of silastic and is fairly soft. It has a metallic skeleton incorporated in its wall to help maintain its tubular shape. This metallic skeleton prevents clamping the shunt. The Sundt shunt also has a bulbous portion on either end to help its stabilization, which is usually achieved with the use of Rummel tourniquets. The Sundt shunt is available in various sizes with an outlying or inlying configuration. The Pruitt-Inahara shunt (Fig. 1.31) has inflatable balloons at each end to stabilize the shunt with a side arm that allows flushing the lumen. It also comes with an inlying or outlying configuration. The outlying configuration allows for performing the endarterectomy with the shunt out of the way. However, during arteriotomy closure, the two ends of the shunt will be protruding through the arteriotomy, making the closure more demanding than with the inlying shunt. A Rummel tourniquet is usually used to stabilize the proximal part of the shunt. The distal end may be stabilized with balloon inflation only. The shunt is provided with two syringes to inflate the balloons. A good habit is to fill each syringe with just the amount of saline necessary to inflate the balloon to the desired size. This practice can help avoid accidental overinflation of the balloons, which could result in balloon rupture or intimal damage. In the new shunts, the distal balloon is also attached to another small safety balloon placed along the distal arm of the shunt. The safety balloon will inflate if the pressure in the distal balloon exceeds the acceptable limit.

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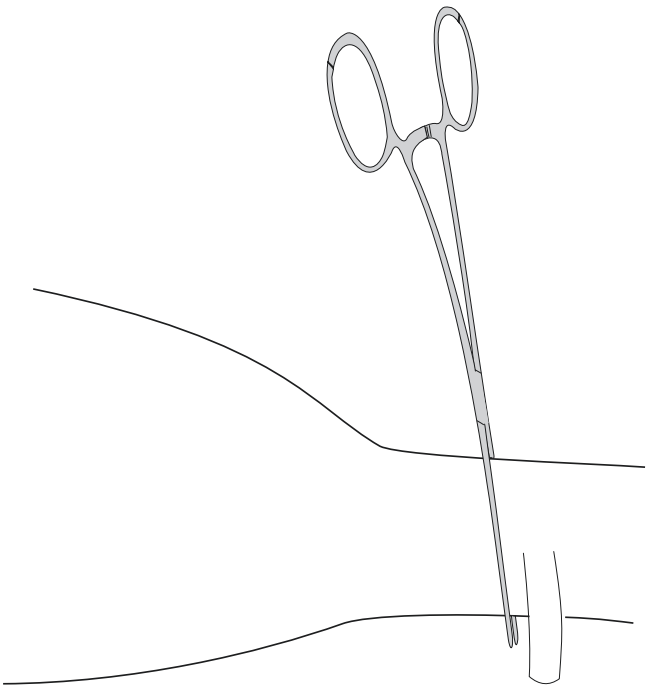

Diagram 1: Straight jaw vascular clamp completely interrupting blood flow.

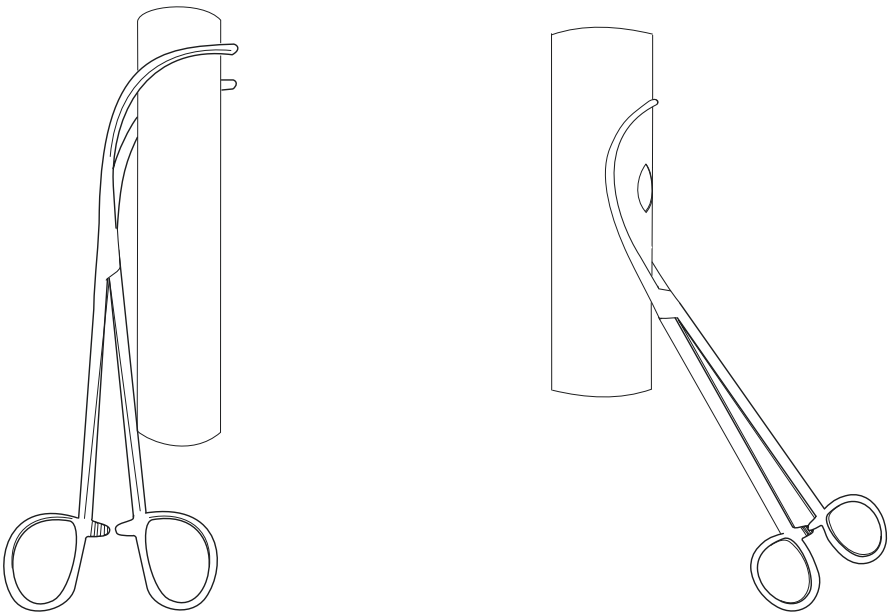

Diagram 2: Curved jaw vascular clamp completely or partially interrupting blood flow.

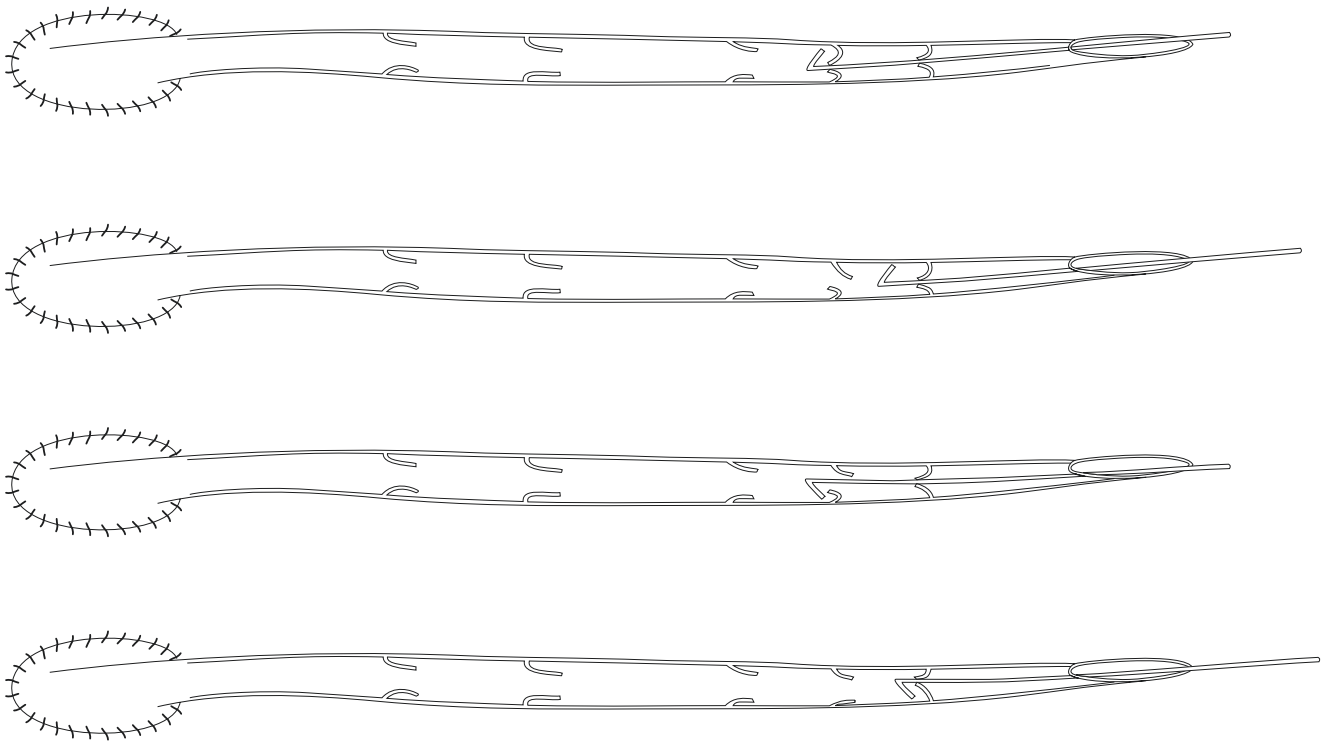

Diagram 3: Mills retrograde valvulotome disrupting valve leaflets.

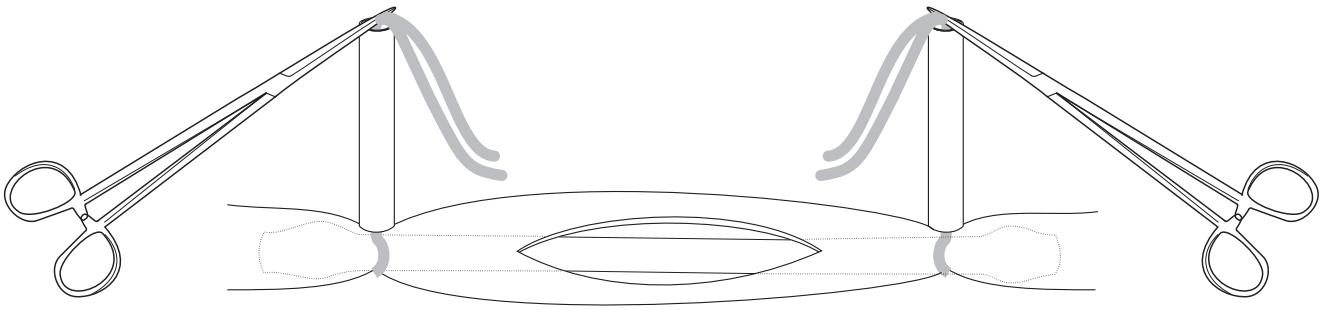

Diagram 4: The inlying shunt lies entirely in the lumen.

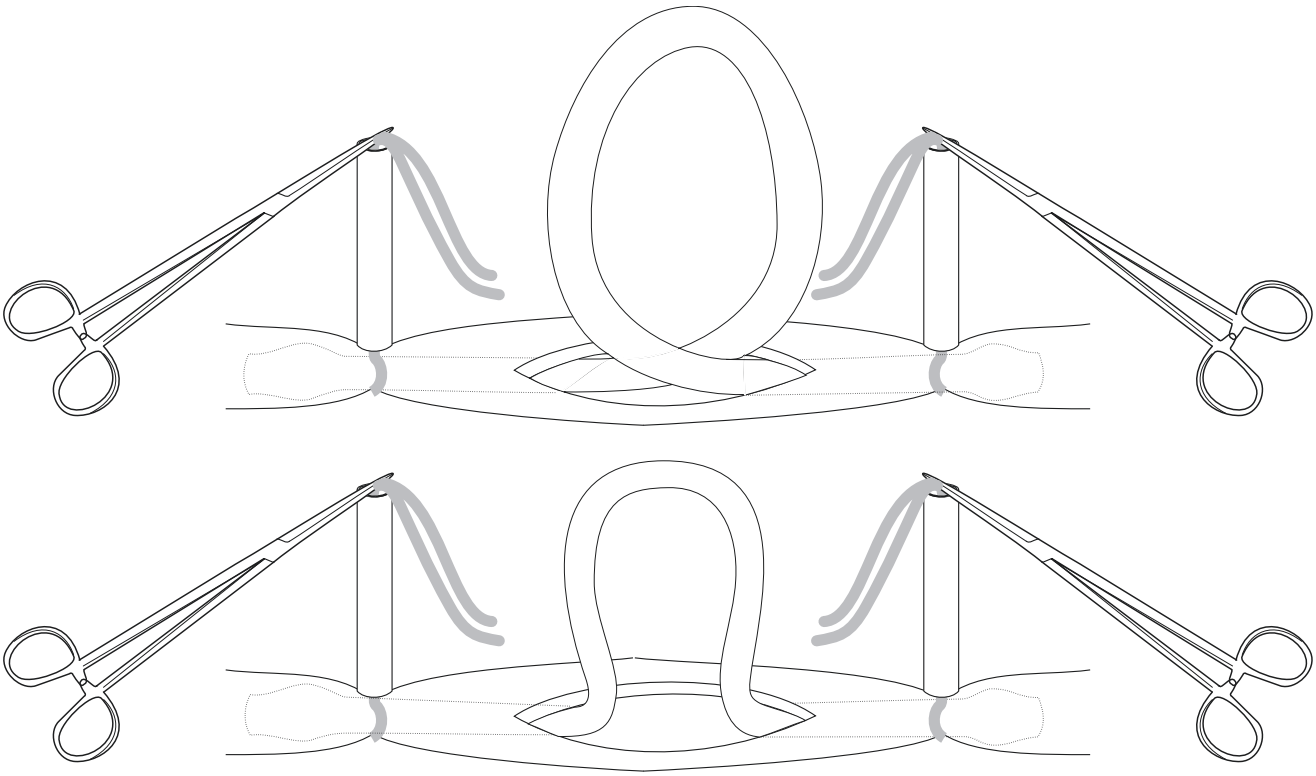

Diagram 5a: Outlying shunt., The outlying shunt can be adjusted to facilitate the endarterectomy.

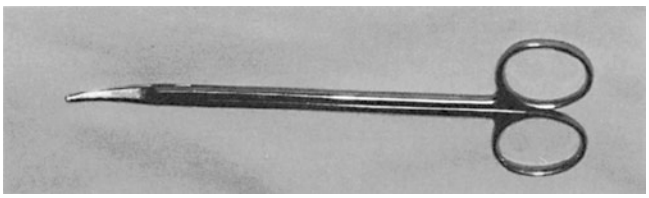

Figure 1.1 Church scissors

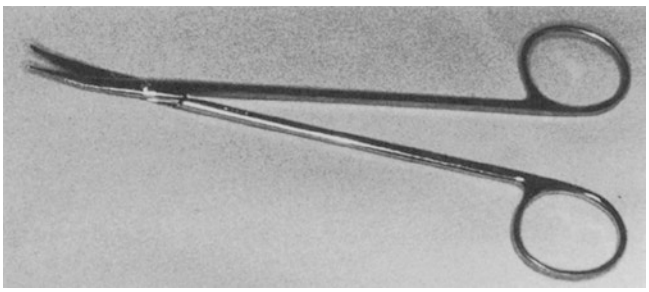

Figure 1.2 Stevens tenotomy scissors

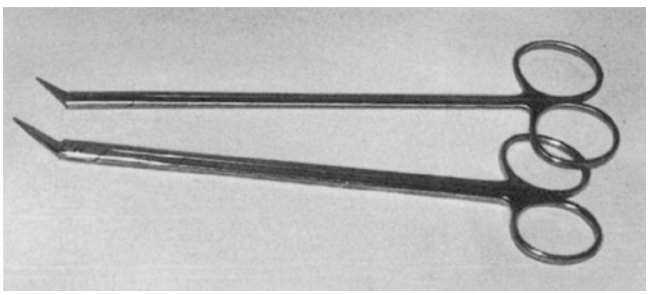

Figure 1.3 Potts scissors

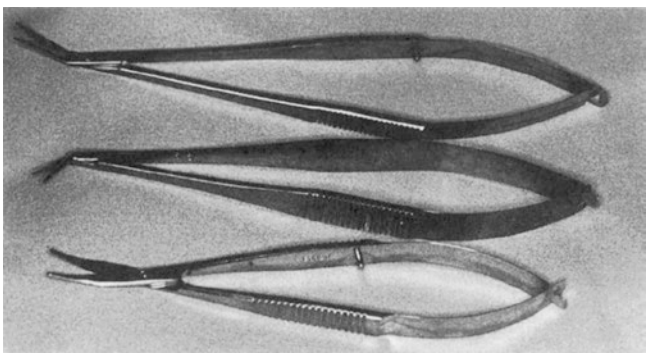

Figure 1.4 Castroviejo scissors

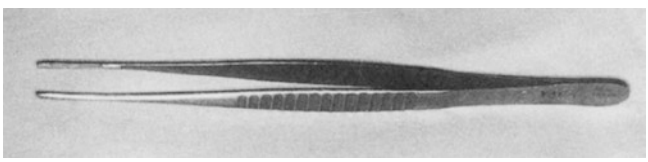

Figure 1.5 Debakey tissue forceps

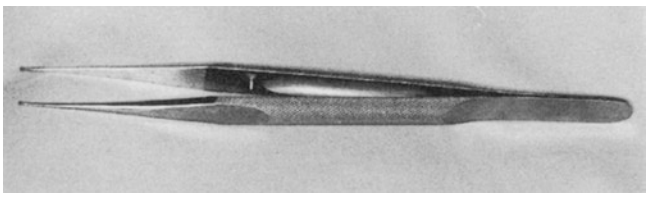

Figure 1.6 Microsuture ring tip forceps

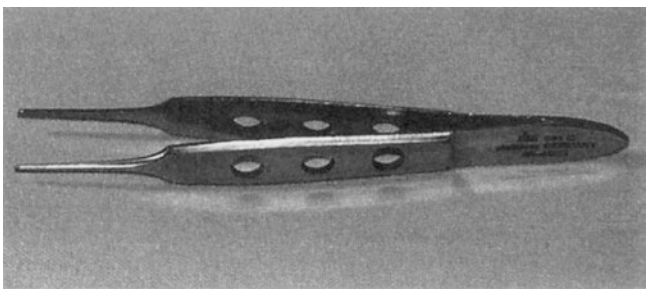

Figure 1.7 Bishop-Harmon forceps

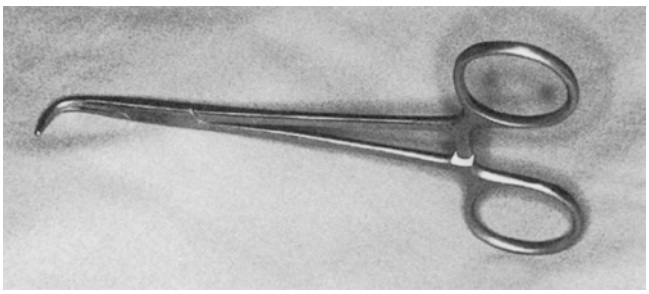

Figure 1.8 Right-angle forceps

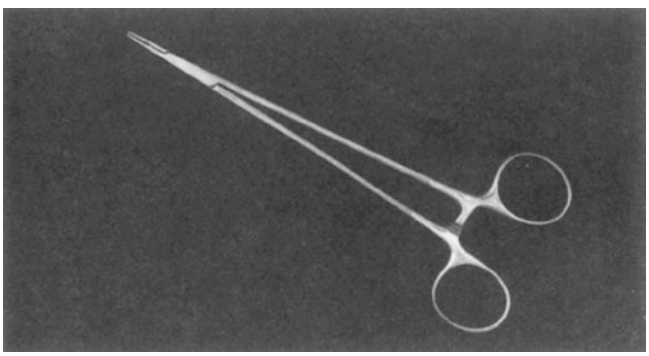

Figure 1.9 Mayo Hegar needle holder

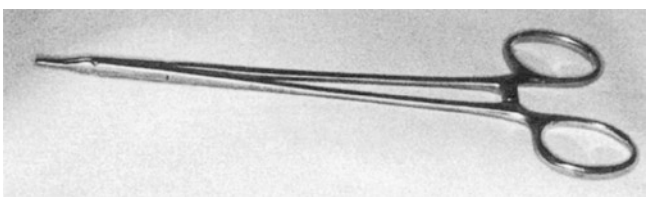

Figure 1.10 Ryder needle holder

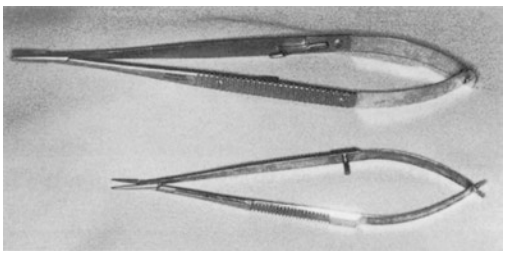

Figure 1.11 Castroviejo needle holder

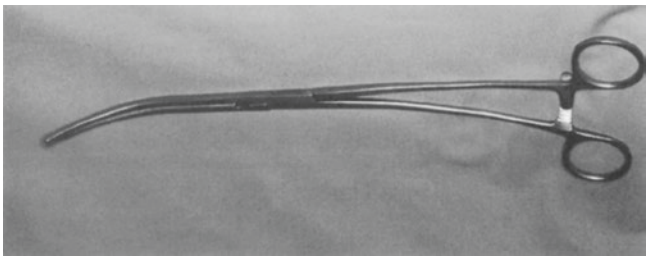

Figure 1.12 (a, b) Debakey aortic aneurysm clamp

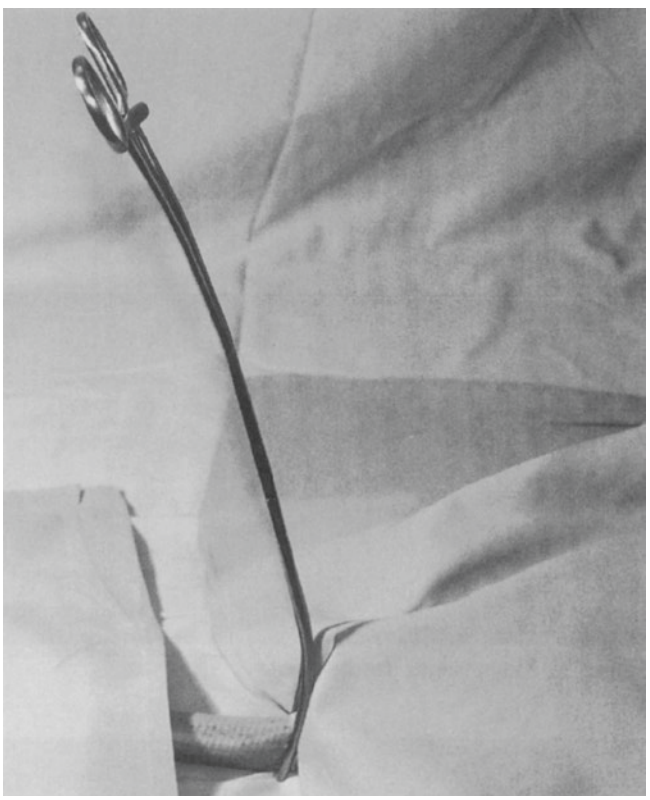

Figure 1.12b

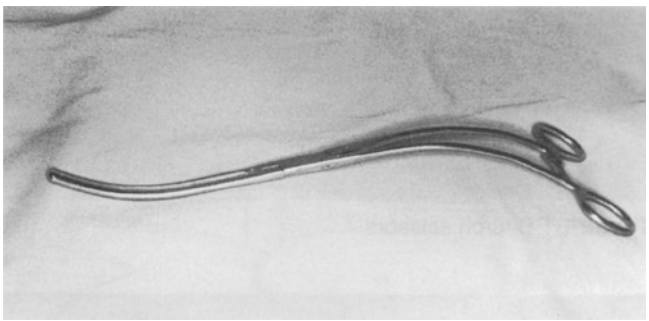

Figure 1.13 (a, b) Debakey-Bahnson aortic aneurysm clamp

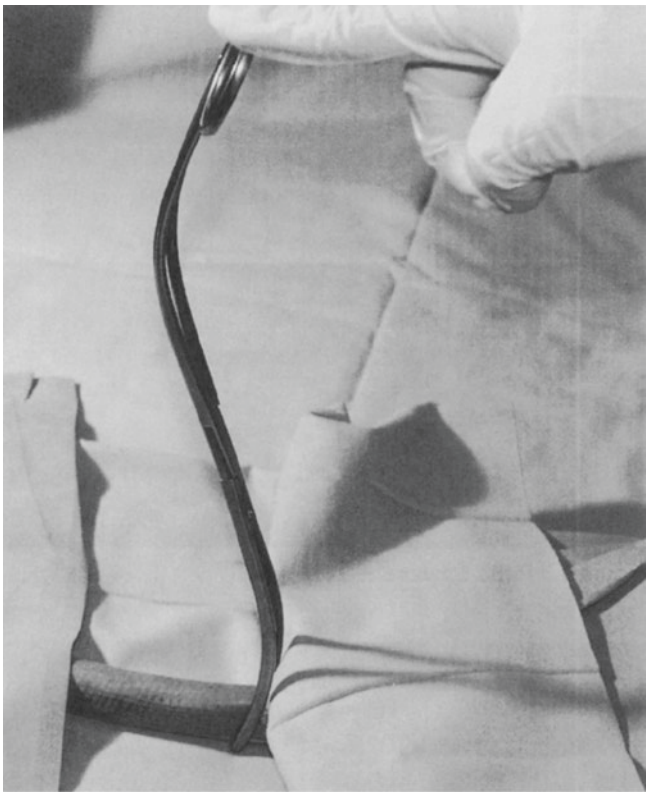

Figure 1.13b

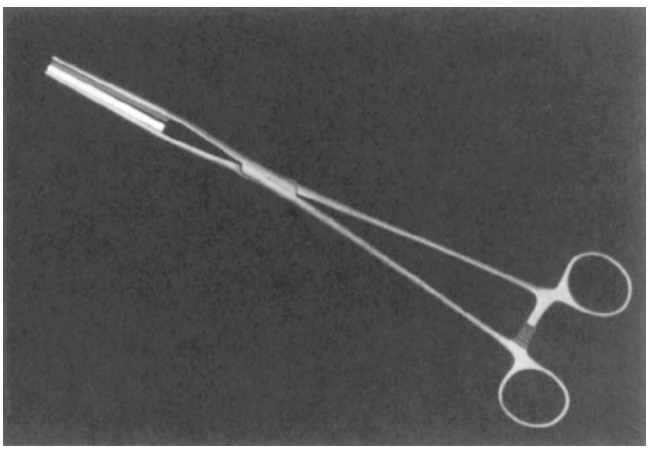

Figure 1.14 Fogarty clamp

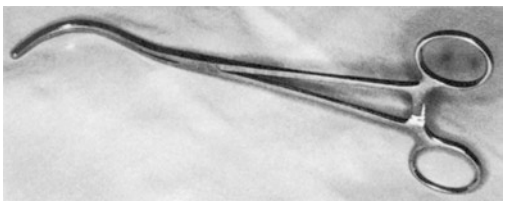

Figure 1.15 Debakey aortic aneurysm clamp

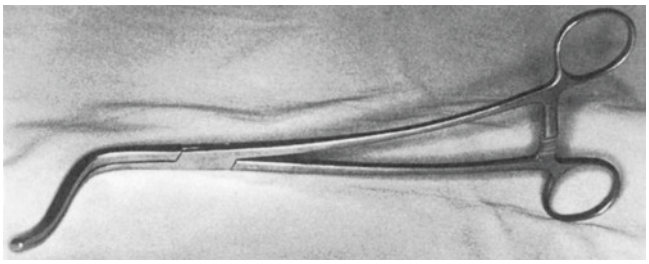

Figure 1.16 (a–c) Lambert–Kay aortic clamp

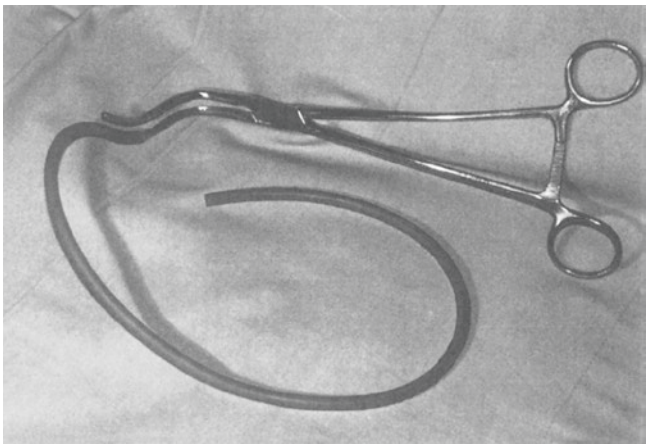

Figure 1.16b

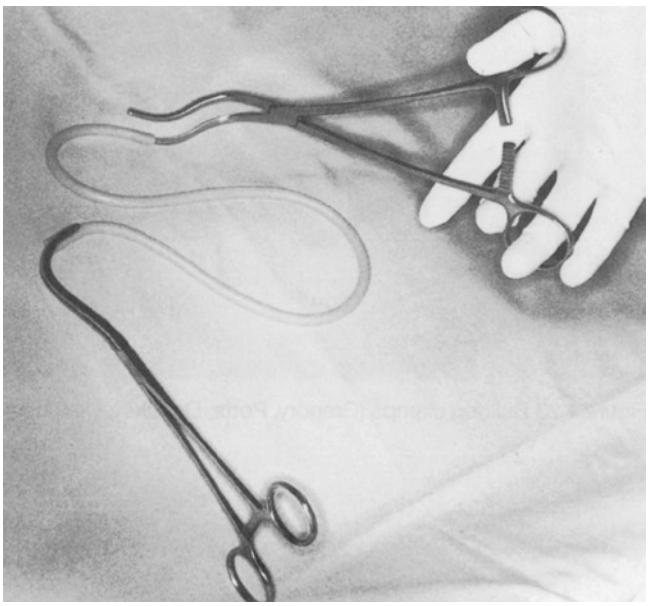

Figure 1.16c

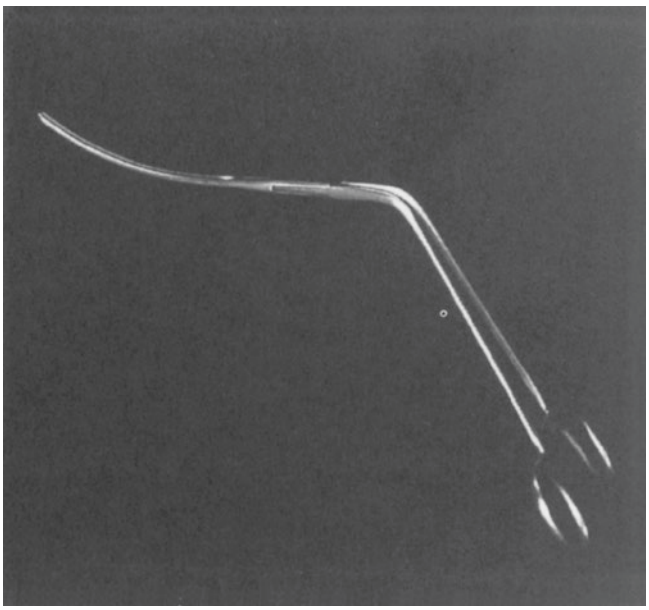

Figure 1.17a Wylie hypogastric clamp

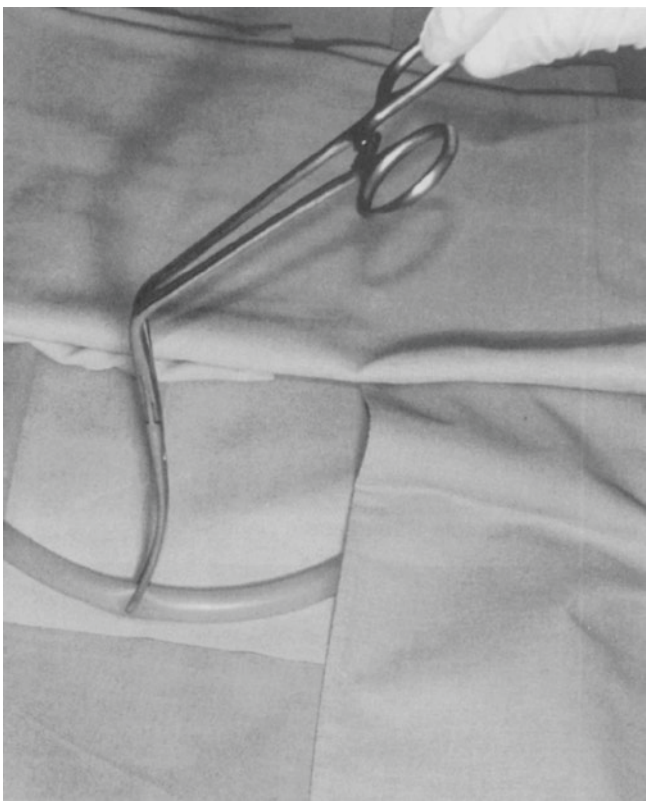

Figure 1.17b

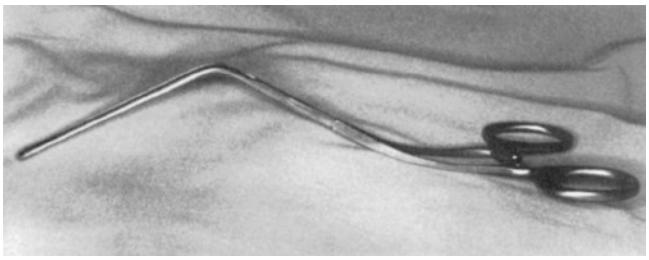

Figure 1.18 Debakey peripheral vascular clamp

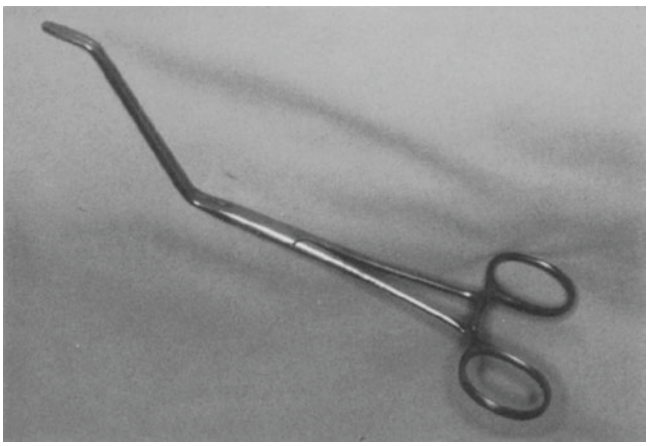

Figure 1.19a Henly subclavian clamp

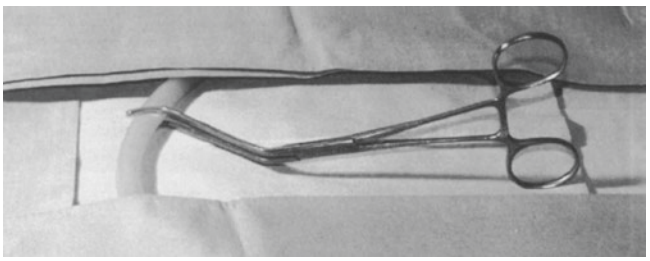

Figure 1.19b

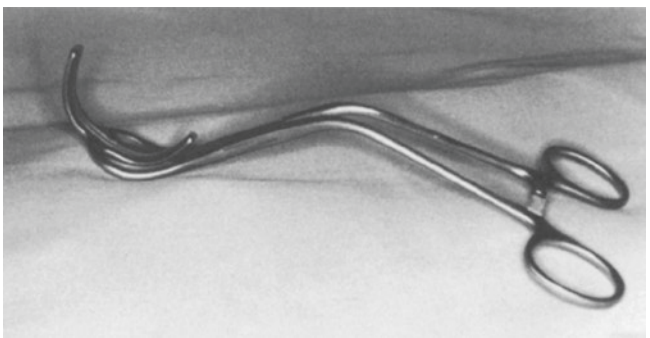

Figure 1.20a Lemole-Strong aortic clamp

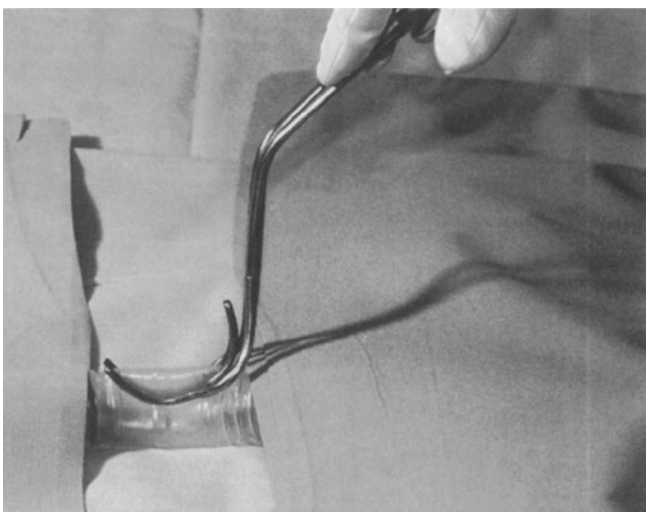

Figure 1.20b

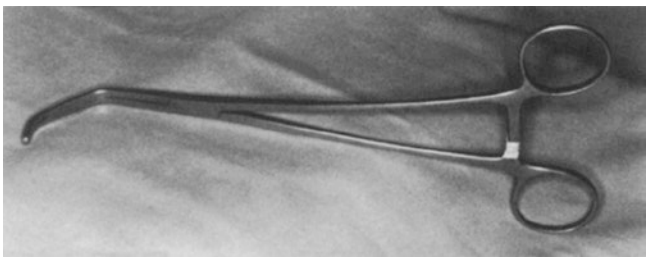

Figure 1.21 Satinsky clamp

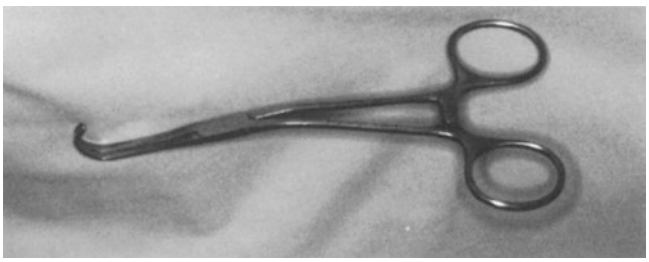

Figure 1.22 Cooley pediatric clamp

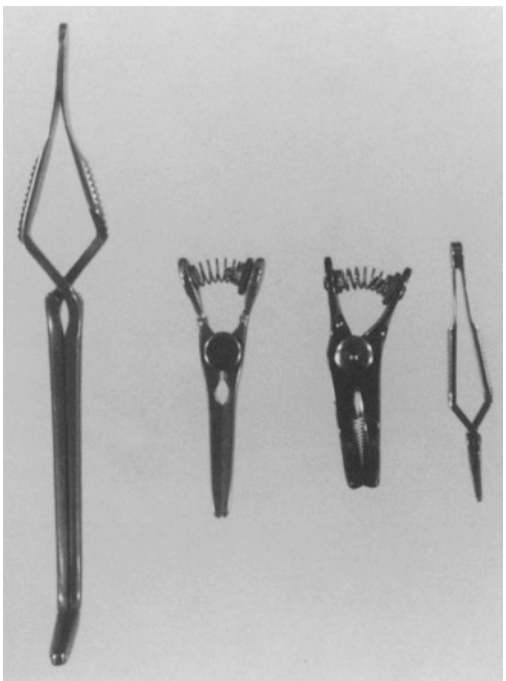

Figure 1.23 Bulldog clamps (Gregory, Potts, Debakey, Diethrich)

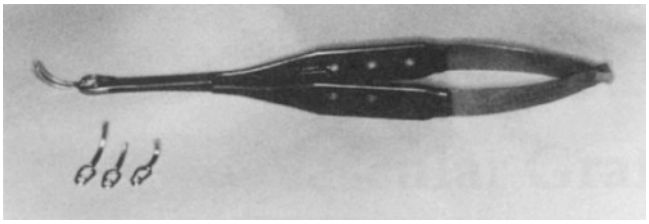

Figure 1.24 Yasargil aneurysm clips and applicator

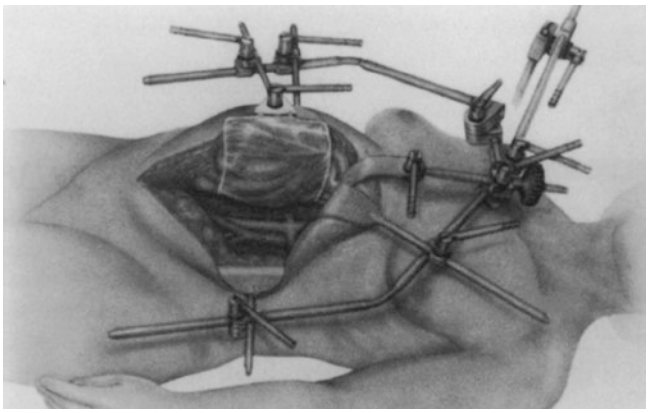

Figure 1.25 Omni-tract retractor

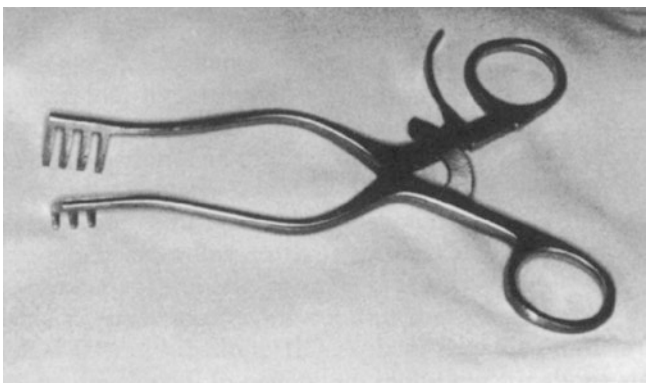

Figure 1.26 Weitlaner retractor

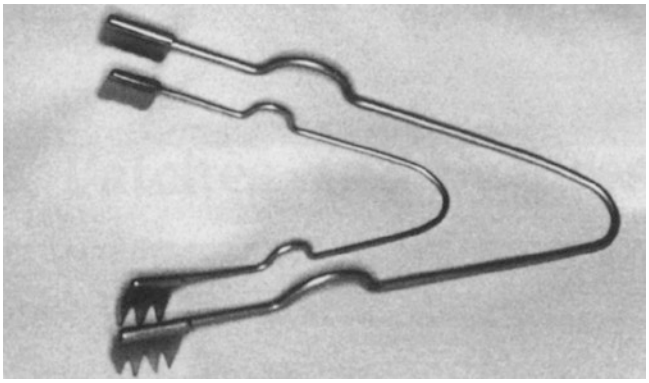

Figure 1.27 Spring retractors

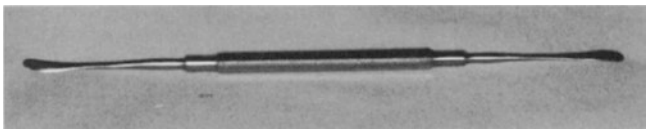

Figure 1.28 Freer double-ended elevator

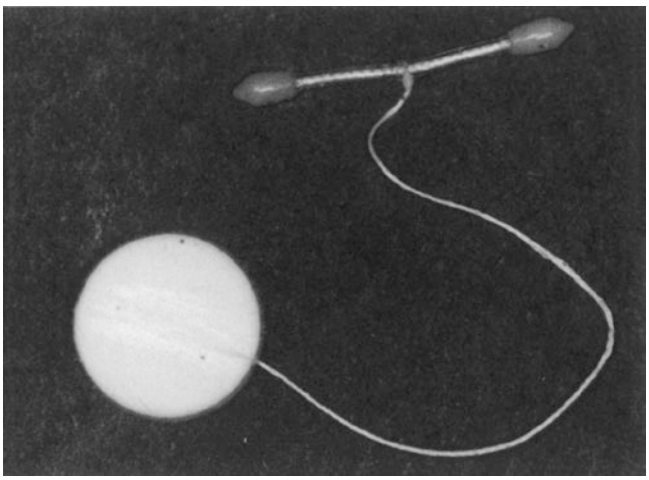

Figure 1.29 Internal occluder

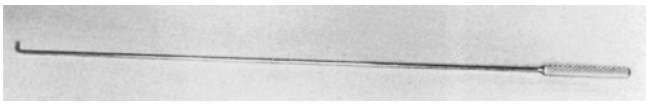

Figure 1.30a Mills valvulotome

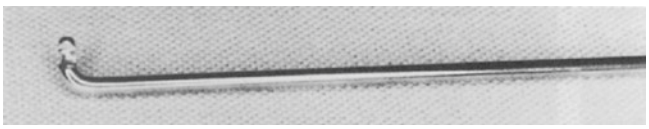

Figure 1.30b

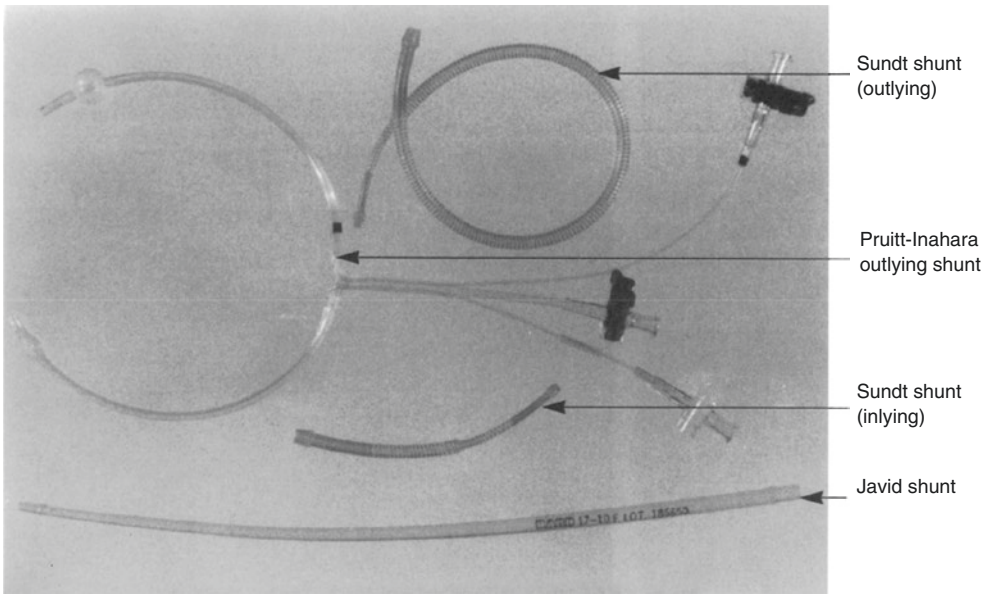

Figure 1.31 Carotid shunts

2

Vascular Grafts, Patches, and Sutures

Jamal J. Hoballah and Mohammad Rachad Wehbe

VASCULAR GRAFTS

Modern vascular surgery became possible with the development of acceptable arterial substitutes. The usefulness of an arterial substitute is determined by several essential qualities. These qualities include porosity, durability, tissue reactivity, and flexibility. The ideal conduit should be impermeable to blood and capable of lasting the duration of the recipient's life. Graft durability is dependent on its ability to maintain its characteristics and strength over time, resisting dilatation and degeneration. Graft durability is also related to its short- and long-term patency rates. The ideal conduit should be able to resist thrombosis even in low flow states. In addition, its compliance, which measures its volume change with variations in pressure, should match that of the replaced arterial segment. Compliance mismatch has been identified as a possible cause of neointimal hyperplasia, which is a leading cause of graft failure. The graft should also stimulate minimal antigenicity and should not induce significant tissue reaction. The conduit should be flexible with good handling characteristics. It should be resistant to infection and easily available for elective or emergency use. Finally, the graft should be affordable. Vascular grafts can be classified according to their source of origin into autogenous, homologous, bovine, and synthetic (prosthetic) grafts. It is hard to find, in the currently available vascular grafts, one conduit that possesses all the characteristics of the ideal arterial substitute; this explains why the ultimate arterial substitute is still to be developed. In general, in high-flow situations, such as aortic reconstructive surgery, large-caliber prosthetic grafts perform well and are the conduits of choice. In infrainguinal reconstructions, the best performance has been achieved with autogenous conduits.

AUTOGENOUS CONDUITS

Veins are the most commonly used autogenous conduits. The veins used as conduits include the greater and lesser saphenous veins, the femoral-popliteal vein, and the cephalic and basilic veins. Arterial segments have also been used

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as autogenous grafts; these include the internal iliac artery, the radial artery, and the internal mammary artery. The latter two have been predominantly used for coronary revascularization and are not reviewed in this chapter. Autogenous conduits should be handled gently to minimize their injury during the harvesting process. One obvious mechanism of injury is crushing the vessel wall with the forceps during the dissection. This can be avoided by grasping only the adventitia of the conduit. Trauma to the conduit can also occur when a silastic loop is used to retract the vessel, and excessive traction is applied on the loop. Another form of injury occurs when small branches are inadvertently avulsed during the dissection or when branches are ligated very close to the body of the conduit, resulting in impingement on the lumen. Another important mechanism of trauma is overdistension of the conduit, leading to considerable endothelial injury. The endothelium can be protected by keeping the intraluminal pressure below 300 mmHg and using chilled whole blood to distend the graft. A cold solution of Ringer's lactate (1 L) or dextran 40 (1 L) mixed with 5000 units of heparin and 60 mg of papaverine can also be used to distend a vein graft. The vein should also be protected from desiccation injury during its exposure, by keeping the vein covered with gauze soaked with warm saline. Papaverine (60 mg/500 mL) can be added to the saline solution in an attempt to decrease spasm in the conduit.

Autogenous veins can be evaluated preoperatively with B-mode ultrasonography. This useful noninvasive method for assessing the availability, size, and quality of the venous conduit can also determine the presence of a duplicate system or other anatomical variations. A duplex surveillance program is recommended to routinely evaluate any autogenous vein bypass postoperatively. This test can identify failing grafts, resulting in graft revision before graft occlusion. Autogenous bypass failure during the first postoperative month is usually the result of technical reasons or poor choice of the inflow or outflow vessels. After the first postoperative month and for the following 2 years, neointimal hyperplasia becomes the most common cause of graft failure. Progression of atherosclerosis is the predominant cause of graft failure after the second postoperative year. Duplex surveillance is usually recommended every 3 months in the first postoperative year, every 6 months in the second year, and yearly thereafter.

Greater Saphenous Vein

In infrainguinal reconstructions, the greater saphenous vein (GSV) is considered the gold standard against which all other conduits are compared. When used as a bypass, the GSV can be harvested or kept in its bed after disrupting its valves (in situ vein bypass). A harvested GSV is either reversed (reversed vein graft) or used in a nonreversed fashion after disrupting the valves (translocated nonreversed vein graft). A learning curve is expected when the valves of a venous conduit are disrupted with a valvulotome. Incomplete disruption of valve leaflets or vein damage can occur with improper manipulation of any valvulotome. A duplicate venous system can be found in the thigh in 35% of the population [17, 18]. When the GSV is of a good size (> 3 mm) and quality, it is expected to perform equally well whether used as a reversed, nonreversed, or in situ bypass. However, vein utilization appears to be greatest with the in situ vein bypass, especially when the vein diameter is less than 3 mm. The patency rates of GSV bypasses to the above-knee popliteal artery have been reported to be comparable to those obtained with prosthetic bypasses at 4-year follow-up. However, the long-term patency of GSV infrainguinal bypasses is superior to that of prosthetic grafts, especially when the bypass extends below the knee [22]. The patency rates of infrainguinal bypasses at various levels performed with the GSV and other conduits are shown in Table 2.1.

Table 2.1. Patency rates of infrainguinal reconstructions at 4 years

	ABOVE-KNEE POPLITEAL	BELOW-KNEE POPLITEAL	REFERENCES #
Greater saphenous vein (primary) (secondary)	70	65–75 81	[1, 2, 3, 4, 5, 6, 7, 8, 15, 20, 21]
Arm vein (primary)	60	70	[4, 6, 10]
Umbilical vein (primary)	70	60	[8]
PTFE (primary)	60	40	[1, 2, 3, 21]

Lesser Saphenous Vein

The lesser saphenous vein serves as a good alternative source of autogenous vein grafts when the GSV is not available. Due to its limited length, the lesser saphenous vein is ideal for usage as a short bypass or for bypass revisions.

Femoral-Popliteal Vein

Although the femoral vein belongs to the deep venous system, it can be harvested and used as a conduit for infrainguinal revascularization [16]. In addition, it has been successfully used to replace infected aortic grafts [10, 11]. When additional length is needed, the harvesting is extended to include the popliteal vein. Following harvesting of the femoral-popliteal vein, the incidence of long-term postoperative swelling does not appear to be of clinical significance [10, 16]. This is noted especially if the patient has a normal deep venous system preoperatively and an intact greater saphenous vein, and if the junction with the profunda femoris vein is preserved. Nevertheless, the use of this conduit for infrainguinal revascularization has not gained wide acceptance, especially when other sources of vein conduits are available.

Arm Veins (Basilic and Cephalic)

The basilic and the cephalic veins can also be used as vein bypasses. These veins are relatively thin and delicate and can be challenging to use. They have a limited length and may also have unsuspected intraluminal pathology related to scarring from previous venipuncture. Arm veins can be used for bypass revisions or as grafts when the greater or lesser saphenous veins are unavailable. They can also be used as segments of composite bypasses. Occasionally, the cephalic and basilic veins can be harvested together as a loop providing the necessary length without having to join them with a composite graft if the antecubital vein is wide enough. In that situation, the valves of one segment will need to be disrupted. A duplex surveillance is essential to assist the long-term patency of arm vein bypasses [6]. The primary patency when a single-segment cephalic vein is used as a bypass is very favorable and so is the cumulative patency of spliced segments [4].

Composite Bypass

When two conduits are joined together to achieve the required length for a revascularization, the bypass is referred to as a composite graft. The conduits are usually joined using an end-to-end or an end-to-side reconstruction. When an end-to-side reconstruction is used, the second segment usually arises from the distal part of the first conduit, and the graft is described as a sequential bypass. The composite bypass is usually constructed from a prosthetic and a vein segment. The prosthetic part is usually kept above the knee with the vein segment

crossing the knee joint to the popliteal or the infrapopliteal arteries. The patency of this type of conduit is limited by the prosthetic component, and its value remains controversial. The composite bypass can also be constructed from two vein segments (composite vein bypass). The vein segments may be harvested from the upper or lower extremity. This composite vein bypass is usually used for infrapopliteal bypasses when the greater saphenous vein is inadequate. The performance of such bypass usually depends on the quality of the veins used.

Internal Iliac Artery

The internal iliac artery has been recommended for usage as a conduit in young patients suffering from renovascular hypertension [9]. Unlike the greater saphenous vein, the internal iliac artery does not appear to develop aneurysmal dilatation when used in children to construct an aortorenal bypass. Aneurysmal dilatation of saphenous vein aortorenal bypasses in children has been noted in 20% of the patients on long-term follow-up [12, 19].

HOMOLOGOUS GRAFTS

Umbilical Vein Grafts

The source of these grafts are umbilical cord veins that are treated with glutaraldehyde. Despite their reinforcement with a Dacron mesh, umbilical vein graft (UVG) can develop aneurysmal dilatation on long-term follow-up. They are mainly used for infrainguinal revascularization [8]. Their superiority over prosthetic grafts remains controversial [15].

Cryopreserved Veins

Cryopreserved veins are greater saphenous veins procured from cadaveric donors. Each donor is supposed to be extensively tested for any infectious disease. The harvested vein is preserved in a special solution and then stored in liquid nitrogen freezers. The veins are available in lengths varying from 50 cm to 80 cm with the inner diameter ranging from 3 mm to 6 mm. The veins are usually matched to the patient's ABO blood group but not necessarily. Cryopreserved vein grafts are costly and require time to thaw, and their superiority over commonly used prosthetic grafts is not proven. Rejection may play a role in delayed failure.

Aortic Allograft

Before the development of prosthetic grafts, aortic segments harvested from cadavers were used to replace the diseased aorta. However, on late follow-up, aortic allografts were noted to suffer from a significant rate of occlusion or aneurysmal degeneration. With the evolution and availability of the current prosthetic grafts, the use of aortic allografts was abandoned. However, an interest in these grafts has been resurrected recently as new studies advocate their utilization for the in situ replacement of infected aortic grafts [23].

BOVINE GRAFTS

Bovine grafts such as Artegraft (Artegraft, Inc. North Brunswick, NJ) are collagen conduits. They are usually composed of a selected section of a bovine carotid artery that has been subjected to enzymatic treatment with ficin and tanned with dialdehyde starch. It is easy to prepare with a quick rinse. These grafts have been mainly used for hemodialysis access. The ease of handling of

these grafts was originally tempered by the early recognition of a high incidence of complications such as thrombosis, aneurysmal formation, and infection. However, the incidence of these complications has been reported to be comparable to that seen with other prosthetic dialysis conduits. Nevertheless, these grafts are not used frequently.

PROSTHETIC GRAFTS

The currently available prosthetic grafts can be generally classified into either textile or nontextile grafts. After the implantation of a prosthetic graft, the graft material is infiltrated by connective tissue that grows through the pores of the wall to reach the luminal surface. The inner lining becomes an organized layer of blood coagulum partially supported by the invading strands of connective tissue. This layer is referred to as pseudointima because it lacks endothelium, except at the level of the anastomoses to the native vessel where some endothelial cells may be found. The pseudointima has a very poor resistance to clotting and does not possess the highly specialized qualities of the true endothelium. The connective tissue forms an outer shell or a "capsule" around the prosthesis, which may vary in thickness, depending on the reactivity of the prosthesis and the characteristics of the surrounding tissues. Ideally, the graft should be well incorporated without an overwhelming connective tissue invasion.

Textile Grafts

Textile vascular prostheses such as Dacron (Dupont, Inc.) are made of polyester. They are usually constructed by extruding polyester fibers and then twisting them together to form a yarn. The polyester yarn is then woven or knitted to produce the graft fabric. Textile grafts are porous. Healing and tissue ingrowth into textile grafts tend to increase with the porosity of the fabric. However, bleeding through the interstices of the grafts will also increase with the porosity of the graft. Textile grafts are usually crimped to provide some degree of elasticity and support across curvatures or joints. However, the elasticity is usually lost after the graft is implanted.

In woven polyester grafts, straight yarns are interlaced in an over-and-under pattern. Depending on the tightness of the weaving process, woven vascular grafts do not necessarily need to be preclotted. These grafts are stiff and do not tend to stretch. Their tissue incorporation is the least among the polyester grafts. They tend to fray or unravel if transected with a regular knife, which can be reduced by cutting with a hot knife or cautery. These grafts were mainly used during thoracic aortic replacements and when preclotting was not possible. Currently, they are less frequently used, as more desirable grafts have become available.

In knitted polyester grafts, loops of yarn are interlaced in various patterns that allow stretching of the graft. These are more porous than the woven grafts. The porosity of these grafts allows good tissue ingrowth into the graft after implantation. Preclotting of the graft with nonheparinized blood is necessary, however, to prevent bleeding through the fabric.

A velour polyester graft is produced by adding supplementary loops of yarns that project outward from the fabric, giving the surface a look and feel of velvet. The velour surface can be added to a woven or knitted core. A double-velour graft has velour on the inner and outer surface of the graft fabric. Other types may have the velour on the outer layer only. The configuration of the velour surface is designed to allow for more efficient preclotting and strong tissue ingrowth into the graft.

To eliminate the need for preclotting before their implantation, textile grafts have been impregnated or coated with sealants such as collagen or gelatin. This

feature is very desirable even though it increases the cost of the graft. Of note, it is the collagen that binds to the rifampin when used in infected cases. Additional innovations to improve prosthetic grafts include impregnation with silver to provide an antimicrobial characteristic and bonding with heparin to decrease thrombogenicity.

Polyester grafts are the most commonly used aortic prostheses. They are available in a tube, bifurcated, or branched configuration. Branched configurations are useful for aortic debranching procedures and open thoracoabdominal aneurysm replacement. Polyester grafts have also been used for infrainguinal reconstruction procedures; however, they remain less popular in the infrainguinal position than other available prosthetic conduits. The main concern with polyester grafts is their tendency to dilate with time, which is more commonly seen with the knitted variety. The long-term significance and clinical consequences of such dilatation remain undetermined. Following is a list of commonly used textile grafts.

			Impregnation	
Hemashield Platinum	Woven	Double velour	Collagen	Maquet
Hemashield Gold	Knitted	Double velour	Collagen	Maquet
INTERGARD Woven	Woven	External-velour	Collagen	Maquet Intervascular
INTERGARD Knitted	Knitted	External-velour	Collagen	Maquet Intervascular
INTERGARD silver	Woven and Knitted	External-velour	Collagen silver	Maquet Intervascular
INTERGARD heparin	Knitted and Ultrathin	External-velour	Heparin	Maquet Intervascular
FlowWeave plus	Woven	N/A		Jotec
FlowWeave Bioseal	Woven	N/A	Collagen	Jotec
FlowNit	Knitted	N/A		Jotec
FlowNit Bioseal	Knitted	N/A	Collagen	Jotec
Perouse Polimaille	Knitted	N/A	Collagen	Vygon
Perouse Polythese	Woven	N/A	Collagen	Vygon
Gelweave	Woven	N/A	Gelatin	Vascutek Terumo
Gelsoft Plus	Knitted	N/A	Gelatin	Vascutek Terumo
Fusion	Knitted outer and PTFE inner		None	Maquet
Fusion Bioline	Knitted outer and PTFE inner		Heparin to inner PTFE layer	Maquet

Expanded Polytetrafluoroethylene

Polytetrafluoroethylene (PTFE) grafts are nontextile grafts. They are produced by extrusion of the Teflon polymer, which is then mechanically stretched to produce a microporous tube. This tube is composed of solid nodes of PTFE inter-

connected by PTFE fibrils. The space between the fibrils represents the pores of the PTFE tube. Stretching the PTFE tube tends to lengthen the fibrils and widen the space between the nodes. PTFE grafts are microporous and do not require any preclotting. Tissue incorporation does occur despite the microporosity of the graft. Some of the first-generation PTFE grafts were noted to develop aneurysmal dilatation on follow-up. Gore-Tex, the PTFE graft produced by W.L. Gore, Inc., has an extra layer of PTFE added to its outer surface. In the other grafts, the manufacturing process has been modified to rectify this concern.

PTFE grafts are available in various lengths and diameters, permitting their utilization in aortic or peripheral reconstructions. They have become a very favored conduit for dialysis access when a primary fistula is not possible. They are also very commonly used for infrainguinal revascularization when autogenous veins are unavailable. The results of aortic PTFE grafts have been very favorable. They do not tend to dilate on long-term follow-up, as noted in the polyester grafts. Nevertheless, their use for aortic reconstructions has not gained wide acceptance. The main concerns have been the handling characteristics of the graft in the aortic location and needle-hole bleeding from the suture line. Nonaortic PTFE grafts can be externally supported by rings placed on the outer surface of the conduit. Wall thickness varies from 0.6 mm to 0.4 mm in the thin wall grafts.

Several modifications have been accomplished in PTFE grafts, in an attempt to further improve their patency and handling characteristics. W.L. Gore has produced a stretch PTFE variety to decrease the compliance mismatch between grafts and native vessels. W.L. Gore also developed a technology of coating the inner surface of the graft with heparin to decrease graft thrombogenicity. Heparin-bonded vascular prosthesis is also offered by FlowLine Bipore (Jotec). A similar innovation in the luminal surface of PTFE grafts was achieved by incorporating carbon particles in the graft, in an attempt to further decrease its thrombogenicity (Carboflo graft, Impra). Another new modification by Impra has been the creation of a special hood configuration at the distal end of the graft to simulate the effect of vein cuffs or patches. Vein cuffs and patches have been advocated as a method to decrease the neointimal hyperplastic response that develops at the distal anastomosis of prosthetic infrainguinal bypasses. The hood configuration is now available for hemodialysis grafts (Venoflo) or infrainguinal grafts (Distaflo). One additional innovation is the combination of Dacron and PTFE in one graft by Maquet (Fusion). The inner layer of the Fusion graft is comprised of extruded, expanded polytetrafluoroethylene (ePTFE). The outer layer is a knit polyester textile, polyethylene terephthalate (PET). These two layers are fused together with a proprietary polycarbonate-urethane adhesive. Heparin coating has been added to this graft Fusion Bioline (Maquet) in the hope of increasing thromboresistance.

The effectiveness of all these modifications on the patency of PTFE grafts appears promising though not fully proven yet. PTFE grafts for nonaortic use are now produced by several manufacturers, including W.L. Gore, Impra (Bard), Atrium (Atrium Medical Inc.), and FlowLine (Jotec), Maquet. Aortic PTFE grafts are currently only manufactured by W.L. Gore.

VASCULAR PATCHES

Patches used in vascular reconstructions are also classified as autogenous or prosthetic. Autogenous patches can be obtained from arm or leg veins. The jugular and facial veins have also served as sources of vein patches. One concern with using vein patches relates to their potential risk of rupture. This risk has been mainly reported with the use of the ankle segment of the greater saphenous vein

during carotid endarterectomy. Vein patch rupture has also been reported when the thigh segment of the saphenous vein has been used during carotid endarterectomy. Greater saphenous vein patch rupture is more likely to result from the quality of the vein rather than its site of origin. Another concern with the use of a segment of the greater saphenous vein as a patch is the fate of the remaining part of the vein. Thrombosis of the vein will eliminate its potential use in the future as a bypass conduit for coronary or infrainguinal revascularization. Another source for autogenous patches is the occluded superficial femoral artery. After harvesting the occluded artery, an endarterectomy is performed, and the endarterectomized vessel is incised longitudinally and used as a patch.

Prosthetic patches are usually made of polyester or PTFE. They share the same characteristics as their graft counterparts. The main concerns with the use of prosthetic patches relate to the possibility of infection, future dilatation, needle-hole bleeding, and handling characteristics. The infection rate of prosthetic patches used during carotid endarterectomy is less than 1%. Although the standard PTFE patches have very desirable handling characteristics, the disturbing needle-hole bleeding noted when used during carotid endarterectomy has curtailed their use in carotid procedures. This led to the introduction by W.L. Gore of the Acuseal patch where the expanded PTFE is combined with an elastometric fluoropolymer to minimize needle-hole bleeding. The old generation of polyester patches had a propensity to dilate, which led to the development of a newer generation with better handling characteristics. Currently, polyester patches are available in various thicknesses and have very desirable characteristics. Needle-hole bleeding is minimal with the newest generation patches, especially when impregnated with collagen or coated with albumin. Whether one patch is better than the others remains inconclusive. A Cochrane review indicated the outcomes between vein and synthetic patches were comparable, except for pseudoaneurysms where more were associated with vein patches than prosthetic ones [14] (odds ratio (OR) 0.09, 95% confidence interval (CI) 0.02–0.49). The clinical significance of this finding was undetermined as the reported numbers were low. Within the synthetic patches, Dacron patches appeared to be associated with a higher perioperative neurologic events and restenosis than PTFE patches although the clinical significance of such findings were undetermined. An interest in bovine pericardium patches is also being noted, as they appear to have excellent early and long-term outcomes [13, 14], and they handle very well. A list of commercially available patches is outlined in Table 2.2.

VASCULAR SUTURES

Vascular reconstructions are conducted with nonabsorbable sutures. These sutures are needed to provide the tensile strength essential to secure the walls of the vessels together until healing is completed. This provision is especially important when prosthetic material is used because these grafts never completely heal and the tensile strength provided by the sutures is needed for the duration of the patient's life. The suture material available for vascular reconstructions include multifilament sutures such as silk and braided polyester, or monofilament sutures such as polypropylene, polybutester, and polytetrafluoroethylene.

SILK SUTURES

Although silk is nonabsorbable, it is biodegradable and tends to lose its tensile strength over time. Silk has been incriminated in the late development of anastomotic pseudoaneurysms. Silk sutures are not used nowadays to construct vascular anastomoses.

Table 2.2. Non-Autogenous Patches

PATCHES	DESCRIPTION	MANUFACTURERS	THICKNESS
Gore-Tex	Expanded polytetrafluoroethylene	W.L. Gore	0.40 mm
Gore-Tex Acuseal	Expanded polytetrafluoroethylene combined with fluoropolymer	W.L. Gore	0.50 mm
Hemashield	Knitted double-velour polyester	Getinge Maquet	0.76 mm
Hemacarotid Knitted	Reversed locknit knitting technique and collagen coated	Getinge Maquet	0.65 mm
Hemacarotid Knitted Ultrathin	Reversed locknit knitting technique; collagen coated; comes also with silver (Hemacarotid silver knitted Ultrathin) and heparin impregnation (Hemacarotid Heparin Knitted Ultrathin)	Getinge Maquet	0.41 mm
Hemashield Finesse platinum	Ultrathin knitted polyester impregnated with collagen	Getinge Maquet	0.36 mm
Intervascular Hemagard	Knitted velour polyester coated with collagen	Getinge Maquet	0.65 mm
Fluropassive thin wall Vascutek	Polyester Köper-knitted, bonded with fluoropolymer, and sealed with gelatin	Vascutek Terumo	0.36 mm
Vascu-Guard	Bovine pericardium cross-linked with glutaraldehyde recalled 2015 for bleeding	(BioVascular, Inc., St. Paul, MN USA)	0.35 mm
Duravess bovine pericardial patch	Bovine pericardium cross-linked with glutaraldehyde	Edwards	0.5+/−0.25 mm

BRAIDED POLYESTER SUTURES (MERSILENE, DACRON, ETHIBOND)

These sutures are nonabsorbable and made of braided fibers of polyester. They maintain their great tensile strength over time and elicit minimal tissue reaction. Mersilene and Dacron are uncoated, resulting in a rough surface. When these sutures are pulled through tissues or tied, a drag feeling is noted, limiting their handling characteristics.

POLYPROPYLENE SUTURES (PROLENE, SURGIPRO, SURGILENE)

Although some surgeons use polyester sutures because of their superior tensile strength, polypropylene sutures have gained a wider popularity and are probably the most commonly used suture material in vascular reconstructions. Made of a monofilament strand of a synthetic linear polyolefin, these polypropylene sutures tend to maintain their tensile strength over time. In addition,

they have a low coefficient of friction and excellent handling characteristics. They maintain their tensile strength in vitro and elicit a minimal transient acute inflammatory tissue reaction. Polypropylene sutures are very smooth. Seven throws are usually placed to secure the knot and avoid unraveling.

POLYBUTESTER SUTURES

The polybutester suture (Novofil; Medtronic) is a type of monofilament nonabsorbable suture. This suture is advertised as being stronger than polypropylene with increased flexibility and little memory. It is coated with polytribolate to reduce drag and improve tissue passage during suturing. The experience in using these sutures in vascular reconstructions remains variable, as most surgeons are used to polypropylene.

POLYTETRAFLUOROETHYLENE SUTURES

Polytetrafluoroethylene (PTFE) sutures also have excellent handling characteristics. They have been developed with the intention of minimizing needle-hole bleeding, which is often seen when polypropylene sutures are used with PTFE grafts or patches. They are designed to have a very minimal difference in the diameter of the needle and the suture line. Thus, theoretically, the PTFE thread should fill all the space created by the penetration of the needle, and the leak around the PTFE thread should be minimal. However, needle-hole bleeding still occurs with PTFE sutures, especially when the needle has been inadvertently subjected to lateral movements when penetrating the vessel wall.

Monofilaments usually have a low tissue friction and a low drag coefficient, which makes them ideal for usage as a continuous suture line. Despite these properties, inappropriate pulling on the thread may result in tearing and longitudinal slits in the vessel walls that could also result in an excessive amount of suture line bleeding. A careful use of a nerve hook could result in tightening of the suture line without tearing the vessel wall.

All sutures are susceptible to fraying and breakage if poorly handled. Suture breakage can develop intraoperatively or postoperatively, resulting in catastrophic complications. Following are some tips in handling suture material.

1. Avoid crushing the suture line with the tissue forceps or the needle holder.
2. Use rubber clamps or plastic-shod clamps to stabilize the unused part of a suture line.
3. Apply the rubber-shod clamps close to the needle rather than in the middle of the suture line.
4. Avoid excessive friction between both ends of the suture line while tying, as this can lead to fraying.
5. If tying was started with a sliding or granny knot, crossing the hands with the following throws is essential to achieve square knots with the remaining throws, and avoid the possibility of unraveling or slipping of the knot.
6. Use sutures appropriately sized for your reconstruction. The following guidelines are suggested for the choice of suture size:

   2–0, 3–0; aorta
   4–0; iliac arteries
   5–0; axillary, common carotid, common femoral, and superficial femoral arteries

5–0, 6–0; internal carotid, popliteal, and brachial arteries
7–0, 8–0; tibial or inframalleolar arteries

NEEDLE SIZE

Sutures used for vascular reconstructions are usually double armed with a needle on each end of the suture. The suture thread is enclosed in the eye of the needle. Thus, the hole in the vessel wall is determined by the size of the needle and the smoothness of introducing the needle through the vessel wall. Several needle shapes are available. Cutting needles have a sharp pyramidal shape and are used for tough tissues such as the skin. They are not used in vascular reconstructions to avoid excessive tears in the vessel wall. Taper needles have a round smooth shape. They are most favored in vascular reconstructions as they puncture the vessel wall with minimal cutting. In very calcified vessels, a hybrid of the taper and cutting needle is available to allow penetration of the needle through the vessel wall. These hybrid needles are called tapercut needles because the tip has a cutting profile, while the rest of the needles have a round design. Unfortunately, the same needle shape and size may be given a different name by a different manufacturer. Surgeons should be familiar with the shapes and names of needles available at their institutions. Choosing the appropriate needle shape and size during a vascular reconstruction is very important. The following guidelines are suggested for choosing the appropriate needle. All the following needles are taper-point needles, except for the V7 and CC (Ethicon), which are tapercut.

VESSEL SIZE	NEEDLE POINT	ETHICON	SYNETURE MEDTRONIC COVIDIEN	GORE-TEX
Small (calcified tibial)	Piercing	CC	KV-1	PT-9
Small (tibial, internal carotid)	Taper	BV-1	CV-1, CVF-1, MV-175-8	TTc-9
Small (tibial)	Taper	BV	CV-11, CVF	TTc-12
Medium (common carotid, femoral, popliteal)	Taper	C-1	CV-11, CVF-11	TTc-13
Large (common iliac)	Taper Taper	RB-1 RB-2	CV-23, CVF-23 CV-22, CVF-22	TH-18 TH-13
Large (aorta anterior wall)	Taper	SH	V-20	TH-26
Large (posterior wall of aorta) Large (aorta)	Taper Piercing	MH V7	V-26 KV-7	TH-35 PH-24

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3

Vascular Anatomy and Exposures

Jamal J. Hoballah

ARTERIES OF THE NECK AND UPPER EXTREMITY

ANATOMY OF THE SUBCLAVIAN AND VERTEBRAL ARTERIES

The Subclavian Artery

The right subclavian artery (SCA) originates from the innominate (brachiocephalic) artery at the base of the neck behind the right sternoclavicular junction (Fig. 3.1). It curves upward and laterally to pass behind the right anterior scalene muscle and then crosses underneath the clavicle and over the first rib to become the axillary artery.

The left subclavian artery originates directly from the aortic arch and ascends in the mediastinum to the base of the neck where it follows, on the left side, a similar course to that of the right subclavian artery (Fig. 3.1).

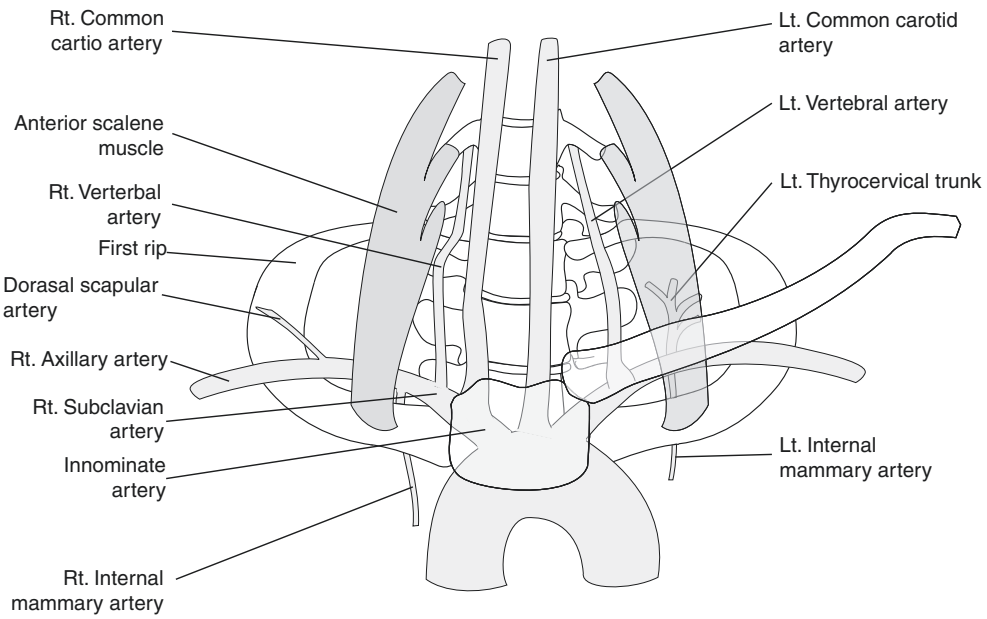

Figure 3.1. Anatomy of the aortic arch vessels.

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The subclavian artery is divided into three parts based on its anatomical relationship to the anterior scalene muscle. The first part is medial, the second part is posterior, and the third part is lateral to the anterior scalene muscle. The branches of the first part of the subclavian artery are the vertebral artery, the internal mammary artery, and the thyrocervical trunk. Usually, no branches originate from the second part of the subclavian artery. The third part of the subclavian artery gives rise to the dorsal scapular artery (Fig. 3.1).

The Vertebral Artery

Each vertebral artery usually originates from the upper posterior part of the subclavian artery as its first branch (Fig. 3.1). Occasionally, the right vertebral artery may originate from the innominate artery and similarly, the left vertebral artery may originate directly from the aortic arch. The vertebral artery ascends in the neck posteriorly and usually enters the transverse process foramen of the sixth cervical vertebra. The vertebral artery then courses cranially through the foramina of the transverse processes of C6–C2. It exits through the transverse foramen of the atlas (C2), and runs in the suboccipital region above the atlas. It then passes through the atlantooccipital membrane and ascends to join the opposite vertebral artery to form the basilar artery. The vertebral artery is arbitrarily divided into four parts: V1 represents the artery from its origin until its entrance into the transverse foramen, V2 is the part that runs between C6 and C2, V3 is from C2 to the atlantooccipital membrane, and V4 is from the atlantooccipital membrane to the basilar artery.

EXPOSURE OF THE INNOMINATE AND SUBCLAVIAN ARTERIES

A median sternotomy is necessary to expose the origin of the innominate and right subclavian arteries [19, 26, 27, 35]. A left anterior thoracotomy through the third or fourth intercostal space is needed to expose and control the origin of the left subclavian artery [26, 27]. The remaining parts of the subclavian arteries are usually exposed through a supraclavicular approach. The various possible incisions used for exposing the aortic arch vessels are diagrammed in Fig. 3.2.

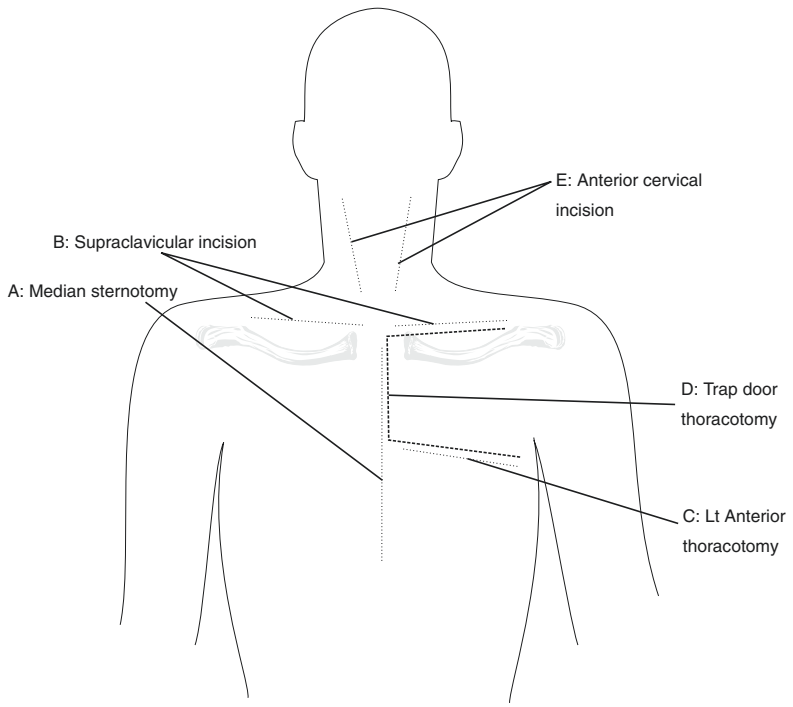

Figure 3.2. Incisions used for exposure of the aortic arch vessels.

Median Sternotomy

A skin incision is performed from the sternal notch to the xiphoid process. The skin incision is deepened through the subcutaneous tissues to the sternum. The clavicular ligament between the sternal heads of the clavicle is divided. The subxiphoid space is carefully dissected to engage an electric sternal saw. The sternum is longitudinally divided in half. A sternal bone spreader is then placed to spread the divided sternum. The thymus remnant is identified in the upper part of the incision and separated in the middle, exposing the left brachiocephalic vein directly beneath it. The left brachiocephalic vein is exposed and circumferentially dissected. A silastic vessel loop is passed around the left brachiocephalic vein and used to retract the vein superiorly, exposing the innominate artery and the origins of the right subclavian and both common carotid arteries (Fig. 3.3). The innominate artery can be mobilized and traced up to its bifurcation. Care should be taken to avoid any iatrogenic injury to the right recurrent laryngeal nerve, as it arches around the origin of the right subclavian artery (Fig 3.4).

The median sternotomy can be extended along a right supraclavicular incision if more distal exposure of the right subclavian artery is necessary. It can also be extended along the anterior border of either sternocleidomastoid muscle if further exposure of either common carotid artery is required (see Fig. 3.2). The left subclavian artery is hard to expose through a median sternotomy because of the posterior path of the aortic arch. If the need to expose the left subclavian artery becomes apparent during a median sternotomy, division of the left brachiocephalic vein has been reported to allow access to the origin of the left subclavian artery. Furthermore, the addition of a supraclavicular incision to the median sternotomy has also been reported to provide adequate access to the left subclavian vessels. However, traditionally, a left anterior thoracotomy is recommended to control the origin of the left subclavian artery. If distal exposure

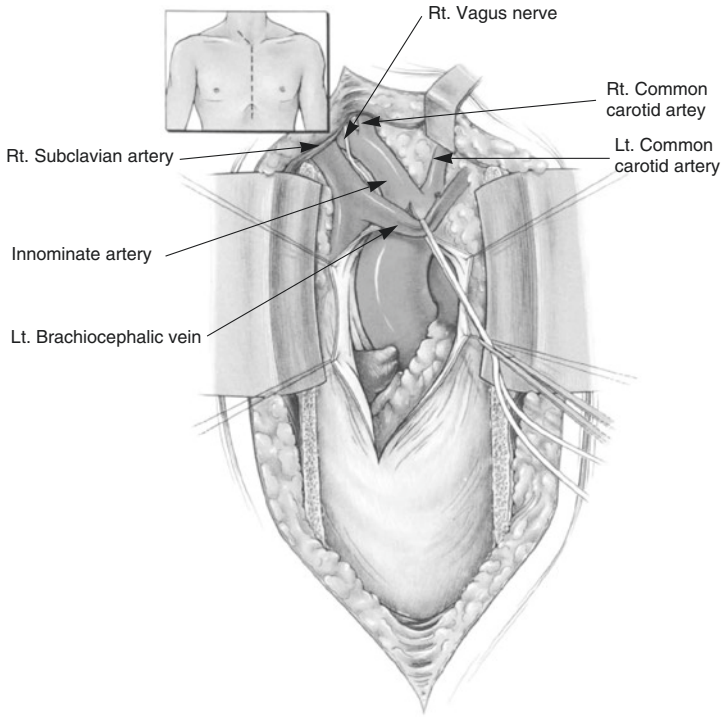

Figure 3.3. A median sternotomy is necessary for exposure of the aortic arch and the origin of the innominate, right subclavian, and right and left common carotid arteries. (From Berguer R, Kieffer E. Surgery of the Arteries to the Head. Springer-Verlag, 1992, with permission.).

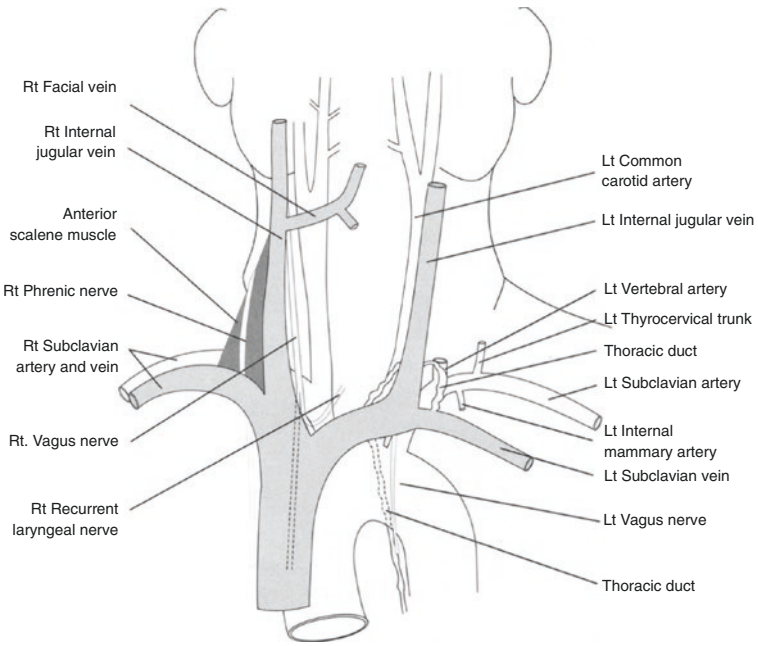

Figure 3.4. Aortic arch vessels and related structures.

of the subclavian artery and vein is needed in an unstable trauma patient, the median sternotomy and left anterior thoracotomy are converted into a trapdoor thoracotomy [26, 27, 35].

Trapdoor Thoracotomy

In this approach, the median sternotomy is connected to an anterior thoracotomy and to a supraclavicular incision (Fig. 3.5). The supraclavicular incision is started 1–2 cm above the sternal notch and carried out parallel to the clavicle. The sternocleidomastoid and the anterior scalene muscles are divided close to the clavicle. The sternal spreader is repositioned to expose the left subclavian vessels. It is important to note that the exposure achieved by the combination of a supraclavicular incision and a median sternotomy may be sufficient, eliminating the need and morbidity of the additional thoracotomy [14]. If the exposure is deemed inadequate, an anterior thoracotomy is started by an infraareolar incision and carried through the fourth intercostal space. The incision is extended into the sternum resulting in a trapdoor thoracotomy. Dividing the clavicle in its middle third can allow further lateral reflection of the thoracic trapdoor, providing an unhindered exposure of the entire left subclavian artery.

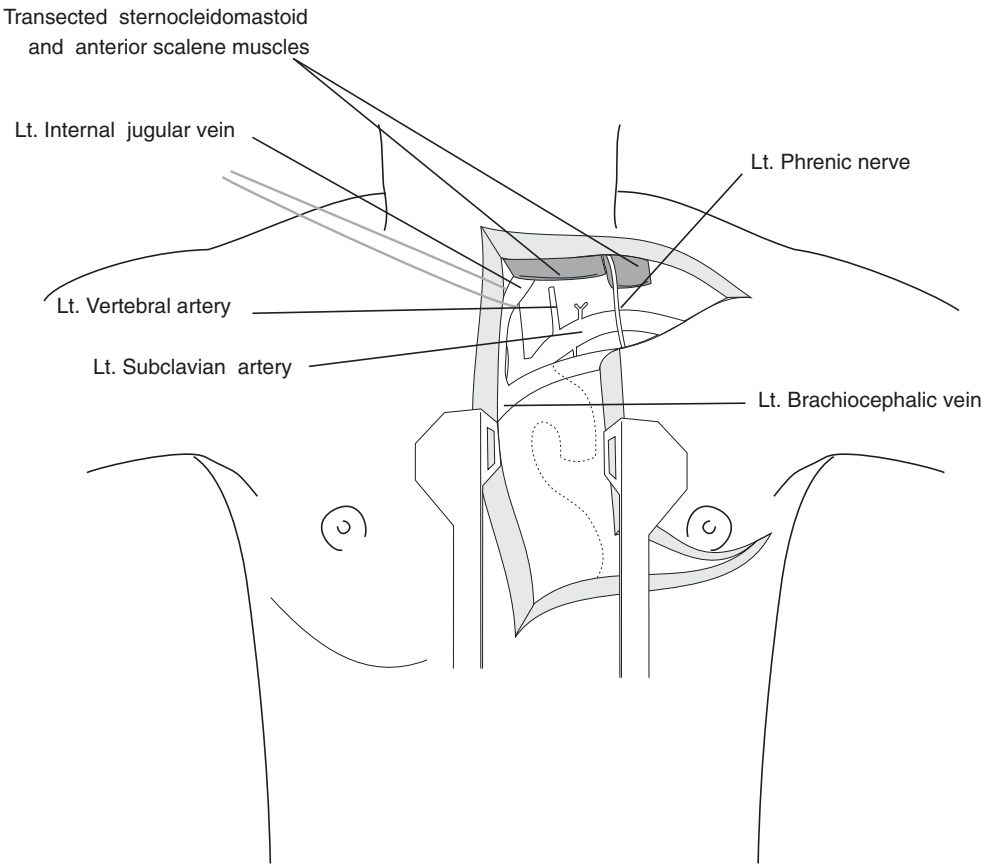

Figure 3.5. Trapdoor thoracotomy is performed by connecting a median sternotomy to a left supraclavicular incision and a left anterior thoracotomy.

Left Anterior Thoracotomy

In elective procedures, a double-lumen endotracheal tube is preferentially used to secure the airways. The skin incision is performed over the left fourth rib from the left sternal edge to the mid axillary line. The incision is deepened through the subcutaneous tissues, exposing the rib cage and the intercostal muscles. Either the third or fourth intercostal space can be used to enter the chest cavity. The intercostal muscles are divided and the pleural space is entered. The left lung is deflated and retracted inferiorly, allowing access to the aortic arch, which is exposed by incising its overlying pleura (Fig. 3.6). The origin of the left subclavian artery is identified as the most distal branch originating from the aortic arch. This approach allows for additional distal exposure of the left subclavian artery through a supraclavicular incision should it become necessary. A left posterolateral thoracotomy can also provide a good exposure of the origin and proximal part of the left subclavian artery [2] (Fig. 3.7). However, this approach is usually reserved for elective conditions where the pathology is limited to the very proximal part of the left subclavian artery. The patient's position in this approach does not allow for additional exposure of the left subclavian artery through a supraclavicular incision.

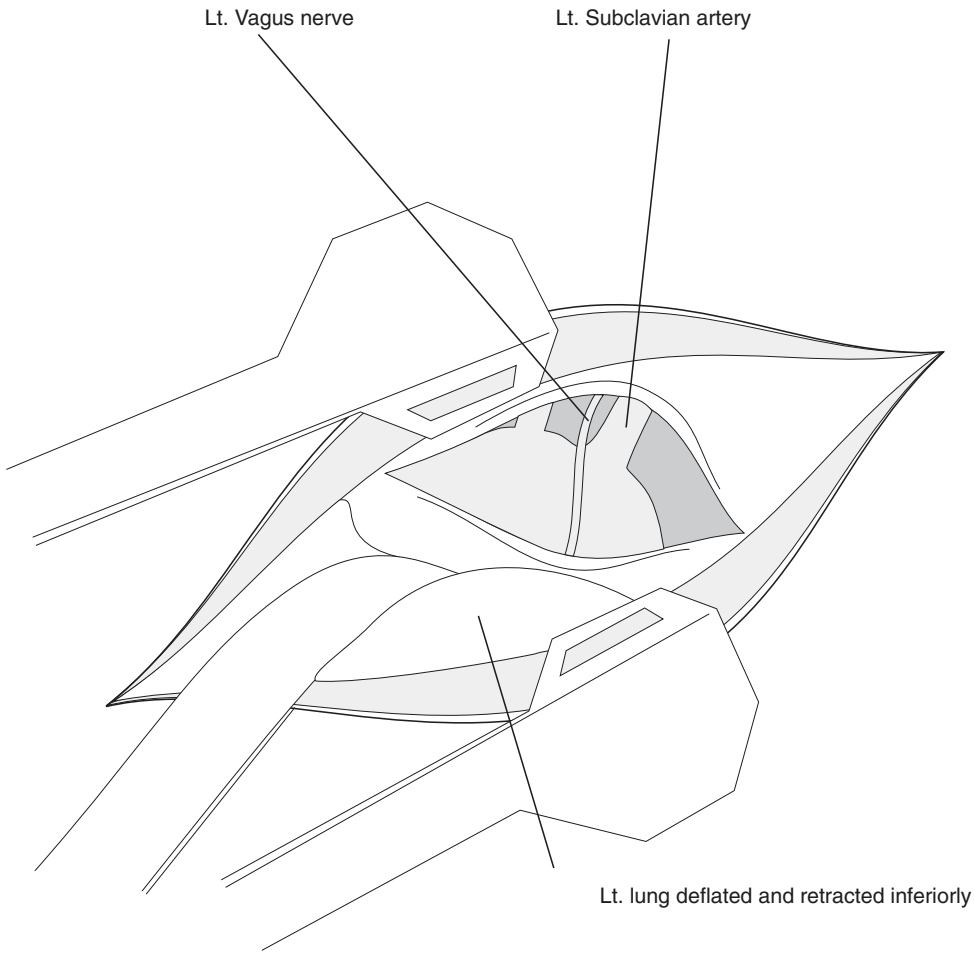

Figure 3.6 A left anterior thoracotomy is necessary for exposure of the origin of the left subclavian artery. This approach allows for additional exposure of the left subclavian artery through a supraclavicular incision

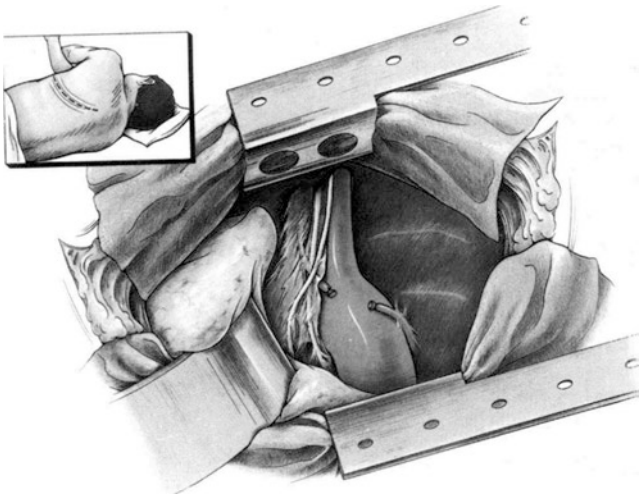

Figure 3.7. A left posterolateral thoracotomy provides exposure of the origin of the left subclavian artery. The patient's position does not allow for additional exposure of the left subclavian artery through a supraclavicular incision. (From Berguer R, Kieffer E. Surgery of the Arteries to the Head. Springer-Verlag, 1992, with permission.).

Supraclavicular Exposure of the Subclavian Artery

The main steps in the supraclavicular approach to the SCA are as follows:

1. Skin incision
2. Division of the platysma muscle
3. Mobilization of the scalene fat pad
4. Division of the anterior scalene muscle

Important structures that can be injured during exposure of the subclavian artery include the phrenic and recurrent laryngeal nerves, the brachial plexus, and lymphatic structures such as the thoracic duct on the left side (see Fig. 3.4).

Details of the Supraclavicular Exposure of the Subclavian Artery A supraclavicular incision is made starting 1–2 cm above the clavicle between the heads of the sternocleidomastoid muscle. The incision extends laterally and parallel to the clavicle for 10–12 cm and is deepened through the subcutaneous tissues to expose the platysma muscle (Fig. 3.8). The platysma muscle is divided with electrocautery to expose the scalene fat pad. The fat pad is mobilized from inferior to superior, starting at the level of the clavicle, to expose the anterior scalene muscle. The phrenic nerve is identified as it lies anterior to the anterior scalene muscle crossing from its lateral to medial side. The scalenus anterior muscle is divided close to its insertion onto the first rib while retracting and protecting the phrenic nerve. Any lymphatics encountered in the line of the plication of postoperative lymph leak. Once the anterior scalene muscle is divided, the subclavian artery can be identified by palpation or insonation with a handheld Doppler probe. The subclavian artery is then dissected and encircled with a silastic loop. This exposure provides full access to the second part of the subclavian artery. Gentle tension on the vessel loop will facilitate additional proximal and distal arterial exposure. Division of the clavicular head of the sternocleidomastoid muscle can help to provide additional proximal exposure [22]. Further mobilization of the distal segment of the first part of the subclavian artery will expose the origins of the thyrocervical trunk, the internal mammary, and the vertebral arteries (Fig. 3.8). The mobilization of this part of the subclavian artery may be facilitated by dividing the internal mammary artery. However, division of the internal mammary artery should be avoided, as this will prohibit its use for possible future coronary artery revascularization.

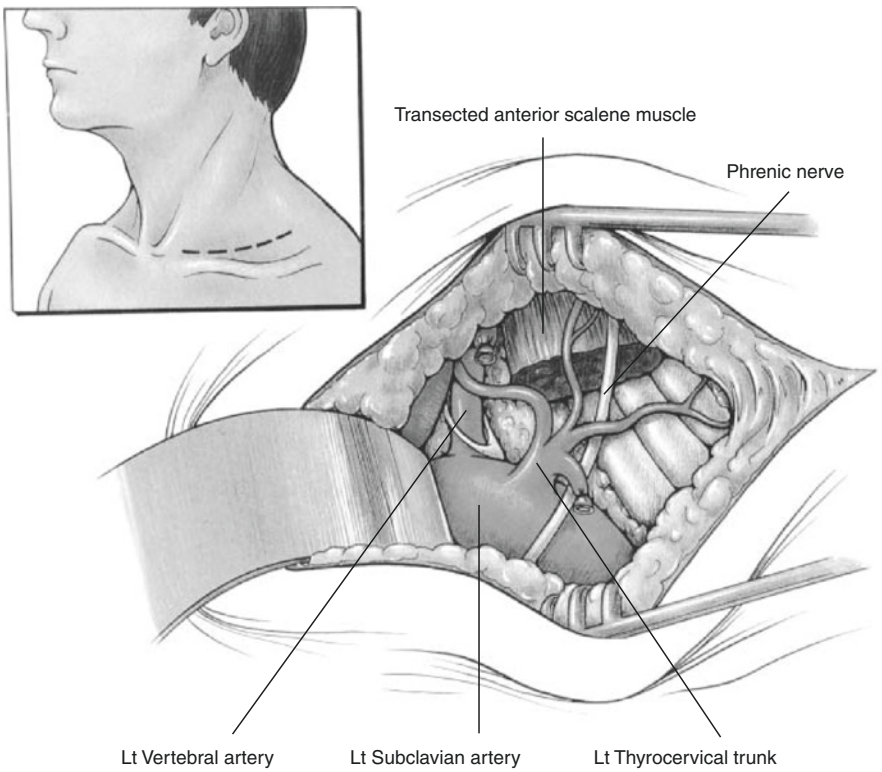

Figure 3.8. A supraclavicular incision is ideal for exposure of the second part and distal segment of the first part of the subclavian artery. It also allows for exposure of the proximal segment of the vertebral artery. (From Berguer R, Kieffer E. Surgery of the Arteries to the Head. Springer-Veriag, 1992, with permission.).

Further medial exposure of the subclavian artery can be obtained by subperiosteal resection of the medial third of the clavicle. The skin incision is extended toward the sternoclavicular junction. The incision is deepened directly over the clavicle to expose the periosteum. The edges of the clavicle are defined. A right-angle clamp is then passed around the clavicle to grab a Gigli saw, which is used to divide the clavicle laterally. The divided clavicle is then grasped with a towel clip and dissected further posteriorly and anteriorly until the head of the clavicle is released from all its ligamentous and fibrous attachments. For more proximal access, a median sternotomy will be necessary to provide additional exposure [14]. In elective procedures, an attempt can be made at dividing the clavicle and reflecting it medially without severing all the ligamentous and fibrous attachments of the sternal head. The reflected medial portion of the clavicle can be replaced in its position at the completion of the vascular procedure and stabilized with a plate for cosmetic purposes and to prevent possible future shoulder discomfort.

EXPOSURE OF THE VERTEBRAL ARTERY

Although the vertebral artery can be accessible at all four segments, V2 and V4 are relatively hard to expose, as they are covered by bony structures. The origin of the vertebral artery and the V1 segment can be exposed using a supraclavicular approach as described in the exposure of the first and second parts of the subclavian artery (see Fig. 3.8). Transection of the clavicular head of the sternocleidomastoid muscle usually facilitates the exposure. Division of the sternal head may also be necessary. The vertebral artery can also be exposed through an anterior cervical incision. This incision can be extended to expose all the segments of the vertebral artery. The incision can be started along the anterior border of the sternocleidomastoid muscle and extended to the sternal notch. The sternocleidomastoid is retracted laterally, exposing the carotid sheath. The anterior cervical incision can also be modified to run between the heads of the sternocleidomastoid muscle. The muscle heads are separated, retracting the clavicular head laterally and the sternal head medially, exposing the carotid sheath. The carotid sheath is then mobilized medially and the dissection is continued posteriorly through its bed, exposing the thyroidal branches crossing from the thyrocervical trunk. Division of these branches is usually necessary to expose the underlying sympathetic chain, stellate ganglion, and vertebral vein. Mobilization of the vertebral vein will expose the first segment of the vertebral artery. Division of the vertebral vein may enhance the exposure.

When a transposition of the V1 segment into the common carotid artery is contemplated, the approach to the vertebral artery through the anterior cervical incision is slightly modified after exposing the carotid sheath. In this situation, instead of mobilizing the carotid sheath medially, it is incised to expose the carotid artery. The carotid artery is then mobilized and retracted medially. The vagus nerve is kept out of harm's way and left adjacent to the jugular vein, which is retracted laterally. The posterior aspect of the carotid sheath is incised, exposing the thyroidal branches of the thyrocervical trunk. The exposure is then continued as previously described (Figs. 3.9 and 3.10). This modification provides a new path for the vertebral artery between the common carotid artery and the internal jugular vein. This new and direct path facilitates the transposition of the vertebral artery into the common carotid artery.

Exposure of V2 will require unroofing of the bony canal in which the vertebral artery runs from C6 to C2. This is performed with the use of a bone rongeur. The vertebral artery is found surrounded by a rich vertebral venous plexus. Exposure of V3 is also obtained through a high cervical incision anterior to the sternocleidomastoid. The part of the vertebral artery between Cl and C2 is usually the segment exposed. The spinal accessory nerve is identified and preserved. The Cl transverse process is palpated, and the muscles inserting in the lower aspect of Cl are resected, exposing V3. This exposure may be facilitated by dividing the attachment of the sternocleidomastoid to the skull. The approach to V4 requires a posterior craniotomy to obtain exposure in the posterior fossa.

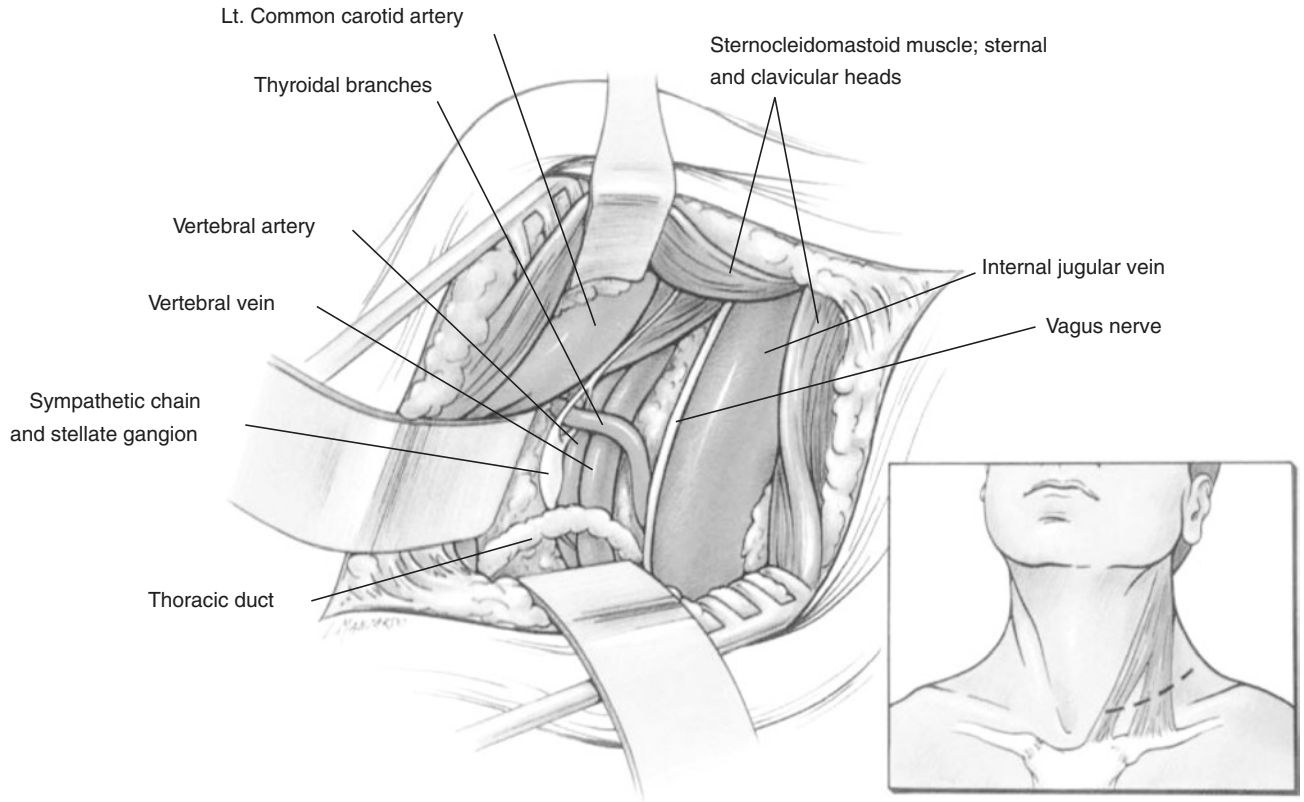

Figure 3.9. The vertebral artery can be accessed by exposing the carotid sheath. The common carotid artery is retracted medially and the jugular laterally. Dissection in the plane posterior to the carotid sheath will reveal the crossing thyroidal branches of the thyrocervical trunk. (From Berguer R, Kieffer E. Surgery of the Arteries to the Head. Springer-Verlag, 1992, with permission.).

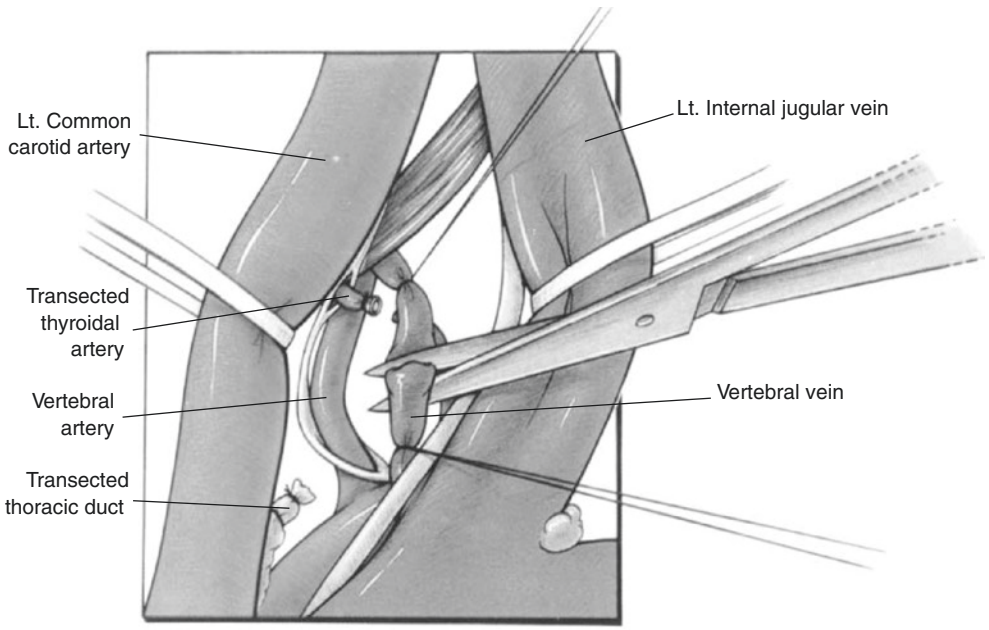

Figure 3.10. Division of the crossing thyroidal branches of the thyrocervical trunk, the thoracic duct, and the vertebral vein will provide exposure of the V1 segment of the vertebral artery along with the stellate ganglion. (From Berguer R, Kieffer E. Surgery of the Arteries to the Head. Springer-Verlag, 1992, with permission.).

ANATOMY OF THE AXILLARY AND BRACHIAL ARTERIES

The Axillary Artery

The axillary artery is the continuation of the subclavian artery after it crosses over the first rib (Fig. 3.11). It runs over the apical part of the chest wall and travels behind the pectoralis minor muscle toward the axillary fossa. The axillary artery is divided by the pectoralis minor muscle into three parts. The first part is the segment between the lateral border of the first rib and the medial border of the pectoralis minor muscle. The second part is the segment posterior to the pectoralis minor muscle. The third part is the segment distal to the lateral border of the pectoralis minor muscle. It extends to the lower border of the teres major muscle.

The Brachial Artery

The brachial artery is the continuation of the axillary artery. It starts at the lower border of the teres major muscle. The brachial artery travels down the arm starting medial to the humerus. It progressively moves into an anterior location and terminates into the radial and the ulnar arteries approximately 1 cm distal to the elbow crease (Fig. 3.11).

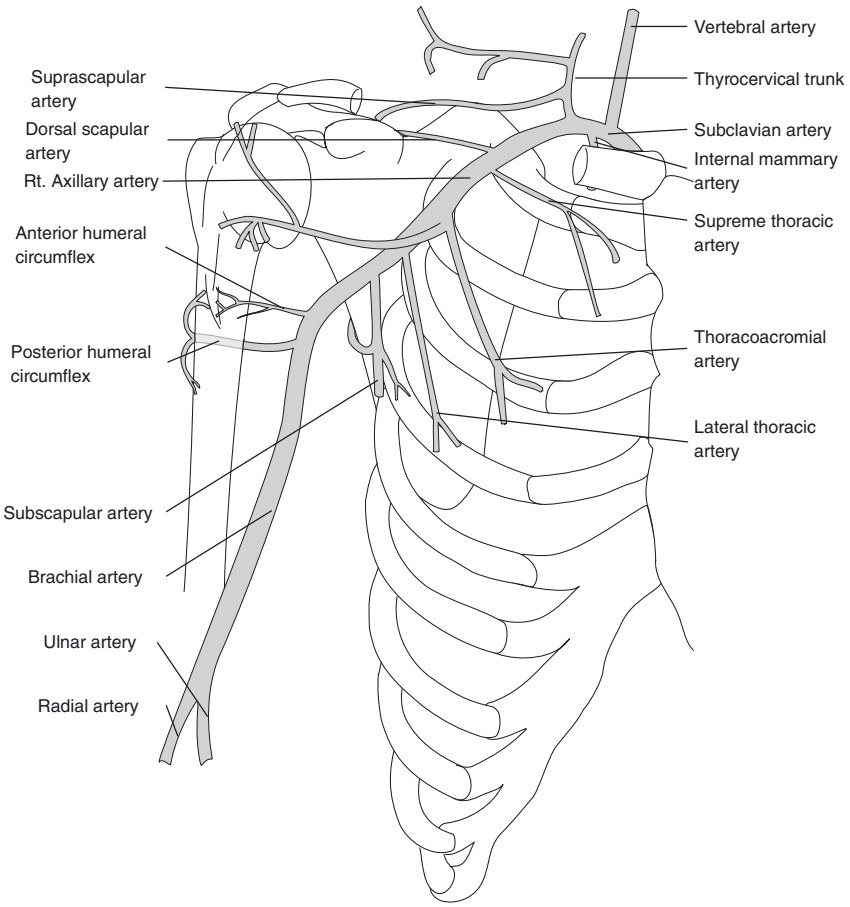

Figure 3.11. The axillary artery and its branches.

Exposure of the Axillary Artery

The main steps in exposing the axillary artery are

1. Skin incision
2. Incision of the pectoralis major muscle fascia
3. Separation of the pectoralis major muscle fibers
4. Division of the pectoralis minor muscle
5. Mobilization of the axillary vein

Details of the Exposure The skin incision is placed 2 cm below the clavicle and extends in a parallel direction to the clavicle for 10–12 cm (Fig. 3.12). After incising the skin and the subcutaneous tissues, the fascia of the pectoralis major muscle is encountered. The fascia is incised, and the incision is deepened toward the chest wall by splitting the pectoralis major muscle bluntly along the length of its fibers to expose the areolar tissue over the chest wall (Fig. 3.12). The medial part of the pectoralis minor muscle is identified toward the lateral aspect of the incision. Digital palpation or Doppler

auscultation over the chest wall medial to the pectoralis minor muscle will reveal the location of the axillary artery The axillary vein is seen partially covering the axillary artery as it lies anterior and superior to it. The axillary vein is mobilized caudally to better expose the axillary artery. Occasionally, the cephalic vein or other venous branches draining into the axillary vein may need to be divided along with branches of the thoracoacromial artery to better expose the axillary artery. The lateral pectoral nerve supplying the pectoralis major muscle lies near the thoracoacromial artery and should be protected.

The first part of the axillary artery can be exposed without having to divide the pectoralis minor muscle. However, division of the pectoralis minor muscle close to its insertion greatly facilitates the exposure of the axillary artery. When the second and third parts of the axillary artery need to be exposed, complete division of the pectoralis minor muscle is necessary. The distal part of the axillary artery is usually difficult to expose from this approach because of the overlying pectoralis major muscle and its attachment on the shoulder. Exposure of the most distal part of the axillary artery from this approach then requires division of the lateral portion of the pectoralis major and the coracobrachialis muscles. Alternatively, the third part of the axillary artery can be exposed via an axillary incision along the lateral border of the pectoralis major muscle. The pectoralis muscle is mobilized laterally and the axillary fossa is entered. The median nerve and the axillary vein will be first exposed. By dissecting superior to these structures, the distal segment of the axillary artery is identified.

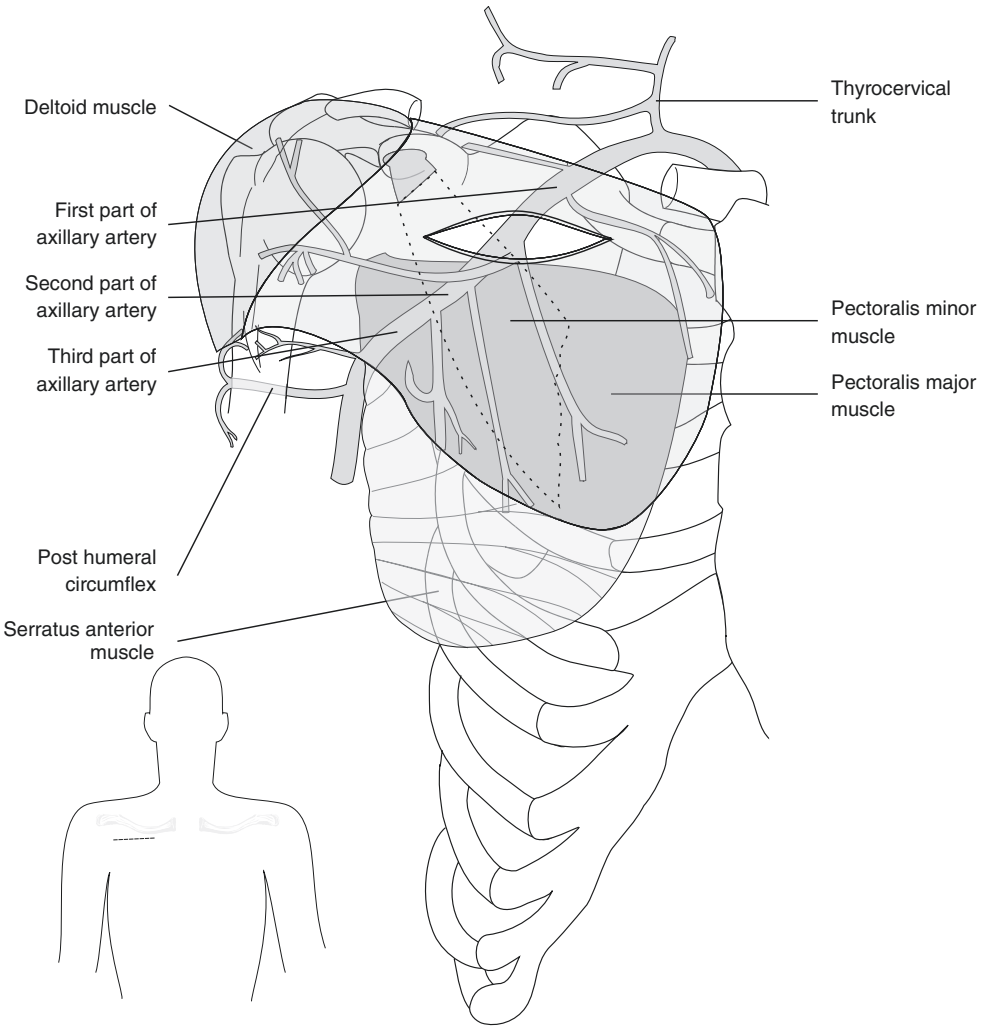

Figure 3.12. Exposure of the axillary artery.

Exposure of the Brachial Artery

In the upper arm, the brachial artery is exposed using a longitudinal incision parallel to the humerus. The incision is placed along the medial border of the biceps brachii muscle. After incising the subcutaneous tissues, the sheath covering the brachial neurovascular bundle is incised. The incision is guided by digital palpation of the brachial pulse or by insonating the artery with a Doppler probe if the pulse cannot be felt. The basilic vein is identified and mobilized posteriorly, exposing the brachial artery lying between the medial cutaneous nerve of the arm and the median and ulnar nerves.

At the elbow level, the brachial artery is exposed using a transverse incision or an S-shaped curvilinear incision. Division of a portion of the biceps brachii aponeurosis will expose the artery as it lies immediately beneath the aponeurosis and medial to the biceps brachii muscle and tendon (Fig. 3.13).

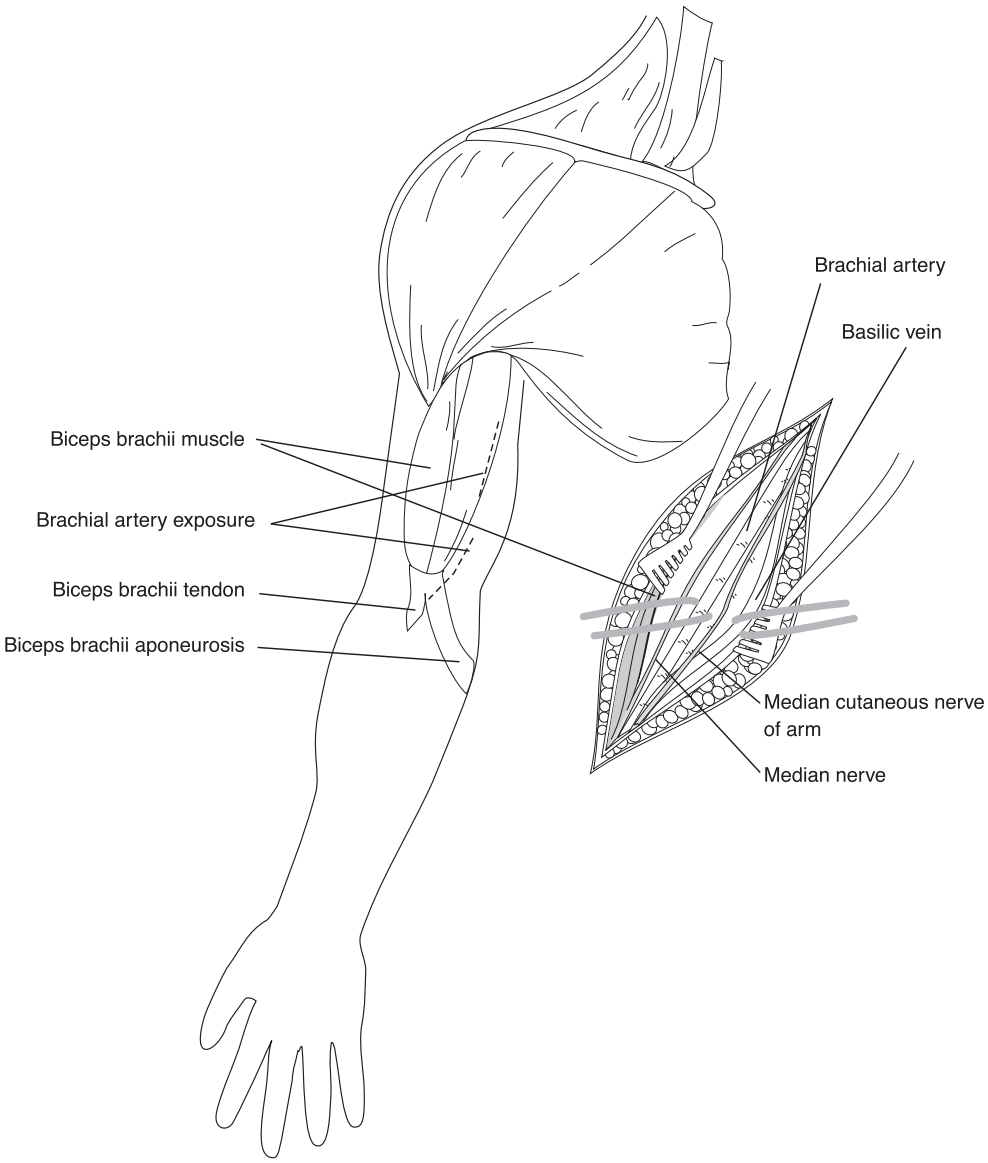

Figure 3.13. Exposure of the brachial artery.

ANATOMY OF THE RADIAL AND ULNAR ARTERIES

The Radial Artery

The radial artery starts at the bifurcation of the brachial artery just below the elbow joint. It continues along the radial side of the forearm to the wrist (Fig. 3.14). It then crosses around the outer side of the wrist to continue behind the extensor tendon of the thumb. The radial artery then connects with the deep branch of the ulnar artery to form the deep palmar arch.

The Ulnar Artery

The ulnar artery starts just distal to the elbow joint as the larger of the two terminal branches of the brachial artery. It crosses along the inner side of the forearm and continues down toward the wrist along the ulnar border of the forearm (Fig. 3.14). It crosses the wrist to divide into two branches that form the superficial and deep palmar arches.

EXPOSURE OF THE RADIAL AND ULNAR ARTERIES

Exposure of the Radial Artery

At the elbow level, the radial artery is accessed by exposing the brachial artery and tracing it distally until it bifurcates. Distally, the radial artery is exposed by performing a 3-cm transverse or longitudinal skin incision a few centimeters proximal to the wrist joint (Fig. 3.14). After incising the skin and the underlying fascia, the radial artery can be identified running between the tendons of the flexor carpi radialis and supinates longus muscles. The former is the most prominent tendon when the wrist is flexed while the latter is the most radial tendon in the incision. Exposure of the Ulnar Artery: At the elbow, the ulnar artery is accessed by exposing the brachial artery and tracing it distally. At the wrist, the ulnar artery is exposed by performing a longitudinal incision along the ulnar aspect of the forearm (Fig. 3.14). The artery is identified just below the skin and the underlying fascia.

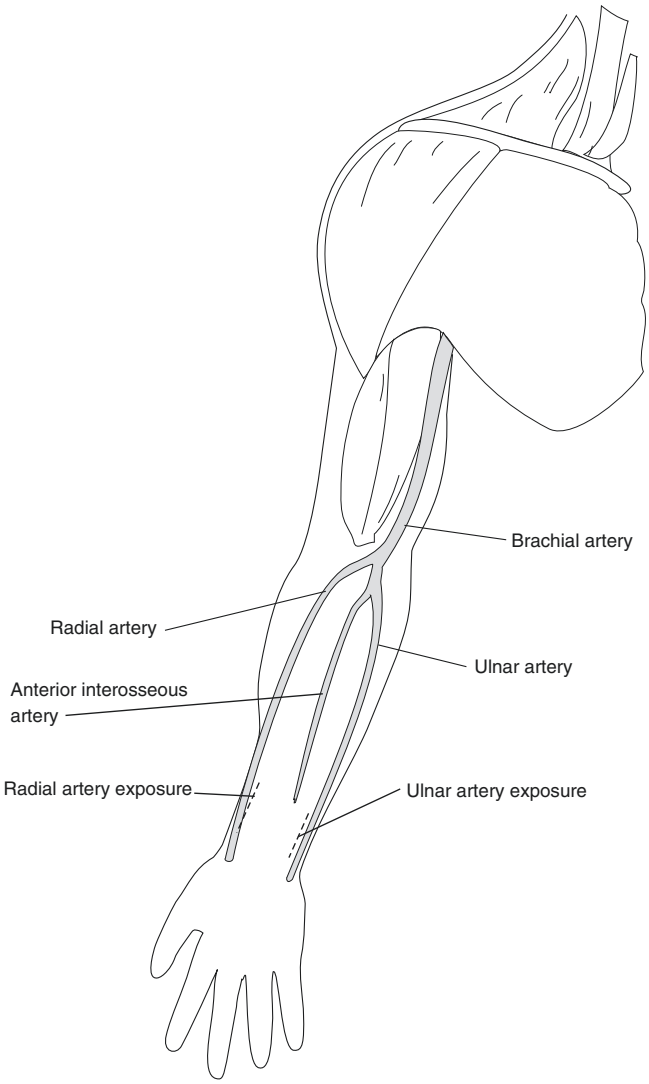

Figure 3.14. Exposure of the radial and ulnar arteries.

ANATOMY OF THE CAROTID ARTERY

The right common carotid artery originates from the innominate artery at the base of the neck behind the right sternoclavicular junction. The left common carotid artery usually originates directly from the aortic arch. The left common carotid artery can share a common ostium with the innominate artery in 16% of the population [3]. It can also originate directly from the trunk of the innominate artery in 8% of individuals [43]. One anomaly of the arch vessels is the retroesophageal subclavian artery, which occurs in 0.5% of the population [3]. In this anomaly, the innominate artery does not exist, and each carotid and subclavian artery originates directly and separately from the aortic arch. The right common carotid artery is the first branch. The left common carotid artery is the second branch and is followed by the left subclavian artery, with the right subclavian artery being the last branch.

Each common carotid artery ascends in the neck in the carotid sheath. The carotid sheath also contains the internal jugular vein, which lies lateral to the carotid artery, and the vagus nerve, which lies deeply between the carotid and the internal jugular vein. At the base of the neck, the common carotid artery lies deep behind the strap muscles and the sternocleidomastoid muscle. However, as the common carotid artery ascends in the neck, it becomes more superficial and is separated from the skin by the carotid sheath, platysma, and partially by the sternocleidomastoid muscle (Fig. 3.15). At the level of the hyoid bone or the fourth cervical vertebra, the common carotid artery bifurcates into the external and internal carotid arteries.

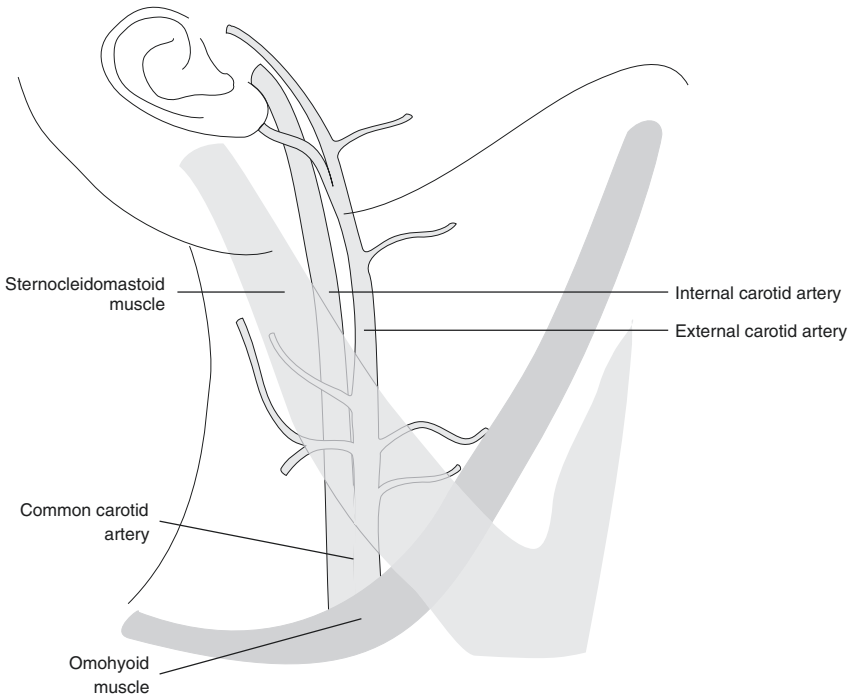

Figure 3.15. The common carotid artery and adjacent muscles.

The External Carotid Artery

As it originates from the common carotid artery, the external carotid artery lies anteromedial to the internal carotid artery (ICA). The first branch of the external carotid artery is the superior thyroid artery, which on occasion may arise directly from the common carotid artery. The other branches that originate from the external carotid artery are given in ascending order: the ascending pharyngeal, the lingual, the facial, the occipital, and the posterior auricular arteries (Fig. 3.16). The two terminal branches of the external carotid artery are the superficial temporal artery and the internal maxillary artery. Branches of the external carotid artery can provide important collateral circulation to the brain when the ipsilateral internal carotid artery is occluded (Fig. 3.17).

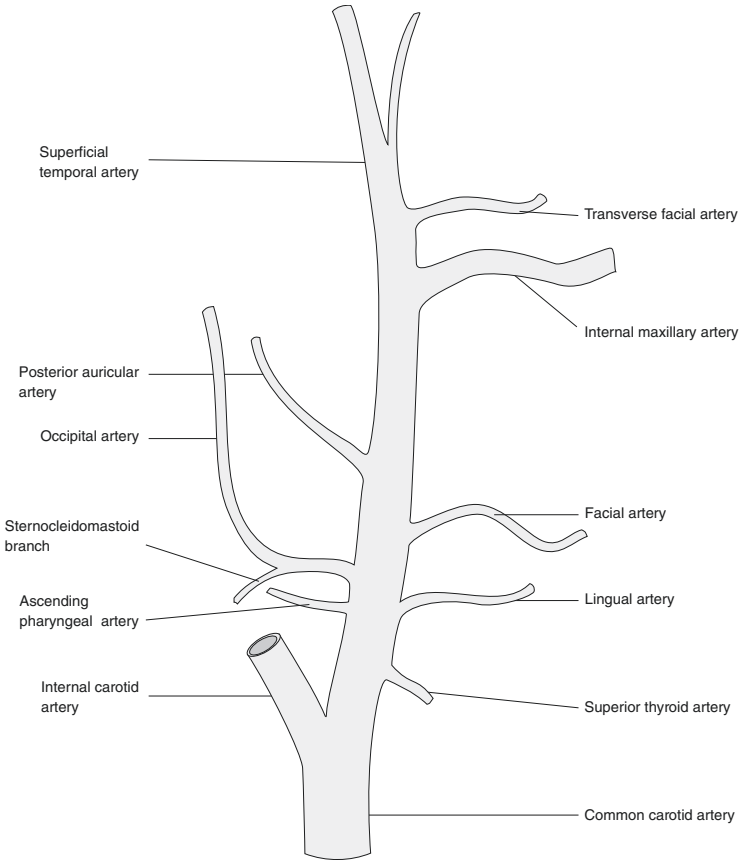

Figure 3.16. Branches of the external carotid artery.

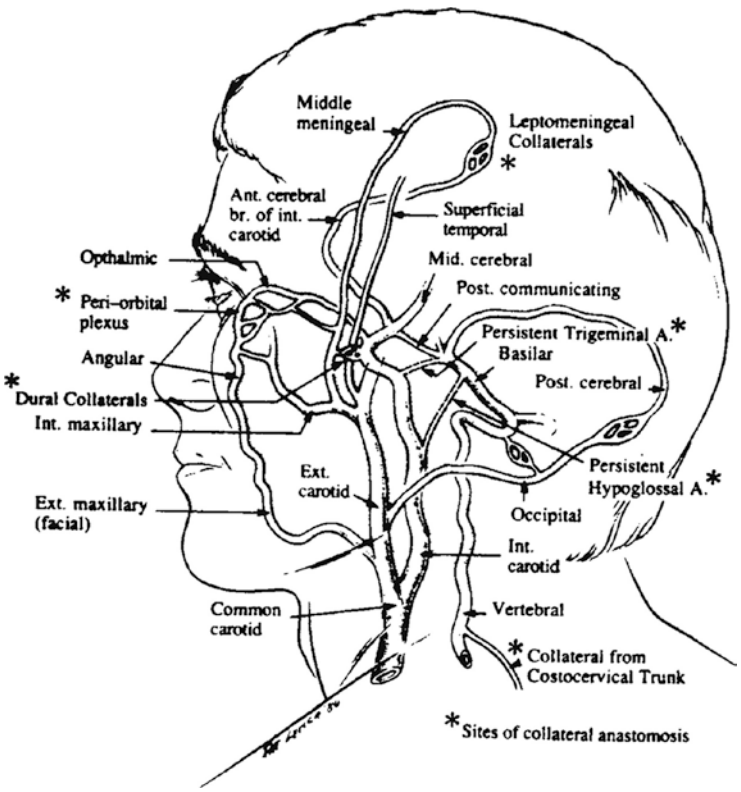

Figure 3.17. Collateral flow through the external carotid artery during internal carotid artery occlusion. *, Sites of collateral anastomosis. (From Gertler et al. J Vase Surg 1987;6:158–76, with permission.).

The Internal Carotid Artery

The internal carotid artery originates from the common carotid artery, usually at the level of the fourth cervical vertebra, lying posterior and lateral to the external carotid artery. The internal carotid artery is divided into three segments: the cervical, petrous, and intracranial segments. The cervical segment extends from the carotid bifurcation to the origin of the carotid canal at the base of the skull. It is crossed anteriorly by the hypoglossal nerve, the occipital artery, the digastric muscle, the stylohyoid muscle, and the posterior auricular artery (Fig. 3.18). The petrous segment represents the internal carotid artery as it advances in the carotid canal to lie in the petrous portion of the temporal bone. The intracranial segment represents the remaining part of the internal carotid artery as it courses on the lateral body of the sphenoid bone, continuing through the cavernous sinus before it pierces the dura to contribute to the cerebral circulation.

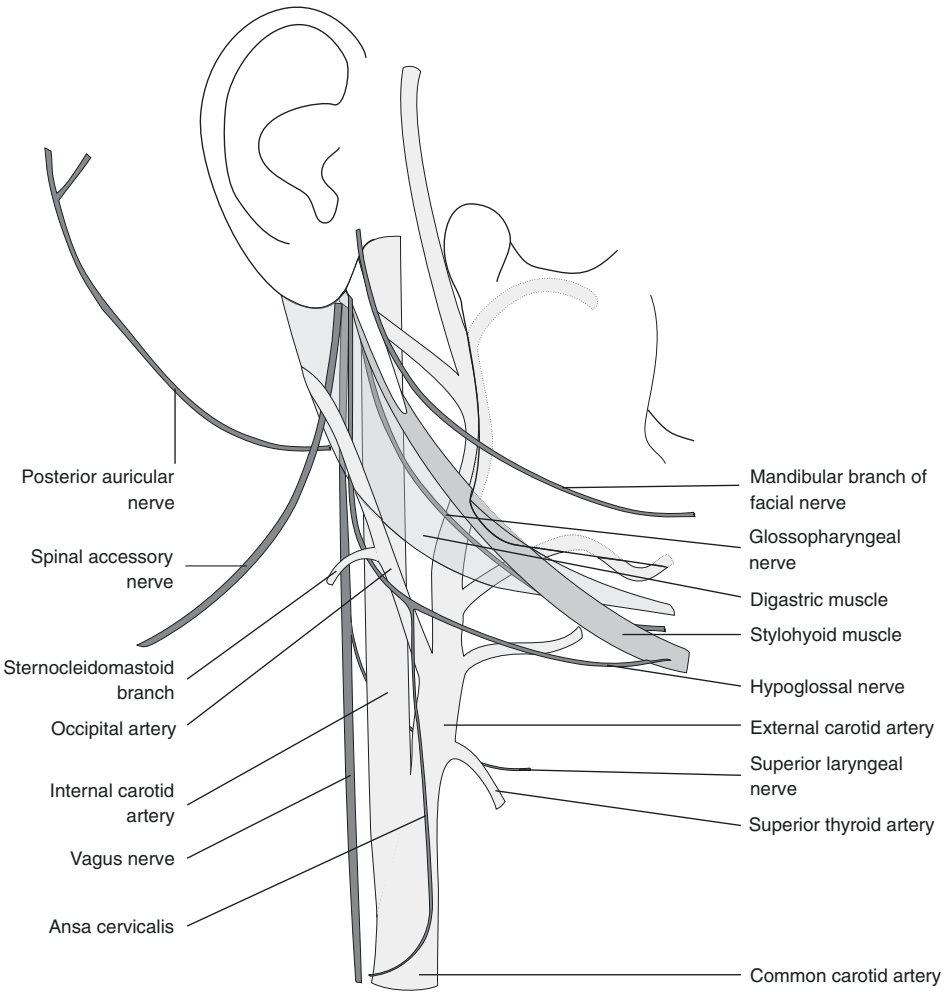

Figure 3.18. The carotid bifurcation and related structures.

The internal carotid artery does not give off any branches in the neck. In the carotid canal, the internal carotid artery gives the caroticotympanic branches to the middle ear. Further up in the cavernous sinus, the internal carotid artery gives off several branches. These branches include the inferior hypophyseal artery, small branches to the dura, a small branch to the middle meningeal branches, an anastomotic branch to the artery of the pterygoid canal, and anastomotic channels with the ascending pharyngeal artery and branches of the maxillary artery. Just after it penetrates the dura, the internal carotid artery gives rise to the ophthalmic artery, which is its first major branch. The internal carotid artery (ICA) then gives rise to the posterior communicating artery just before dividing into the anterior and middle cerebral arteries. The posterior communicating artery communicates with the posterior cerebral artery. The anterior cerebral arteries are joined by the anterior communicating artery, completing the circle of Willis (Fig. 3.19). The branches of the internal carotid artery play an important role in providing collateral cerebral pathways in the presence of occlusive disease of the internal carotid artery.

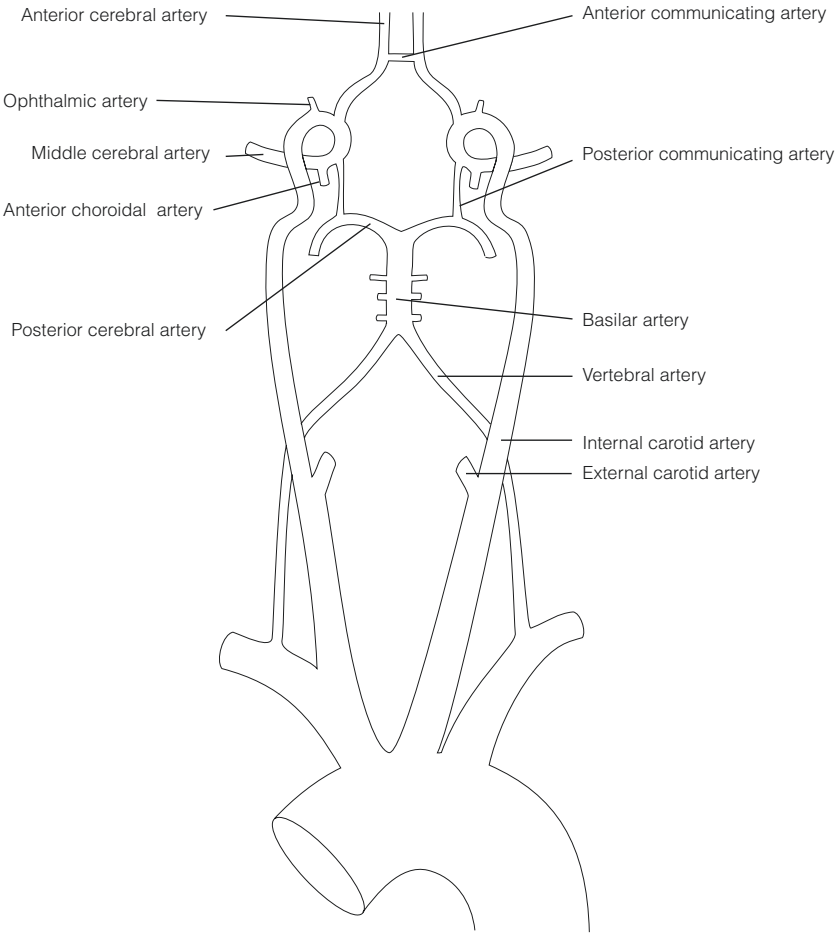

Figure 3.19. Circle of Willis.

Carotid Artery Exposure

To expose the origin and the first few centimeters of the common carotid artery, a median sternotomy is necessary. More distally, the common carotid artery is exposed through a neck incision. The main steps in exposing the common, external, and internal carotid arteries in the neck are as follows:

1. Skin incision
2. Division of platysma muscle
3. Mobilization of the sternocleidomastoid laterally
4. Incising the carotid sheath
5. Mobilization of the internal jugular vein
6. Division of the facial vein

Details of the Neck Exposure of the Common Carotid Artery and Its Bifurcation Most commonly, a longitudinal incision along the anterior border of the sternocleidomastoid muscle is used to expose the common carotid artery and its bifurcation (Fig. 3.20). Transverse neck incisions along a flexion skin crease starting 5 cm below the angle of the mandible can also be used; however, they require the creation of skin flaps and can be cumbersome if high exposure of the internal carotid artery becomes necessary. The longitudinal incision starts two fingers breadth above the sternal notch and extends

along the anterior border of the sternocleidomastoid muscle. If necessary, the incision can be extended posteriorly behind the ear toward the mastoid process to aid in distal exposure [17]. The subcutaneous tissues and the platysma muscle are incised, exposing the sternocleidomastoid muscle. The dissection is carried out throughout the length of the incision along the upper and medial borders of the sternocleidomastoid, dividing the small vessels that supply it. A self-retaining retractor is placed to retract the sternocleidomastoid muscle laterally, thus exposing the anterior aspect of the internal jugular vein.

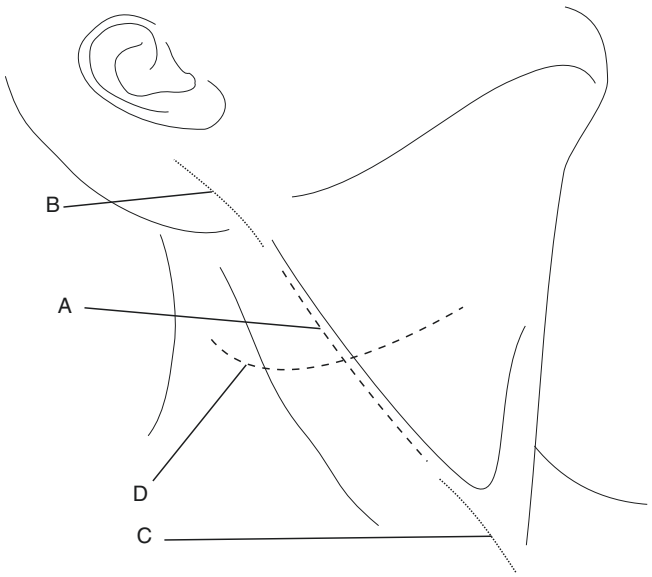

Figure 3.20. Exposure of the carotid bifurcation. (a): Incision anterior to sternocleidomastoid muscle. (b): Extension behind the ear towards the mastoid process for high exposure of the internal carotid artery. (c): Extension towards the sternal notch for proximal common carotid exposure. (d): Transverse cervical incision; extension of exposure is limited.

Dissection is now performed along the medial edge of the internal jugular vein. The attachments of the lateral aspects of the carotid sheath to the sternocleidomastoid are left undisturbed, so that, when the sternocleidomastoid muscle is retracted laterally, the jugular vein will be retracted along with it. The dissection is carried out along the medial border of the internal jugular vein throughout the length of the incision. The facial vein is identified as it usually marks the level of the carotid bifurcation (see Fig. 3.4). The facial vein is divided and suture ligated, thus exposing the carotid bifurcation. Any other venous branches draining facial structures into the medial aspect of the jugular vein that are identified are also ligated and divided. Occasionally, the facial vein is replaced by two smaller veins located superior and inferior to its usual location.

Once the internal jugular vein has been mobilized laterally, the carotid artery is easily identified. A "minimal touch" technique is very important during the dissection of an atherosclerotic carotid artery to prevent distal embolization. If additional proximal exposure of the common carotid artery is needed, the incision can be extended to the sternal notch and the omohyoid muscle overlying the carotid sheath is divided. The ansa cervicalis or some of its branches are often noted crossing over the common carotid artery. The ansa cervicalis can be divided without any significant sequelae. The proximal segment of the ansa usually leads to the hypoglossal nerve. The carotid dissection is continued superiorly until the carotid bifurcation is reached. Dissection along the medial aspect of the common carotid artery at the level of the carotid bifurcation will first identify the superior thyroid artery. Further dissection superiorly exposes the external carotid artery and its branches.

Dissection along the lateral border of the common carotid artery leads to the internal carotid artery. The upper set of the deep cervical lymph nodes are often

encountered between the carotid bifurcation and the digastric muscle. These lymphatic structures can obscure the location of the internal carotid artery and the hypoglossal nerve. It is thus important to proceed very carefully at this level to avoid any iatrogenic nerve injury The lymphatics are carefully mobilized, exposing the areolar tissues overlying the internal carotid artery up to the level of the digastric muscle.

It is prudent to avoid using electrocautery in the vicinity of nerves in the neck as this can cause iatrogenic nerve damage. The nerves that can be injured during a carotid exposure are the vagus nerve, the hypoglossal nerve, the glossopharyngeal nerve, the mandibular branch of the facial nerve, and the posterior auricular nerve [23] (Fig. 3.21). The vagus nerve is usually lying posteriorly between the carotid artery and the jugular vein. It is the nerve most commonly injured during carotid endarterectomy. It can be injured by the dissecting scissors during mobilization of the carotid artery or by the vascular clamps if inadvertently clamped while occluding the common or internal carotid arteries.

The hypoglossal nerve is usually seen running inferior and parallel to the digastric muscle. Occasionally, the hypoglossal nerve can lie in a more inferior location or closer to the edge of the external carotid artery. It can be injured during the mobilization of the internal carotid artery, especially if the exposure is compromised by inadequate hemostasis. This injury will result in deviation of the extended tongue toward the affected side. The mandibular branch of the facial nerve can be injured as a result of direct compression by a handheld retractor applied below the angle of the mandible to improve the carotid exposure. This injury will result in drooping of the ipsilateral lower lip when the patient is asked to show the teeth. The posterior auricular nerve can be injured when the dissection is carried out along the anterior border of the upper part of the sternocleidomastoid.

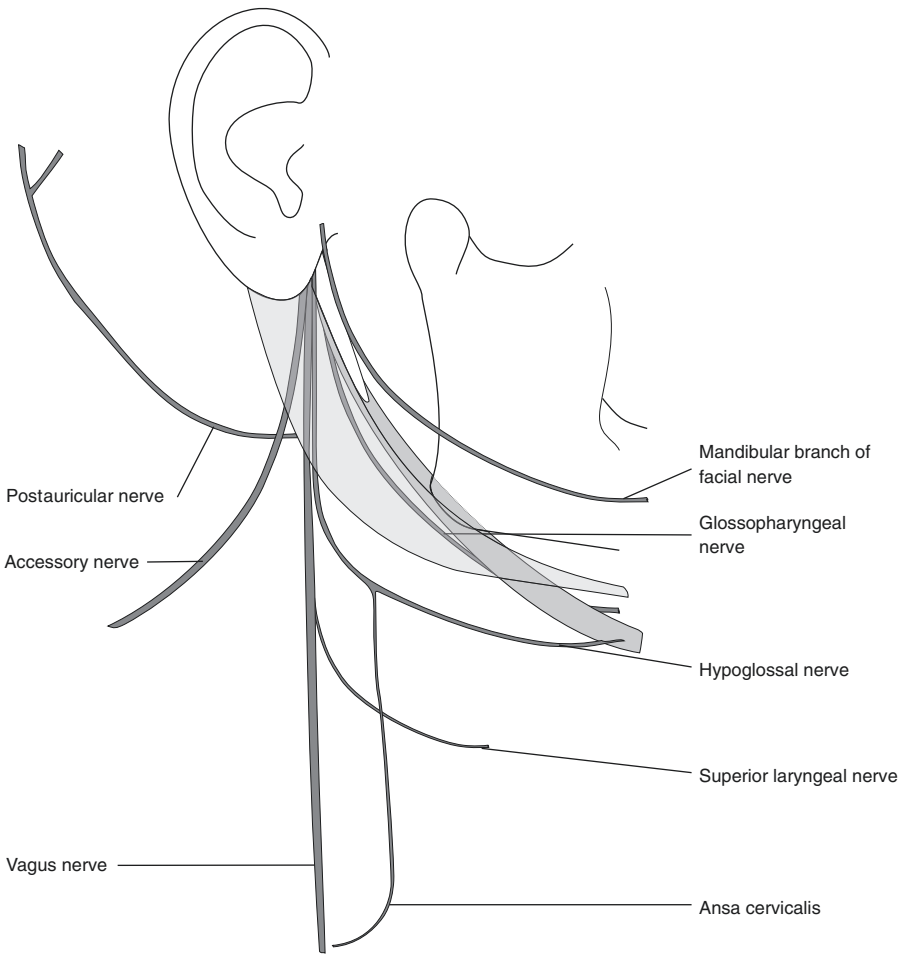

Figure 3.21. Regional nerves at risk during exposure of the common carotid artery and its branches.

High Exposure of the Internal Carotid Artery

High exposure of the internal carotid artery can be achieved by dividing its overlying muscles and mobilizing the hypoglossal nerve (Fig. 3.22). The hypoglossal nerve is mobilized by dividing the ansa cervicalis close to the hypoglossal nerve. The divided distal segment of the ansa cervicalis can be used to provide gentle traction on the hypoglossal nerve [29]. A branch of the occipital artery to the sternocleidomastoid muscle usually acts as a sling that tethers the hypoglossal nerve. Bleeding from this branch can compromise the exposure, whereas its ligation and division along with its accompanying vein allow considerable mobilization of the hypoglossal nerve. Further cephalad, division of the occipital artery aids in additional mobilization of the hypoglossal nerve. Division of the digastric muscle provides further exposure above the level of the hypoglossal nerve (Fig. 3.23).

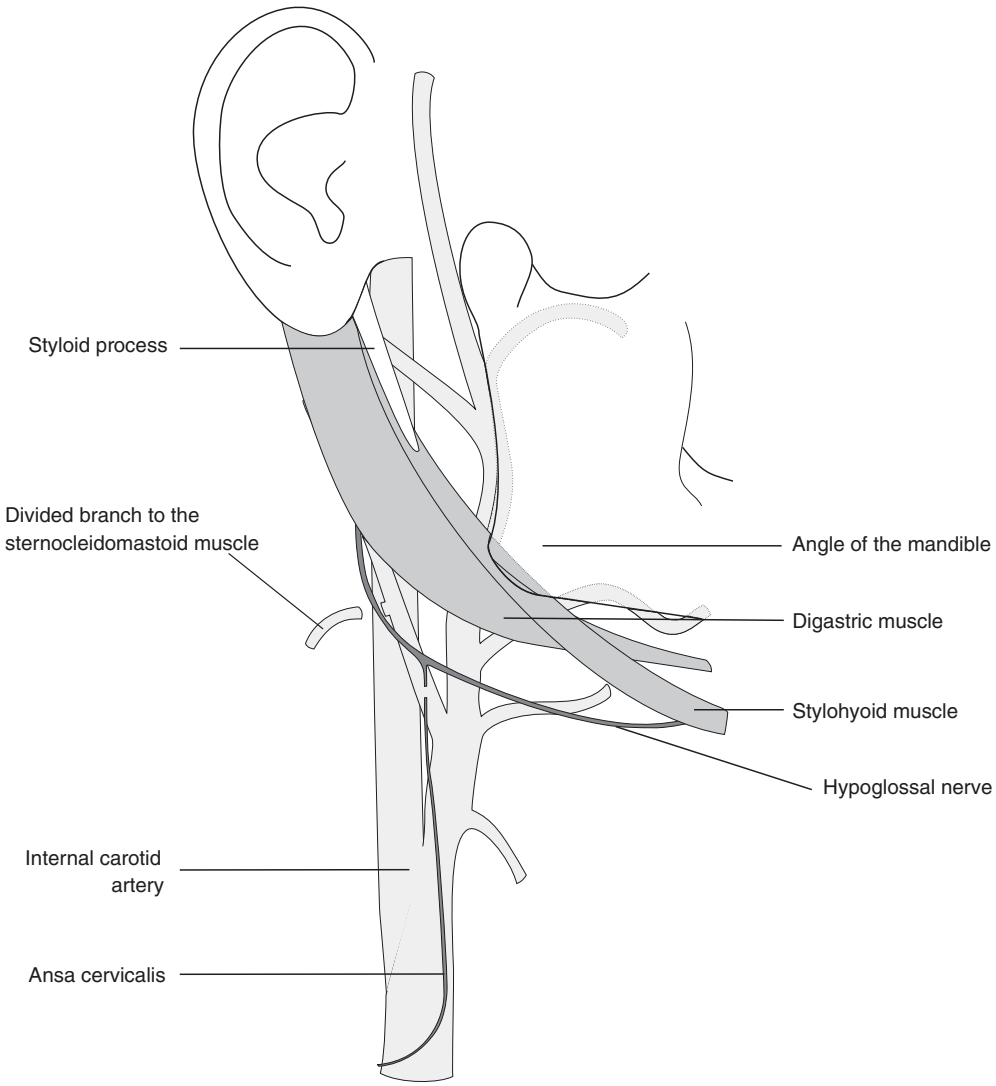

Figure 3.22. Mobilization of the hypoglossal nerve.

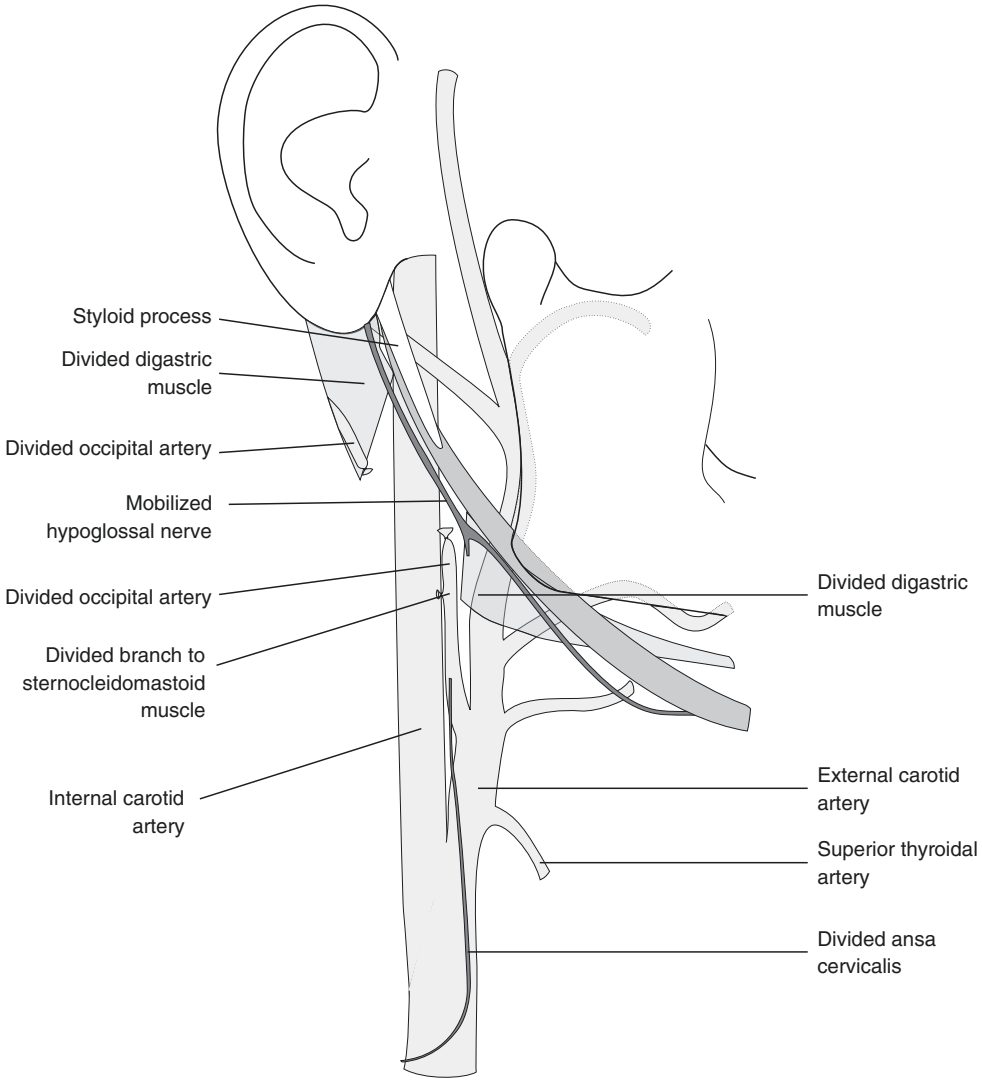

Figure 3.23. High exposure of the internal carotid artery.

If the exposure provided by these methods is inadequate, a mandibular subluxation may be necessary to achieve a higher dissection of the internal carotid artery [16]. Mandibular dislocation should be avoided, as it can cause permanent damage to the temporomandibular joint. Various mandibular osteotomies have also been described to achieve high exposure of the internal carotid artery at the level of Cl. However, such procedures are very infrequently performed as they are usually needed for the management of rare aneurysmal or traumatic pathology. When the need for high exposure is anticipated, nasotracheal intubation can be very helpful as this widens the space behind the angle of the mandible, thus facilitating higher internal carotid artery exposure [4] (Fig. 3.24).

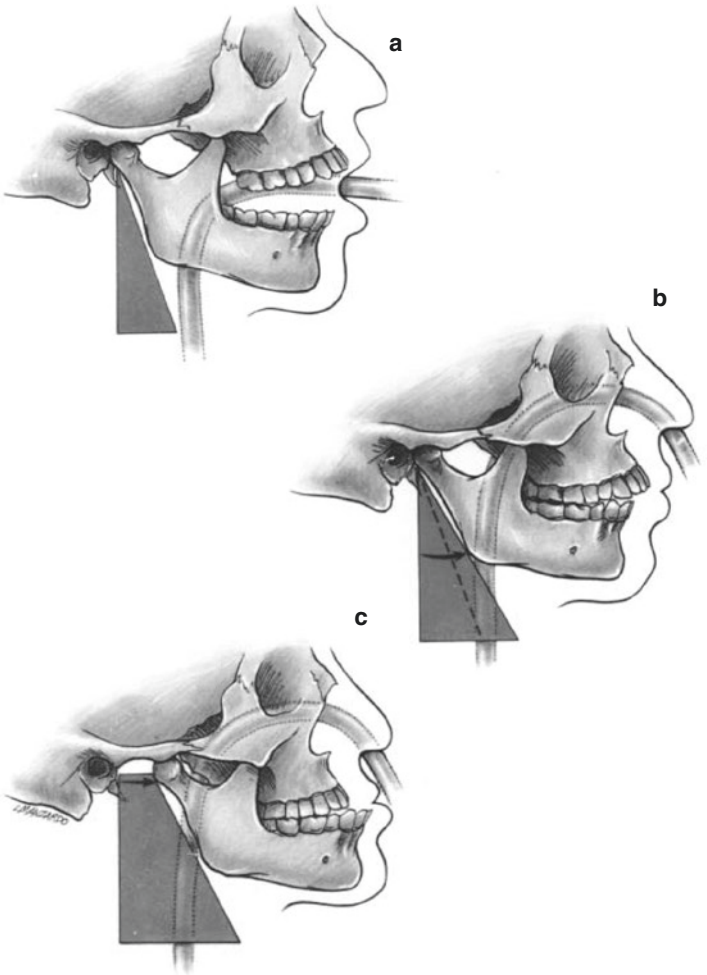

Figure 3.24. High exposure of the internal carotid artery. (**a**) Orotracheal intubation. (**b**) Nasotracheal intubation improves high exposure of the internal carotid artery. (**c**) Mandibular subluxation allows additional exposure. (From Berguer R, Kieffer E. Surgery of the Arteries to the Head. Springer-Verlag, 1992, with permission).

ABDOMINAL AORTA AND ITS BRANCHES

ANATOMY OF THE ABDOMINAL AORTA AND ITS BRANCHES

The Abdominal Aorta

The aorta enters the abdominal cavity through the aortic hiatus at the level of the 12th thoracic vertebra. At that level, the aorta is surrounded by the right and left crura of the diaphragm and lies on the anterior aspect of the vertebral column. The aorta runs distally in the retroperitoneum anterior to the spine until the level of the fourth lumbar vertebra, where it bifurcates into the right and left common iliac arteries. Throughout its course in the abdomen, the aorta gives off several branches. These include the inferior phrenic arteries, the celiac artery, the superior mesenteric artery (SMA), the right and left renal arteries, the inferior mesenteric artery, the gonadal arteries, the lumbar arteries, and the middle sacral artery. The surgical anatomy and exposure of the major branches that may require revascularization are reviewed next.

The Celiac Artery

The celiac artery originates from the anterior aspect of the aorta shortly after it enters the abdominal cavity at the level of the upper part of the first lumbar vertebra. The celiac artery is a short trunk surrounded by a plexus of sympathetic nerves. The celiac artery runs for 1–2 cm before it gives off the left gastric, the splenic, and the common hepatic arteries (Fig. 3.25).

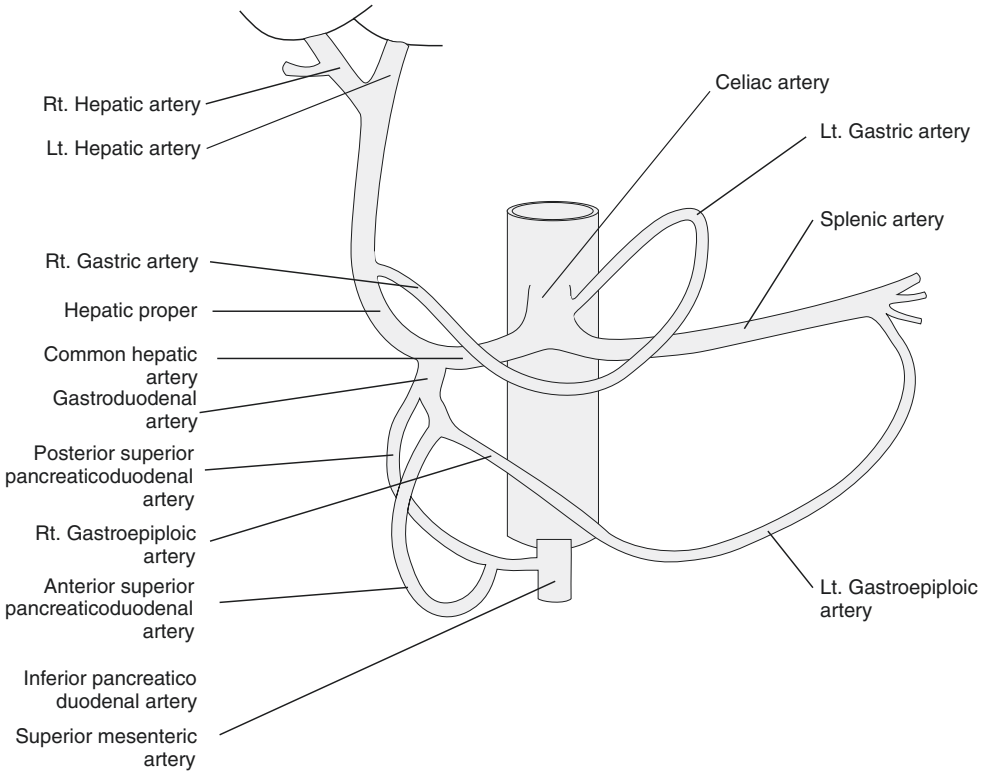

Figure 3.25. The celiac artery and its branches.

The Common Hepatic Artery

The common hepatic artery arises from the celiac artery behind the posterior wall of the lesser sac and continues to the right along the upper border of the pancreas before it divides into the gastroduodenal artery and the proper hepatic artery. The proper hepatic artery continues into the hepatoduodenal ligament usually giving off the right gastric artery before dividing into the right and left hepatic arteries (Fig. 3.25). The proper hepatic artery lies anterior to the portal vein and lateral to the common bile duct.

The Superior Mesenteric Artery

The superior mesenteric artery arises from the aorta 1–2 cm below the origin of the celiac artery about the level of the midpart of the first lumbar vertebra. It starts behind the neck of the pancreas and then passes between the pancreas and the duodenum to enter the root of the mesentery. The superior mesenteric artery gives off several important branches. These include the inferior pancreaticoduodenal artery (which represents a main communicating vessel to the celiac artery), the middle colic artery, the right colic artery, the ileocolic artery, and numerous jejunal branches [18] (Fig. 3.26).

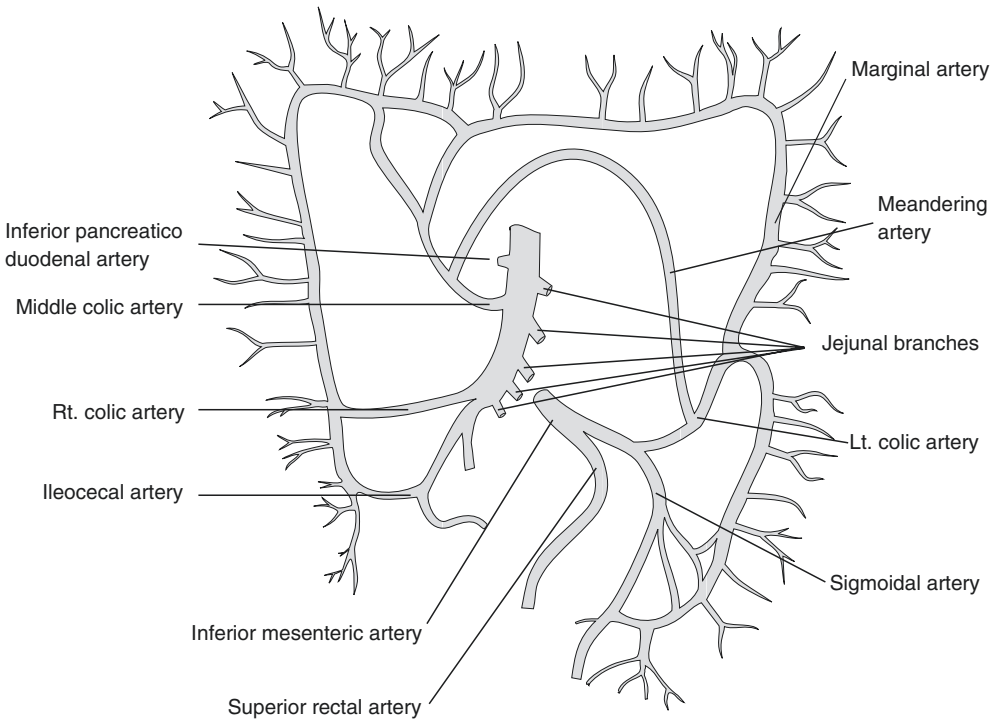

Figure 3.26. The superior and inferior mesenteric arteries and their branches.

The Renal Arteries

The right and left renal arteries originate at the level of the upper part of the second lumbar vertebra from the posterolateral aspect of the aorta. The left renal artery continues inferiorly and posteriorly behind the left renal vein toward the left kidney giving off the inferior adrenal artery and then dividing into the anterior and posterior segmental arteries. On the right side, the renal artery runs behind the vena cava and then posterior to the junction of the right renal vein and the vena cava. The right renal artery then runs for 2–3 cm before it divides into the segmental branches. Multiple renal arteries originating from the aorta are commonly encountered.

The Inferior Mesenteric Artery

The inferior mesenteric artery originates at the level of the lower part of the third lumbar vertebra from the left anterolateral aspect of the aorta. Its origin is surrounded by sympathetic nerves. Transection or injury to these sympathetic nerves can lead to sexual dysfunction, most commonly retrograde ejaculation [15]. The inferior mesenteric artery runs for 1–2 cm before it divides into the superior rectal artery, the sigmoidal artery, and the left colic artery (Fig. 3.26).

The Common Iliac Artery

At the level of the fourth lumbar vertebra, the aorta usually lies slightly to the left of the midline as it bifurcates into the right and left common iliac arteries. Each common iliac artery runs downward and laterally to the pelvic brim before dividing into the internal iliac and external iliac arteries. The right common iliac artery is usually longer than the left common iliac artery. Proximally, the right common iliac artery runs over the inferior end of the vena cava and the termination of the left common iliac vein and is crossed anteriorly by the terminal portion of the ileum. The left common iliac artery has a similar course to the right common iliac artery and is crossed anteriorly by the root of the sigmoid mesocolon. At the level of the iliac bifurcation, each common iliac artery is crossed by a ureter. The internal iliac artery continues medially to enter the pelvis, giving origin to the middle and inferior rectal arteries. The external iliac artery continues in the retroperitoneum along the pelvic brim crossing underneath the inguinal ligament to become the common femoral artery. The external iliac artery gives off the inferior (deep) epigastric and the deep iliac circumflex branches.

Exposure of the Abdominal Aorta and Its Branches

The abdominal aorta and its branches can be exposed through a transperitoneal or retroperitoneal approach.

Transperitoneal Approach to the Abdominal Aorta and Its Branches (Figs. 3.27, 3.28, and 3.29) The main steps in exposing the abdominal aorta and its branches after entering the peritoneal cavity are as follows:

1. Retract the transverse colon anteriorly and to the right
2. Retract the splenic flexure posteriorly and laterally
3. Divide the peritoneal periaortic attachment of the duodenum
4. Reflect the small bowel and duodenum to the right
5. Incise the retroperitoneum overlying the aorta
6. Identify the left renal vein
7. Transect the inferior mesenteric vein if necessary

The transperitoneal approach can be performed through a midline, paramedian, or transverse incision. Once the abdominal cavity is entered, the transverse colon is reflected upward and to the right (Fig. 3.27). The small bowel is wrapped with a moist towel or placed in a plastic bag and retracted laterally to the right. The ligament of Treitz and the attachment of the duodenum to the paraaortic tissues are sharply incised. The duodenum is dissected off the aorta and retracted along with the small bowel to the right (Fig. 3.28). The aorta is palpated and the overlying peritoneum is incised up to the level of the left renal vein (Fig. 3.29). The inferior mesenteric vein is also identified. Division of the inferior mesenteric vein can provide additional exposure if necessary by allowing further lateral retraction of the left colon. However, it is important to avoid dividing any accompanying arterial branch as it may provide important collateral circulation to the left colon.

Transabdominal Exposure of the Infrarenal Aorta

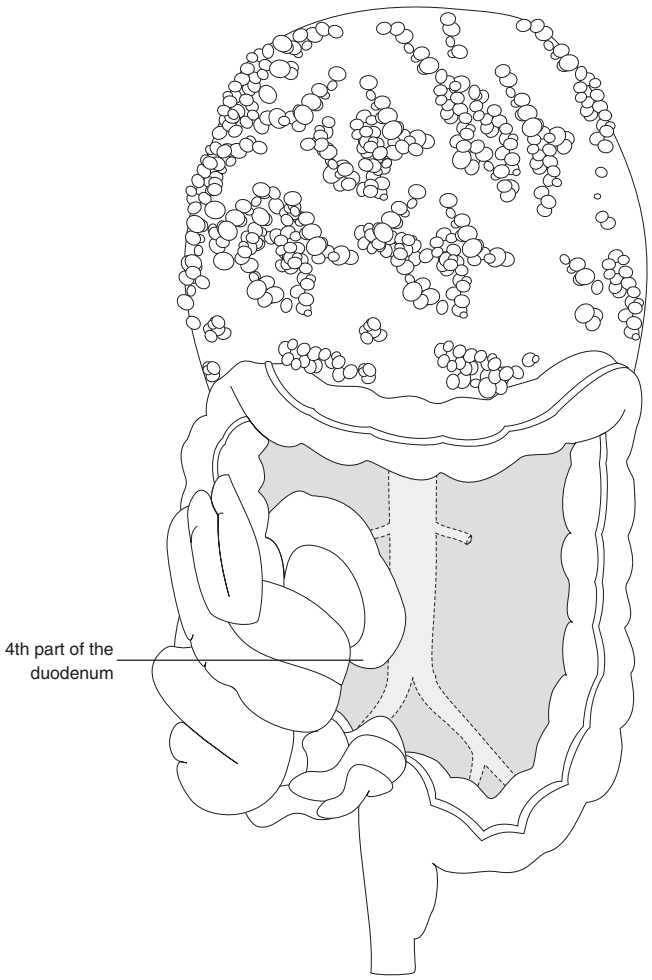

Figure 3.27. The transverse colon is retracted superiorly and the small bowel is retracted to the right, identifying the duodenum and the ligament of Treitz.

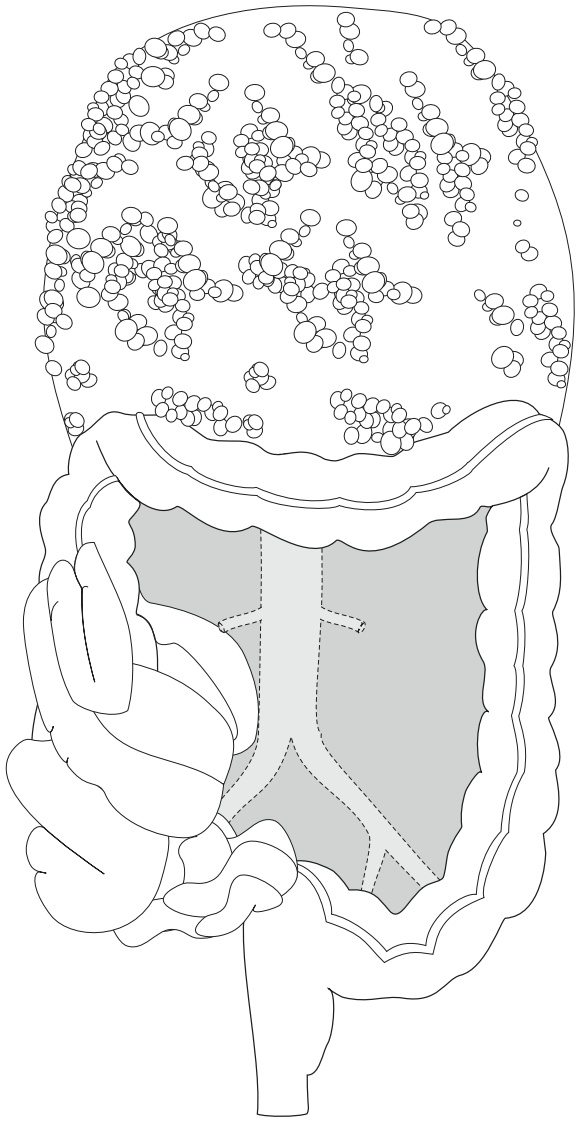

Figure 3.28. The peritoneal attachments of the duodenum are incised and the duodenum is mobilized to the right.

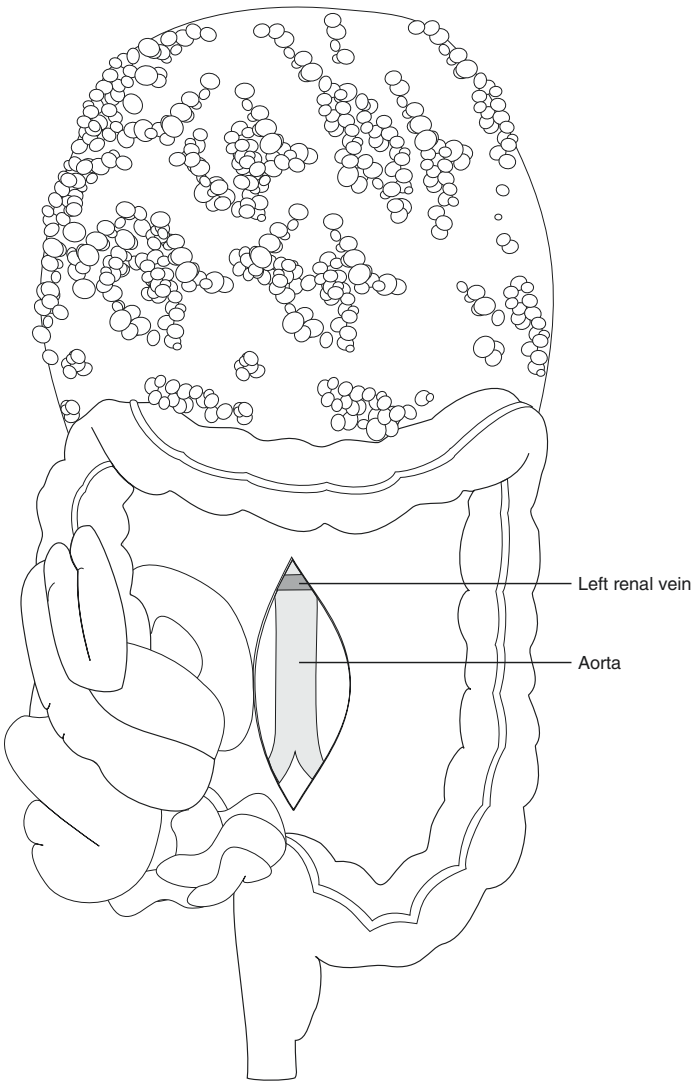

Figure 3.29. The peritoneum over the aorta is incised up to the level of the left renal vein.

Transperitoneal Exposure of the Juxtarenal Aorta and Renal Arteries (Figs. 3.30, 3.31, 3.32, and 3.34) The left renal vein is identified. Dissection on the lateral aspect of the vein will reveal its tributaries, which include the adrenal vein superiorly and the lumbar and the gonadal veins inferiorly (Fig. 3.30). The gonadal and lumbar veins often have a common trunk. It is important to gently dissect, ligate, and divide these branches to obtain free mobilization of the left renal vein. The left renal vein can then be retracted anteriorly and cephalad (Fig. 3.31). Division of the adrenal vein allows retraction of the left renal vein caudally (Fig. 3.32). The exposure of the suprarenal aorta can also be facilitated by the division of the left renal vein. However, when division of the left renal vein is contemplated, the adrenal, lumbar, and gonadal branches must be preserved to maintain collateral venous drainage for the left kidney [33]. The renal vein is divided close to its junction with the vena cava (Figs. 3.33 and 3.34). Resuturing of the divided left renal vein is not usually necessary unless there is evidence of left kidney venous congestion.

Dissection posterior to the left renal vein will reveal the origin of the left renal artery. Posterior attachments of the left crus of the diaphragm can be divided to allow further freeing of the aorta. Lymphatics are frequently noted crossing over the aorta at the level of the left renal vein. These lymphatics are gently dissected, ligated, and transected to prevent the development of postoperative chylous ascites. Dissection on the right lateral aspect of the aorta reveals the origin of the right renal artery under the junction of the left renal vein and the inferior vena cava. Dissection along the medial aspect of the vena cava reveals several venous branches such as the right gonadal and lumbar veins. Division of these branches allows for lateral mobilization of the vena cava; this will improve the exposure of the proximal right renal artery as it passes behind the inferior vena cava.

Dissection around the origins of the right and left renal artery allows for suprarenal aortic exposure. The left renal vein is usually mobilized circumferentially and then retracted caudally or cephalad to expose the pararenal and suprarenal aorta. As aortic dissection is carried out proximal to the renal arteries, sympathetic nerves and ganglia will be encountered. The division of these structures allows identification of the origin of the superior mesenteric artery, which is the most proximal branch of the aorta that can be accessed through this approach.

Transabdominal Exposure of the Juxtarenal Aorta and Renal Arteries

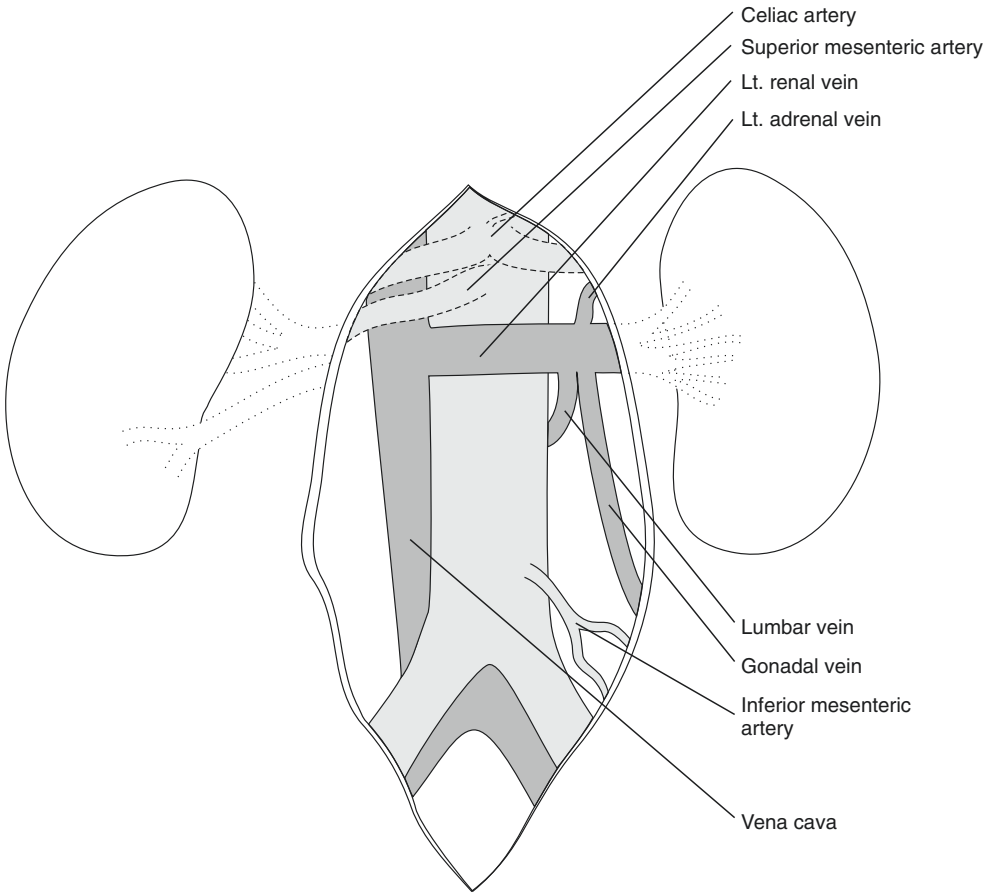

Figure 3.30. The left renal vein and its branches are exposed.

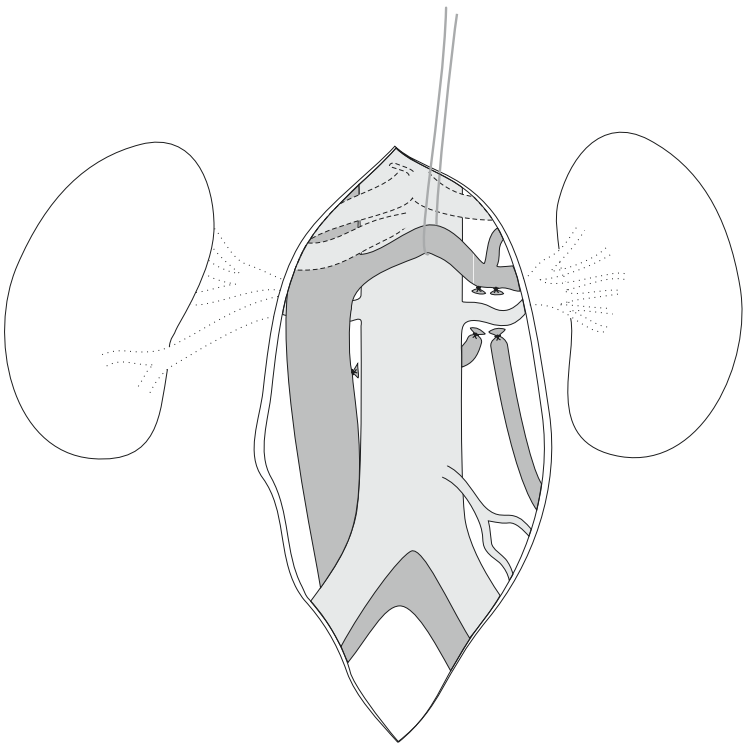

Figure 3.31. Division of the gonadal and lumbar veins allows cephalad mobilization of the left renal vein, exposing the left renal artery.

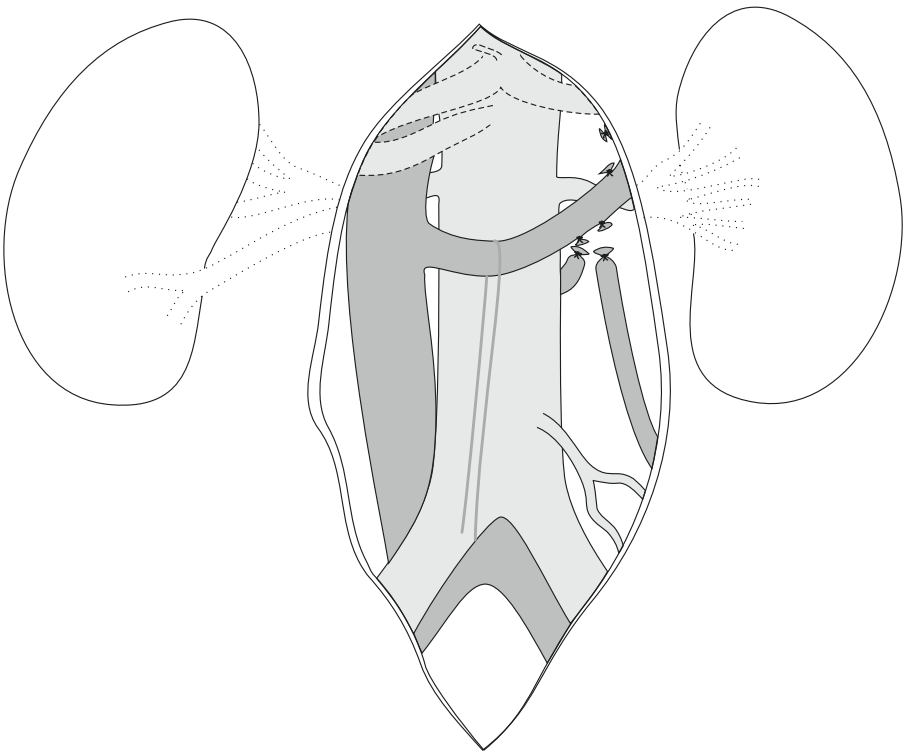

Figure 3.32. Division of the adrenal branch will allow mobilization of the left renal vein caudad for pararenal exposure.

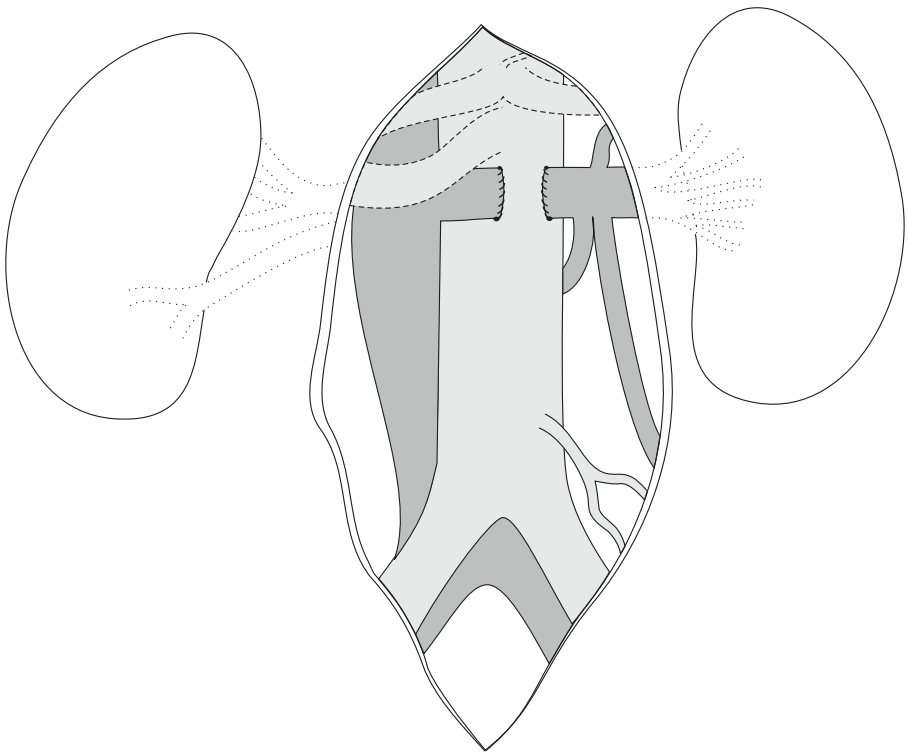

Figure 3.33. When division of the left renal vein is contemplated, the division line is carried close to the junction with the vena cava.

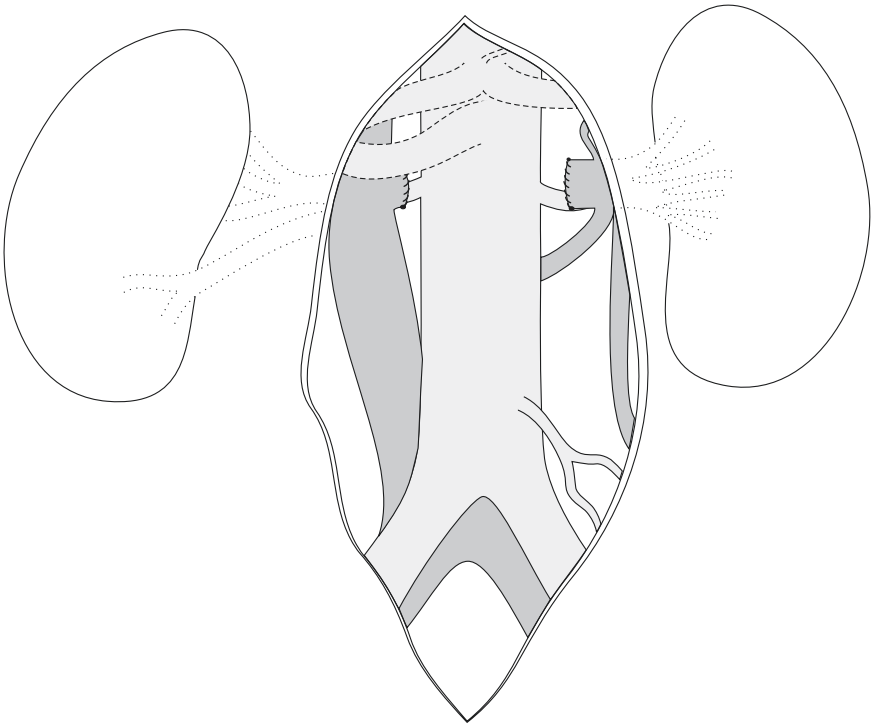

Figure 3.34. Further mobilization of the divided renal vein will facilitate the exposure of the pararenal aorta.

Exposure of the Left Renal Artery (Figs. 3.35 and 3.36)
The left renal artery can be approached through the mesentery of the left colon, as already described in the exposure of the juxtarenal aorta, or by reflecting the left colon and splenic flexure downward [11, 12, 39]. In the latter approach, the peritoneal attachment of the left colon and the splenic flexure are taken down (Fig. 3.35). The left colon is reflected medially and caudally (Fig. 3.36). The renal vein branches are identified and the left renal vein is visualized. Dissection along the caudal aspect of the left renal vein will reveal the left renal artery, which can be followed distally to its segmental branches.

Transabdominal Exposure of the Left Renal Artery

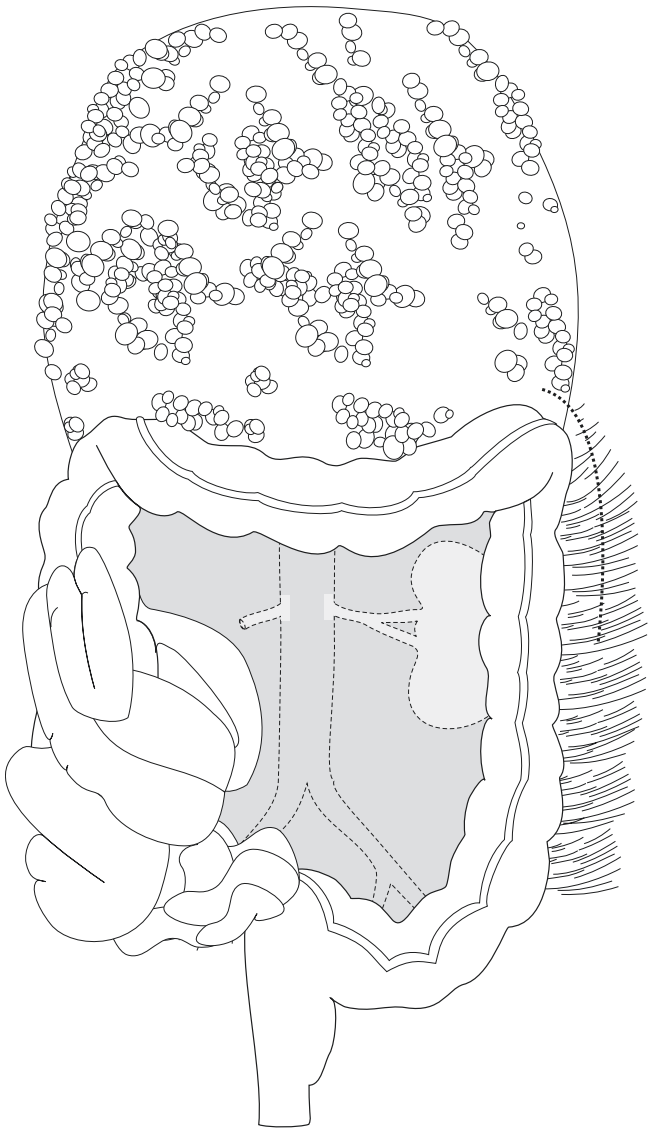

Figure 3.35. The left renal artery can be exposed by reflecting the splenic flexure and the left colon medially.

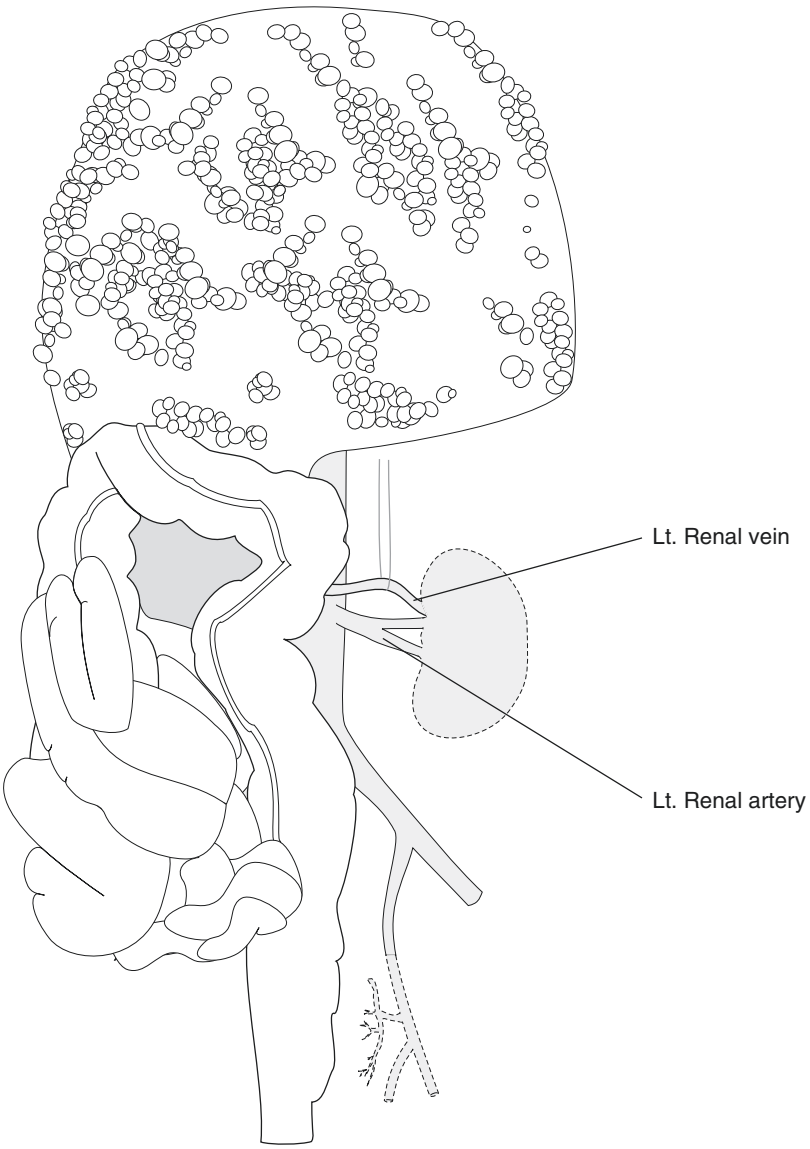

Figure 3.36. The lateral peritoneal attachments of the left colon are incised. The splenic flexure is mobilized carefully to avoid any iatrogenic injury to the spleen. The left renal artery can be exposed beneath the left renal vein.

Exposure of the Right Renal Artery (Figs. 3.37, 3.38, and 3.39)
The exposure of the proximal part of the right renal artery is outlined in the section on the exposure of the pararenal aorta [11, 12, 39]. The distal part of the right renal artery can be exposed by first mobilizing the second and third parts of the duodenum using a Kocher maneuver. The peritoneum lateral to the second part of the duodenum is incised and the duodenum and head of pancreas are reflected medially and anteriorly (Figs. 3.37 and 3.38). The inferior vena cava is exposed beneath the duodenum and the right renal vein is identified. Dissection around the caudal aspect of the right renal vein will reveal the right renal artery (Fig. 3.39). The right renal artery can often be palpated as a cord structure as it crosses underneath the vena cava. The right renal artery is then exposed and dissected proximally and distally until it divides into its segmental branches. The division of the adrenal arterial branch usually allows for additional mobilization of the proximal renal artery.

Transabdominal Exposure of the Right Renal Artery

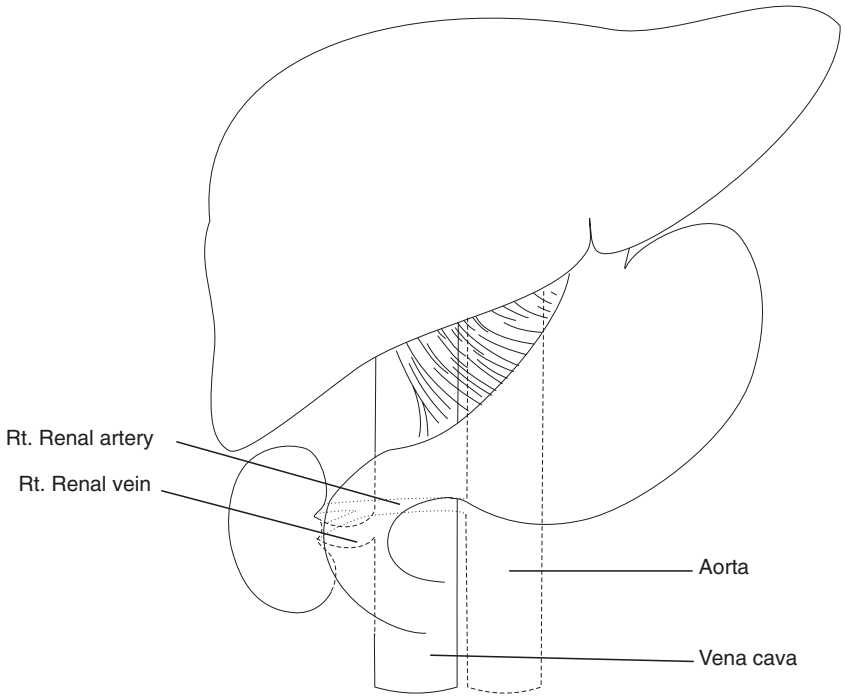

Figure 3.37. The right renal artery and adjacent structures.

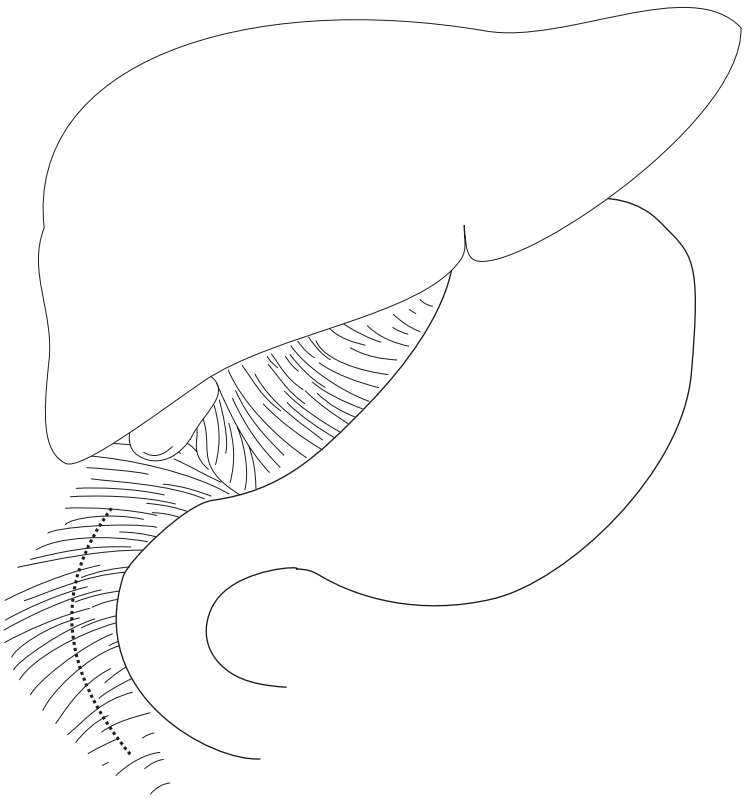

Figure 3.38. The peritoneum lateral to the duodenum is incised and a Kocher maneuver is performed.

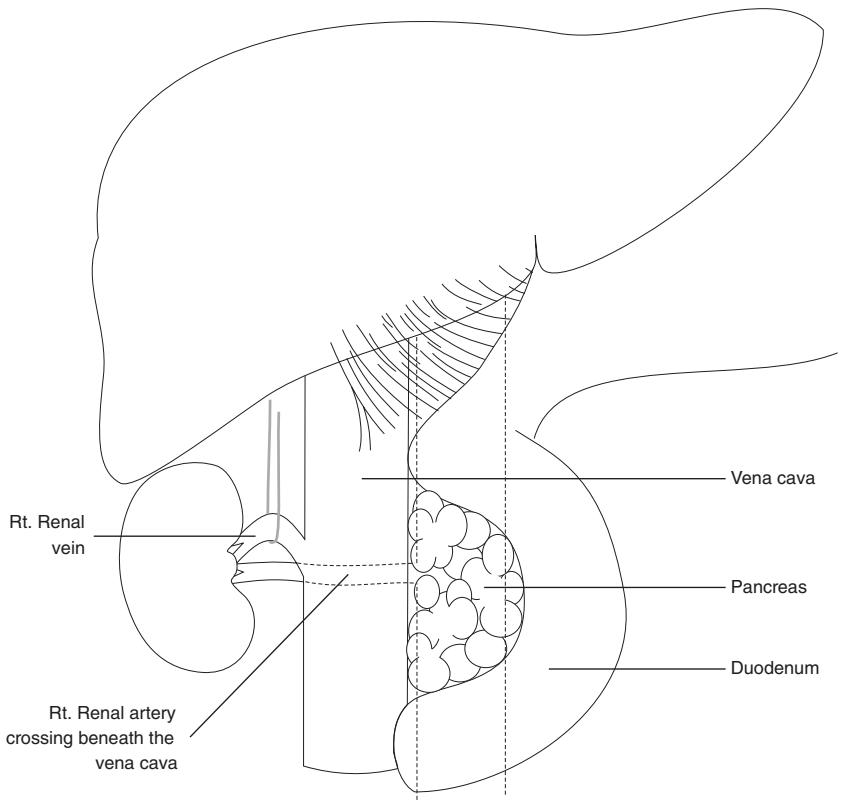

Figure 3.39. The duodenum is reflected medially. The right renal vein is mobilized superiorly, exposing the right renal artery.

Exposure of the Aorta and Its Branches at the Diaphragm

Transperitoneally, the aorta at the diaphragmatic hiatus can be accessed through the lesser sac using blind dissection or under direct vision [44]. Blind dissection can be utilized for emergency control of the supraceliac aorta during the replacement of a ruptured abdominal aortic aneurysm. Exposure under direct vision can also be used for providing urgent control of the supraceliac aorta during the repair of a ruptured abdominal aortic aneurysm. It is also ideal for the construction of an antegrade aortoceliac or aortomesenteric bypass for chronic visceral ischemia. This exposure usually provides access to 4–5 cm of the aorta proximal to the origin of the celiac artery. It has also been recommended for aortic control in the presence of significant scarring from previous aortic surgery [21]. Furthermore, it is also preferred by some over clamping above the renal or superior mesenteric arteries when aortic control proximal to these vessels is necessary. This approach, however, is not suitable for replacing aortic aneurysmal pathology involving the superior mesenteric or celiac arteries because of the overlying pancreas and adjacent structures. To expose this segment of the aorta through a transabdominal incision, the viscera of the left upper quadrant will need to be reflected medially, a procedure referred to as medial visceral rotation. Alternatively, this segment of the aorta can also be exposed using a thoracoabdominal or retroperitoneal approach. The medial visceral rotation can eliminate the morbidity of extending the exposure into a thoracoabdominal approach. The thoracoabdominal approach cannot be avoided when exposure of the thoracic aorta is also required.

Transperitoneal Blind Dissection of the Supraceliac Aorta

The lesser sac is entered and one hand is introduced toward the diaphragm to palpate the aorta as it exits from the aortic hiatus (Fig. 3.40). The presence of a nasogastric tube will help in identifying the location of the esophagogastric junction. Using the index finger, the right and then left crura of the diaphragm

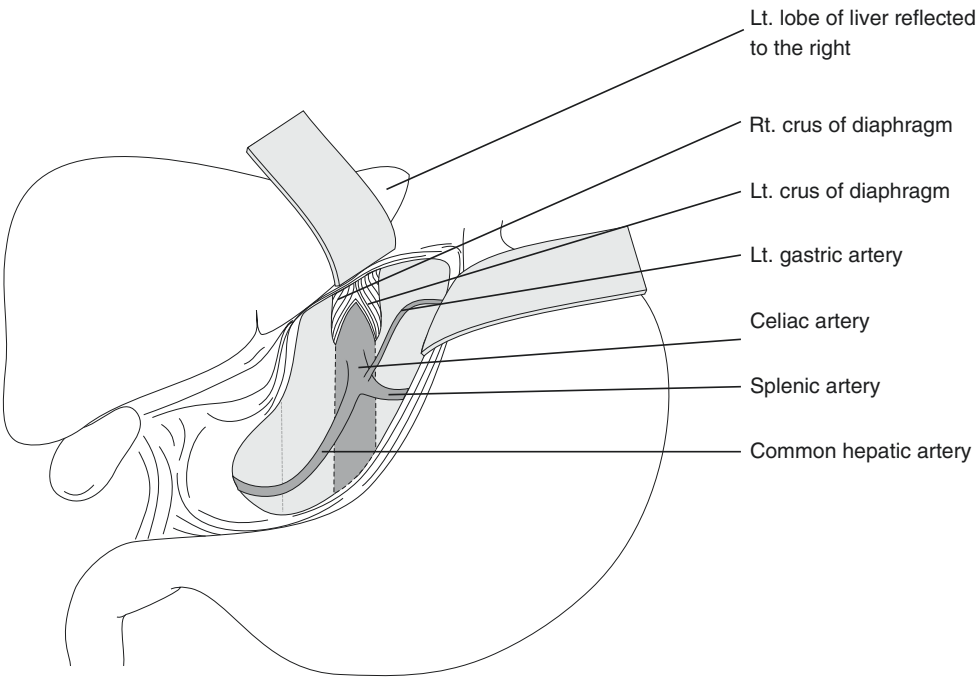

Figure 3.40. Transabdominal exposure of the supraceliac aorta.

are palpated and gently dissected away from the aorta. The aorta is then bluntly dissected on each side along its longitudinal axis down to the vertebral column using a sweeping motion of the index finger. The aorta is then pinched between the index finger and the thumb to ensure adequate dissection. The aorta is then straddled by the second and third fingers. The blades of an aortic clamp are then carefully guided over the fingers to control the dissected part of the supraceliac aorta.

Transperitoneal Exposure of the Supraceliac Aorta

When the supraceliac aorta is exposed under direct vision for elective or emergency control, the triangular ligament of the liver is first divided. Care should be taken to avoid injuring the hepatic veins or vena cava as the medial part of the triangular ligament is being divided close to the diaphragm. The left lobe of the liver is retracted to the right. The lesser omentum is incised. The stomach and esophagogastric junction are then gently retracted to the left. This can be facilitated by the presence of a nasogastric tube. The right crus of the diaphragm is identified. Using a right-angle clamp, the fibers of the right crus of the diaphragm are engaged and then divided. This will provide good visualization of the right edge of the supraceliac aorta. The left aspect of the aorta is exposed next. The dissection is carried out inferiorly and then superiorly, dividing the medial arcuate ligament and exposing the most distal part of the thoracic aorta. This provides an adequate space for cross-clamping the aorta under direct vision. Ligation and division of the phrenic arteries may be necessary to enhance the exposure.

Transperitoneal Exposure of the Celiac Artery

To expose the celiac artery, the supraceliac aorta is exposed under direct vision as previously described. The dissection is extended inferiorly on the anterior aspect of the supraceliac aorta [45, 47]. Fibrous bands, sympathetic nerves, and the celiac ganglia usually lie anterior to the celiac artery. Division of these structures will expose the celiac artery (Fig. 3.40).

Exposure of the Hepatic Artery

The lesser omentum is incised. The stomach is reflected inferiorly. Palpation along the upper border of the pancreas will reveal the location of the hepatic artery. A 2×3-cm lymph node is often noted in that area. Mobilization of the lymph node will usually reveal the common hepatic artery directly inferior to it. The common hepatic artery is dissected and encircled with a silastic vessel loop. Gentle traction of the vessel loop will facilitate the exposure of the common hepatic artery as it divides into the proper hepatic and the gastroduodenal arteries (Figs. 3.41 and 3.42).

Transabdominal Exposure of the Common Hepatic Artery

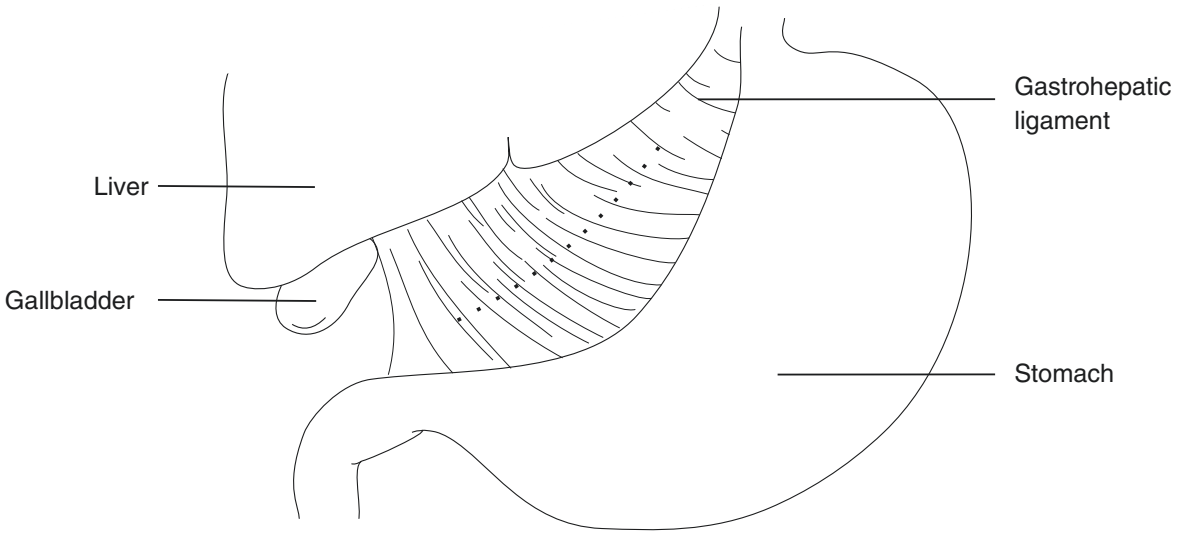

Figure 3.41. The hepatoduodenal ligament is incised.

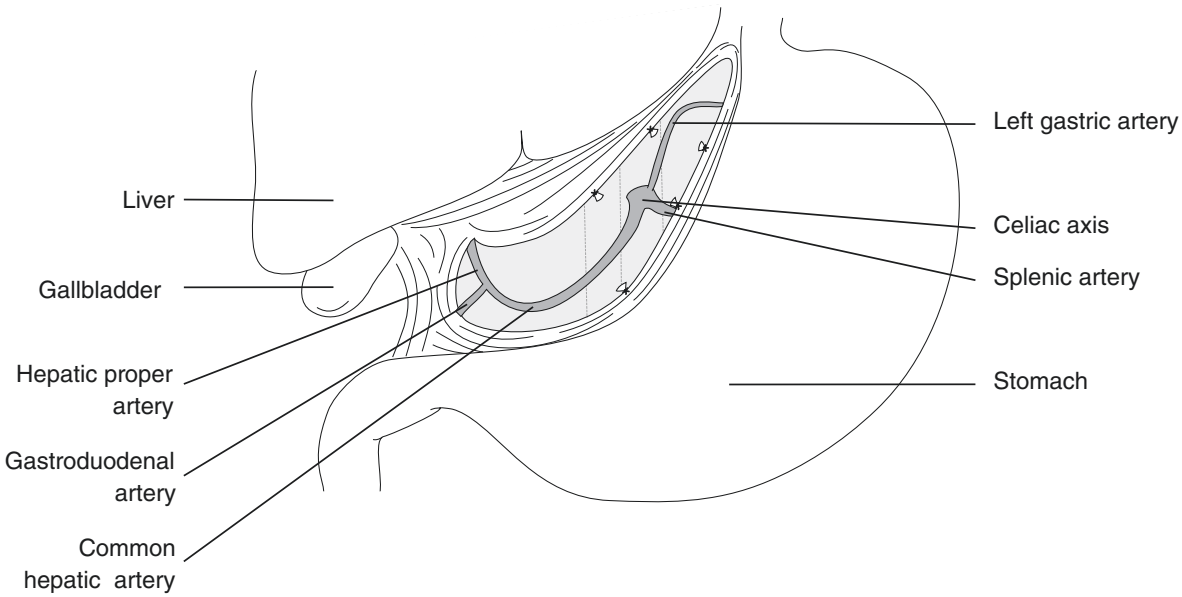

Figure 3.42. The common hepatic artery is dissected.

Transperitoneal Exposure of the Superior Mesenteric Artery

The origin of the superior mesenteric artery can be accessed through the lesser sac by exposing the aorta at the level of the celiac artery and then carrying out the dissection distally on the anterior aspect of the aorta [45, 47]. The upper border of the pancreas is mobilized to allow for exposure of the origin of the superior mesenteric artery as it lies just underneath it. Further distal exposure of the superior mesenteric artery from this approach is limited by the overlying pancreas. Thus, 3–5 cm distal to its origin from the aorta, the superior mesenteric artery is best exposed by an incision at the root of the small bowel mesentery. The transverse colon is retracted anteriorly and cephalad and the small bowel is reflected caudally (Fig. 3.43). The root of the small bowel mesentery is palpated, revealing the location of the vascular pedicle. The peritoneum overlying the root of the mesentery is incised. The superior mesenteric vein and artery are exposed. The superior mesenteric artery is identified and mobilized to the patient's left side (Fig. 3.44). The superior mesenteric artery is further dissected distally, exposing its branches. This approach allows for the exposure of the superior mesenteric artery from the level of the middle colic to the ileocolic branch.

Transabdominal Exposure of the Superior Mesenteric Artery

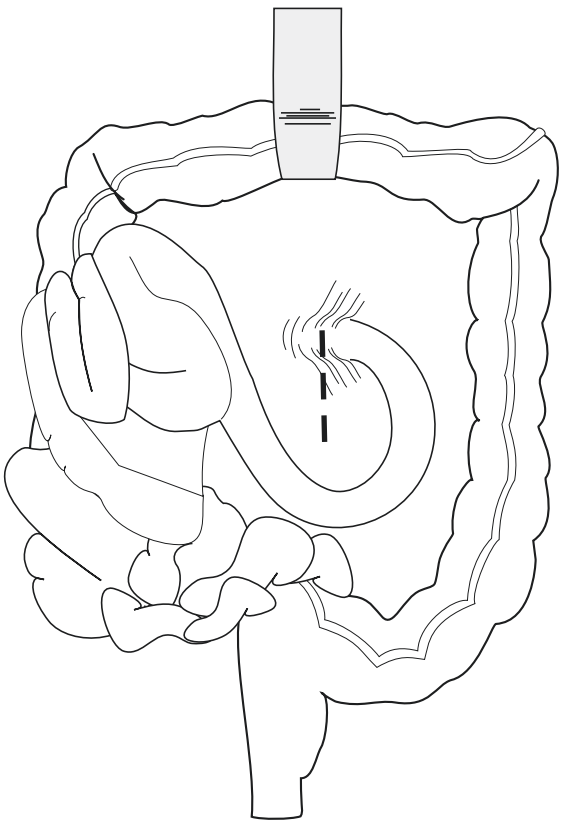

Figure 3.43. The peritoneum in the base of the mesentery is incised.

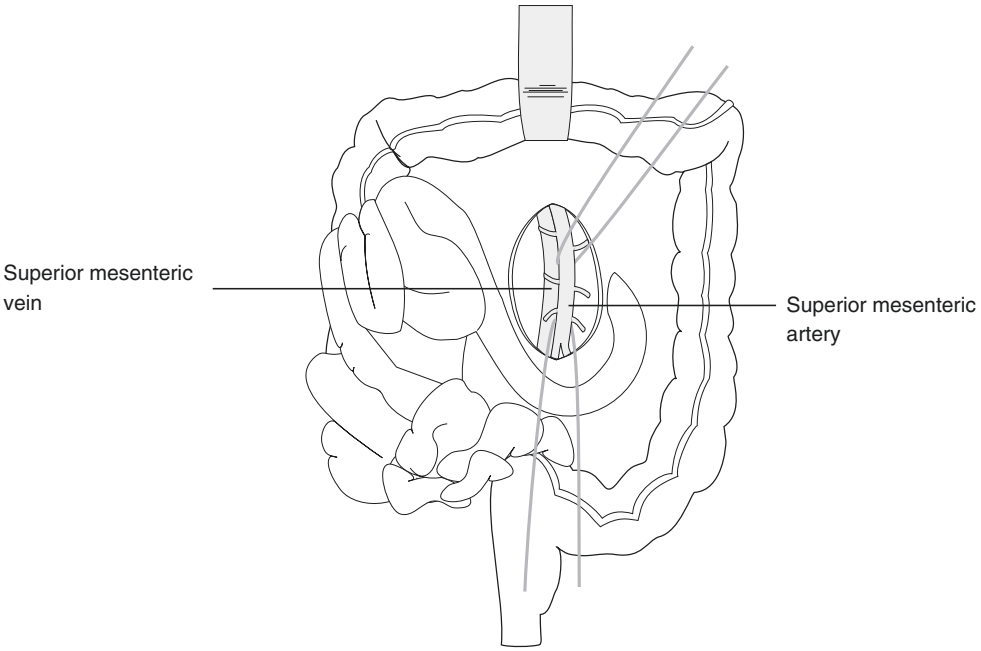

Figure 3.44. The artery is dissected and identified, usually to the left of the superior mesenteric vein. This approach allows the exposure of the superior mesenteric artery up to the level of the origin of the middle colic artery.

Exposure of the Suprarenal Abdominal Aorta and Its Branches Through a Medial Visceral Rotation

The suprarenal aorta and its branches can also be exposed through a transabdominal incision up to the level of the diaphragm by performing a medial visceral rotation [40, 41]. In this approach, the left colon, the spleen, the pancreas, and the stomach are mobilized and reflected medially. The left lateral peritoneal reflection is incised, mobilizing the descending colon. The incision is carried out cephalad and around the spleen through the phrenocolic and lienorenal ligaments. The plane of the dissection can be either anterior or posterior to the left kidney. In the former, the kidney and adrenal gland are left undisturbed, and the plane of dissection is carried out between the pancreas and Gerota's fascia. In the latter, the kidney and adrenal gland are rotated anteriorly and reflected medially along with the spleen, the pancreas, and the stomach (Fig. 3.45). At this stage, the aorta is well exposed along with the origin of the celiac and superior mesenteric arteries. Although this exposure can avoid the addition of a thoracic incision, it can be challenging in overweight patients or in the presence of a narrow costal angle. Furthermore, care should be taken to avoid avulsing the splenic capsule during this exposure.

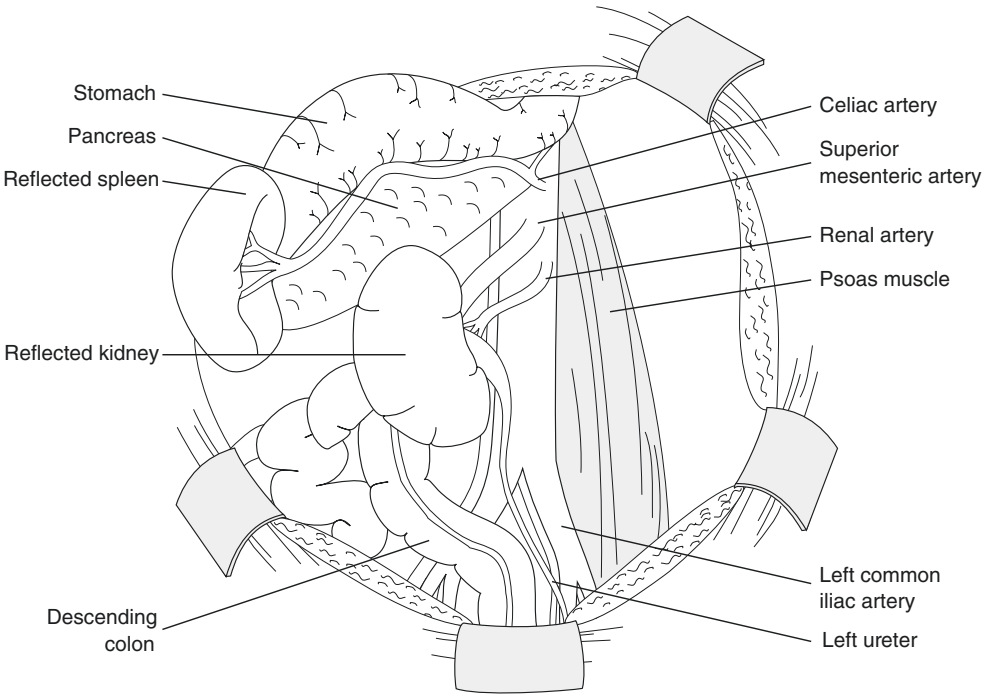

Figure 3.45. Medial visceral rotation.

Retroperitoneal Exposures of the Abdominal Aorta and Its Branches

The abdominal aorta can be exposed through a right or left retroperitoneal approach [34, 37, 38]. The left-sided approach is the most commonly used because of its versatility. Unlike the right retroperitoneal approach, the left retroperitoneal approach is ideal for celiac or superior mesenteric artery revascularization procedures or for exposure of the juxtarenal or suprarenal abdominal aorta. The right retroperitoneal approach can be useful in selected situations such as left retroperitoneal exposures and scarring or if there is a need for right renal revascularization.

The main steps in exposing the aorta through a retroperitoneal approach are as follows:

1. Skin incision
2. Division of the external oblique, internal oblique, and transversus muscles
3. Entering the retroperitoneal space
4. Mobilization of the peritoneal contents
5. Identifying the lumbar vein
6. Exposing the abdominal aorta
7. Identification of the left renal artery

Details of the Left Retroperitoneal Exposure

The patient is positioned with the left side of the chest rotated almost at a 90-degree angle and the pelvis at a 30-degree angle to the horizontal (Fig. 3.46). The skin incision is performed from the lateral edge of the rectus muscle to the tip of the 11th rib. Extension of the skin incision beneath the 12th rib or into the 11th interspace may be needed to improve the exposure. This may also be achieved by resecting the 12th rib. The incision is deepened through the subcutaneous tissues. The external oblique is then incised followed by the internal oblique and the transverse oblique muscles. The retroperitoneum is entered posteriorly at the lateral aspect of the incision. The peritoneum is mobilized cranially and caudally, allowing the peritoneal contents to be retracted medially. The peritoneum is mobilized anterior to the psoas muscle toward the aorta. Cephalad, the plane of the dissection can be either anterior (Fig. 3.47) or posterior to the left kidney. In the former, the aortic exposure is similar to that obtained through a transabdominal approach, with the left renal vein crossing over the aorta.

Retroperitoneal Exposure of the Abdominal Aorta

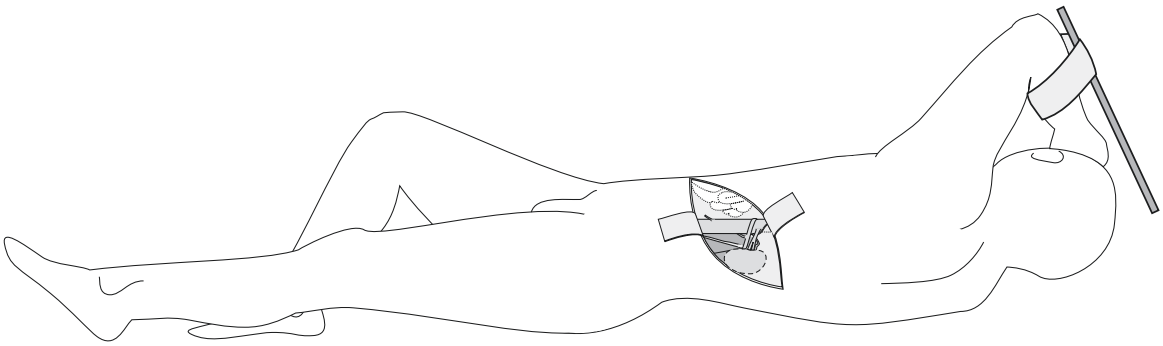

Figure 3.46. Patient's position for the left retroperitoneal approach to the abdominal aorta.

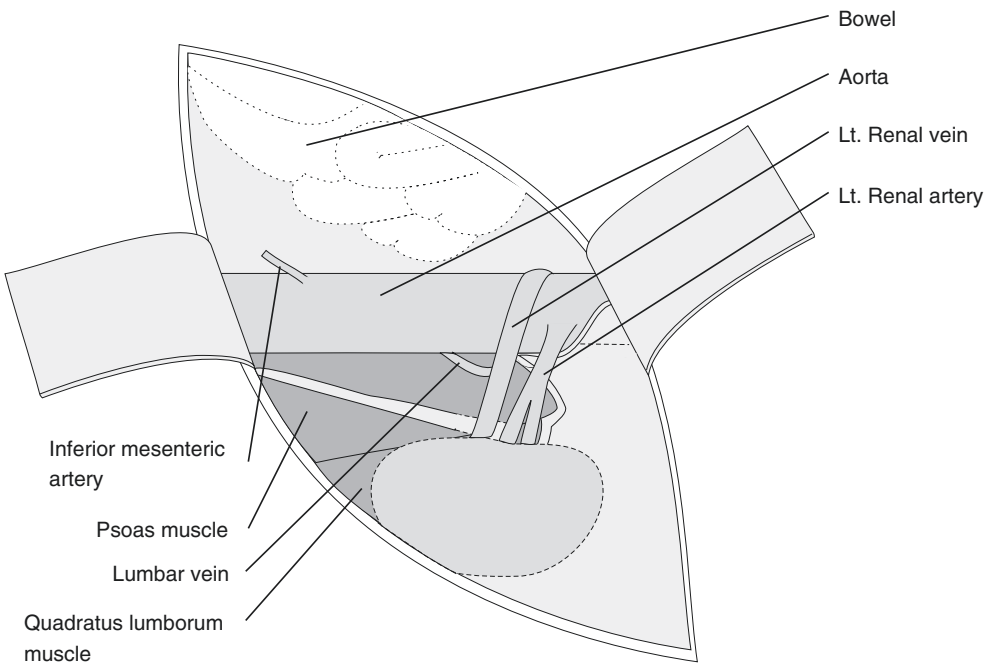

Figure 3.47. Retroperitoneal exposure of the infrarenal aorta with the left kidney undisturbed.

When the plane of the dissection is posterior to the kidney, the kidney is elevated from its bed and reflected anteriorly and medially (Fig. 3.48). This approach facilitates the exposure of the pararenal aorta without having to mobilize the left renal vein. The aorta is palpated anterior to the lumbar vertebrae. The dissection is carried out superiorly over the aorta. Dissection is facilitated by dividing the periaortic tissues on the most posterior and lateral aspect of the aorta. At that level, there are no significant branches or structures that can be injured. Dissection of the aorta is then extended superiorly until the left crus of the diaphragm is encountered. Anteriorly, a large lumbar vein crossing over the aorta to join the left renal vein is noted (Fig. 3.48). This lumbar vein usually marks the level just below the origin of the left renal artery. The left renal artery can be easily palpated and then exposed and dissected as needed (Fig. 3.48). Division of the left crus of the diaphragm at that level will provide additional proximal exposure. The right renal artery cannot be exposed from this approach unless the aorta is transected at the infrarenal level. In this situation, the proximal part of the right renal artery can be exposed from beneath the stump of the transected aorta.

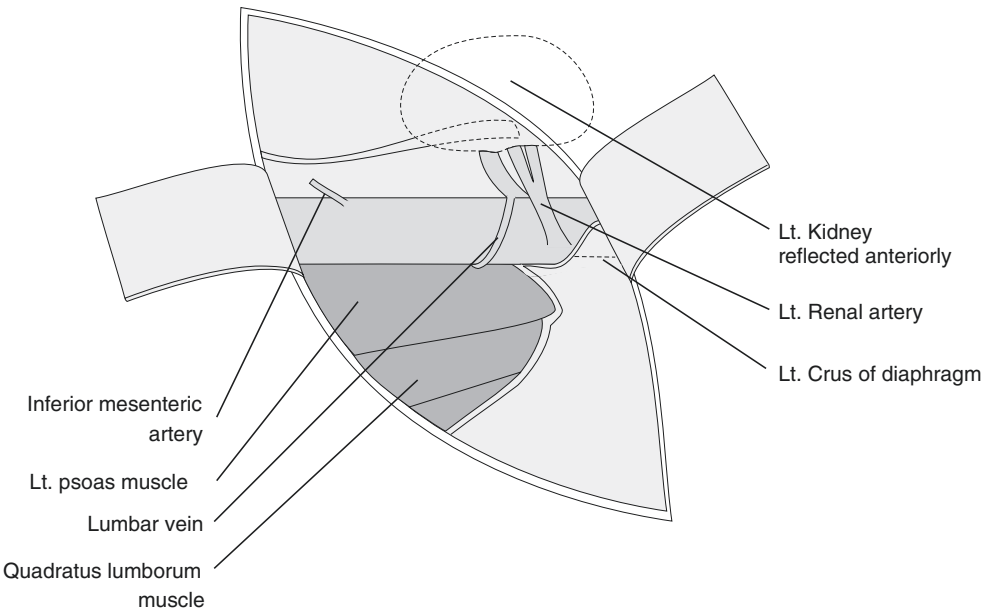

Figure 3.48. Retroperitoneal exposure of the abdominal aorta with the left kidney reflected anteriorly.

Distally, the aorta can be dissected down to its bifurcation. Frequently, exposure of the common iliac arteries is also necessary during the same procedure. The exposure of the left common and external iliac arteries can be performed bluntly or sharply by extending the dissection distally from the aorta. The exposure of the right common and proximal external iliac arteries is more demanding. However, division of the inferior mesenteric artery at its origin from the aorta permits additional retraction of the peritoneum and its content to allow further exposure and dissection of the right common iliac artery. If the main reason for exposing the right common iliac artery from this approach is to secure distal vascular control, this step can be facilitated by occluding the right common iliac artery from within the aortic wall using a balloon-occluding catheter.

Retroperitoneal Approach to the Suprarenal Aorta and Its Branches

If supraceliac control is anticipated, the skin incision is usually carried out to the level of the tenth rib and into the ninth interspace. The infrarenal aorta is exposed, as previously described, up to the level of the left crus of the diaphragm. The left crus of the diaphragm is completely divided, exposing the supraceliac aorta. The celiac and the superior mesenteric arteries can be exposed and circumferentially dissected at their origin (Fig. 3.49). In this approach, the aorta can be exposed up to a few centimeters above the origin of the celiac artery. The pleural cavity is not usually entered and the diaphragm is left intact except at the hiatus. If more proximal exposure is necessary, a thoracoabdominal approach will become necessary.

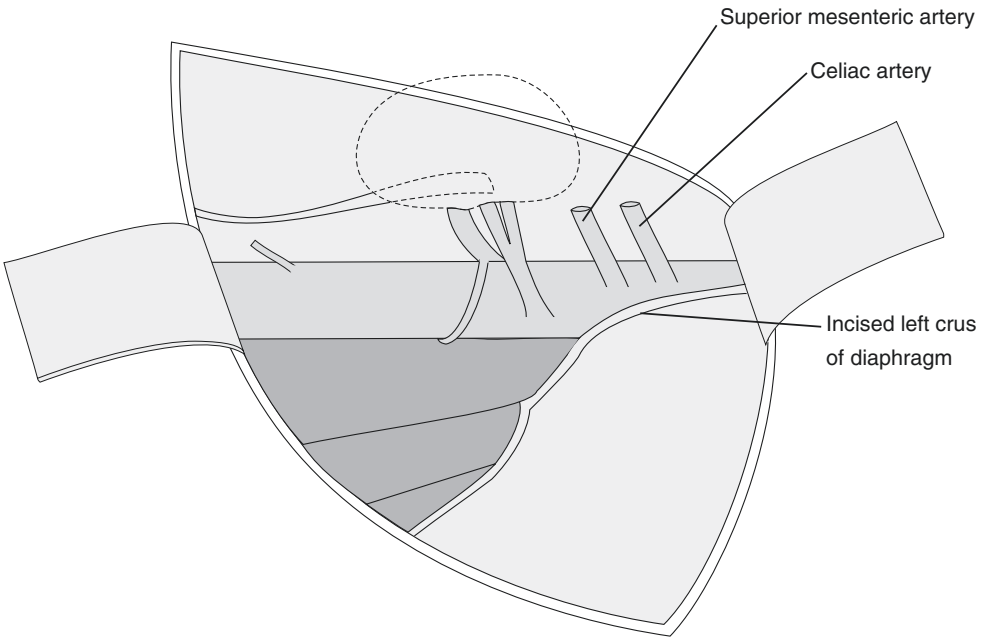

Figure 3.49. Retroperitoneal exposure of the suprarenal aorta.

Thoracoabdominal Exposure of the Thoracic and Upper Abdominal Aorta

Exposure of the thoracic and upper abdominal aorta is achieved through a thoracoabdominal approach [6, 13]. The abdominal portion of the thoracoabdominal exposure can be through a transperitoneal approach or retroperitoneal approach. In the former, a vertical midline abdominal incision is carried into the chest, usually in the sixth or eighth intercostal space, depending on the extent of the proximal exposure needed (Fig. 3.50). The sixth intercostal space can provide exposure to the level of the origin of the left subclavian artery. The thoracic incision is usually carried back posteriorly to the level of the latissimus dorsi muscle. Once the pleural cavity is entered, the diaphragm can be divided radially or circumferentially. The circumferential incision has the advantage of preserving the phrenic nerve's attachments to the diaphragm. The stomach, spleen, and distal pancreas are then mobilized medially, exposing the origin of the celiac and superior mesenteric arteries. In the retroperitoneal thoracoabdominal approach, it is usually easier to start with the thoracic part of the incision, divide the diaphragm, and then progress into the retroperitoneal space, starting at the level of the left crus of the diaphragm. This will facilitate developing the retroperitoneal plane and extending the exposure into the abdomen through an oblique or left paramedian incision (Fig. 3.51).

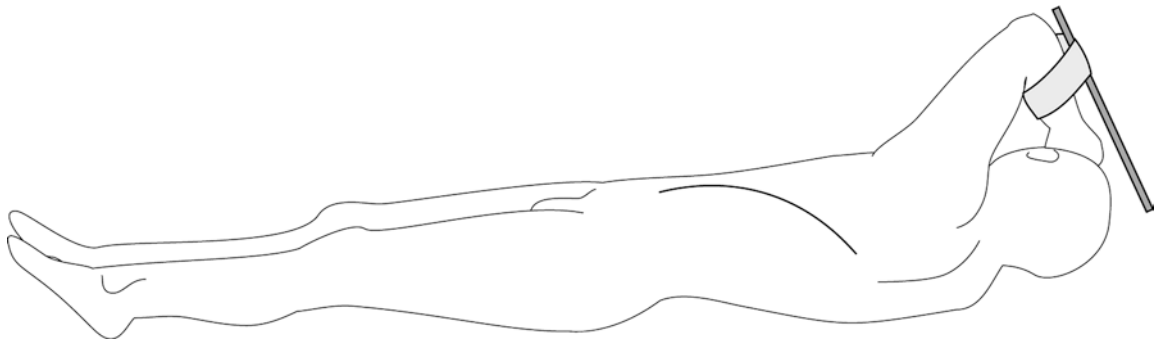

Figure 3.50. Patient's position for the thoracoabdominal retroperitoneal approach to the abdominal and thoracic aorta.

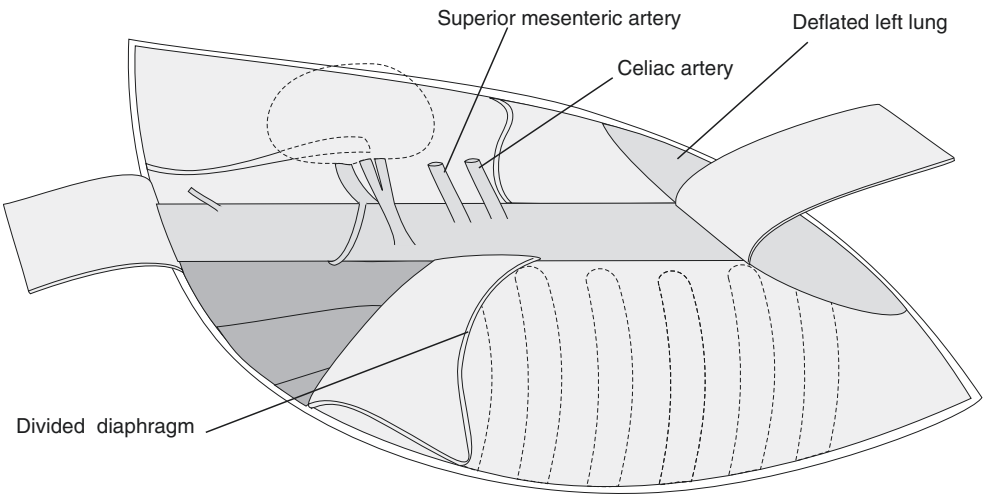

Figure 3.51. Thoracoabdominal retroperitoneal approach.

Transperitoneal Exposure of the Iliac Arteries

The origin of the common iliac arteries can be accessed by exposing the aorta as previously described and carrying out the dissection distally to the aortic bifurcation. On the right side, the cecum and the small bowel are usually retracted superiorly and laterally. The peritoneum overlying the aorta is incised and the incision is extended along the right common iliac artery. The right common iliac artery is then dissected distally to the level of the iliac bifurcation. At that level, the right ureter is noted crossing the iliac bifurcation. Exposure of the right external iliac artery can be achieved by incising the peritoneum over the artery distal to the ureter toward the inguinal ligament. On the left side, frequently only a few centimeters of the proximal common iliac artery can be dissected because of the overlying sigmoid mesocolon. Further exposure can be obtained by reflecting the sigmoid colon medially. The peritoneal attachments of the sigmoid colon to the lateral abdominal wall are incised. The left psoas muscle is identified and the external iliac artery is palpated medially. Dissection of the external iliac artery at that level is performed and extended distally and proximally toward the common iliac artery. The internal iliac artery can be identified along the medial and inferior aspects of the left common iliac artery (Fig. 3.52).

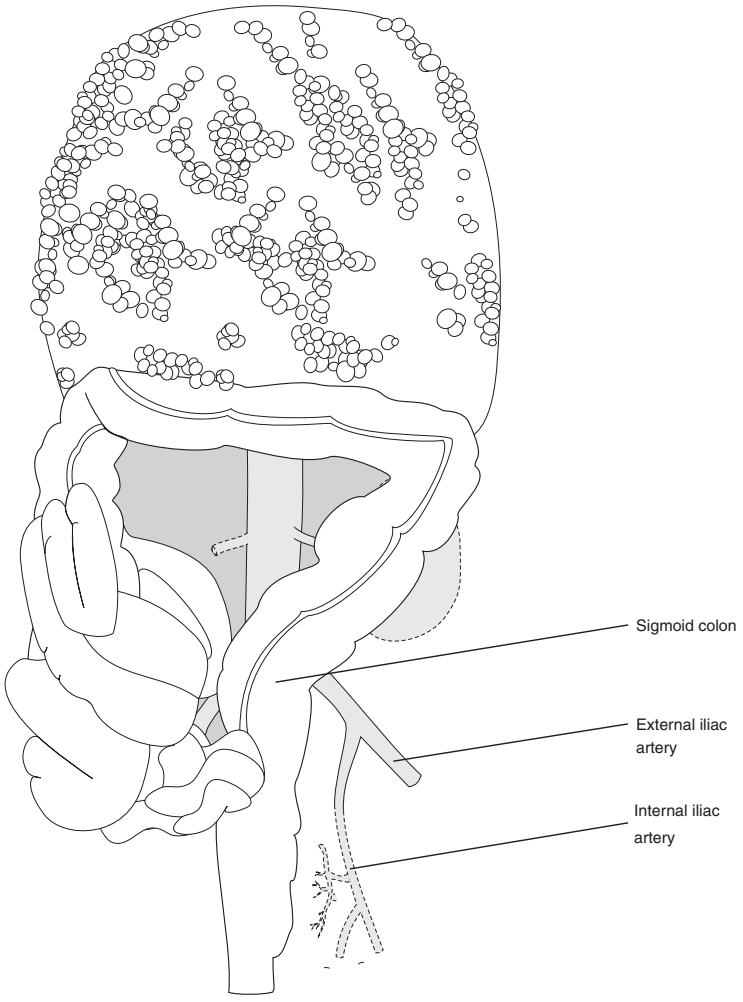

Figure 3.52. Transabdominal exposure of the left iliac arteries.

Retroperitoneal Exposure of the Iliac Arteries

The retroperitoneal exposure of the iliac vessels is very similar to the retroperitoneal approach to the aorta, with the main variation being the location of the incision. Most commonly, a curvilinear incision is used, starting from the lateral border of the left rectus muscle and extending to the midaxillary line. For the common iliac artery, the incision starts approximately 5 cm above the symphysis pubis and is 2–3 cm lower for the exposure of the external iliac artery (Fig. 3.53). The distal part of the external iliac artery can also be exposed using a longitudinal infrainguinal incision placed over the common femoral artery. This latter vessel is exposed proximally. The inguinal ligament is retracted superiorly and anteriorly and may also be divided, providing exposure to the distal 5-cm segment of the external iliac artery.

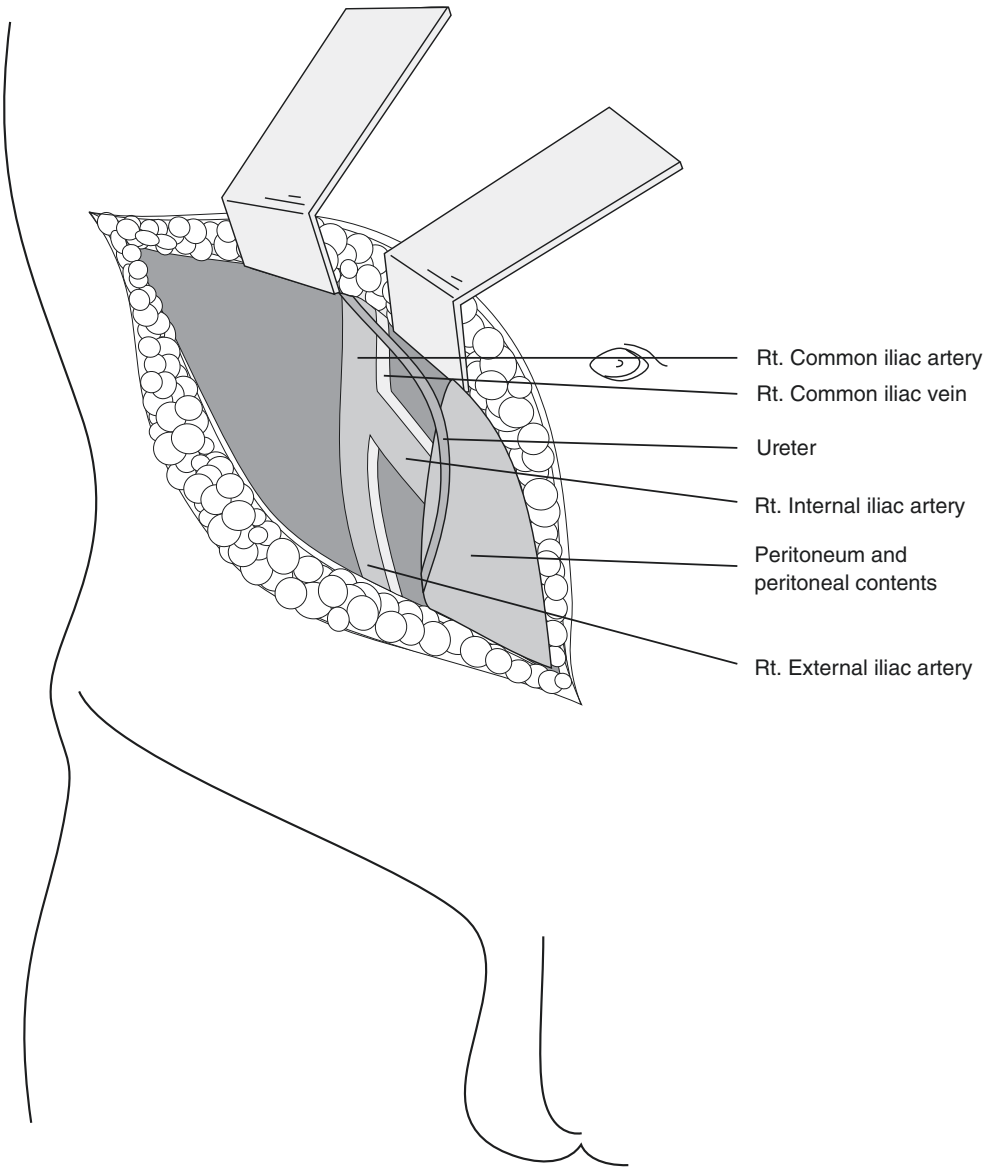

Figure 3.53. Retroperitoneal exposure of the iliac arteries.

ARTERIES OF THE LOWER EXTREMITY

ANATOMY OF THE ARTERIES OF THE LOWER EXTREMITIES

The Common Femoral Artery

The common femoral artery is the continuation of the external iliac artery after it passes beneath the inguinal ligament. It is surrounded by the femoral nerve laterally and the common femoral vein medially. Proximally, the common femoral artery and vein are enclosed in a fibrous sheath referred to as the femoral sheath. The femoral artery travels in the femoral triangle, which is made by the sartorius muscle laterally, the adductor longus muscle medially, and the inguinal ligament superiorly. The floor of the triangle is made by the iliopsoas muscle laterally and the pectineus muscle medially. The common femoral artery gives off the superficial iliac circumflex and the superficial epigastric arteries proximally and divides distally into the deep and superficial femoral arteries (Fig. 3.54).

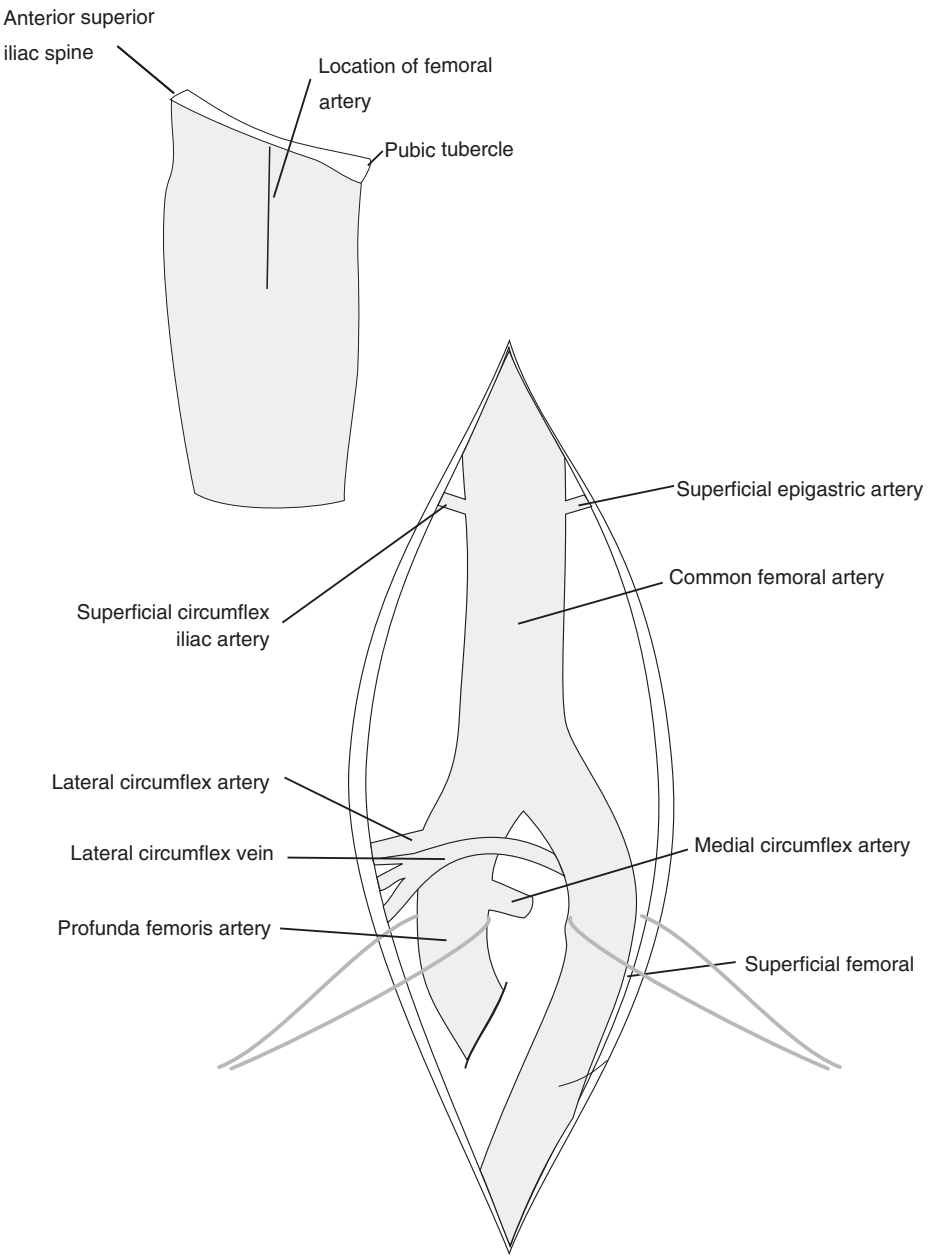

Figure 3.54. Exposure of the common femoral artery and its bifurcation.

The Profunda Femoris Artery

The profunda (deep) femoral artery originates from the posterolateral aspect of the common femoral artery. It follows a posterior and lateral course running parallel and medial to the femur over the pectineus and adductor brevis muscles. The profunda femoris artery ends distal to the femoral triangle between the adductor longus and magnus muscles. The proximal part of the profunda femoris artery gives off the lateral and medial femoral circumflex branches. These branches may also originate directly from the common femoral artery. Awareness of these anatomical variations is important to avoid unexpected retrograde bleeding from these branches upon performing a femoral arteriotomy. More distally, the profunda femoris artery gives off three large perforating branches. For the sake of describing surgical exposures, the profunda is divided arbitrarily into three zones. The proximal zone extends from its origin to just distal to the lateral femoral circumflex artery. The distal zone is the part distal to the femoral triangle and is usually distal to the second perforating muscle branch. The middle zone is the segment between the proximal and distal zones (Fig. 3.55).

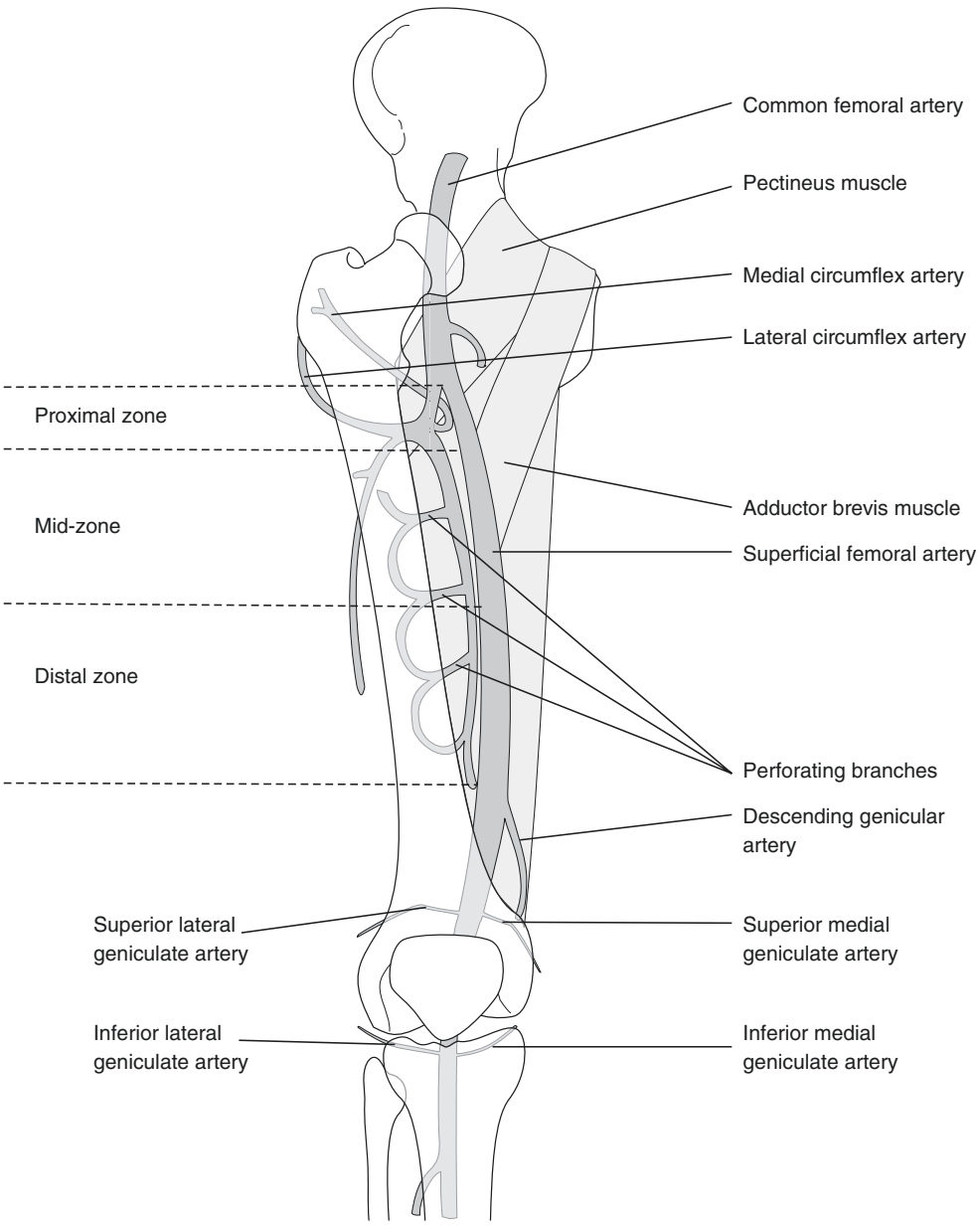

Figure 3.55 Deep femoral artery.

The Superficial Femoral Artery

The superficial femoral artery is the continuation of the common femoral artery. It runs along the anteromedial aspect of the thigh and is bounded laterally by the sartorius muscle and medially by the adductor longus muscle. In the midthigh, it moves medially into a deep and posterior location traveling through the adductor magnus muscle in the adductor (Hunter) canal. It then exits from the adductor hiatus in the distal thigh to become the suprageniculate popliteal artery (Fig. 3.56). During its course, the superficial femoral artery provides several muscular branches as well as the descending genicular artery.

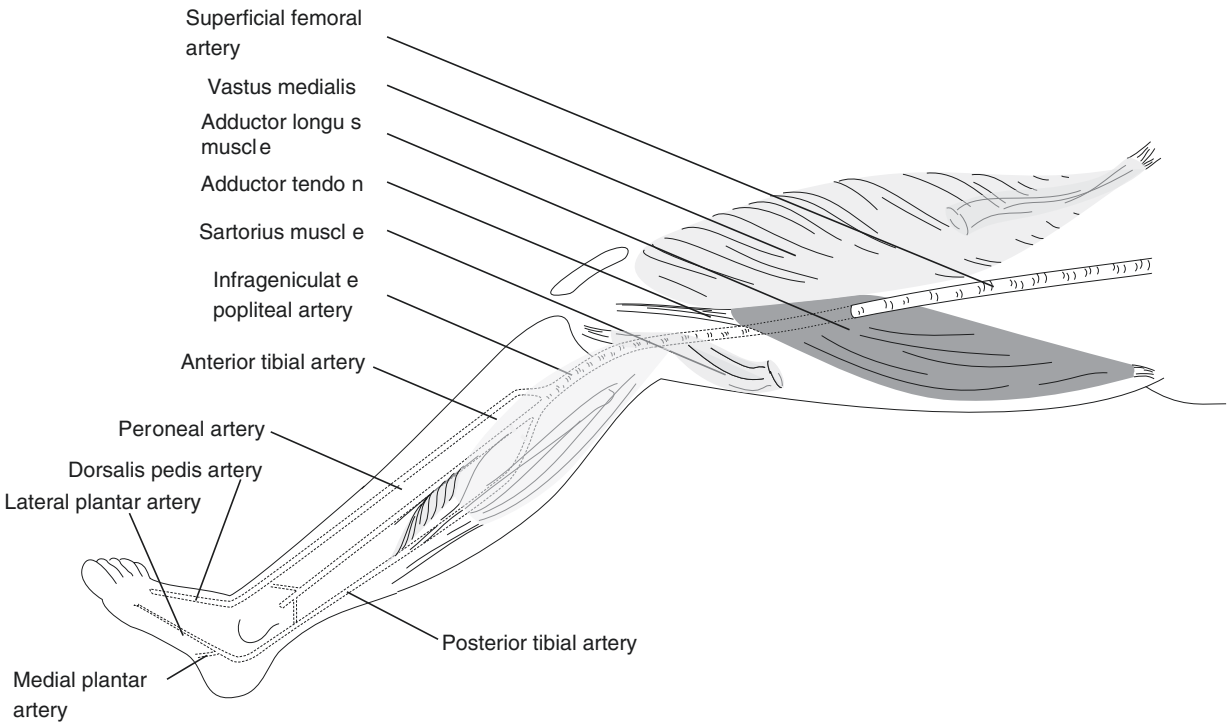

Figure 3.56. The superficial femoral artery and adjacent muscles.

The Popliteal Artery

The popliteal artery is the direct continuation of the superficial femoral artery. It has a suprageniculate and infrageniculate component. The suprageniculate (above-knee) popliteal artery starts distal to the adductor canal and travels between the two heads of the gastrocnemius muscle anterior to the popliteus muscle. It continues beyond the knee joint as the infrageniculate (below-knee) popliteal artery for 4–6 cm until it divides into the anterior tibial artery and the tibioperoneal trunk. The popliteal artery gives off several genicular branches. Above the knee, it gives off the superior medial and the superior lateral genicular arteries. Below the knee joint, it gives off the inferior lateral and the inferior medial genicular arteries (Fig. 3.55). These genicular branches provide a rich network between the superficial femoral artery, the profunda femoris artery, and the tibial arteries. This collateral network can be very useful in the presence of chronic occlusive disease of the superficial femoral and popliteal arteries.

The Anterior Tibial Artery

The anterior tibial artery represents the first major branch of the infrageniculate popliteal artery. It curves anteriorly and laterally and penetrates the interosseus membrane to lie between the anterior tibialis muscle and the extensor hallucis longus (Figs. 3.56 and 3.57). The anterior tibial artery continues its course in the anterior compartment of the leg, lying on the interosseus membrane down to the ankle level, where it becomes the dorsalis pedis artery.

The Tibioperoneal Trunk

The tibioperoneal trunk is the direct continuation of the popliteal artery. It usually runs for 1–3 cm before bifurcating into the peroneal and the posterior tibial arteries.

The Peroneal Artery

The peroneal artery runs in the deep posterior compartment of the leg as a direct continuation of the tibioperoneal trunk. The peroneal artery runs posterior and medial to the fibula surrounded by the posterior tibialis muscle anteriorly and medially and the flexor hallucis longus posteriorly (Figs. 3.56 and 3.57). During its course in the leg, the peroneal artery gives off branches to its adjacent muscles. In the lower leg, the peroneal artery gives off a communicating branch to the posterior tibial artery and another communicating branch that perforates through the interosseus membrane to connect with the anterior tibial artery (Fig. 3.56). The peroneal artery terminates at the ankle as small branches to the lateral malleolus and calcaneus.

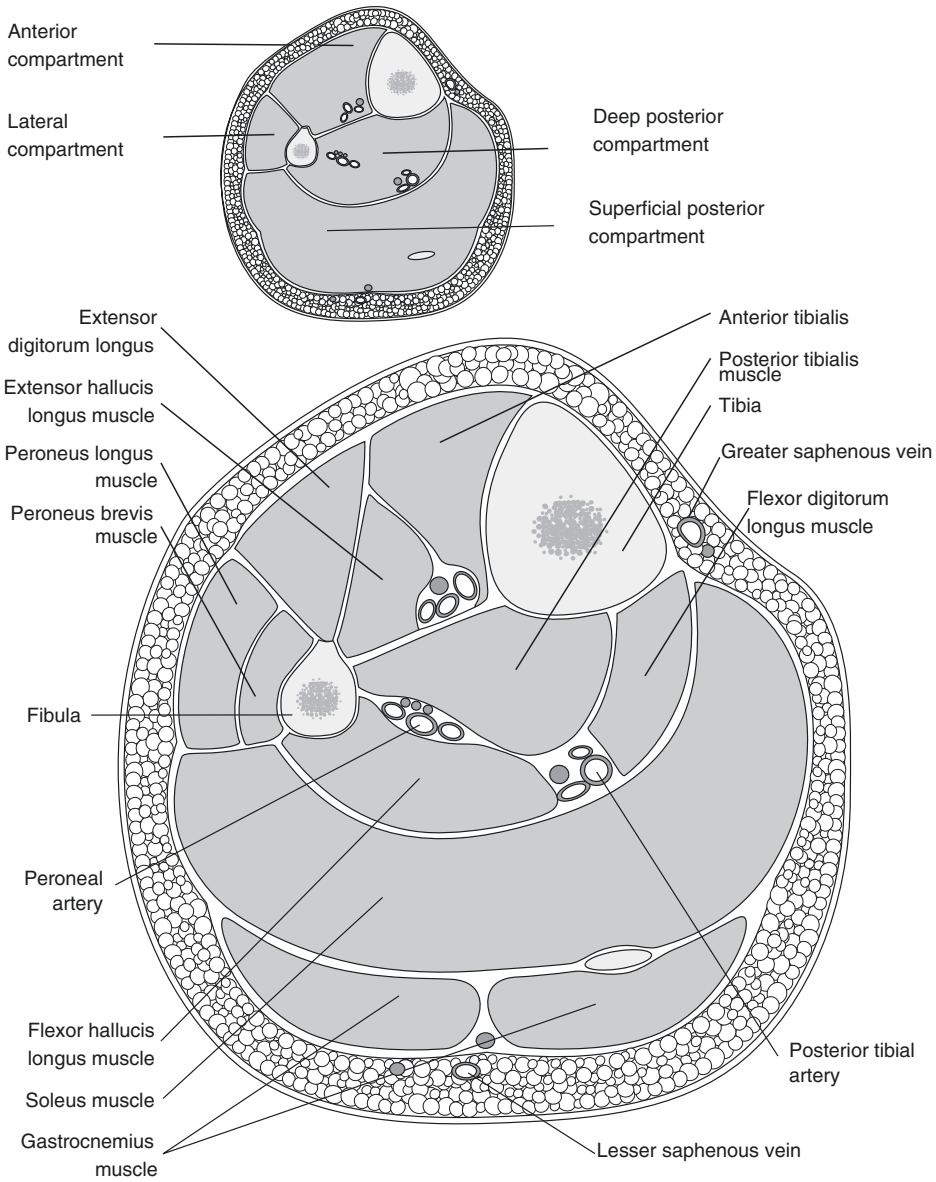

Figure 3.57. Cross section of the leg above midlevel.

The Posterior Tibial Artery

The posterior tibial artery originates from the tibioperoneal trunk and courses medially as it runs in the deep posterior compartment of the leg. The posterior tibial artery is surrounded by the flexor digitorum longus anteriorly, the flexor hallucis longus posteromedially, and the tibialis posterior muscle posterolaterally (Figs. 3.56 and 3.57). At the ankle level, the posterior tibial artery continues

into the foot and divides into the medial and lateral plantar arteries. The lateral plantar artery is usually the larger branch. It courses in a lateral direction deep to the abductor halluces muscle and the flexor digitorum brevis muscle to supply the deep plantar arterial arch. The medial plantar artery is the smaller branch of the posterior tibial artery, and it courses in a medial direction to supply the medial forefoot and terminate in the plantar arch.

Exposure of the Common Femoral Artery and Its Bifurcation

A vertical skin incision placed over the femoral pulse is usually used to expose the common femoral artery and its bifurcation. If the femoral pulse is not palpable, the incision is guided by the following anatomical landmarks. The pubic tubercle and the anterior superior iliac spine are palpated and the incision is placed at a point midway between these two structures. In addition, when the femoral pulse is absent, the presence of calcification in the common femoral artery may help to identify its location. The calcified femoral artery can often be palpated by rolling the fingers gently over the femoral region. Occasionally, matted inguinal lymph nodes could give a similar sensation and may be misleading. The incision is deepened through the subcutaneous tissue. If the saphenous vein is encountered during the exposure, this indicates that the dissection is more medial than necessary. If nerves are encountered, the dissection is more lateral than the actual location of the femoral artery. Encountered lymphatics are ligated and divided to avoid postoperative lymph leaks. The femoral sheath is identified and incised. The common femoral artery is then identified and dissected. As the dissection is continued distally, a change in the caliber of the exposed artery will be noted. The change in the vessel caliber marks the origin of the profunda femoris artery and the transition from the common femoral to the superficial femoral artery. The superficial femoral artery can be further exposed and dissected distally by extending the incision inferiorly (see Fig. 3.54).

Medial Exposure of the Proximal Profunda Femoris Artery

The profunda femoris artery can be approached by exposing the common femoral artery at its bifurcation and then proceeding with the dissection along its lateral and posterior aspects to expose the origin of the profunda femoris artery (see Fig. 3.55). Circumferential dissection of the common femoral bifurcation to identify any posterior branches originating from the common femoral artery is important to avoid unexpected retrograde bleeding from these branches upon creating an arteriotomy. Immediately after its origin from the common femoral artery, the profunda femoris is often crossed by venous branches. The first large venous branch is usually the lateral femoral circumflex vein, which crosses over the profunda femoris artery to join the superficial femoral vein (see Fig. 3.54). Division of these veins is essential to expose the profunda femoris artery further distally. The dissection can be carried out distally tracing the profunda femoris artery and its branches for 5–8 cm.

Medial Exposure of the Mid- and Distal Zones of the Profunda Femoris Artery

Mid- and distal zones of the profunda femoris artery can be exposed without exposing the common femoral bifurcation [31]. A 10- to 12-cm skin incision is performed over the medial aspect of the sartorius muscle. The superficial femoral artery and vein are exposed; they are retracted without dissecting them along with the sartorius muscle anteriorly and laterally. The dissection is then continued posteriorly toward the femur. A fibrous layer between the adductor longus muscle and the vastus medialis muscle is noted and incised longitudinally. The location of the profunda femoris artery underneath this layer can be identified by palpation or by using a sterile Doppler. Generally, one of the veins accompanying the profunda femoris artery is first visualized. Dissection and mobilization of the accompanying vein will expose the profunda femoris artery.

Medial Exposure of the Superficial Femoral Artery in the Upper Thigh

A longitudinal incision is performed along the course of the inferior border of the sartorius muscle. The incision is deepened through the subcutaneous tissues until the muscular fascia is identified. Care is taken to avoid injuring the greater saphenous vein. The fascia is incised and the sartorius muscle is identified. Dissection along the inferior border of the sartorius muscle is performed, and the sartorius muscle is retracted laterally, exposing the superficial femoral artery and vein.

Lateral Exposure of the Common Femoral Artery and Its Bifurcation

The common femoral artery can also be exposed through an incision placed lateral to its anatomical location [5]. The incision can be either medial or lateral to the sartorius muscle. In the former, the skin incision is made 4 cm lateral to the femoral pulse. The incision is deepened to the level of the sartorius muscle without creating any skin flaps. The sartorius muscle is mobilized laterally and the incision is deepened medially toward the femoral vessels until the femoral sheath is identified. The femoral sheath is incised along its lateral aspect, exposing the femoral arteries. When the exposure is started lateral to the sartorius muscle, the incision is made approximately 6–8 cm lateral to the femoral pulse. The incision is carried down through the subcutaneous tissues until the fascia lata is identified. The fascia lata is incised and the sartorius muscle identified. The dissection is then continued posterior to the sartorius muscle in the direction of the femoral vessels. This usually requires mobilization of the proximal part of the sartorius muscle, which often necessitates transection of the first two segmental arterial branches supplying the sartorius muscle. The femoral sheath is then identified from beneath the sartorius muscle as the dissection is being carried out medially. The femoral sheath is then incised along its lateral border, exposing the common femoral artery. Extending the incision distally will allow for exposure of the superficial femoral artery as well as the profunda femoris artery. The superficial femoral artery is identified in a plane directly posterior and medial to the sartorius muscle. The profunda femoris artery is identified by dissecting in a deeper plane posterior to the sartorius muscle. This is achieved by incising the connective tissue membrane that extends from the adductor longus to the vastus medialis. The first vessel identified is usually the femoral circumflex artery. After transecting its accompanying vein and dissecting toward its origin, the profunda femoris artery is exposed [30] (Fig. 3.58).

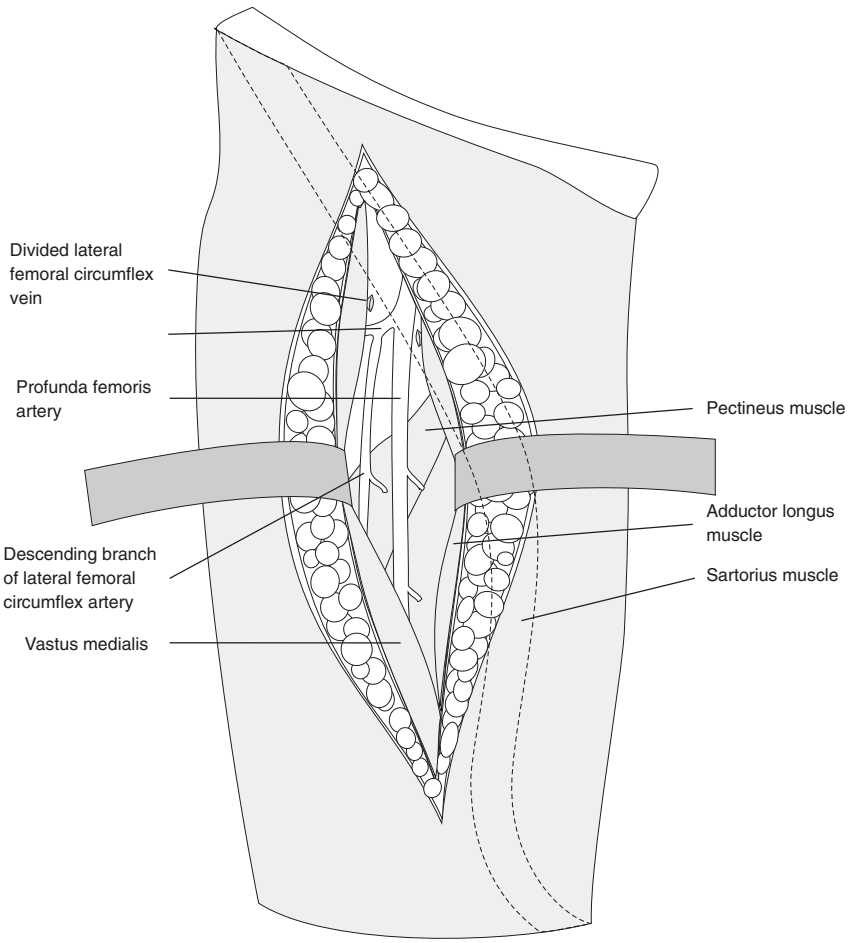

Figure 3.58. Lateral exposure of the profunda femoris artery.

Medial Exposure of the Supragenicular Popliteal Artery

A longitudinal skin incision is performed from the level of the knee joint extending 10–12 cm proximally (Fig. 3.59). The incision is usually placed along the anticipated location of the anterior border of the sartorius muscle when a prosthetic bypass is being used. If the ipsilateral greater saphenous vein is being used as a bypass, the same incision used to expose the vein can also be employed to expose the popliteal artery above the knee. The incision is deepened through the subcutaneous tissue (Fig. 3.60) until the adductor tendon is identified anteriorly and the upper border of the sartorius muscle is noted posteriorly.

Medial Exposure of the Supragenicular Popliteal Artery

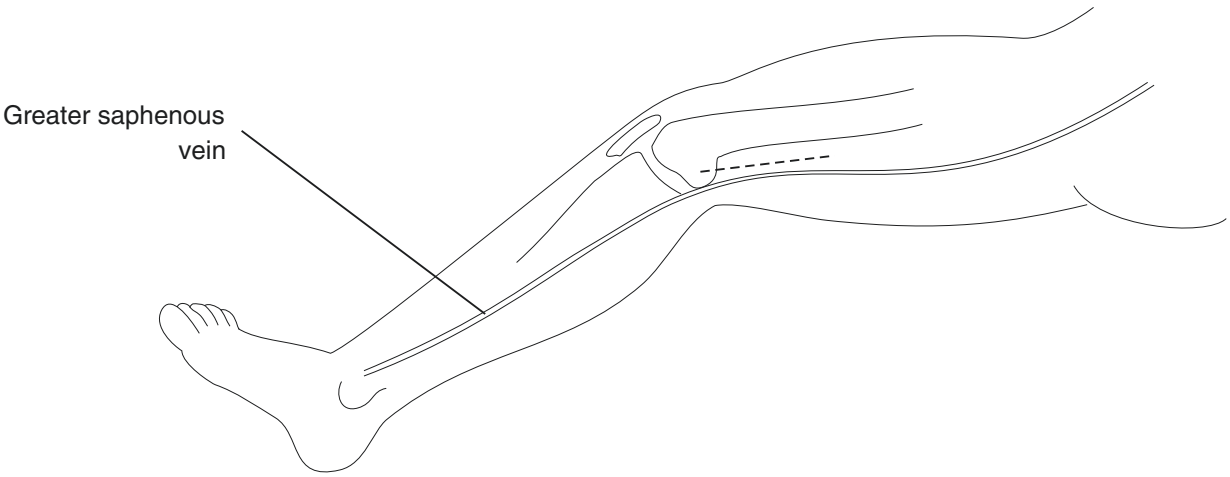

Figure 3.59. Incision for exposure of the supragenicular popliteal artery.

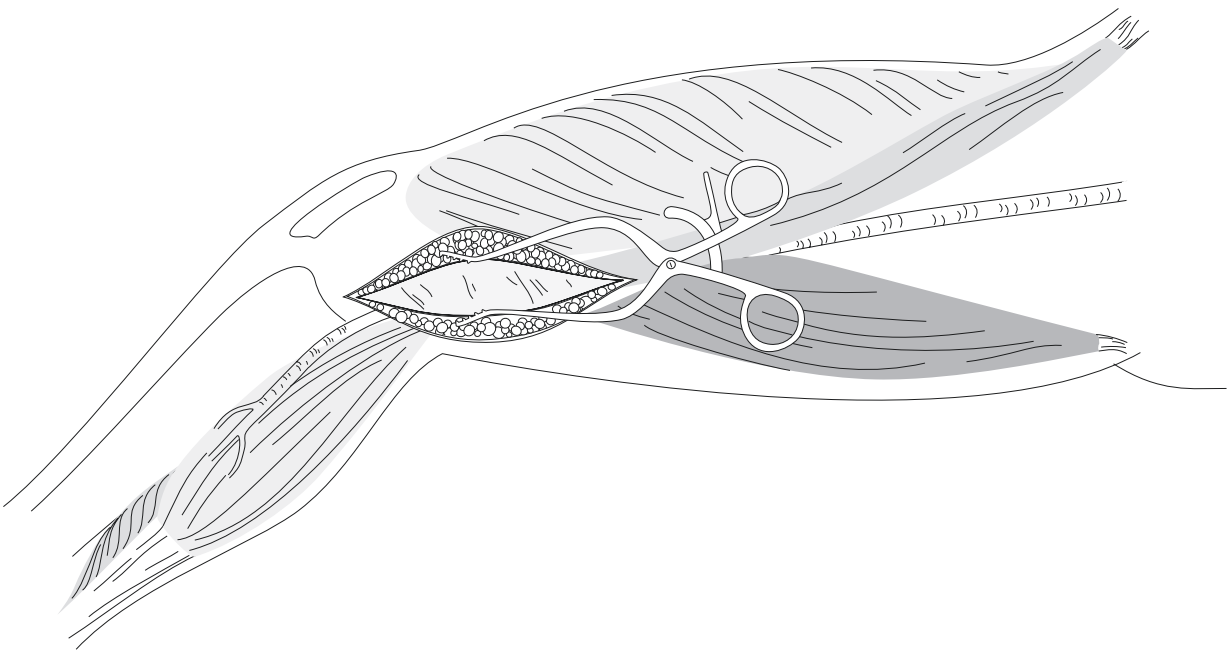

Figure 3.60. The incision is deepened through the subcutaneous tissues.

The fascia between the adductor tendon and the sartorius muscle is incised and the popliteal fossa is entered (Fig. 3.61). Self-retaining retractors are placed in a deeper plane retracting the adductor tendon anteriorly and the sartorius muscle posteriorly (Fig. 3.62). To improve the exposure, the knee is bent and a rolled towel is placed underneath the proximal thigh; placing the rolled towel directly under the knee can compress the popliteal fossa rather than allowing it to open up for the exposure of the popliteal vessels. In patients with occlusive disease, the hardened calcified popliteal artery can be easily palpated in the popliteal fossa. The popliteal artery can be dissected proximally until it is seen exiting from the adductor canal. Care should be taken at this level to avoid injury to the greater saphenous nerve as it exits from the adductor canal and courses anteriorly to run with the greater saphenous vein. Distally, the popliteal artery can be dissected to the level of the knee joint.

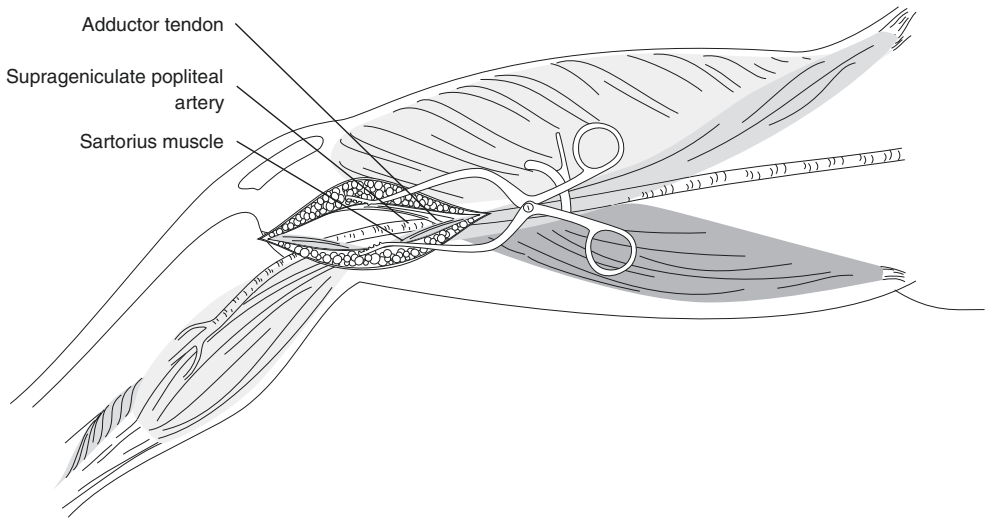

Figure 3.61. The popliteal fossa is entered inferior to the adductor tendon.

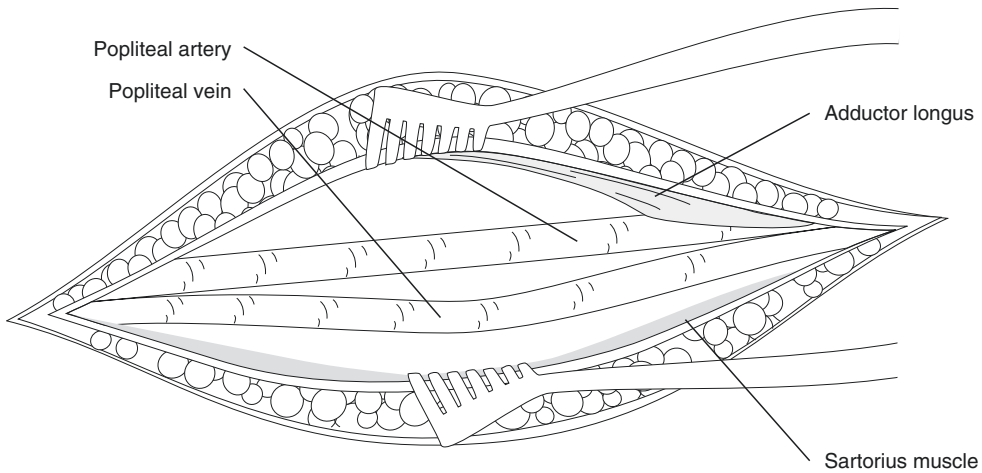

Figure 3.62. The retractor is placed deeper, exposing the popliteal vessels.

Lateral Exposure of the Supragenicular Popliteal Artery

The supragenicular popliteal artery can also be exposed through a lateral approach [24, 32, 43]. A 10- to 12-cm longitudinal incision is made from just above the knee joint extending proximally along the lateral aspect of the distal thigh (Fig. 3.63). The incision lies 1 cm posterior to and parallel to the iliotibial tract. Once the deep fascia is incised, the space between the iliotibial tract and biceps femoris muscle is opened exposing the above-knee popliteal artery (Fig. 3.64). The distal superficial femoral artery can be exposed by extending the incision more proximally and incising the adductor magnus muscle.

Lateral Exposure of the Supragenicular Popliteal Artery

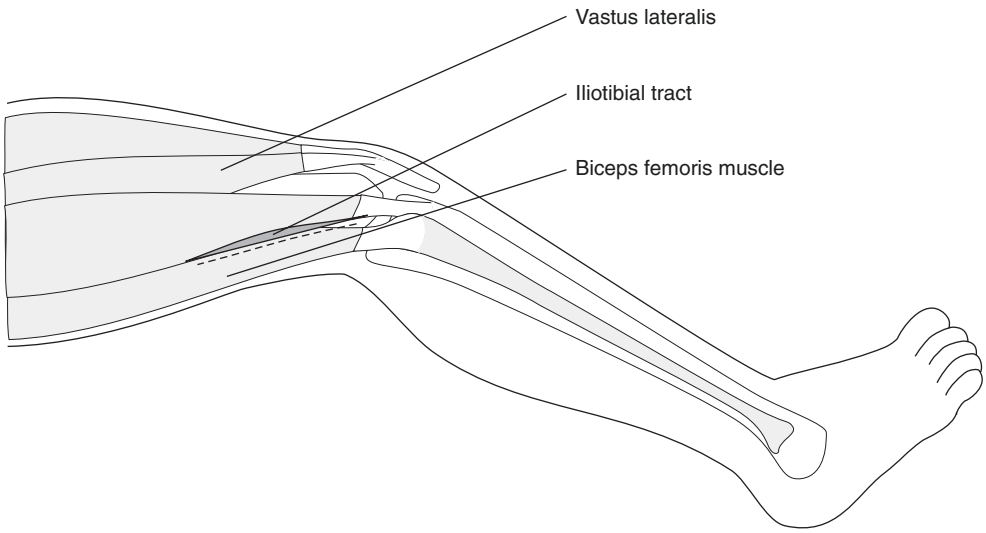

Figure 3.63. Incision for the lateral exposure of the supragenicular popliteal artery.

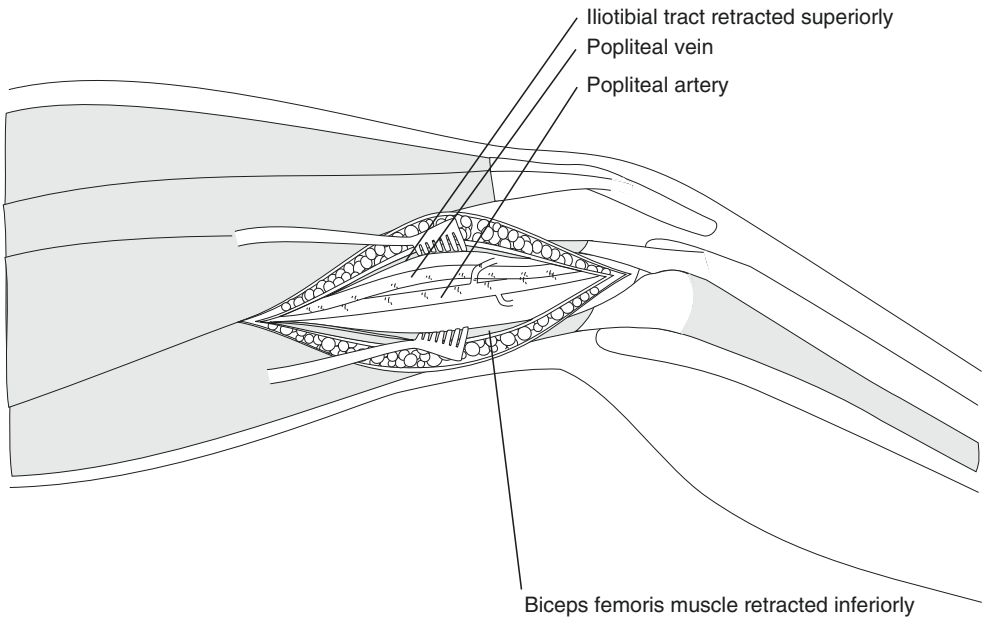

Figure 3.64. The popliteal space is entered between the iliotibial tract and the biceps femoris muscle.

Medial Exposure of the Infrageniculate Popliteal Artery
A longitudinal skin incision is made from the level of the knee joint and extended distally for 10–12 cm (Fig. 3.65). The incision is deepened through the subcutaneous tissue avoiding injury to the greater saphenous vein at that level. The incision is deepened until the underlying fascia is identified (Fig. 3.66). The fascia is incised and the popliteal space is entered between the gastrocnemius and soleus muscles using a sweeping motion with the index finger. With the knee bent, self-retaining retractors are applied to retract the gastrocnemius muscle posteriorly and laterally, exposing the popliteal space further (Fig. 3.67). The tendons of the semimembranosus and semitendinosus muscles are identified in the upper corner of the incision and divided (Fig. 3.68).

Medial Exposure of the Infrageniculate Popliteal Artery and Its Trifurcation

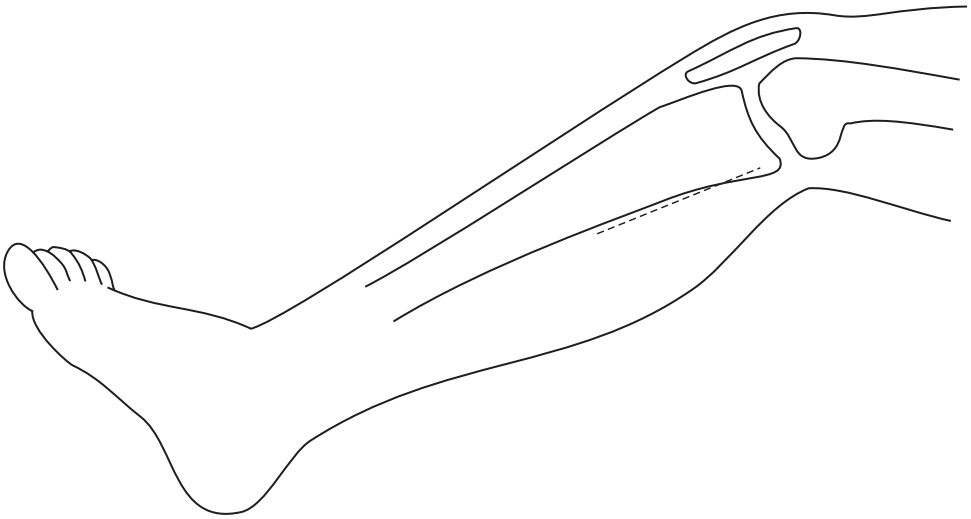

Figure 3.65. Incision site for infrageniculate popliteal artery.

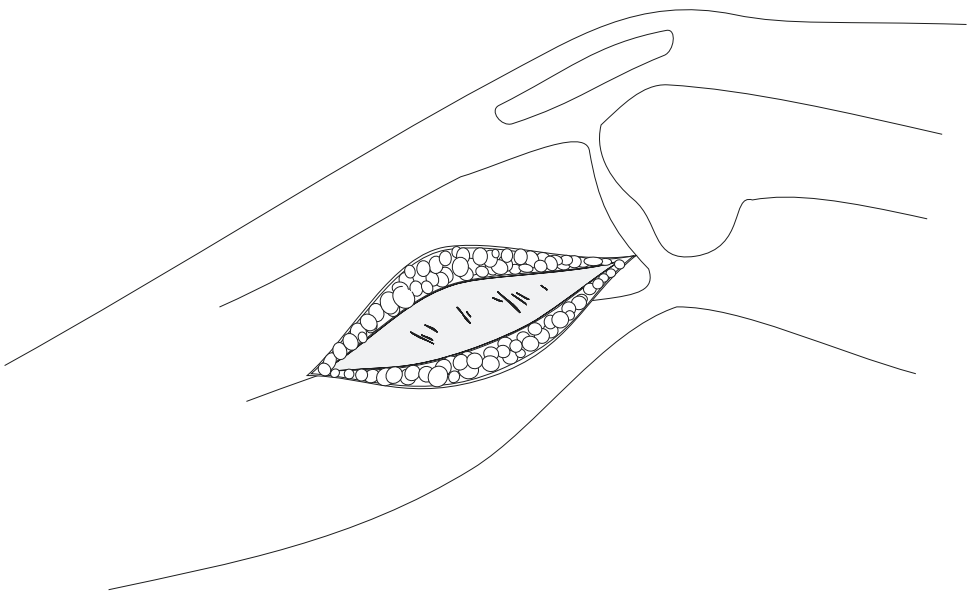

Figure 3.66. The incision is deepened through the subcutaneous tissues.

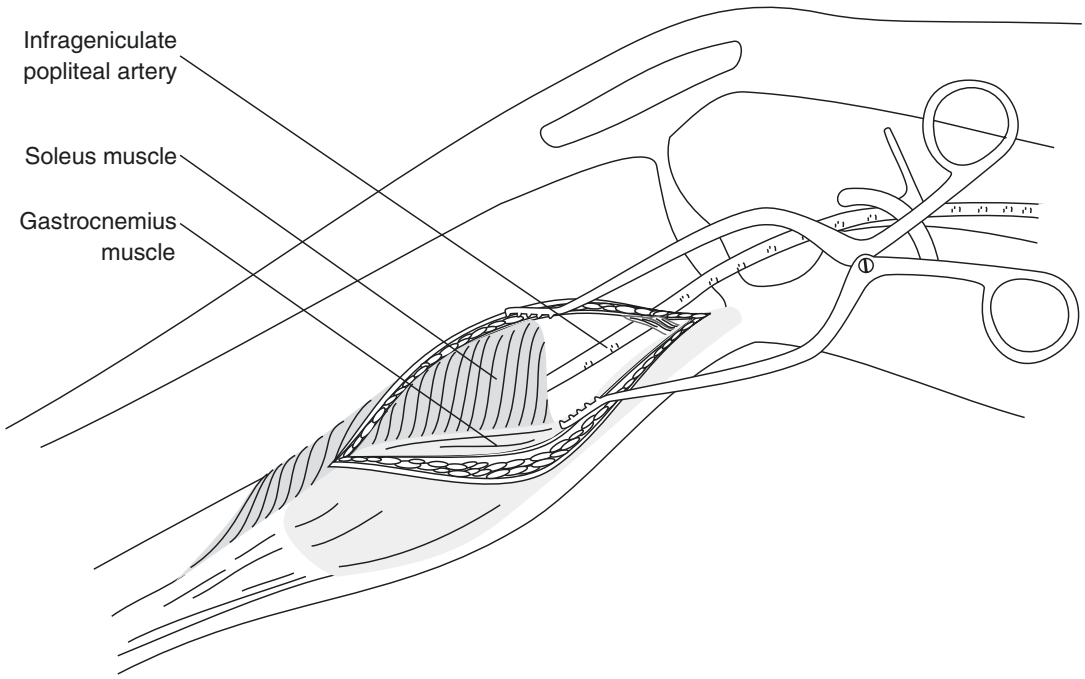

Figure 3.67. The popliteal fossa is entered, retracting the gastrocnemius muscle interiorly and laterally.

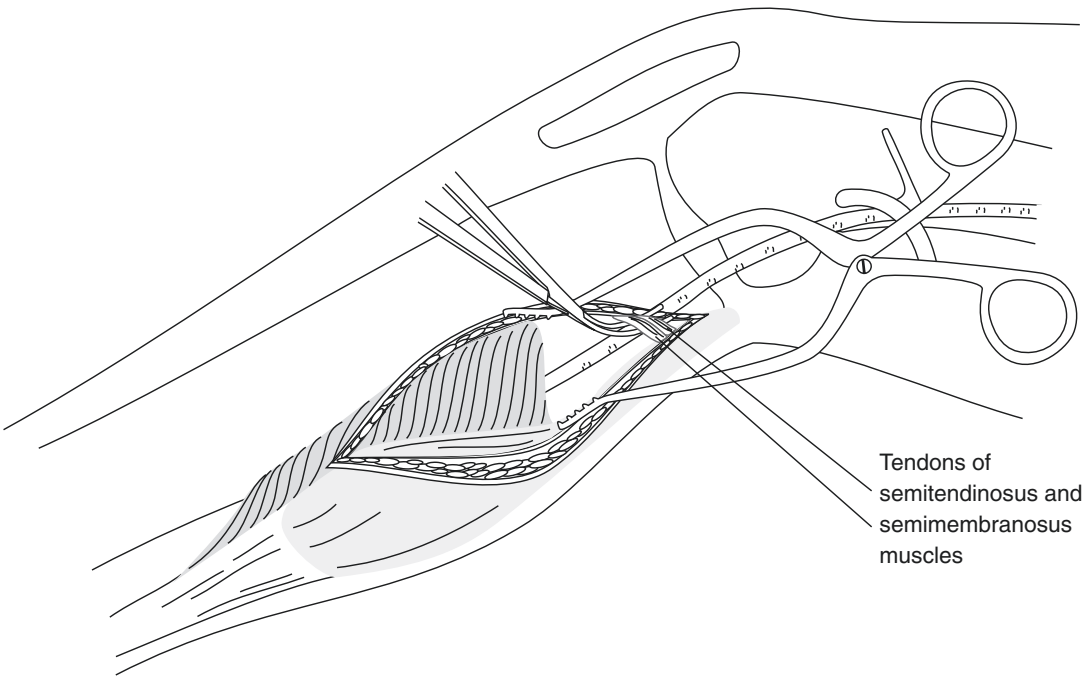

Figure 3.68. The exposure can be improved by dividing the tendons of the semitendinosus and semimembranosus muscles.

On the distal aspect of the incision, the soleus muscle is usually seen covering the popliteal artery at the level of its trifurcation. Dissection in the areolar tissue will identify the popliteal vascular bundle (Fig. 3.69). The popliteal vein is then identified lying anterior to the popliteal artery. It is not uncommon to find two popliteal veins surrounding the popliteal artery. The anterior popliteal vein is mobilized, exposing the popliteal artery. The popliteal artery is then dissected and encircled with a silastic vessel loop. Gentle traction on the vessel loop will assist in the extension of the dissection proximally and distally (Fig. 3.70).

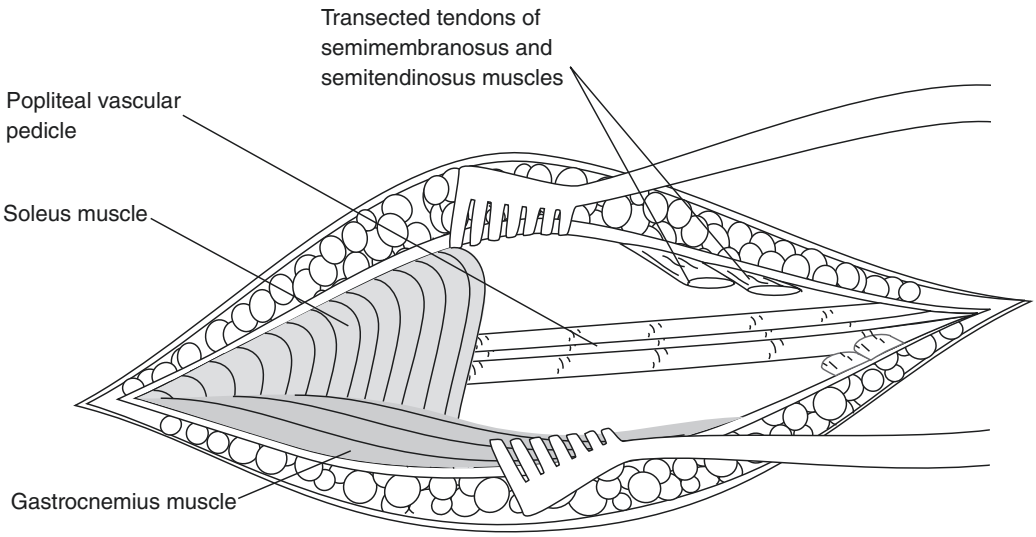

Figure 3.69. The retractor is placed deeper and the popliteal vessels are exposed.

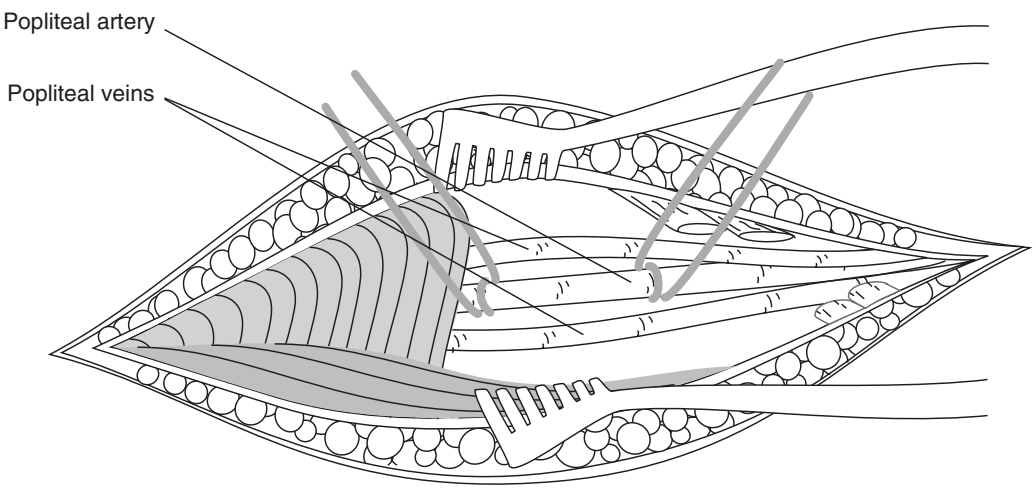

Figure 3.70. The popliteal artery is dissected.

To obtain exposure of the popliteal artery at its bifurcation, the portion of the soleus muscle covering the popliteal artery must be incised. A right-angle clamp can be placed underneath the soleus muscle to guide the transection of the muscle with electrocautery (Fig. 3.71). Soleal veins may be encountered and will need to be suture ligated. The origin of the anterior tibial artery is usually first identified. Very commonly, an anterior tibial vein will be seen crossing over the artery and joining the popliteal vein. The anterior tibial vein and other similar crossing veins may need to be ligated and divided to allow for the exposure of the origin of the anterior tibial artery as well as the takeoff of the tibioperoneal trunk (Fig. 3.72). The anterior tibial artery can be further dissected for another 1.0–2.0 cm by incising the interosseous membrane and the muscular fibers beneath it; this allows additional exposure of the anterior tibial artery from the medial aspect of the leg. Exposure of the tibioperoneal trunk is obtained by additional division of the soleus muscle. Care is taken to gently dissect the tibial veins crossing over the tibioperoneal trunk and the origins of the peroneal and posterior tibial arteries.

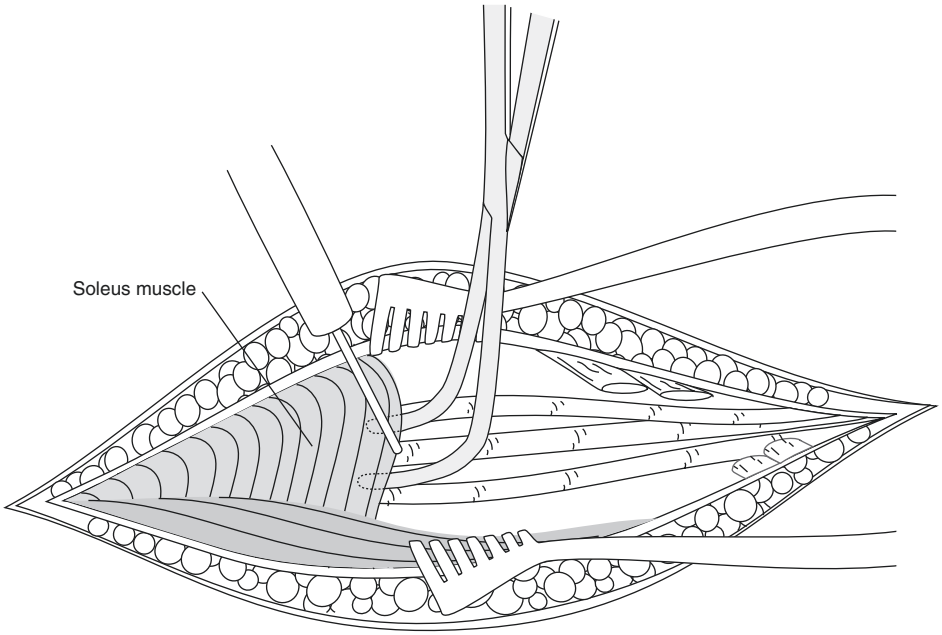

Figure 3.71. The soleus muscle is divided to expose the popliteal trifurcation.

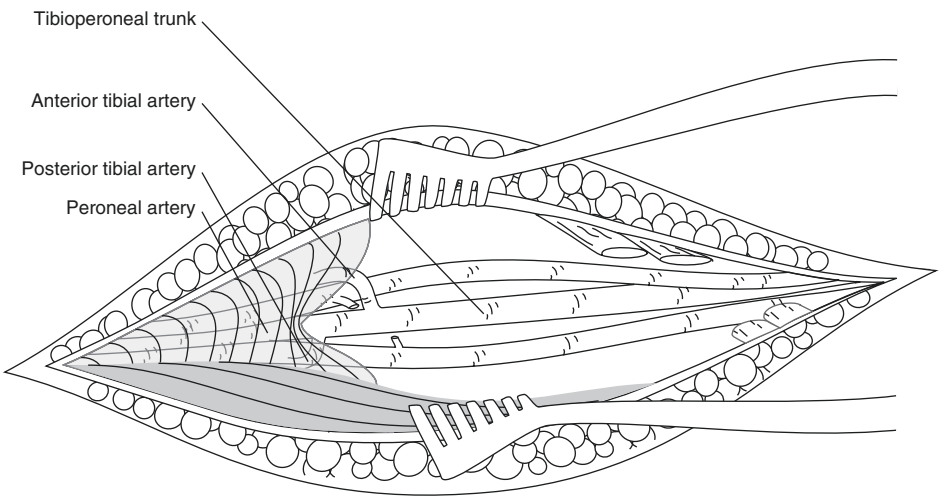

Figure 3.72. Crossing tibial veins are divided to expose the origin of the tibial vessels.

Lateral Exposure of the Infrageniculate Popliteal Artery

The more commonly used lateral approach to expose the popliteal artery involves resection of the proximal fibula [7, 8, 24, 42, 43]. A longitudinal incision is made starting at the head of the fibula and extending distally for 10–12 cm. The incision is deepened through the subcutaneous tissue. The common peroneal nerve is identified as it crosses over the neck of the fibula and is gently dissected and mobilized. The incision is deepened over the fibula, exposing the periosteum. The periosteum is incised and elevated off the fibula. A right-angle clamp is carefully passed under the fibula and can be used to separate the fibula from its posterior attachments. The fibula is transected approximately 6–8 cm distal to its neck. The proximal segment is lifted up with a bone grasper, and the muscular and ligamentous attachment of the fibula and the biceps femoris tendon are divided. The proximal part of the fibula is removed and the popliteal fossa is entered. The popliteal artery is palpated and dissected (Figs. 3.73 and 3.74). The tibial nerve is usually identified crossing the below-knee popliteal artery from the lateral to the medial direction and is separated from it by the popliteal vein. More distal dissection allows a very satisfactory exposure of the trifurcation vessels. Exposure of the infrageniculate popliteal artery through a lateral approach without fibular resection has also been described. However, this exposure is usually more limited than when the proximal fibula is resected.

Lateral Exposure of the Infrageniculate Popliteal Artery

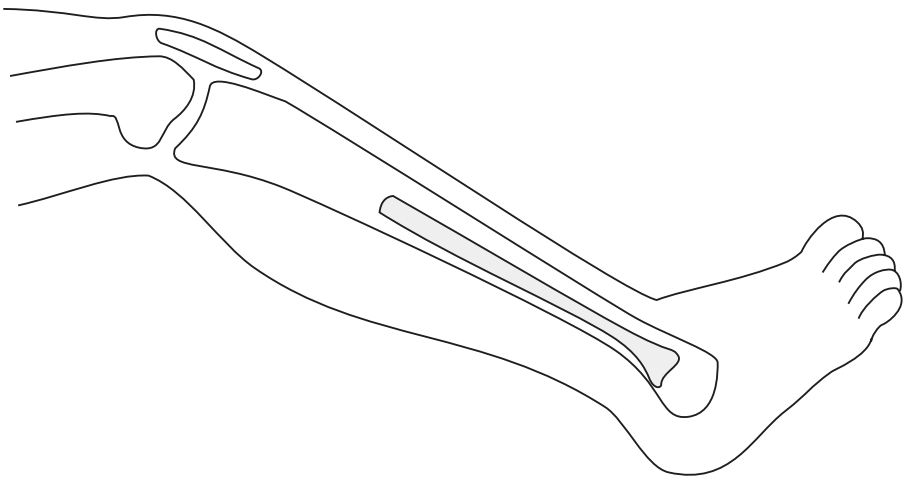

Figure 3.73. Lateral exposure of the below-knee popliteal can be achieved by resecting an 8-cm segment of the upper fibula. The common peroneal nerve is dissected as it crosses over the head of the fibula and protected.

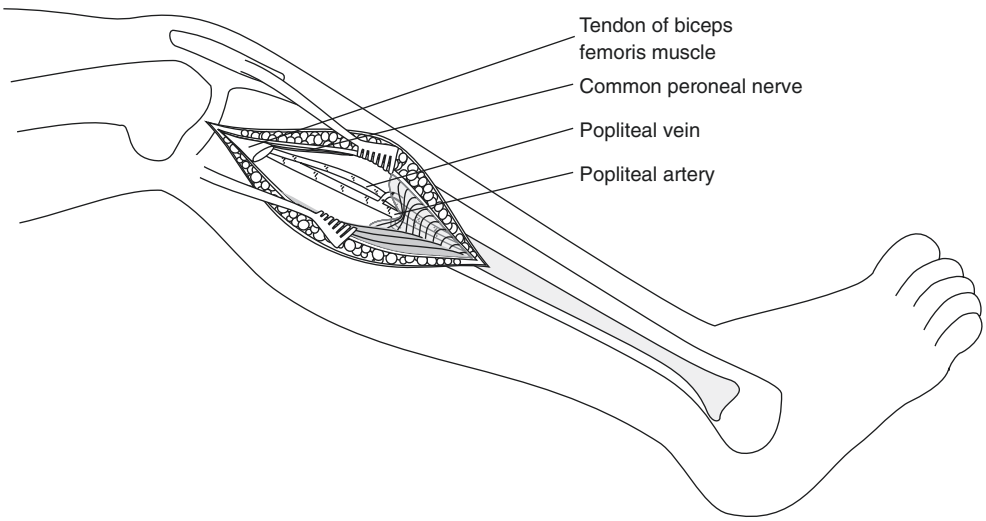

Figure 3.74. The popliteal space is entered by incising the posterior periosteum of the excised fibula.

Posterior Exposure of the Popliteal Artery (Fig. 3.75)

The popliteal artery can also be exposed through a posterior approach. This approach has been used in the management of very large popliteal artery aneurysms. The approach, which provides a good exposure of the midpopliteal artery at the level of the knee joint, requires placing the patient in a prone position. An S-shaped incision measuring 12–14 cm is then performed starting along the medial aspect of the distal thigh. The incision is deepened through the subcutaneous tissues exposing the popliteal fascia. The popliteal fascia is incised and the popliteal space is entered. The first structure encountered is usually the tibial nerve, which is protected along with the common peroneal nerve. The popliteal vein is next identified and dissected, exposing the popliteal artery (Fig. 3.75). Proximal exposure is achieved by retracting the biceps femoris muscle laterally and the hamstring muscles medially. Dissection of the distal part of the popliteal artery is achieved by retracting the heads of the gastrocnemius muscle, exposing the origin of the anterior tibial artery as the popliteal artery dips underneath the soleus muscle. The extent of the proximal and distal dissection of the popliteal artery using this approach is limited.

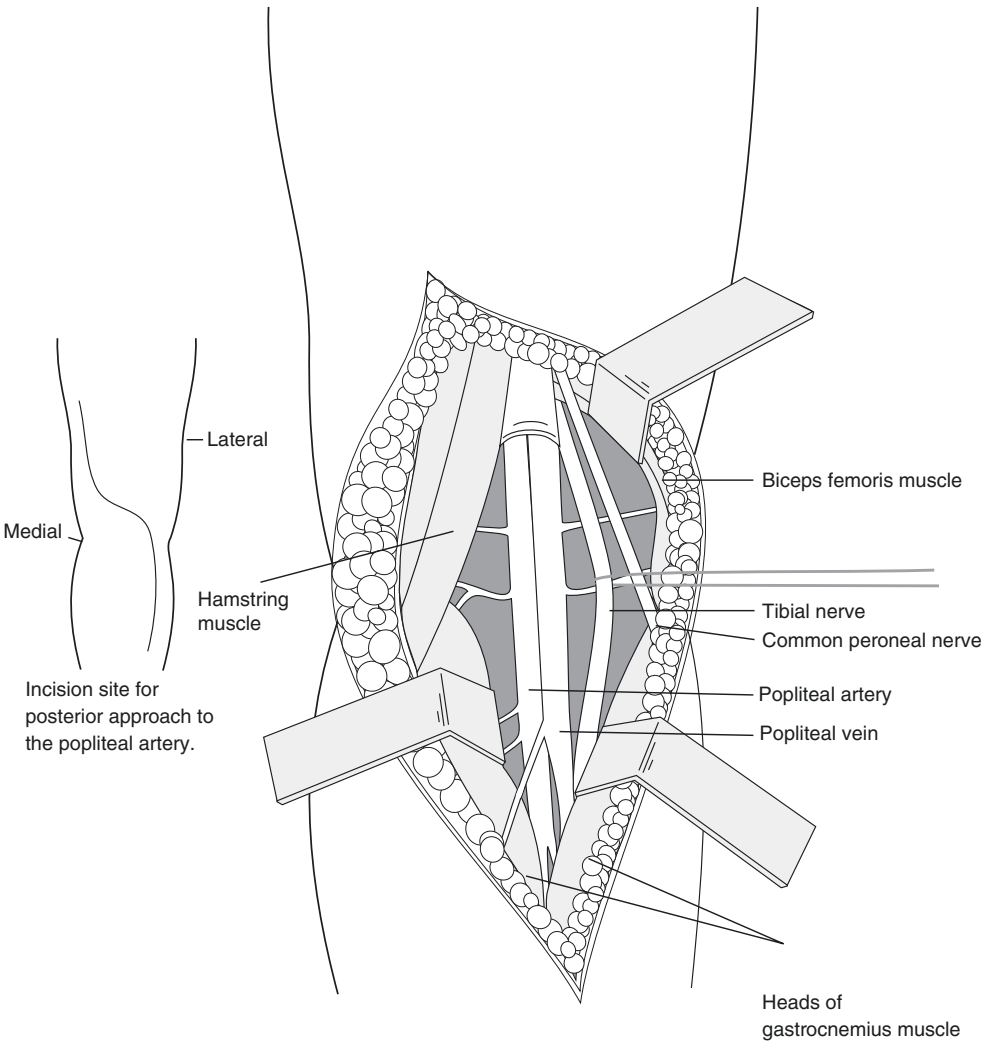

Figure 3.75. Posterior exposure of the popliteal artery.

Exposure of the Posterior Tibial Artery in the Upper Leg (Figs. 3.76, 3.77, 3.78, 3.79, 3.80, and 3.81)

A 10- to 12-cm longitudinal skin incision is made along the long axis of the lower extremity. The skin incision is made 2 cm posterior to the edge of the tibia (Figs. 3.76 and 3.77). Once the incision is deepened through the subcutaneous tissue, the anterior fascia of the soleus muscle is identified (Fig. 3.78). This fascia and the soleus muscle fibers are divided along the length of the incision, exposing the posterior fascia of the soleus muscle. The posterior fascia is then incised with care to avoid injury to the underlying vascular bundle [25] (Fig. 3.79). After the fascia is incised, inspection at that level will reveal one muscle attached to the tibia, which is the flexor digitorum longus muscle (FDL). The second muscle posterior to FDL is the flexor hallucis longus muscle (FHL). The posterior tibial artery and veins are usually lying in the groove between the FDL and the FHL muscles (Fig. 3.80). The tibialis posterior muscle is lateral to the posterior tibial vascular bundle of the leg.

The exposure of the posterior tibial artery below the middle of the leg is similar to that above the middle of the leg. However, at the lower level of the leg, the soleus muscle is usually attenuated. The posterior tibial artery and veins will be seen between the tendons of the flexor digitorum longus muscle and the flexor hallucis longus muscle (Fig. 3.81).

Exposure of the Posterior Tibial Artery

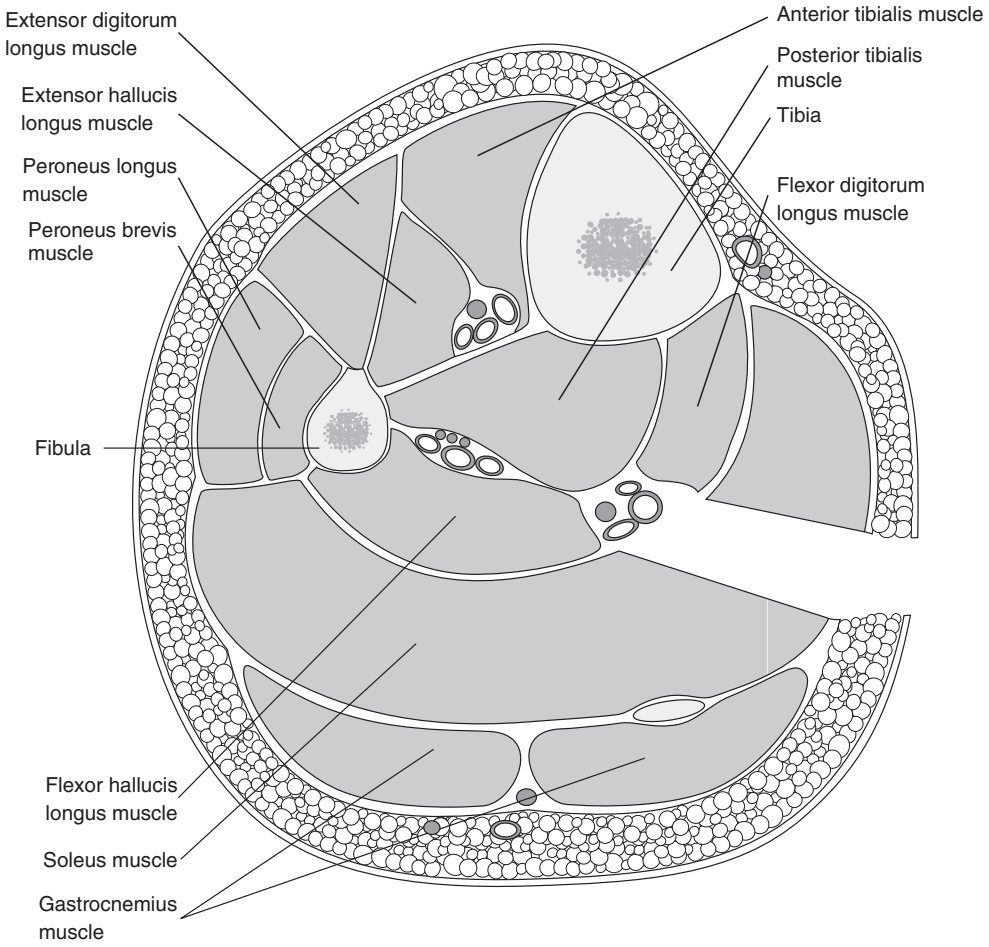

Figure 3.76. Exposure of posterior tibial artery, cross-sectional view.

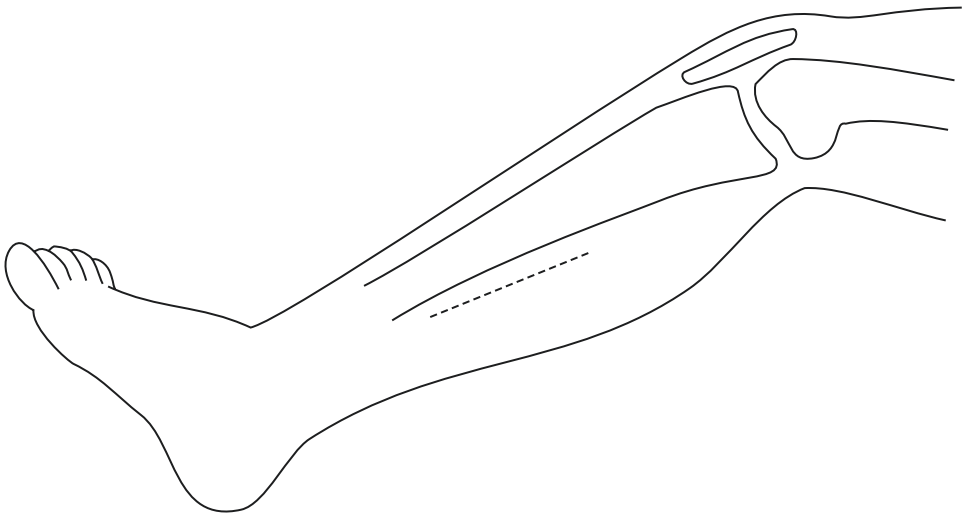

Figure 3.77. Incision site for exposure of the posterior tibial artery in the midleg.

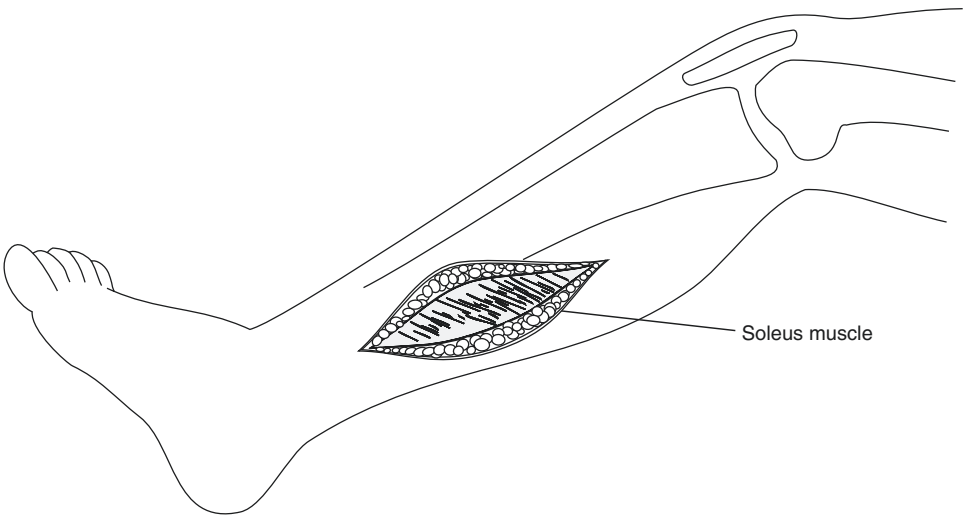

Figure 3.78. The incision is deepened, exposing the fascia overlying the soleus muscle.

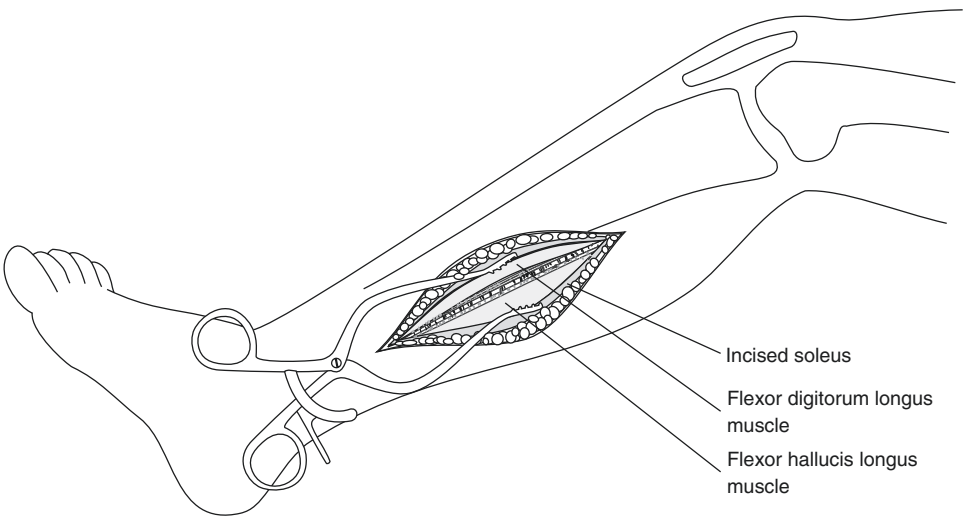

Figure 3.79. The soleus muscle is incised exposing the posterior tibial vessels.

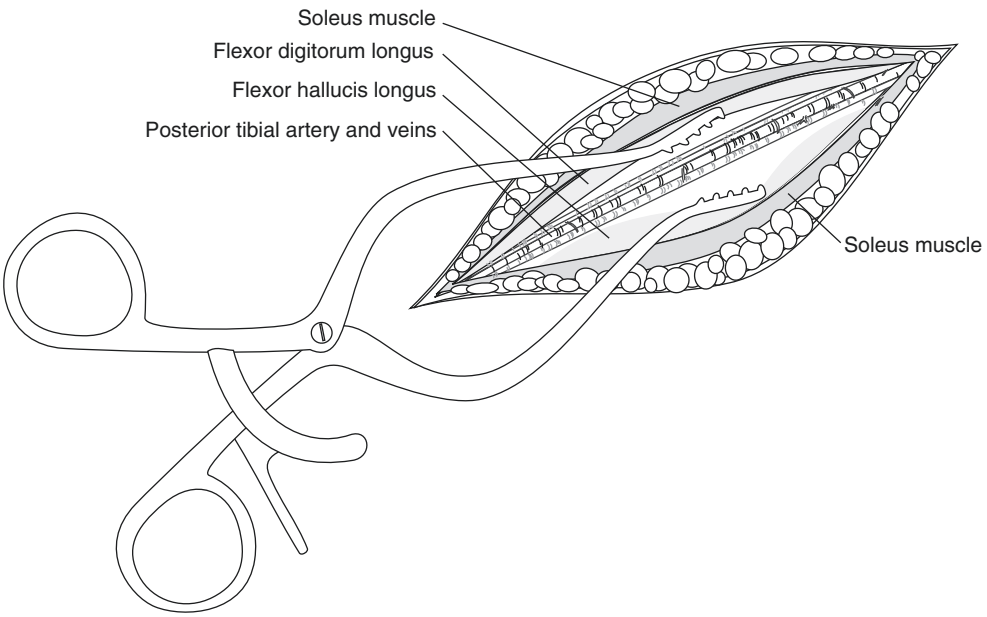

Figure 3.80. The posterior tibial vessels are exposed between the flexor digitorum longus and flexor hallucis longus muscles.

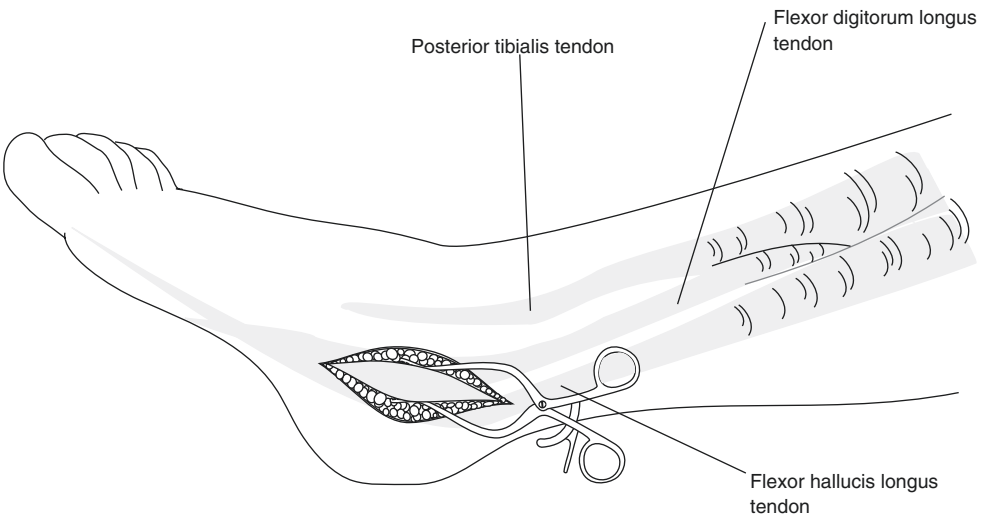

Figure 3.81. Exposure of the posterior tibial artery at the ankle.

Exposure of the Posterior Tibial Artery at the Ankle

An 8- to 10-cm skin incision is performed at the ankle. The incision is deepened through the subcutaneous tissue until the flexor retinaculum is identified. The flexor retinaculum is divided and the posterior tibial artery is identified between the tendons of the flexor digitorum longus and the flexor hallucis longus (Fig. 3.81).

Exposure of the Plantar Arteries (Fig. 3.82)
A 6- to 8-cm skin incision is performed between the medial malleolus and the calcaneous. After deepening the incision through the subcutaneous tissue, the flexor retinaculum is identified. The flexor retinaculum is incised exposing the posterior tibial artery and veins, which are usually surrounded by the tendinous sheath of the flexor digitorum longus superiorly and the flexor hallucis longus inferiorly. The posterior tibial artery is followed distally until it bifurcates into the medial and lateral plantar arteries [1]. The lateral plantar artery can be further exposed by dividing its overlying muscles, mainly the abductor hallucis and the flexor digitorum brevis muscles (Fig. 3.82).

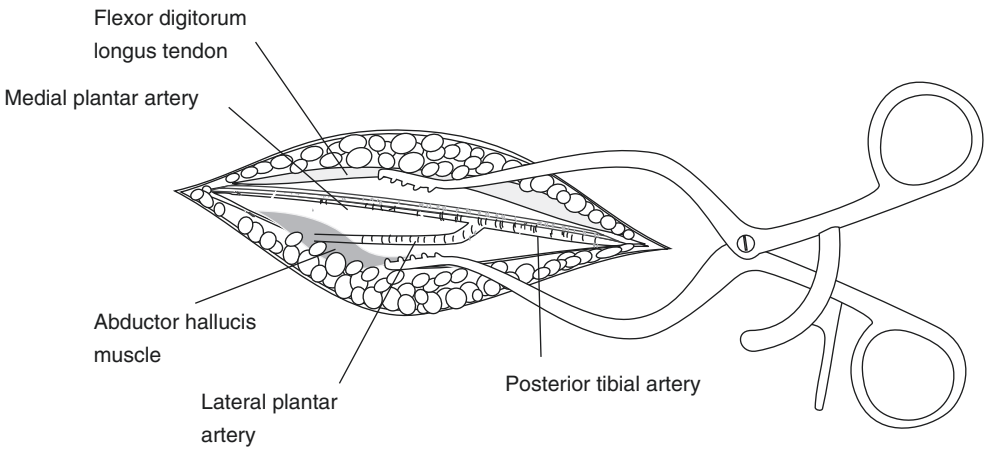

Figure 3.82. Exposure of the posterior tibial and plantar arteries at the ankle.

Medial Exposure of the Peroneal Artery (Figs. 3.83 and 3.84)
The medial exposure of the peroneal artery in the upper leg starts by exposing the posterior tibial neurovascular bundle as described earlier [10, 28]. The posterior tibial neurovascular bundle can be retracted anteriorly along with the flexor digitorum longus muscle (Fig. 3.83) or posteriorly along with the flexor hallucis longus muscle (Fig. 3.84). The former approach is preferred in the upper leg and can also be used in the lower leg. The latter approach is preferred by some surgeons in both the mid- and lower leg [20, 46]. After exposing the posterior tibial vessels, the dissection is continued toward the fibula in the tissue plane (intermuscular septum) between the posterior tibialis muscle and the flexor hallucis longus muscle. Deep in the wound, a fascial layer will be identified. Incision of this fascial layer will usually expose one of the veins surrounding the peroneal artery. Further dissection and mobilization of this vein posteriorly exposes the peroneal artery. This usually requires division of a few small and delicate venae comitantes crossing over the peroneal artery. The exposure of the peroneal artery in the lower leg can be challenging in patients with heavy musculature and large-sized legs. In this situation, a lateral approach with resection of a fibular segment may be preferred.

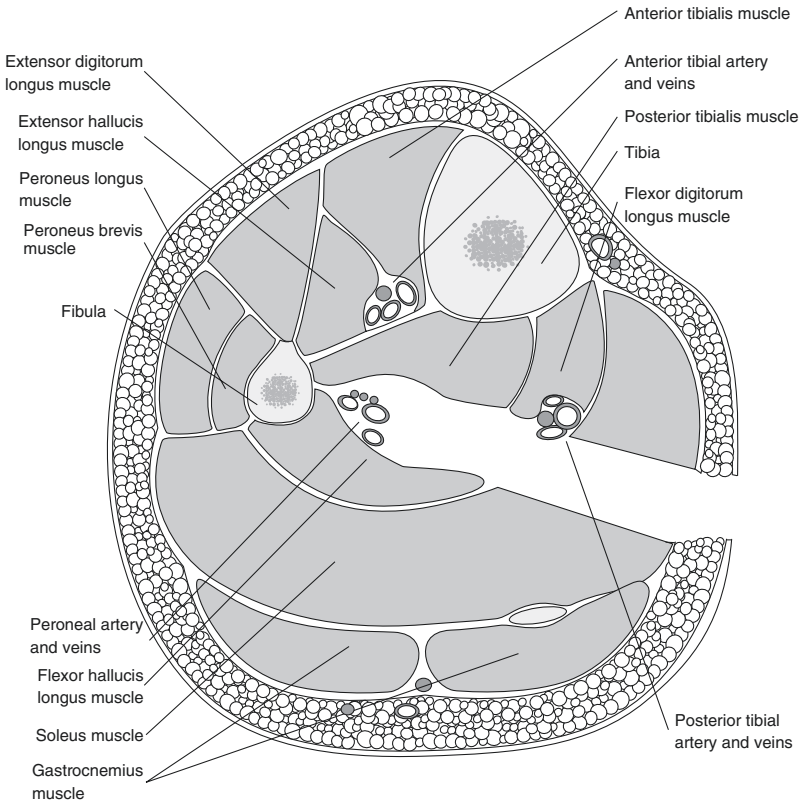

Figure 3.83. Medial approach to peroneal vessel, cross-sectional view. In the upper leg, the posterior tibial vessels can be retracted anteriorly.

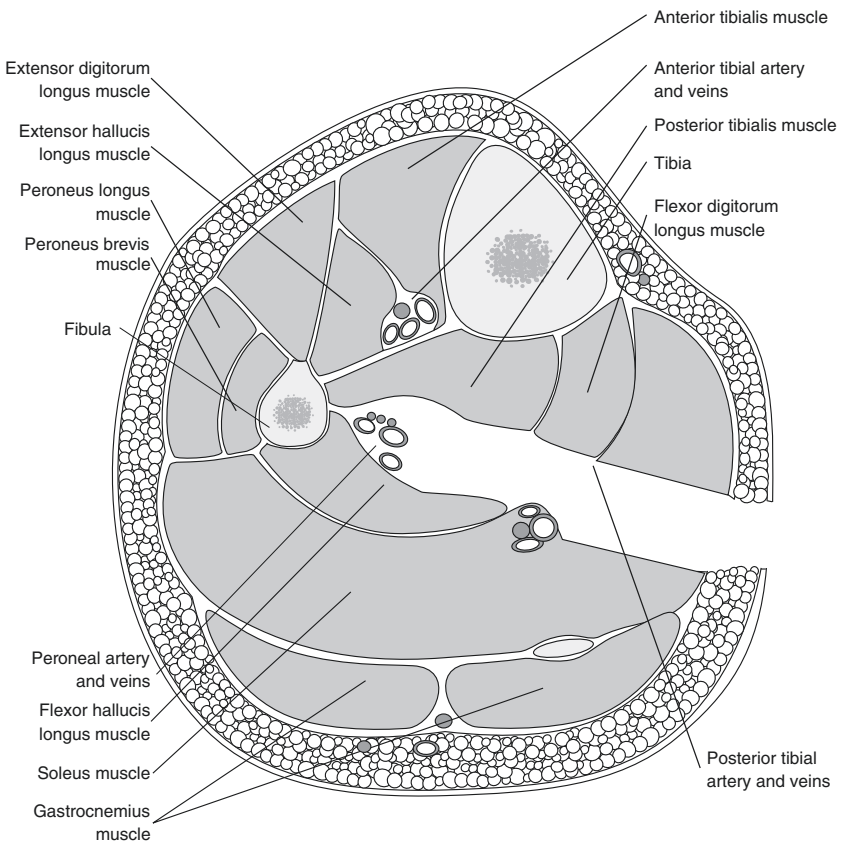

Figure 3.84. Medial approach to the peroneal artery in the mid-and lower leg, cross-sectional view. The posterior tibial vessels are retracted posteriorly. Dissection along the intermuscular septum toward the fibula will lead to the peroneal vessels.

Lateral Exposure of the Peroneal Artery

The lateral approach to the peroneal artery provides a more superficial access to the artery than the medial approach (Fig. 3.85). This access could facilitate the exposure and the construction of an anastomosis to the peroneal artery. An 8- to 10-cm longitudinal skin incision is made over the lateral aspect of the fibula and centered over the segment to be exposed (Fig. 3.86). If the proximal part of the peroneal artery is to be exposed, care should be taken to avoid injury to the common peroneal nerve as it crosses the neck of the fibula.

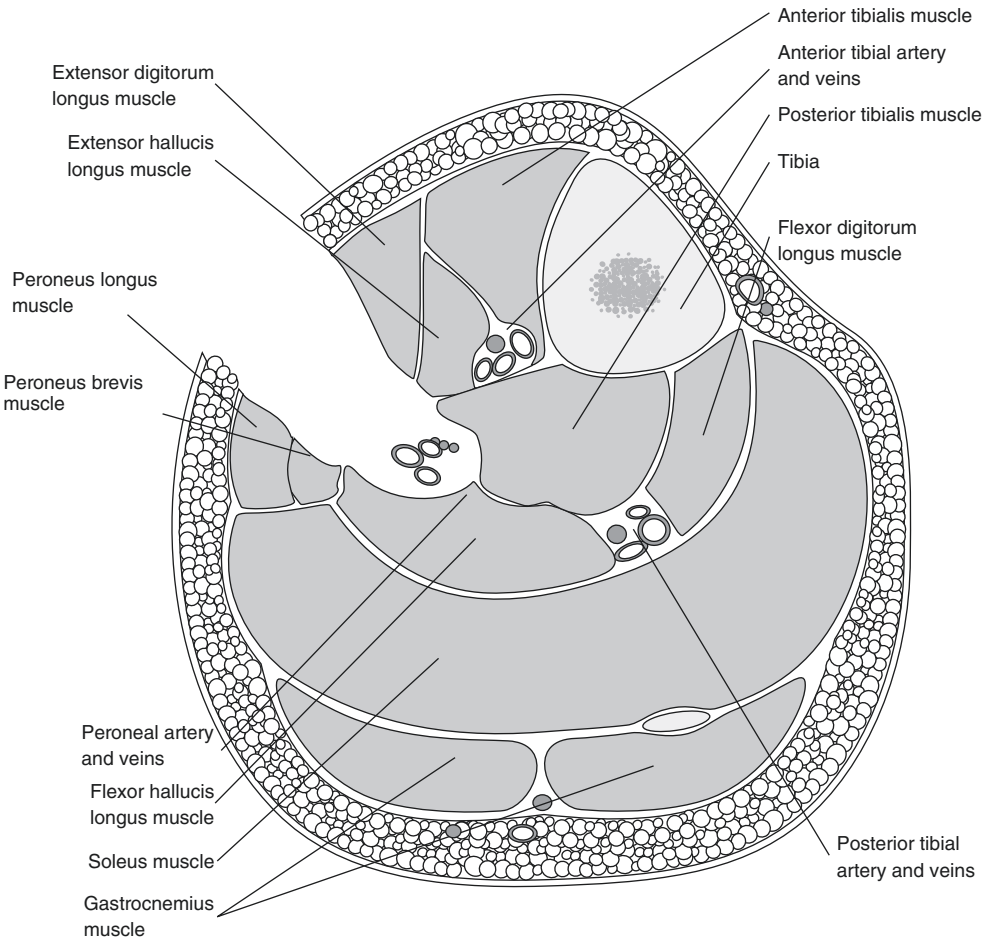

Figure 3.85. Lateral approach to the peroneal artery, cross-sectional view.

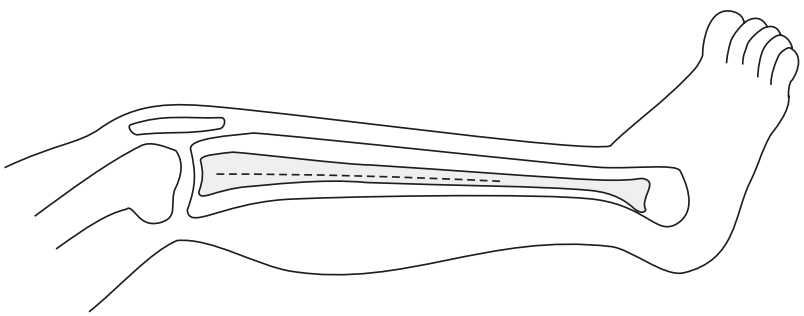

Figure 3.86. A 10- to 12-cm incision is made over the fibula.

The incision is deepened until the fibula is exposed (Fig. 3.87). The periosteum is elevated circumferentially and the fibula is cleared of all tissue attachments. A right-angle clamp is passed underneath the fibula to engage one end of a Gigli saw. The Gigli saw is used to transect the fibula at the proximal and distal end of the incision (Fig. 3.88). It is important to completely clear the tissues from the fibula before passing the right-angle clamp below it to avoid injury to the underlying peroneal vessels. The exposed segment of fibula is carefully excised. The periosteum of the resected fibula is then incised exposing the peroneal artery and venae comitantes that lie just beneath it (Fig. 3.89). This approach provides an excellent exposure of the peroneal artery down to its terminal branches, especially in redo procedures.

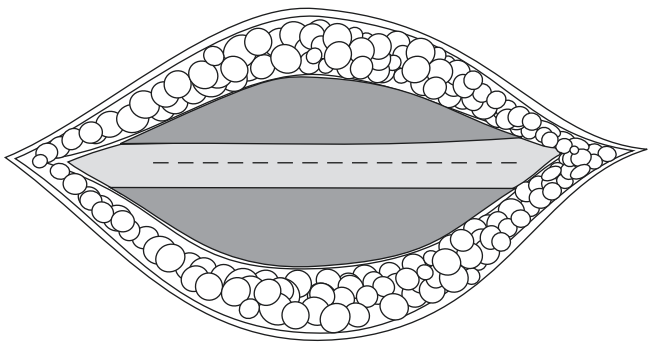

Figure 3.87. The incision is deepened until the periosteum is exposed.

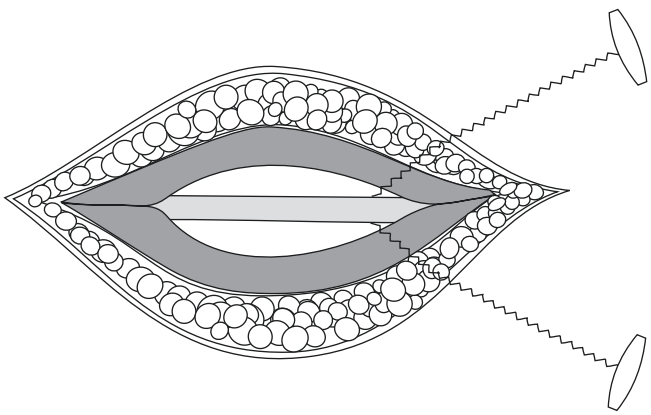

Figure 3.88. The periosteum is elevated and a Gigli saw is passed around the fibula.

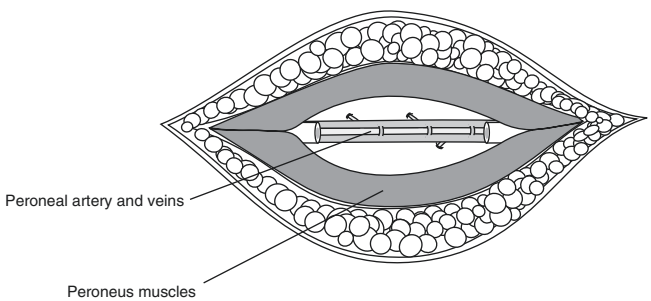

Figure 3.89. An 8-cm segment of fibula is resected exposing the peroneal vessels underneath the periosteum.

Exposure of the Anterior Tibial Artery

The anterior tibial artery is usually exposed through a lateral approach (Fig. 3.90). However, the proximal few centimeters of the anterior tibial artery can be exposed from a medial approach by exposing the distal popliteal artery and incising the interosseus membrane [9]. To assist in the exposure of the anterior tibial artery through a medial approach, digital pressure is applied on the anterolateral compartment, displacing the anterior tibial artery medially. Nevertheless, the anterior tibial artery will remain in a deep location, making an anastomosis from this medial approach rather challenging.

Exposure of the Anterior Tibial Artery

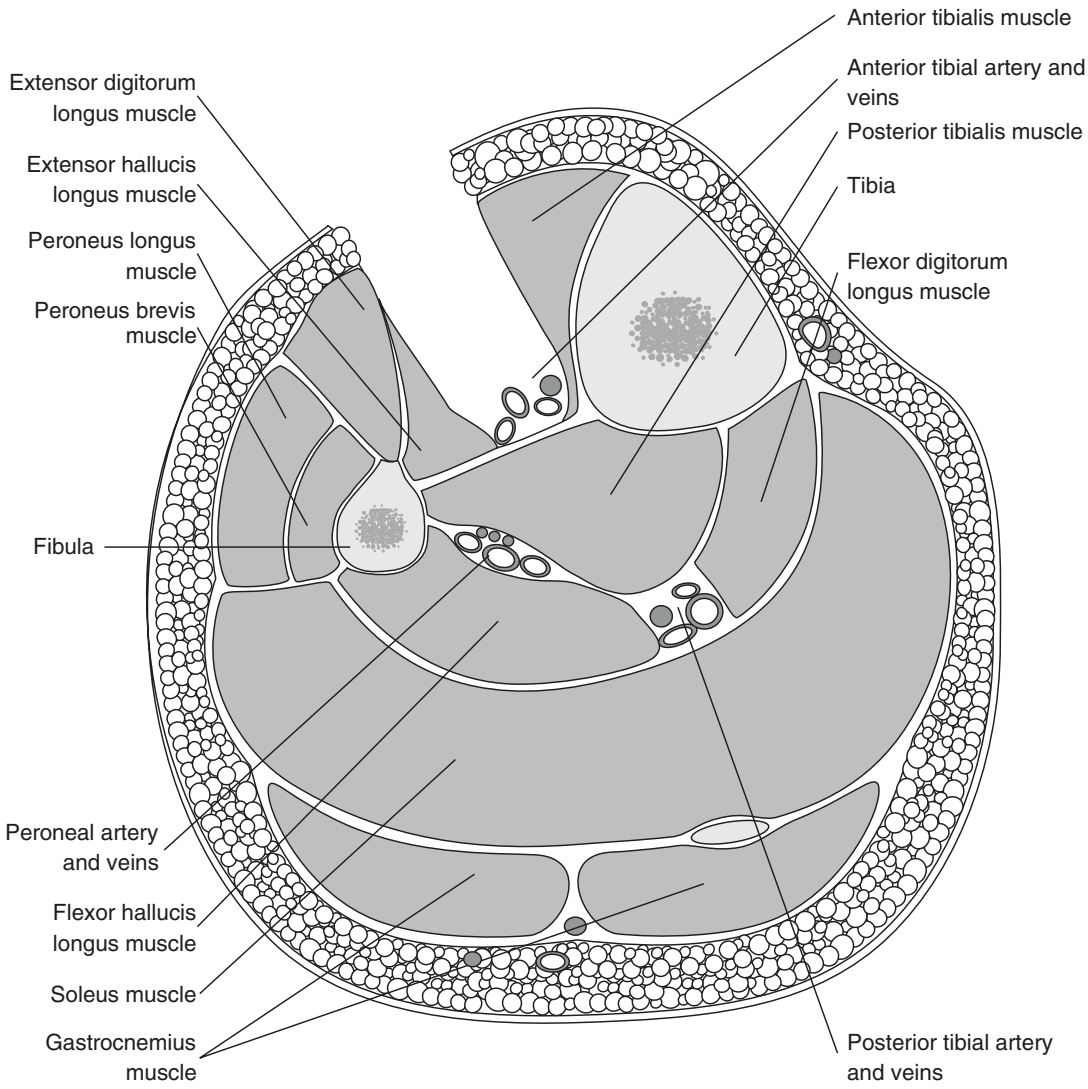

Figure 3.90. Exposure of the anterior tibial artery, cross-sectional view

The lateral approach to the anterior tibial artery is achieved through a longitudinal incision performed parallel to the tibia (Fig. 3.91). The incision starts 2 cm inferior to the tibia and extends for 10–12 cm. The skin incision is deepened through the subcutaneous tissue until the fascia is identified (Fig. 3.92). The fascia is incised longitudinally. The first muscle attached to the tibia is the tibialis anterior muscle. The next muscle identified inferior to the tibialis anterior muscle is the extensor hallucis muscle. The longitudinal cleft between these two muscles is entered. A gentle blunt dissection is carried out toward the interosseus membrane (Fig. 3.93). The anterior tibial artery and veins and peroneal nerve will be seen at the deep aspect of the incision (Fig. 3.94). The exposure of the vessels is enhanced by placing the self-retaining retractors deeper in the wound (Fig. 3.95). Due to the size of the musculature of the leg proximally, the proximal portion of the anterior tibial artery is usually more difficult to expose than the distal anterior tibial artery as it lies in a deeper location.

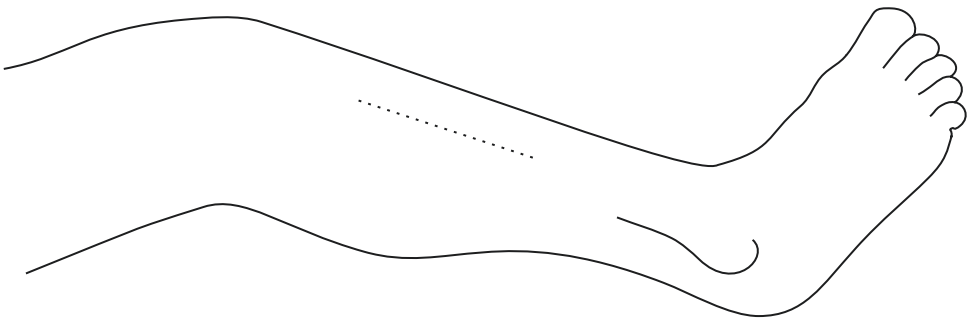

Figure 3.91. A 10- to 12-cm incision is performed 2 cm inferior and parallel to the tibia.

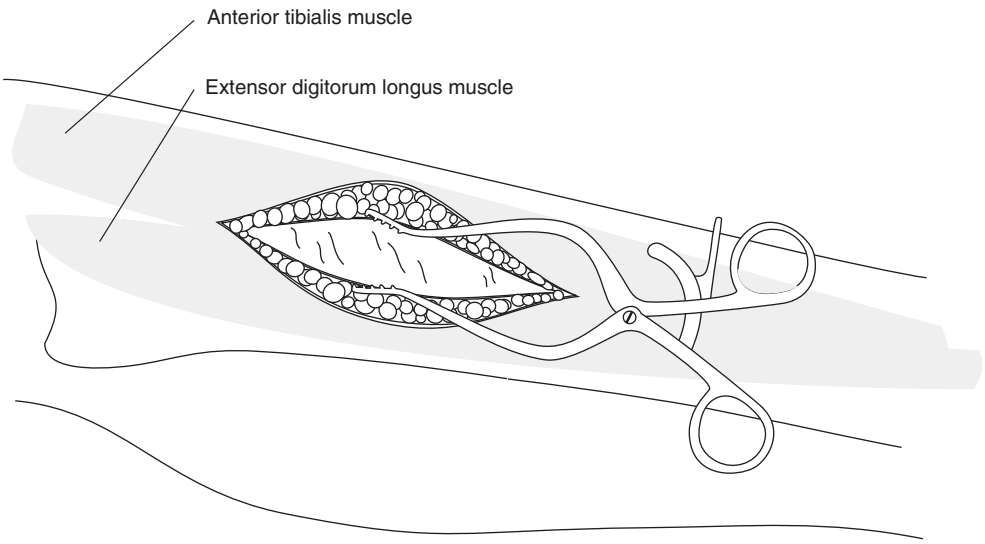

Figure 3.92. The incision is deepened through the subcutaneous tissue until the fascia is identified.

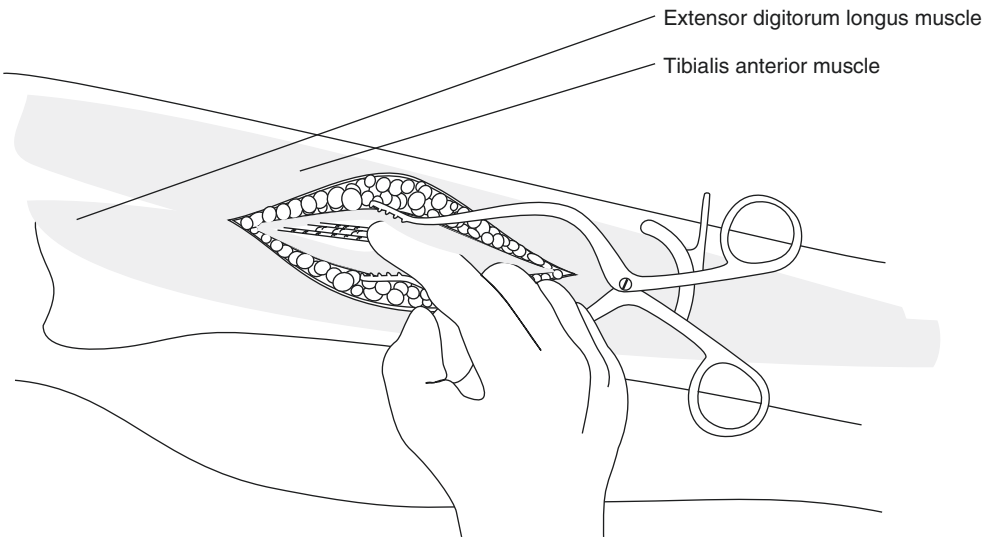

Figure 3.93. Using a sweeping motion, the anterior tibialis is separated from the extensor muscles.

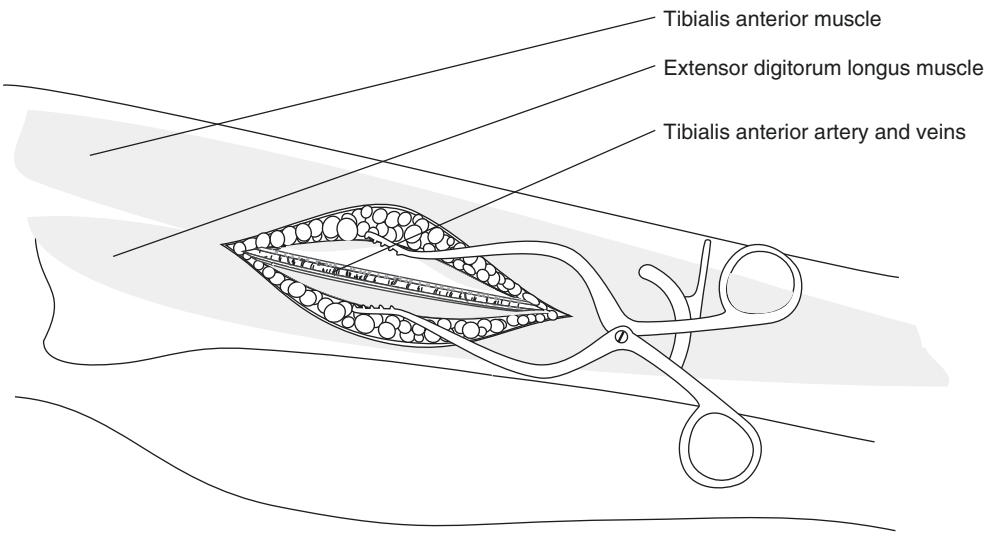

Figure 3.94. The anterior tibial artery and veins are identified.

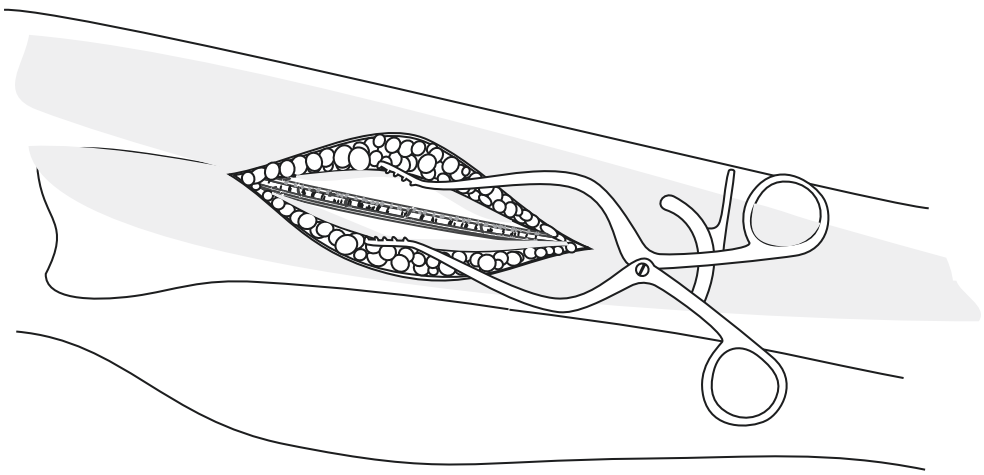

Figure 3.95. The self-retaining retractor is placed in a deeper position to improve the exposure.

Lateral Exposure of the Anterior Tibial Artery in the Lower Leg

In the lower leg, the anterior tibial artery lies between the tendinous portions of the extensor muscles. A 10- to 12-cm incision is made parallel to the tibia and 2 cm inferior and lateral to it. The first tendon close to the tibia is the tendon of the tibialis anterior muscle. On the posterior aspect, the tendon of the extensor hallucis longus muscle is noted. As the anterior tibial artery progresses to become the dorsalis pedis, it will be seen continuing into the foot and passing underneath the tendon of the extensor hallucis longus muscle, which crosses from lateral to medial to attach on the greater toe. More distally, just above the ankle, the anterior tibial artery is exposed by a short longitudinal incision with retraction of the extensor digitorum longus muscle laterally and the extensor hallucis longus muscle medially (Fig. 3.96). The dorsalis pedis artery is best exposed beyond the flexor retinaculum in the first metatarsal space (Fig. 3.97). Mapping the dorsalis pedis artery preoperatively with duplex ultrasonography can guide the placement of the skin incision.

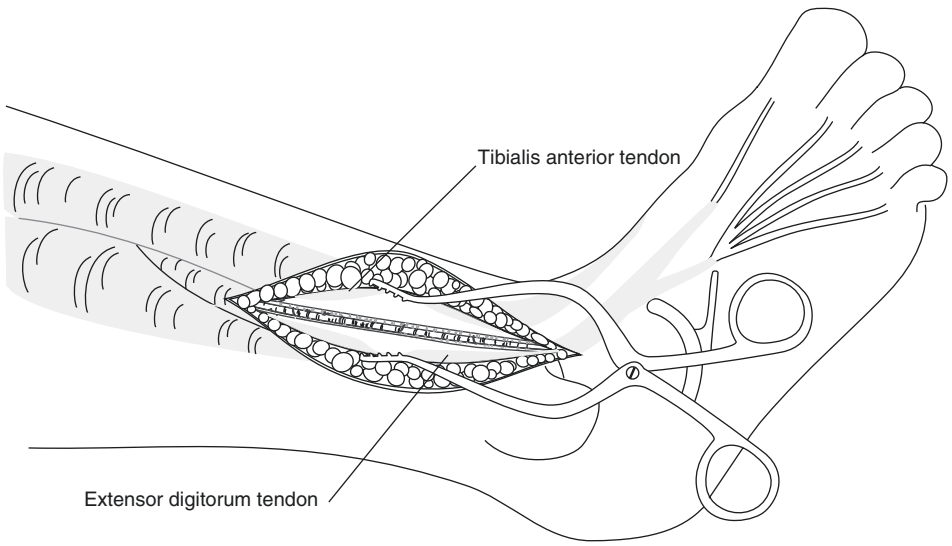

Figure 3.96. Exposure of the anterior tibial artery at the ankle.

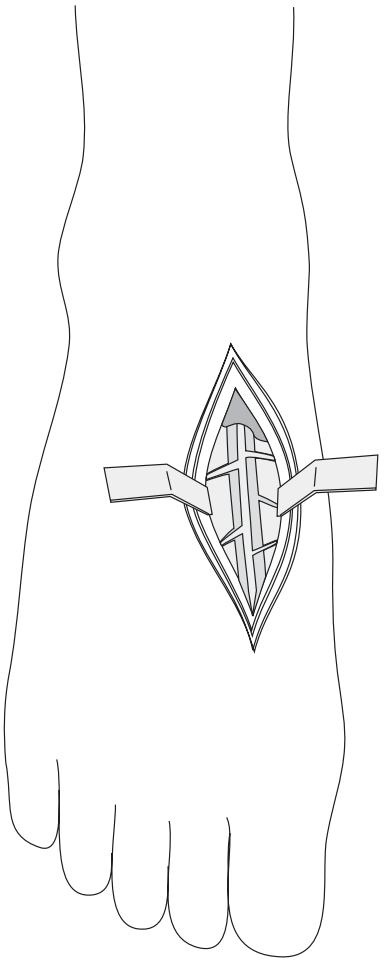

Figure 3.97. Exposure of the dorsalis pedis artery.

VEINS OF THE UPPER AND LOWER EXTREMITIES

ANATOMY OF THE VEINS OF THE UPPER EXTREMITY

The Cephalic Vein

The cephalic vein starts from the volar aspect of the wrist and ascends along the radial aspect of the forearm. In the forearm, the cephalic vein is also referred to as the radial vein. At the level of the elbow, it receives the median cephalic vein and then continues in the upper arm along the lateral border of the biceps brachii muscle (Fig. 3.98). At the level of the shoulder, it continues in the groove between the deltoid and pectoralis major muscles and then starts to move into a deeper plane to join the axillary vein below the clavicle.

The Basilic Vein

The basilic vein starts on the ulnar aspect of the wrist. It ascends along the ulnar aspect of the forearm to join the anterior ulnar and the median antecubital veins at the level of the elbow joint (Fig. 3.98). The basilic vein then ascends along the inner border of the biceps brachii muscle and penetrates the deep fascia at the middle of the arm to run along the brachial artery. It continues onward to become the axillary vein.

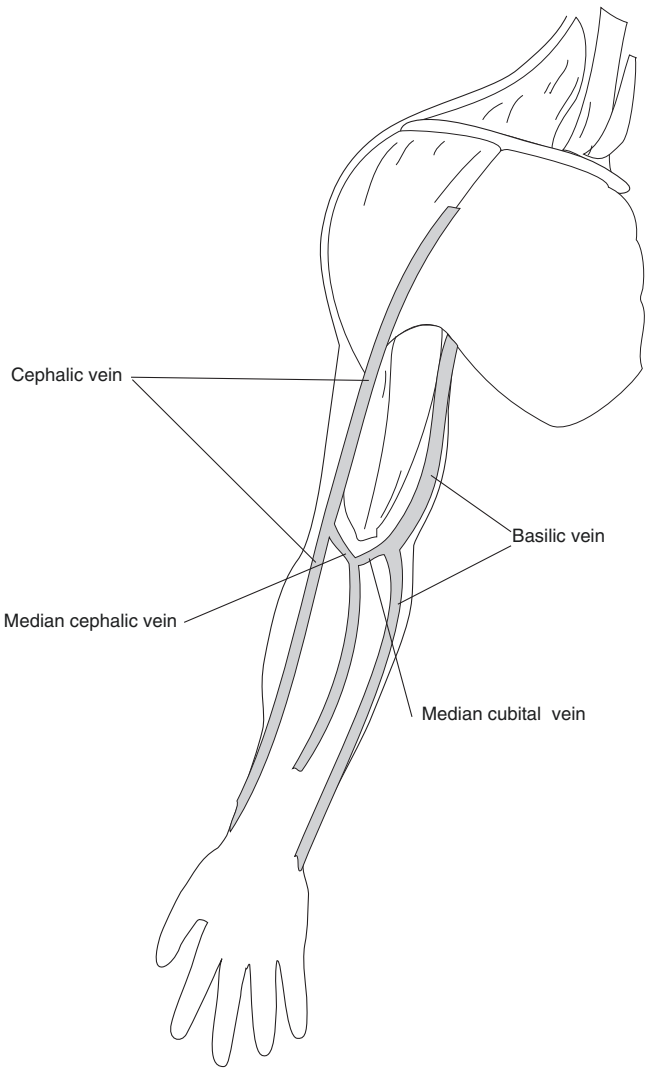

Figure 3.98. Veins of the upper extremity.

EXPOSURE OF THE VEINS OF THE UPPER EXTREMITY

Exposure of the Cephalic Vein

In the upper arm, the cephalic vein can be exposed by starting an incision along the outer border of the biceps femoris muscle. The skin incision is deepened through the subcutaneous tissues and fat. The vein usually lies immediately underneath the skin. The vein can be traced upward until it disappears in the deltopectoral groove. In the forearm, the cephalic vein is exposed by a skin incision placed directly over the vein. A tourniquet applied above the elbow joint can help identify the location of the vein before incising the skin.

Exposure of the Basilic Vein

The basilic vein can be accessed by exposing the median antecubital vein at the elbow and then tracing it upward. Alternatively, a longitudinal incision along the medial border of the biceps brachii muscle is performed. The incision is deepened through the subcutaneous tissues and superficial fascia, exposing the basilic vein (see Fig. 3.13).

ANATOMY OF THE VEINS OF THE LOWER EXTREMITY

The Greater Saphenous Vein

The greater saphenous vein starts on the medial side of the arch of the dorsum of the foot. It ascends anterior to the tip of the medial malleolus and then over the subcutaneous surface of the lower end of the tibia. The greater saphenous vein continues up to the knee where it moves posterior to the back part of the internal condyle of the femur and then follows the course of the sartorius muscle up to the inguinal region (Fig. 3.99). Below the knee, the greater saphenous vein is accompanied by the great saphenous nerve and lies in a superficial subcutaneous plane. Above the knee, it gradually moves into a deeper subcutaneous plane and penetrates the fascia lata in the upper thigh through the fossa ovale to join the common femoral vein. Frequently a duplicate system can be found in the thigh (35%) or in the leg. The length of the greater saphenous vein in an adult man is estimated to be 60 cm. The vein contains approximately 8–12 valves, with more valves present in the below-knee segment.

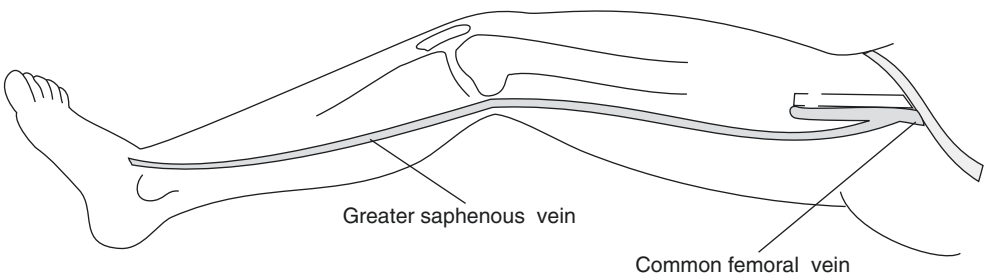

Figure 3.99. Anatomy of the greater saphenous vein.

The Lesser Saphenous Vein

The lesser saphenous vein starts posterior to the lateral malleolus along the lateral border of the Achilles tendon. It crosses above the Achilles tendon and reaches the midline of the posterior aspect of the leg. The lesser saphenous vein continues upward in the subcutaneous tissues and usually penetrates the muscular fascia at the level where the tendon of the gastrocnemius muscle starts. The vein runs just below the fascia to join the popliteal vein between the heads of the gastrocnemius muscle (Fig. 3.100). The lesser saphenous vein is accompanied by the lesser saphenous nerve and measures approximately 30 cm.

The Superficial Femoral Vein

The superficial femoral vein is the continuation of the popliteal vein at the level of the adductor magnus tendon (Fig. 3.100). It ascends in the thigh along the superficial femoral artery receiving several muscular branches. In the inguinal region, it receives the profunda femoris and then the greater saphenous veins and becomes the common femoral vein. In the lower thigh, the superficial femoral vein lies anteromedial to the superficial femoral artery and then moves into a more posterior location running posterior to the artery in the mid- and upper thigh. As it becomes the common femoral vein, it lies medial to the common femoral artery on the same plane.

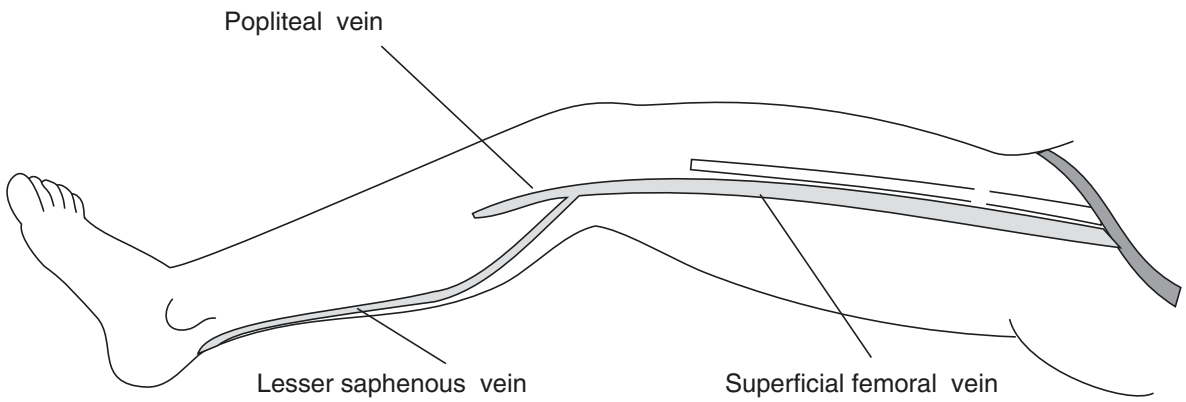

Figure 3.100. Anatomy of the lesser saphenous and superficial femoral-popliteal veins.

Exposure of the Greater Saphenous Vein

Preoperative evaluation of the greater saphenous vein with duplex ultrasonography allows mapping the location of the greater saphenous vein. The skin incision can be carried out over the marked skin. Alternatively, the following anatomical landmarks can be used. At the ankle level, a longitudinal incision is placed 1 cm anterior and superior to the medial malleolus. The vein is usually identified directly beneath the skin. At the inguinal region, the incision is started 1.5 cm medial to the femoral pulse and extends at a 30-degree angle to the vertical axis of the lower extremity. If the femoral pulse is not palpable, the incision is started 1.5 cm medial to a point midway between the pubic tubercle and the anterior superior iliac spine. The incision is deepened through the subcutaneous tissues and Scarpa fascia to expose the vein (Fig. 3.101). Currently, various methods are available to allow for endoscopic harvesting of the greater saphenous vein through a single small inguinal incision and or additional 1- to 2-cm incisions placed at various locations above or below the knee.

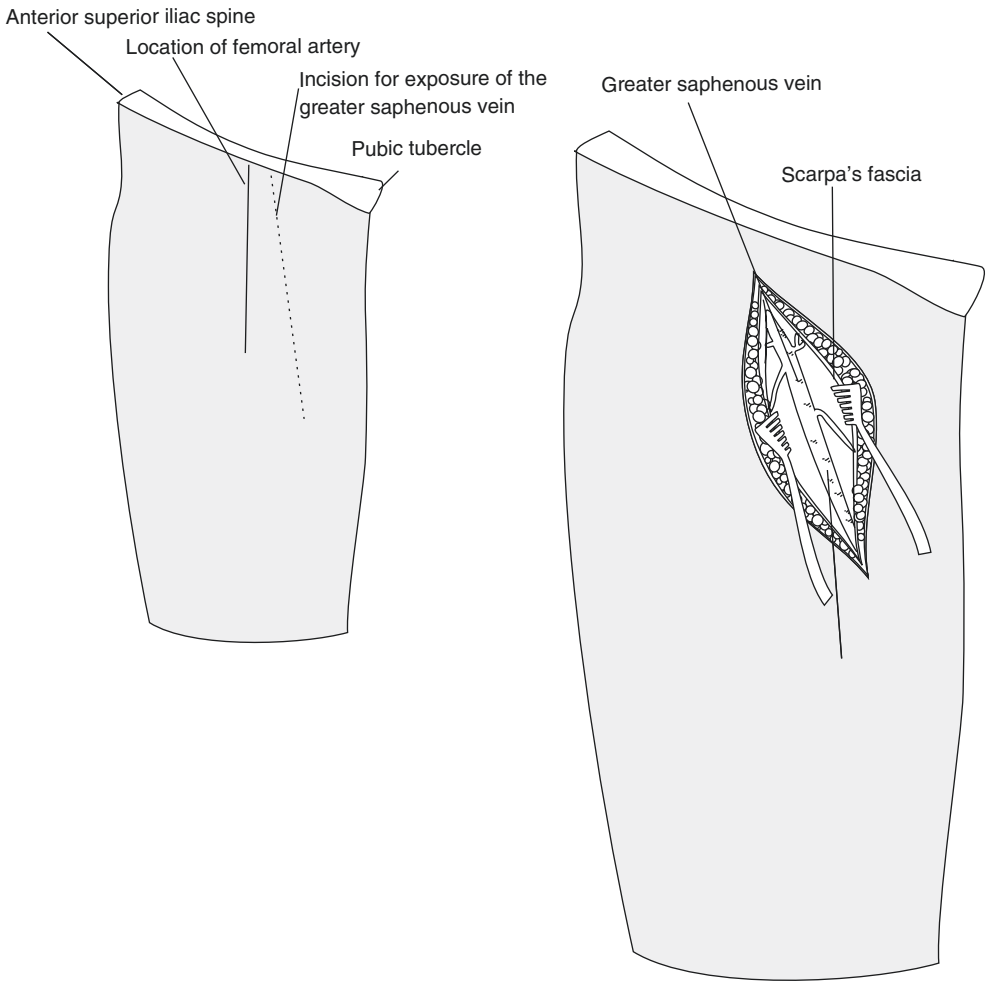

Figure 3.101. Exposure of the greater saphenous vein.

Exposure of the Lesser Saphenous Vein

It is preferable to assess and mark the lesser saphenous vein preoperatively with duplex ultrasonography. If vein mapping is not available, a longitudinal skin incision is started in the middle of the posterior aspect of the calf. The incision is deepened through the subcutaneous tissue until the fascia is identified. The fascia is incised, exposing the saphenous vein directly underneath it. The lesser saphenous vein can be harvested with the patient lying prone or supine. The prone position facilitates the exposure; however, this will usually require turning the patient back to a supine position and reprepping and draping. When the patient is lying supine, external rotation of the leg and the gastrocnemius muscle allows access to the lesser saphenous vein. However, the junction to the popliteal vein remains challenging to expose from this approach. The lesser saphenous vein can also be approached through a medial skin incision, but this requires the creation of large skin flaps and allows access to only a short segment of the vein.

Exposure of the Superficial Femoral Vein

The exposure of the superficial femoral vein is similar to that of the superficial femoral artery. A longitudinal skin incision is performed along the outer border of the sartorius muscle. The incision is deepened through the subcutaneous tissues and fat, exposing the muscular fascia. The muscular fascia is incised and the entire sartorius muscle is mobilized and retracted inferiorly and medially, preserving its segmental blood supply. This procedure will expose the vascular pedicle in the upper thigh and the adductor canal in the lower thigh.

The superficial femoral vein is separated from the artery in the upper thigh and encircled with a silastic vessel loop and then traced toward the knee. The tendinous portion of the adductor canal is incised to expose the superficial femoral vein at that level. When harvesting the superficial femoral vein, multiple large branches are usually identified. Double or suture ligation of these branches is recommended. At the inguinal region, it is important to preserve the junction with the profunda femoris vein to prevent excessive venous hypertension in the lower extremity [36].

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4

Basic Steps in Vascular Reconstructions

Jamal J. Hoballah

Several basic steps are usually carried out during the performance of a vascular reconstruction:

Blood vessel exposure
Blood vessel dissection
Tunneling
Anticoagulation
Blood vessel control
Creation of a blood vessel incision
Preparation of a patch or a bypass
Construction of the suture line
Securing hemostasis
Evaluating the vascular reconstruction

BLOOD VESSEL EXPOSURE

When exposing a blood vessel, the approach that provides a simple and direct access to the vessel of interest is usually the most desirable. In general, the skin incision is placed along the longitudinal axis of the vessel to be exposed. This will facilitate proximal and distal extensions of the exposure. Anatomical landmarks or palpation of the pulse are used to select the site of the skin incision. In patients with scarring due to previous procedures (redo operations), or in the presence of infection, an alternate approach may be possible. This may provide access to the blood vessels through non-scarred planes. The common and alternate arterial exposures are listed in Table 4.1. The anatomy and various exposures of these vessels are reviewed in Chap. 3.

BLOOD VESSEL DISSECTION

Blood vessels are usually dissected sharply using a blunt-tipped scissors. A 15 blade can also be used for the dissection and is especially valuable when dealing with scarred tissues in redo procedures. An inadvertent vascular incision caused by a knife may be easier to repair than a tear produced by a scissors. As the vessel is being exposed, self-retaining retractors are usually placed at

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Table 4.1. Vessel anatomy and exposure

Artery	Common exposure	Alternate
Common carotid: origin and most proximal	Median sternotomy	
Common carotid: distal and carotid bifurcation	Anterior border of sternocleidomastoid	Transverse neck
Vertebral: origin	Supraclavicular incision	Anterior neck
Subclavian		
Origin Rt	Median sternotomy	
Origin Lt	Anterior thoracotomy (3rd intercostal space)	Trapdoor
First part	Supraclavicular incision	
Second part	Supraclavicular incision	
Third part	Supraclavicular incision	
Axillary	Infraclavicular incision	Axillary
Brachial	Medial incision	
Suprarenal aorta	Transabdominal medial visceral rotation (MVR)	Retroperitoneal Thoracoabdominal, (TA)
Celiac	Transabdominal, MVR	Retroperitoneal, (TA)
Superior mesenteric	Transabdominal, MVR	Retroperitoneal, (TA)
Infrarenal aorta	Transabdominal	Retroperitoneal
Common and external iliac	Transabdominal	Retroperitoneal
Internal iliac	Transabdominal	Retroperitoneal
Common femoral	Medial incision	Lateral incision
Profunda	Medial incision	Lateral to sartorius
Superficial femoral	Medial incision	Lateral to sartorius
Popliteal	Medial incision	Lateral incision, Posterior approach
Popliteal, below knee	Medial incision	Lateral incision with resection of fibula
Peroneal	Medial incision	Lateral incision with resection of fibula
Posterior tibial	Medial incision	Lateral incision with resection of fibula
Anterior tibial	Lateral approach	Medial approach

progressively deeper levels, applying traction on the tissues to be divided. Retractors should be carefully applied to avoid injury to neighboring vessels or nerves. Once the vessel is adequately exposed, the adventitia on its anterior surface is carefully grasped with a Debakey forceps. While applying gentle traction on the adventitia and countertraction on the surrounding tissues, sharp dissection along the sidewall of the vessel will identify an avascular plane between the vessel and its surrounding tissues. This plane is developed on each side of the vessel and followed posteriorly to achieve circumferential dissection of the vessel. Although circumferential dissection may be appealing, it is not always necessary. For example, when exposing the infrarenal aorta during an aortic reconstruction, dissection on each side of the aorta down to the spine without circumferential dissection may be sufficient for achieving vascular control. Anterior exposure of the tibial vessels may be all that is needed when a pneumatic external tourniquet or an internal vessel occluder is used for vascular control. Similarly, circumferential dissection is not required when a partially occluding clamp is used to achieve vascular control.

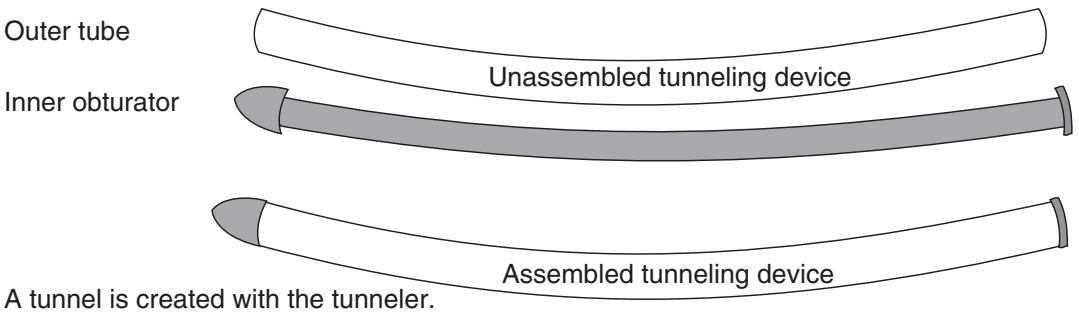
Blood vessels can be traced proximally and distally, anticipating their cylindrical shape and adjacent vascular structures. Throughout the dissection, the vessels should be handled gently; only the adventitia should be grasped with

the forceps. Grasping the full thickness of the vessel wall can cause intimal damage. Silastic vessel loops may be passed around a vessel and used for vessel retraction. However, only gentle traction on the vessel loop should be used to avoid damage to the vessel wall. The sites of major vascular branches can be anticipated from knowledge of surgical anatomy. Dividing arterial branches should be avoided, as they may represent important collateral channels.

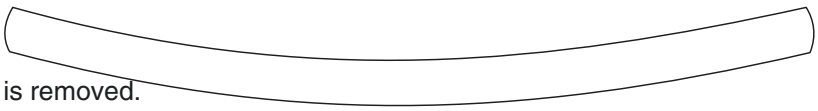
TUNNELING

Tunneling

Bypasses can be tunneled along the vessel being bypassed (anatomically) or extra-anatomically. When the tunnel is of a short distance, it can be created with the Metzenbaum scissors alone or in conjunction with blunt finger dissection. Tunneling devices can also be used to pass the graft from one location to another and are essential when the tunnel is of a long distance. Two different types of tunneling devices exist. In one type, the tunneling device is made of an outer tube and an inner obturator. Once the tunnel is created, the obturator is removed and a passer is used to grab the graft and pass it through the outer part of the tunneling device. In the other type, the tunneling device is made of one part with interchangeable heads of different dimensions. After creating the tunnel with the tunneling device, the graft is tied to the tunneller. By withdrawing the tunneller, the graft is pulled into the desired location.



A tunnel is created with the tunneler.



The inner obturator is removed.

A grasper is passed through the outer tube.

The graft to be tunneled is tied to the passer and withdrawn into the tunnel.

Alternatively a tunneler with interchangeable heads of different sizes can be used.

Tunneling

Tunneling is preferably done before systemic anticoagulation with heparin. The graft should be carefully passed through the tunnel to avoid any twists. In addition, especially when using an autogenous conduit, the graft should be checked very carefully for hemostasis before tunneling to avoid bleeding in the tunnel. The anatomical location of various tunnels created in commonly performed vascular procedures are listed as follows:

Axillofemoral bypass: In the chest, the tunnel is created to pass anterior to the rib cage and posterior to the pectoralis major muscle. The graft is usually tunneled along the midaxillary line. The graft continues subcutaneously and crosses over the inguinal ligament medial to the anterior superior iliac spine. Adequate length should be available to avoid excessive tension on the proximal anastomosis to the axillary artery. Otherwise, a Y-deformity or, very rarely, disruption of the axillary anastomosis could occur. A counterincision may be required especially in large individuals. The counterincision is usually made halfway between the inguinal and the infraclavicular incisions.

Femorofemoral bypass: The tunnel in a femorofemoral bypass is subcutaneous. It can be started with the Metzenbaum scissors and further developed by blunt finger dissection or with the use of a C-shaped tunneller. A gentle C-curve is important to avoid kinking of the femorofemoral graft at the level of the femoral anastomosis. It is also important to tunnel just anterior to the fascia of the external oblique muscle and to avoid tunneling in a very superficial plane.

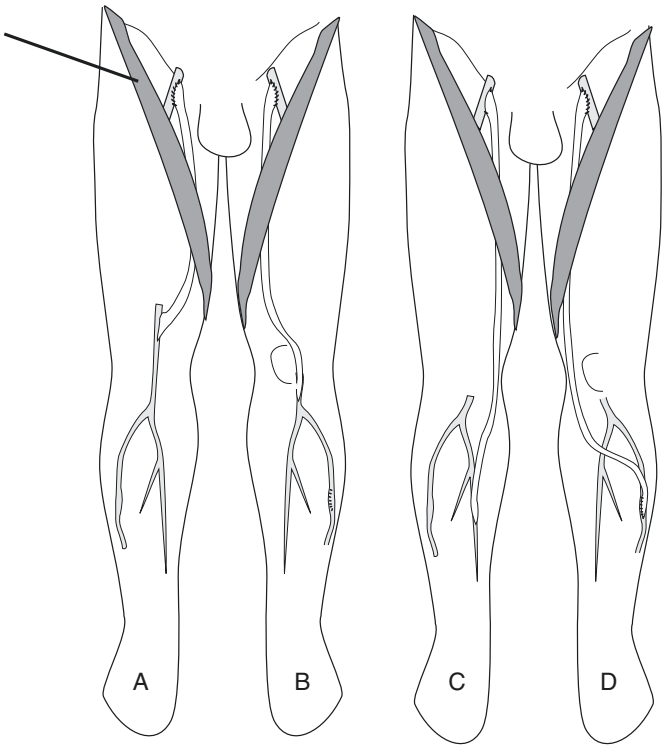
Aortobifemoral bypass: Tunneling for the limbs of the aortobifemoral bypass is usually accomplished with blunt finger dissection. One finger is introduced below the inguinal ligament over the external iliac artery. Another finger is introduced over the common iliac artery and advanced toward the inguinal ligament until both fingers meet. Care is taken to keep the tunnel posterior to the ureter. Otherwise, fibrosis and stricture of the ureter can develop in the future where the ureter is sandwiched between the iliac arteries and the graft limb. An aortic Debakey clamp can be introduced in the tunnel from the inguinal region toward the aorta to grasp and pull the graft limb through the tunnel.

Infrainguinal bypass: Except for an in situ bypass, infrainguinal grafts usually need to be tunneled. The tunnel can be subcutaneous, subfascial, or subsartorial. An advantage of a subcutaneous tunnel is the easy access to the graft should a revision become necessary. If skin flaps were developed during the dissection or vein harvesting, placing the bypass in a deeper subfascial or subsartorial location may be preferred, especially when the wound appears to be at increased risk for infection or nonhealing. The adductor canal is not usually used as a tunnel. Prosthetic grafts are infrequently placed subcutaneously.

Above-knee femoropopliteal bypass: A prosthetic graft is usually placed in a subsartorial or subfascial tunnel. An autogenous vein bypass is placed in a subcutaneous, subfascial, or subsartorial tunnel.

Below-knee femoropopliteal bypass: A prosthetic graft is usually tunneled subsartorially until the above-knee location. From the suprageniculate to the infrageniculate popliteal artery, tunneling behind the knee joint is usually achieved by blunt finger dissection. It is important to make sure that the tunnel is created between the heads of the gastrocnemius muscle; otherwise, an iatrogenic entrapment syndrome can develop. A similar tunnel can be used with an autogenous vein bypass. Alternatively, a subcutaneous or subfascial tunnel can be used.

Tunneling

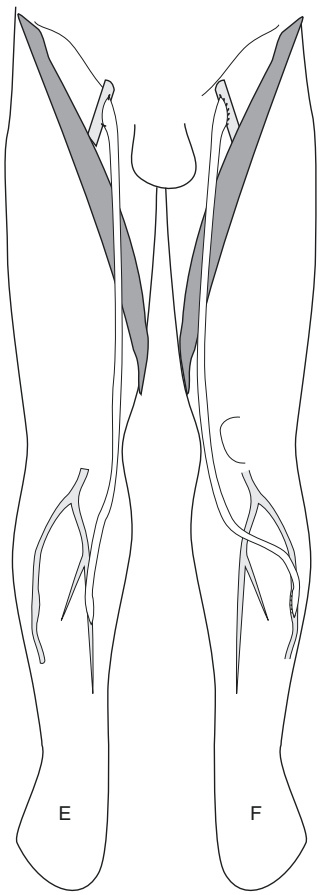


The bypass to the above-knee popliteal artery is tunneled subsartorially. (A)

The bypass to the below-knee popliteal artery is tunneled subsartorially to the above-knee level and then tunneled anatomically behind the knee between the heads of the gastrocnemius muscle. (B)

The bypass to the posterior tibial artery is tunneled subsartorially and then subfascially or subcutaneously below the knee. (C)

The bypass to the anterior tibial artery is tunneled subsartorially above the knee and then through the interosseus membrane. (D)

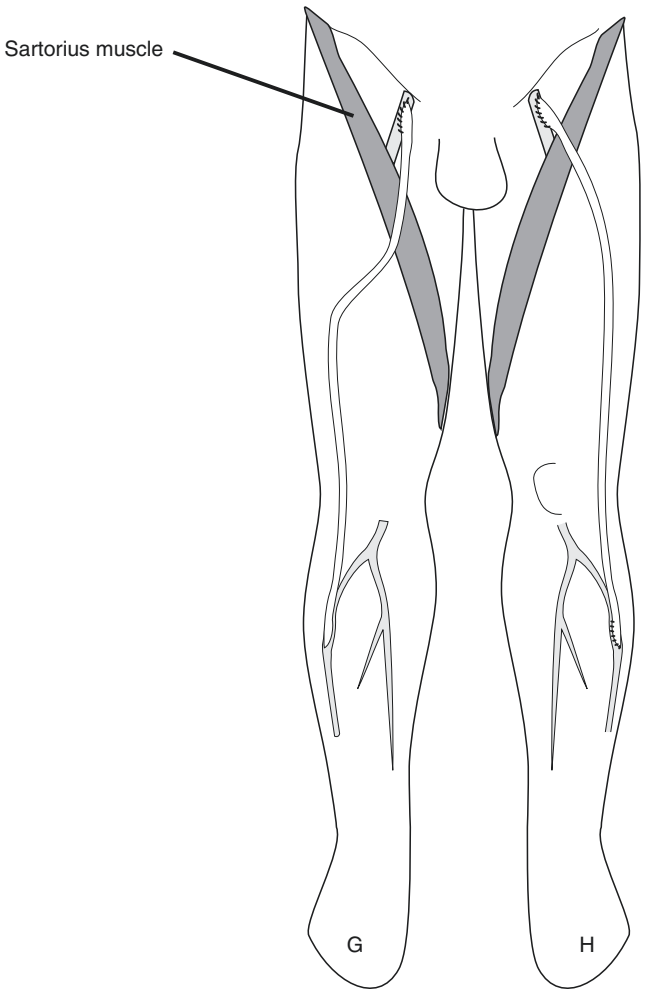


Vein bypasses to the infrapopliteal arteries can also be tunneled subfascially or subcutaneously. (E)

Subcutaneous vein passes to the anterior tibial artery can cross into the leg from medial to lateral anterior to the tibia. (F)

Tunneling

Infrapopliteal bypass: Tunneling to the infrapopliteal level is performed following the same principles used for tunneling a below-knee femoropopliteal bypass. From the infrapopliteal level, autogenous bypasses to the posterior tibial or peroneal artery are usually subcutaneous or subfascial, while prosthetic bypasses to the same vessels are placed subfascially. Several options are available for tunneling from the infrapopliteal level to the anterior tibial artery. The bypass can be tunneled from medial to lateral through the interosseus membrane or anterior to the tibia in a subcutaneous tunnel. Bypasses to the anterior tibial artery can also be tunneled on the lateral aspect of the lower extremity. In this situation, the bypass crosses from medial to lateral in the thigh and then continues toward the leg in a lateral subcutaneous tunnel. At the knee level, the bypass is usually tunneled between the lateral tibial condyle and the head of the fibula. This tunneling method can also be used for bypasses to other infrapopliteal vessels exposed through a lateral approach. When using a lateral approach, grafts originating from the proximal common femoral artery are usually tunneled above the sartorius muscle. Grafts originating from the superficial or deep femoral arteries are best tunneled deep to the sartorius muscle to avoid an acute angulation of the proximal conduit.



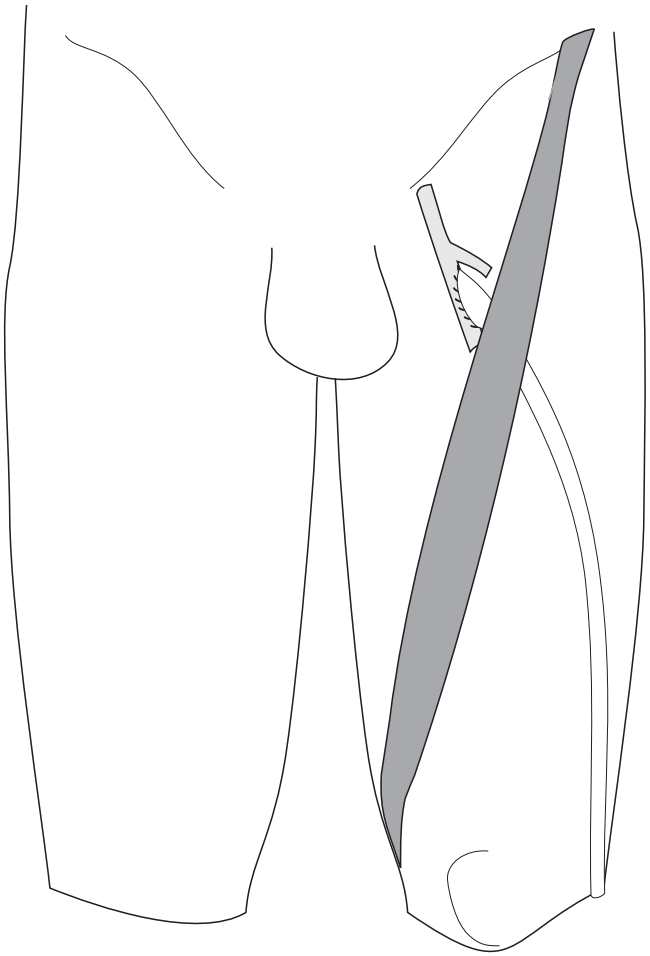
Subcutaneous bypasses to the anterior tibial artery can also cross from medial to lateral in the thigh and then continue in a lateral tunnel between the head of the fibula and the lateral tibial condyle.

A gentle S-shaped curvature is recommended in the thigh, as shown in the right leg (G).

Another route of tunneling is shown in the left leg. This can provide a shorter bypass and is ideal for grafts originating from the common femoral artery (H).

Tunneling

Grafts originating from the superficial femoral or deep femoral arteries are best tunneled deep to the sartorius muscle to avoid acute angulation of the graft in its proximal segment.



Tunneling is also performed during the creation of arteriovenous (AV) fistulae for hemodialysis. Arteriovenous fistulae can be classified into autogenous (primary) or secondary fistulae. In the primary, the vein is anastomosed directly to the artery. In the secondary fistulae, a prosthetic graft is used to connect the artery to the vein. The primary fistulae are constructed using the cephalic or basilic veins. Arteriovenous fistulae to the cephalic vein are constructed at the wrist (radiocephalic) or at the elbow (brachiocephalic) depending on the quality of the cephalic vein. If the cephalic vein is unavailable, arteriovenous fistulae to the basilic vein are constructed at the wrist (radiobasilic) or at the elbow (brachiobasilic) depending on the quality of the basilic vein.

Radiocephalic fistulae: The radiocephalic fistula (Cemino) is usually the fistula of choice if the vein is adequate from the wrist up to the deltopectoral groove. Tunneling is not needed for the creation of this fistula, as it is usually done through a transverse incision from the level of the cephalic vein to the radial artery. If longitudinal incisions were used to expose the radial artery and the cephalic veins, a subcutaneous skin flap is usually created. The cephalic vein is transected and passed under the skin flap to reach the artery in a gentle curve.

Brachiocephalic fistulae: The brachiocephalic fistula is performed at the elbow by exposing the cephalic vein and brachial artery through a transverse elbow crease incision. The cephalic vein is dissected distally and transected, and then sutured to the brachial artery in an end-to-side fashion. This fistula does not require any tunneling.

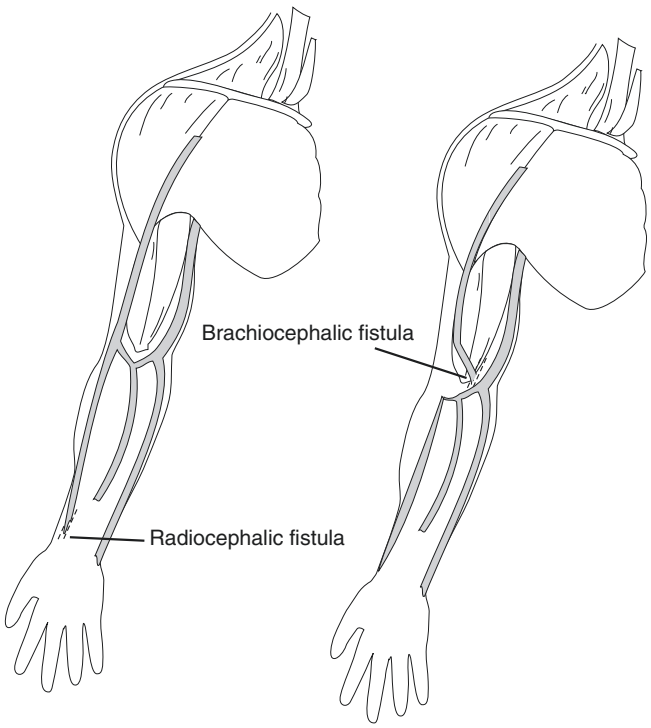
Tunneling

Radiobasilic fistulae: The primary fistulae created with the basilic vein require tunneling. Below the elbow, the basilic vein lies on the ulnar aspect of the forearm, which places the fistula in an undesirable position for dialysis. The vein can then be mobilized through a longitudinal incision placed over the course of the vein. The vein is transected at the wrist and then freed all the way up to the elbow. A tunnel is then created from the level of the radial artery to the antecubital fossa. The basilic vein is then passed through the tunnel and is now placed on the palmar aspect of the forearm in an easily accessible location. The tunnel is created subcutaneously to allow easy access to the vein.
Brachiobasilic fistulae: The basilic vein in the upper arm can also be used for dialysis; however, because of its deep location and being adjacent to the artery, puncture of this vein in its anatomical position is challenging and uncomfortable for the patient. To achieve an autogenous primary fistula, the basilic vein can be completely mobilized from the elbow to the axilla. All communicating branches are ligated and divided. The basilic vein is then transected at the elbow and freed completely up to the axilla. A tunnel is then created from the level of the brachial artery and then along the anterior border of the biceps brachii muscle in a subcutaneous plane. This will allow easy access to the fistula for venipuncture.

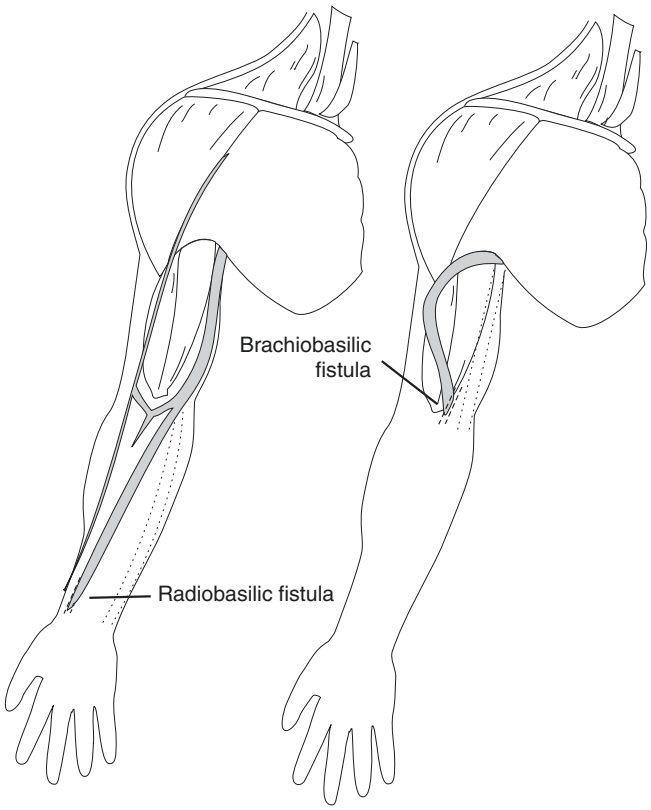
Prosthetic arteriovenous (AV) fistulae can be placed in the forearm or upper arm. The alternatives in the forearm include a straight or a loop fistula.

Straight forearm arteriovenous grafts: The straight fistula connects the radial artery to the best available vein at the level of the elbow. The tunnel is created subcutaneously. It is important to avoid creating the tunnel in a subdermal plane, as this could compromise the overlying skin. It is also important to avoid tunneling the graft too deep or subfascially, as this will make puncturing the graft more difficult.
Loop forearm arteriovenous grafts: In the loop forearm fistula, one end of the graft is connected to the brachial artery just distal to the elbow joint. The other one is connected to the best available vein in the antecubital area. During the tunneling of the forearm loop fistula, it is important to avoid an acute angle in the distal part of the forearm, as this could result in kinking of the graft and thrombosis of the fistula. A 3-cm skin incision at the level of the distal forearm is performed and a small pocket is created between the muscular fascia and the subcutaneous tissue. A subcutaneous tunnel is then created on the ulnar side of the forearm, from the brachial incision to the distal forearm counterincision. The graft is then passed into the tunnel. Another similar tunnel is then created along the radial aspect of the forearm. The other end of the graft is then pulled through the tunnel. The graft is inspected through the counterincision to ensure the presence of a gentle curve. In general, the forearm loop configuration is more desirable than the straight because of a lower rate of thrombosis that can be related to the small size of the radial artery at the wrist.
Straight upper arm arteriovenous grafts: In the upper arm, a prosthetic graft can be placed from the brachial artery to the basilic vein. It is important to tunnel this graft in an anterior location to allow it to facilitate venipuncture. The tunnel is created similar to that of the primary basilic fistula along the anterior border of the biceps brachii muscle.
Loop upper arm arteriovenous grafts: Loop upper arm arteriovenous grafts are created by connecting the brachial artery in the upper arm to the basilic vein in the proximal upper arm. This graft is created when the brachial artery at the elbow cannot be used as an inflow source. The tunneling is similar to that performed for the forearm loop arteriovenous grafts. The counterincision is usually 2 cm proximal to the elbow joint.

Tunneling

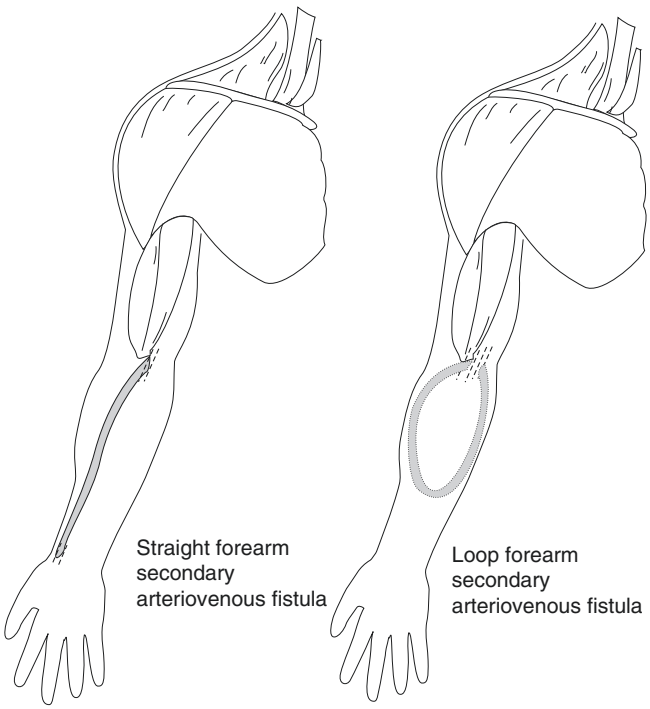


Tunneling is not usually necessary for the creation of arteriovenous fistulae to the cephalic vein.

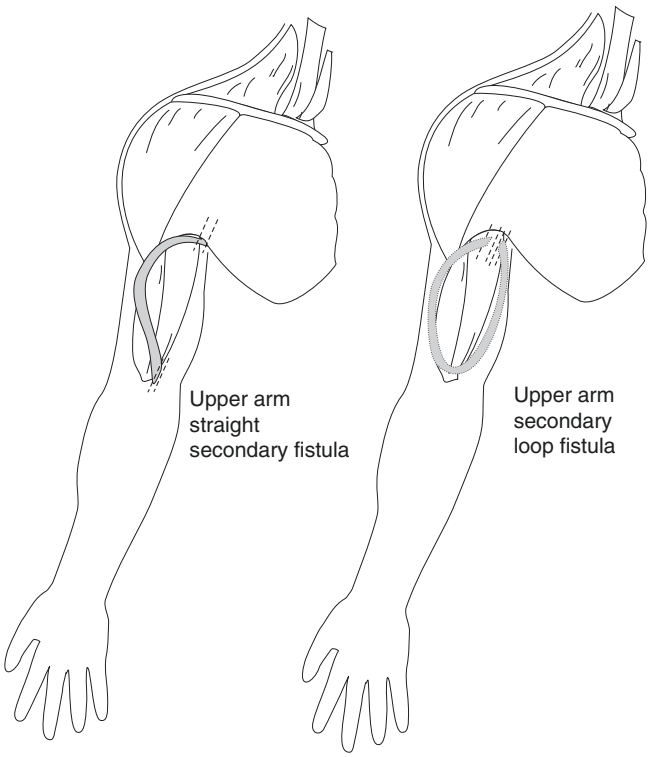


Tunneling is necessary for the creation of a primary arteriovenous fistula to the basilic vein to make the vein accessible for venipuncture.

Tunneling



A gentle smooth curve is necessary when tunneling for a loop forearm fistula.



A gentle curve is necessary when creating a straight or looped upper arm fistula.

ANTICOAGULATION

Anticoagulation

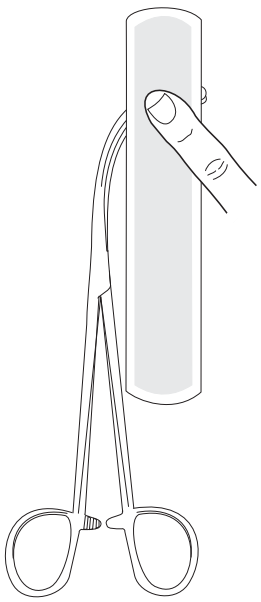
Before occluding the blood vessels to perform a vascular reconstruction, systemic anticoagulation is usually necessary to prevent thrombosis in the distal circulation during the period of cross-clamping. Systemic anticoagulation is usually achieved by the administration of heparin intravenously. A loading dose of 75–100 international units/kg is often used in vascular procedures. Most surgeons will wait 3–5 minutes after the heparin administration before cross-clamping. The effect of a single dose will last approximately 3–4 hours. Supplemental doses of heparin may be necessary if the duration of the cross-clamping is extended beyond 2 hours. Intraoperative dosing of heparin can be guided by measuring the activated clotting times during the procedure.

Antiplatelet therapy is commonly used in conjunction with carotid surgery or infrainguinal reconstructions. Aspirin is usually started preoperatively. Low-dose aspirin irreversibly acetylates cyclooxygenase in platelets, which then prevents platelet synthesis of thromboxane A2. Enteric-coated aspirin, 325 mg daily, is usually continued indefinitely. Aspirin may be used in conjunction with warfarin or direct oral anticoagulants (DOACs) but with caution, as the patients can become more prone to develop bleeding complications. The safety of clopidogrel in peripheral vascular surgery has been evaluated in several studies. Data available suggest that peripheral vascular surgery can be safely performed with patients receiving clopidogrel, even if used in combination with aspirin, especially in symptomatic carotid surgery, peripheral bypass surgery, and endovascular abdominal aortic repair. Open aortic aneurysm replacement inpatients on clopidogrel as single or dual therapy remains controversial due to the smaller number of such patients in most studies and in fear of type 2 errors. In general, most surgeons prefer not to conduct open aortic replacement in patients on dual antiplatelet therapy because of concerns of excessive bleeding complications.

Dextran is also used as an antiplatelet agent. It is started intraoperatively and continued as an intravenous infusion, usually over the ensuing 24 hours. Dextran is a polysaccharide, which decreases platelet adhesiveness and aggregation. It is available in two forms, dextran 40 and dextran 70. Dextran 40 is the form generally used during vascular procedures as an antiplatelet agent, while dextran 70 is more commonly used as an intravascular volume expander. Anaphylactic and allergic reactions can be reduced by infusion of dextran 1, a solution of short-chain dextrans, before starting dextran 40. The dosage of dextran used during vascular reconstructions is 500 mL intravenously followed by 500 to 1000 mL over the following 24 hours, given as a continuous infusion. The major potential complications with dextran use are bleeding and fluid overload.

BLOOD VESSEL CONTROL

Before occluding the vessels to create the vascular incision, the vessels are assessed for presence of atherosclerotic plaque. The dissected artery can be gently palpated with the index finger or pinched between the index finger and the thumb to check for the presence of atheromatous plaque. However, assessment with finger palpation alone may not be adequate. A useful method is to compress the blood vessel with the index finger against a right-angle clamp. This will allow a good evaluation of the vessel with respect to the presence and location of atherosclerotic plaque. Palpation of an artery should be carried out gently and cautiously, as rough manipulation could result in distal embolization and breakage of atheromatous debris into the distal circulation. This could be catastrophic when handling the carotid artery, where a “no-touch” technique should be followed when dissecting around the carotid bulb or anticipated atheromatous plaque.



Blood Vessel Control

Vascular Clamps
Rummel Tourniquet

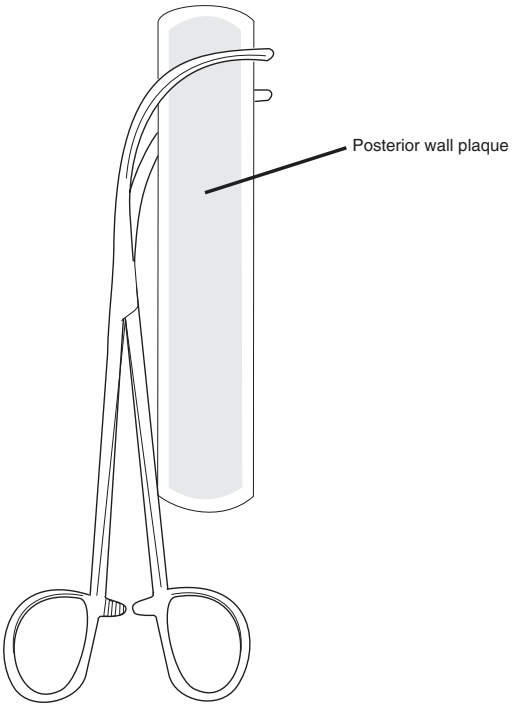
Several methods are available for controlling blood vessels. These methods include the use of atraumatic vascular clamps, tapes with Rummel "tourniquet, silastic vessel loops, internal occluders, or external pneumatic tourniquet.

VASCULAR CLAMPS

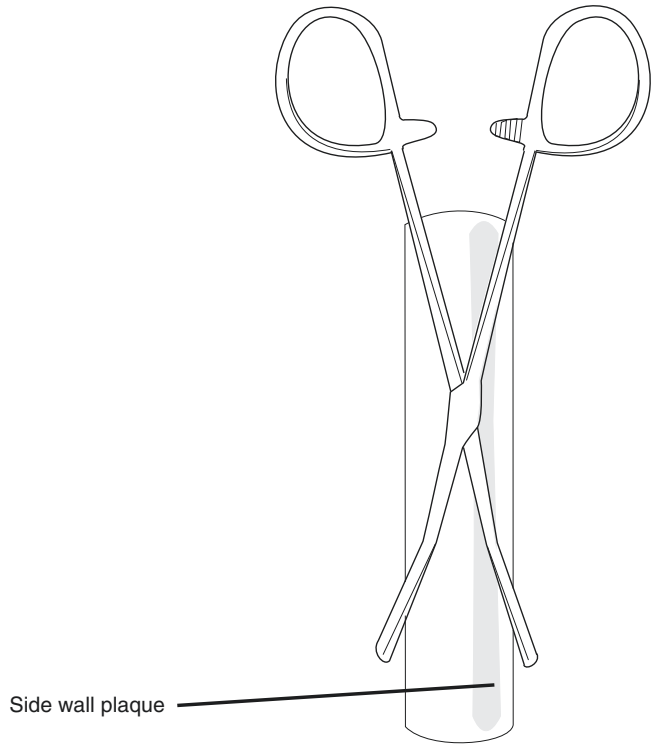
In the absence of plaque, the vascular clamp is applied in the simplest manner that would not obscure the incision or exposure. In a diseased artery, the presence and location of an atheromatous plaque will dictate the method of clamp application. The vascular clamp should be applied in a manner that would oppose the soft wall of the artery against the hard plaque without breaking the plaque or tearing the artery.

Before applying a vascular clamp, it is a good habit to check the number of notches needed for complete apposition of the clamp jaws. Excessive clamping may result in injury at the clamp application site even with the use of an "atraumatic" vascular clamp.

When dealing with smaller arteries, such as the profunda femoris or external carotid artery, self-compressing clamps such as the bulldog clamps or aneurysm clips can be very useful. The aneurysm clips (Heifetz clips or Yasargil clips) require a special applicator for placing them, which facilitates their delivery and removal in deep locations.



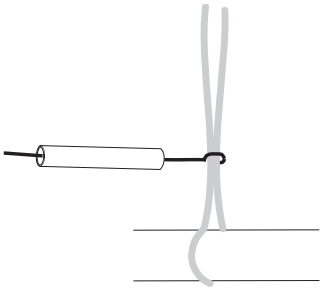
In the presence of posterior plaque, the vascular clamp is applied to appose the anterior and posterior walls together.



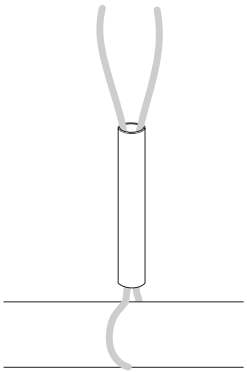
In the presence of a plaque on the sidewall, the vascular clamp is applied to appose the lateral and medial walls against each other.

A Rummel tourniquet can be used to achieve vascular control in medium-sized arteries, such as the common femoral or common carotid arteries.

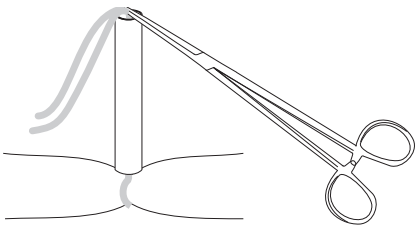
Blood Vessel Control
Silastic Vessel Loops



An umbilical tape is placed around the blood vessel.



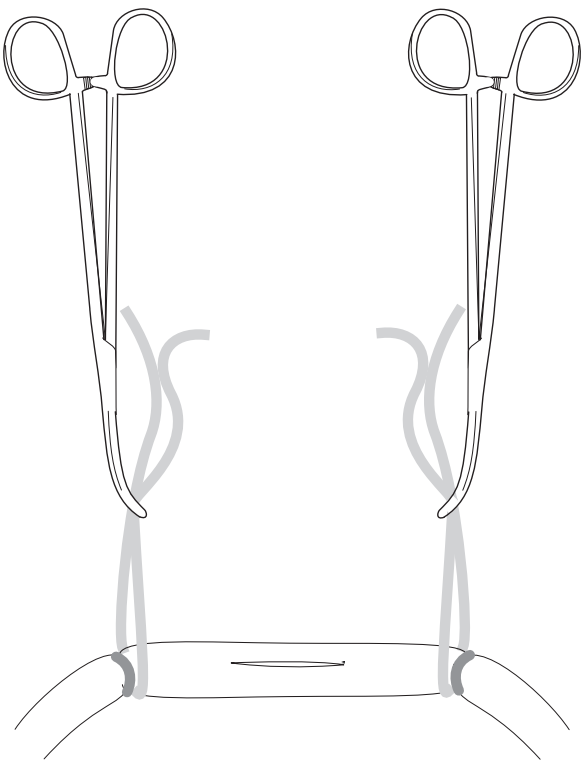
The umbilical tape is introduced through a segment of the rubber catheter using a snare.



The rubber catheter is pushed against the artery and stabilized by clamping the umbilical tape.

SILASTIC VESSEL LOOPS

Silastic vessel loops are often used to encircle blood vessels. Gentle tension on the vessel loop can help in providing traction on a blood vessel and facilitating the exposure. When double looped, tension on the vessel loop usually results in blood flow interruption. However, excessive tension on the vessel loops can damage the vessel wall. Thus, the least amount of tension capable of interrupting blood flow should be applied. When dealing with very small branches, the vessel loops can be bulky to use and may be replaced by a double loop of 4-0 silk.



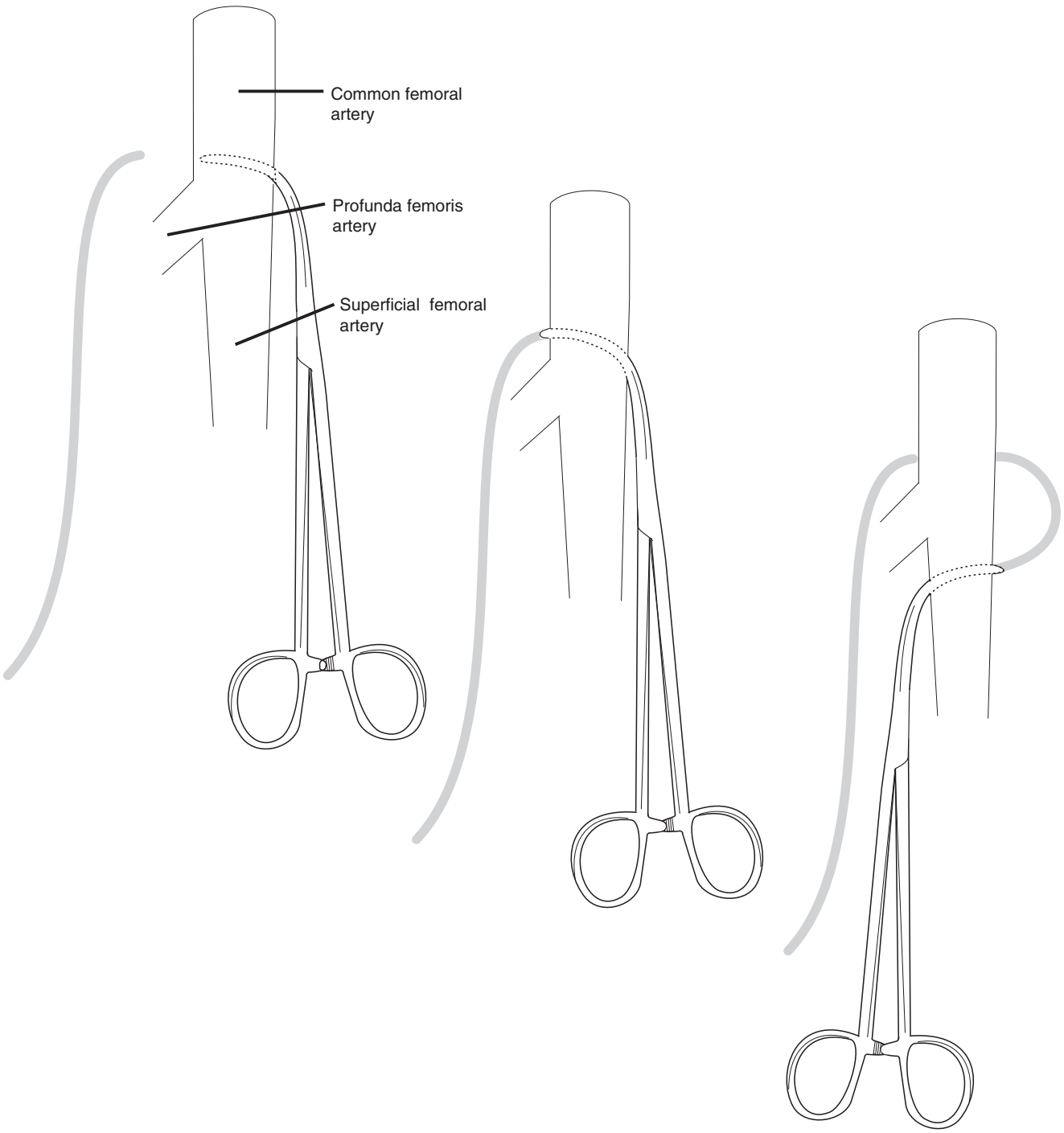
Vessel loops may fail to interrupt the blood flow if used with prosthetic grafts or diseased vessels of the size of the common femoral artery. In addition, if two vessel loops are used for proximal and distal control, the blood vessel segment between the loops may be placed in undue tension, and the process of placing the sutures in the arterial wall could be made unnecessarily difficult.

This problem could be avoided by replacing the distal vessel loop with an aneurysm clip.

Blood Vessel Control

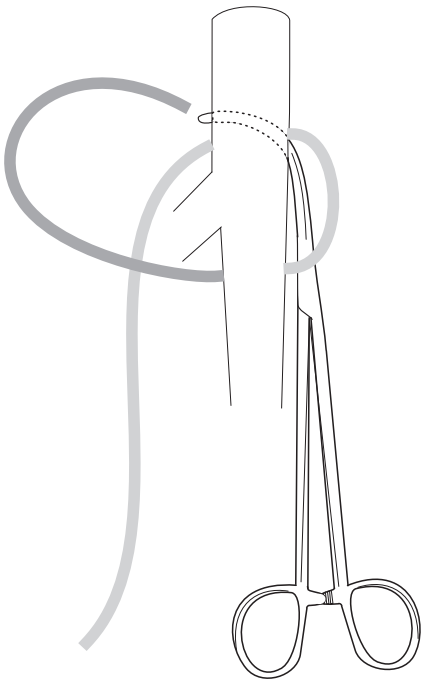
Silastic Vessel Loops

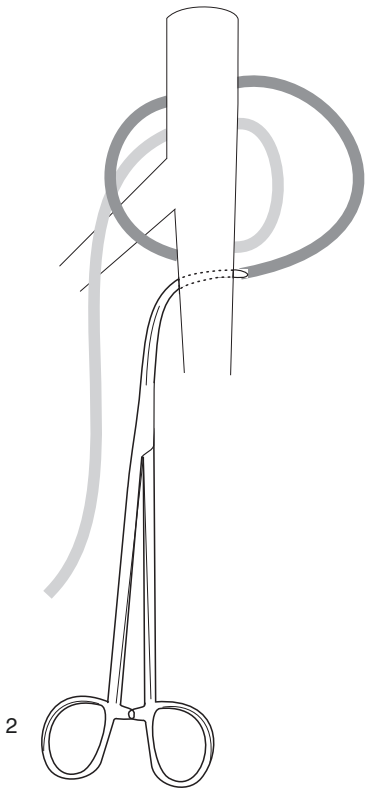
Vessel loops can be used to control side branches without having to dissect them circumferentially. This can be particularly helpful when obtaining control of the profunda femoris artery in scarred tissue planes. In this situation, only the common femoral and superficial femoral arteries are dissected. As shown in the following, the vessel loop is passed underneath the common femoral artery and then underneath the superficial femoral artery.

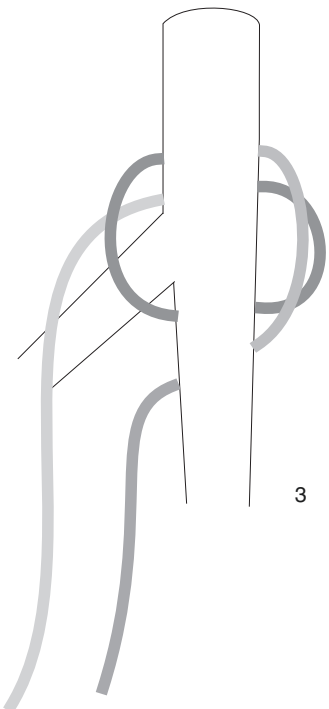


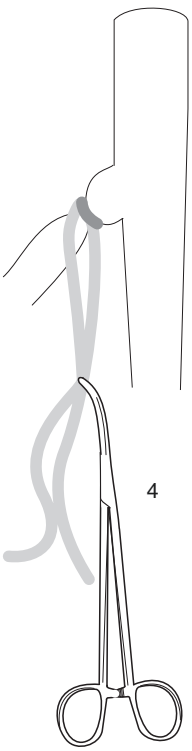
Blood Vessel Control
Silastic Vessel Loops

This process is repeated, which results in placing a double loop around the profunda femoris artery. This double loop can also control branches originating from the posterior aspect of the common or deep femoral arteries.









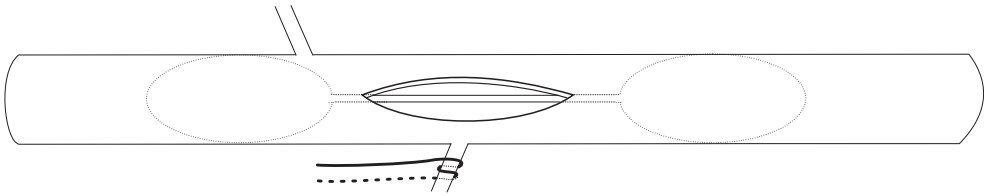
Blood Vessel Control

Internal Occluders

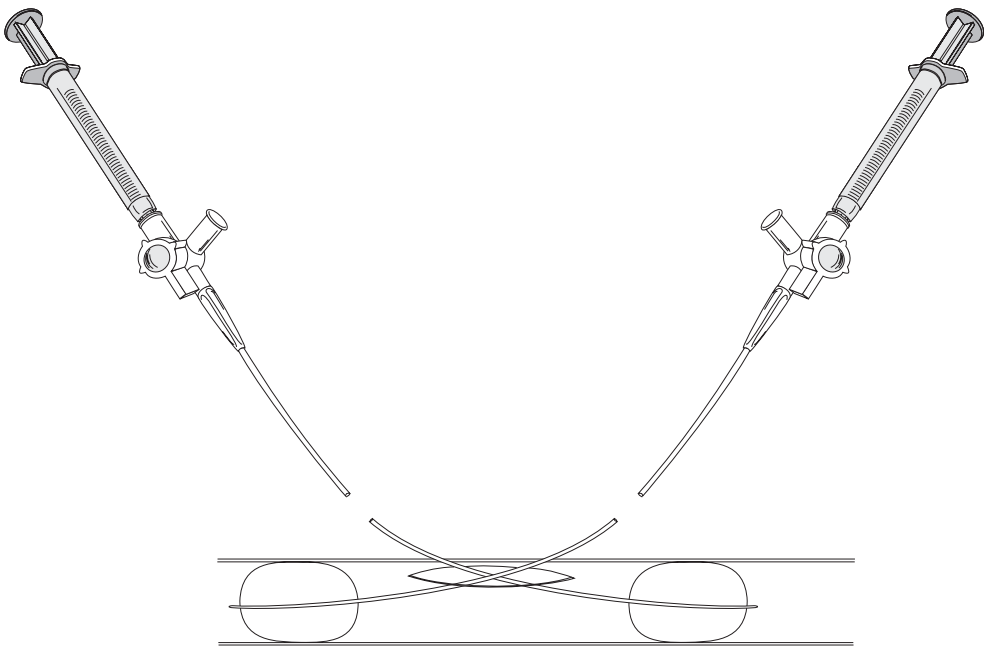
INTERNAL OCCLUDERS

Internal occluders are dumbbell-shaped devices that are available in different sizes. They are particularly useful in controlling infrapopliteal vessels. They are inserted through arteriotomy, and they interrupt the blood flow from within the lumen. Thus, only exposure of the anterior surface of the vessel is required, and circumferential dissection becomes unnecessary. This method eliminates the need for external occlusion of the tibial vessels, which could result in arterial spasm or vessel injury, especially in calcified vessels.

The appropriate size of internal occluder should be chosen. A small size could result in bleeding around the occluder. A large size could damage the intima if forced into the lumen. Occasionally, the presence of branches at the site of the arteriotomy or adjacent to the beginning or end of the arteriotomy may result in persistent bleeding. These branches will need to be controlled with silk loops to achieve a dry field.

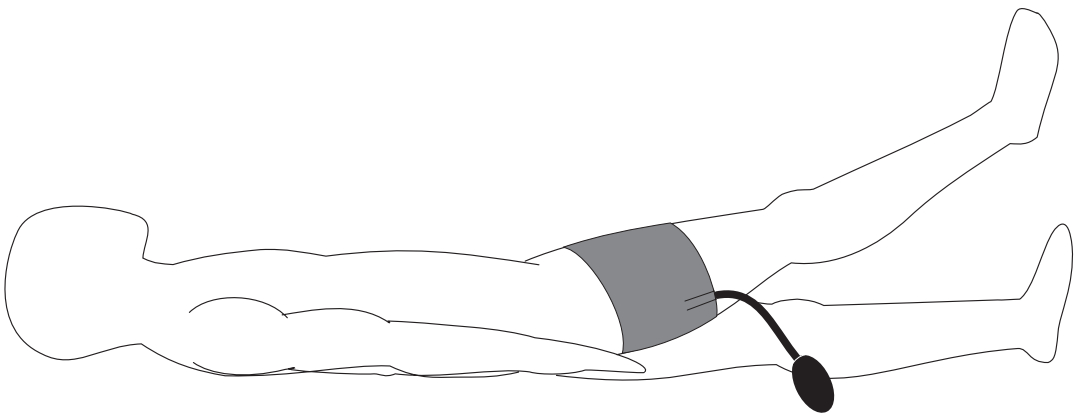


In the presence of heavy calcification, the arteriotomy may not allow the insertion of the internal occluders. Vascular control can be obtained by occluding the vessels from within using two balloon catheters, each attached to a three-way stopcock.



EXTERNAL PNEUMATIC TOURNIQUET

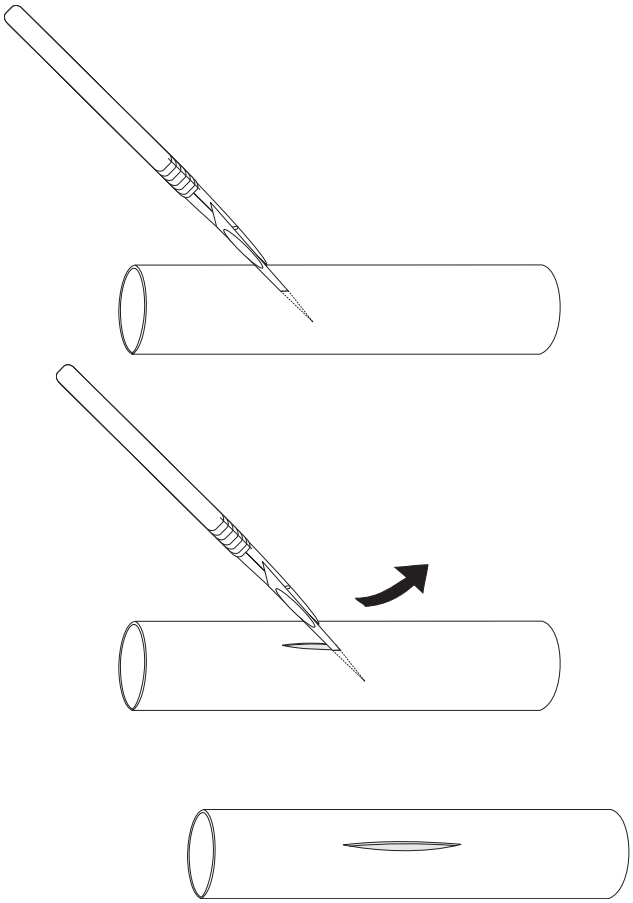
The external pneumatic tourniquet is another method of controlling the infrageniculate blood vessels. This method interrupts the blood flow without placing any intraluminal objects or any clamps that could hinder the exposure or potentially injure the vessel. The tourniquet is particularly helpful in the presence of heavily calcified blood vessels. A sterile tourniquet is applied, usually around the midthigh over a cotton roll. The leg is elevated and drained of the venous blood with the use of an Esmarch bandage. The tourniquet is inflated to a pressure of 250 mmHg, and the arteriotomy is created. If the field is not adequately dry, the inflation pressure can be increased to 350 mmHg. If bleeding persists, occluding the profunda femoris artery may provide the desired hemostasis. The alignment of the graft should be well established and double checked before inflating the tourniquet to avoid any twists or unpleasant surprises when the tourniquet is deflated.



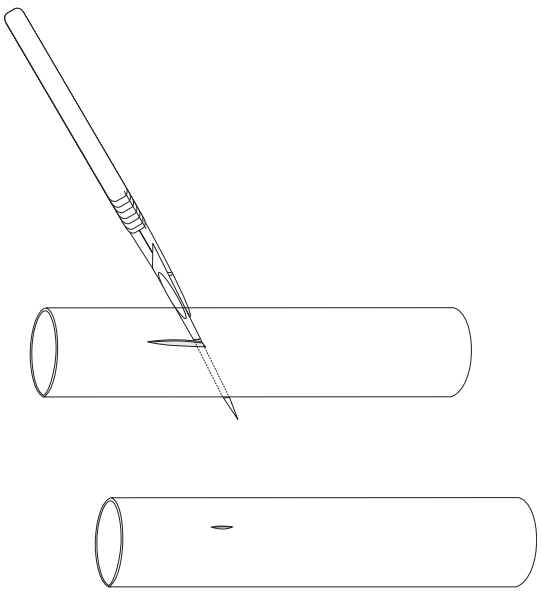
A similar concept to the external pneumatic tourniquet is the "Boazul roll-on cuff" (Boazul Medical AB). These cuffs are made of latex and are available in four different sizes. After choosing the appropriate size, the cuff is inflated to 120 mmHg, rolled on to the extremity proximal to the site where vascular control is desired, and then secured in place using a wedge. These cuffs can be autoclaved and reused. Furthermore, they eliminate the need for an Esmarch bandage as venous drainage is accomplished during the rolling of the cuff.

Creation of Blood Vessel Incision

CREATION OF A BLOOD VESSEL INCISION



An 11 blade is usually used to start the incision in the blood vessel. The blade is introduced at a 45-degree angle and then advanced in a forward movement, simulating an airplane during takeoff. This will create an opening large enough to easily accommodate the blade of a Potts scissors. The Potts scissors is used to extend the incision to the desired length.



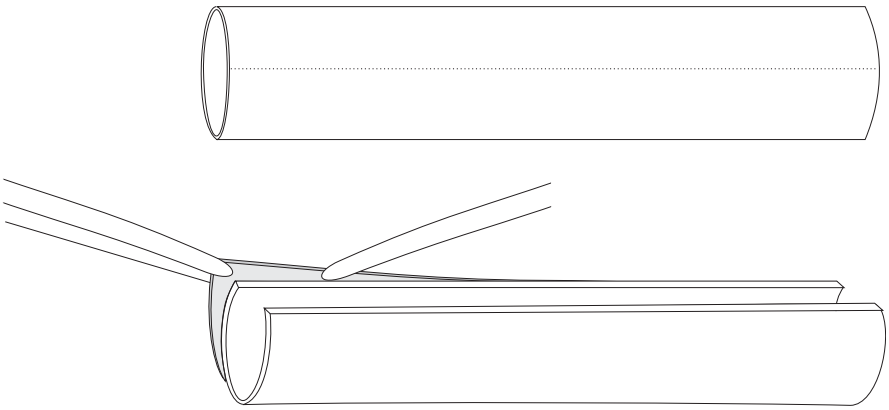
Introducing the blade too deeply can result in an injury to the back wall.

Introducing the blade without a forward movement can result in a very small arteriotomy and a struggle in introducing the blade of the Potts scissors.

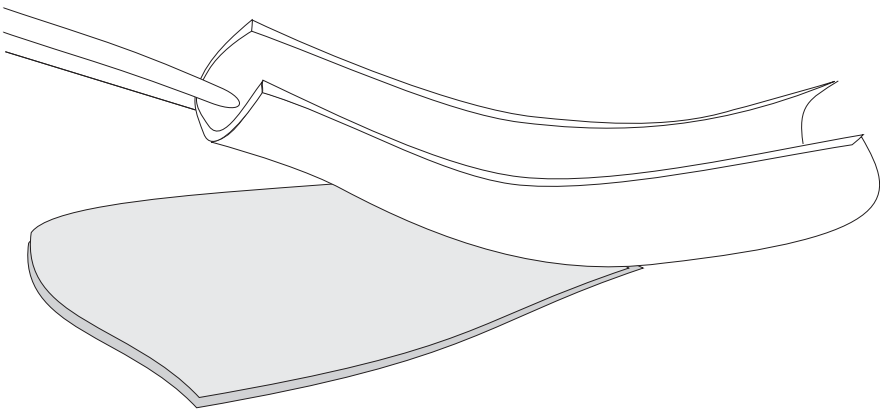
PREPARATION OF A PATCH

Preparation of a Patch

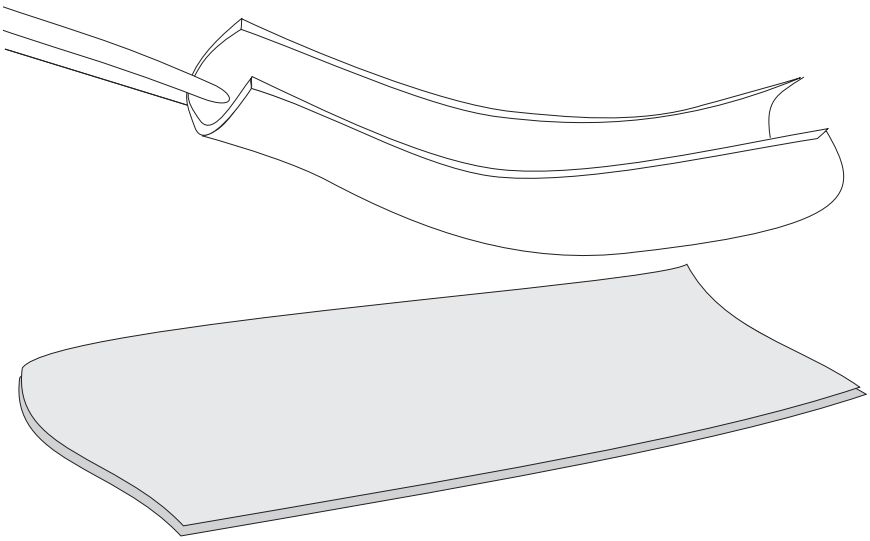
Prosthetic or autogenous patches can be used. Vein patches are usually prepared by harvesting a segment of vein and incising it along its longitudinal axis.



Alternatively, a segment of an occluded superficial femoral artery is harvested. The artery is incised along its longitudinal axis.

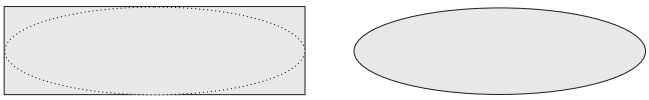


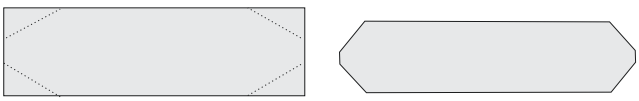
The patch is created by performing an endarterectomy of the harvested segment.



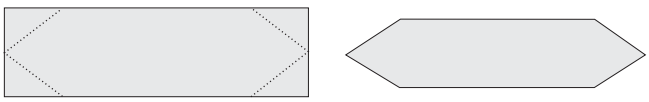
Preparation of a Patch

The patch is prepared for the reconstruction. The edges of the patch are usually trimmed to match the incision in the vessel. Several shapes can be created.





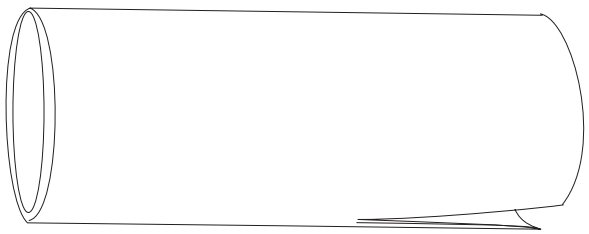
If the edges of the patch are trimmed leaving an acute angle, the placement of the apical sutures can be technically demanding.

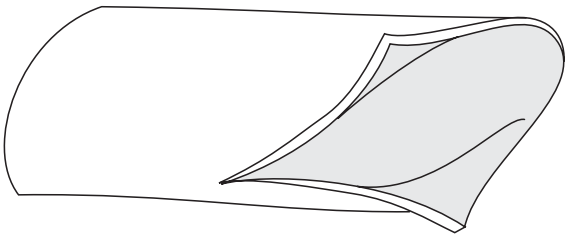


PREPARATION OF A BYPASS

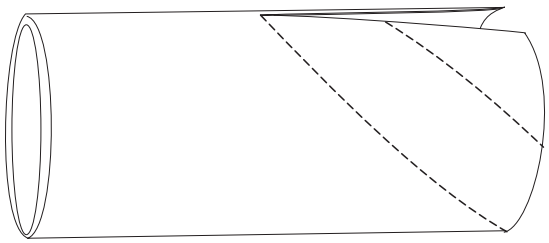
"Measure twice, cut once." When preparing an autogenous vessel for an anastomosis, the vessel is often transected at a right angle and then slit on its posterior aspect, resulting in spatulating the vessel end. Alternatively, the edges of the graft are trimmed to various degrees. The same method can be used with prosthetic grafts.

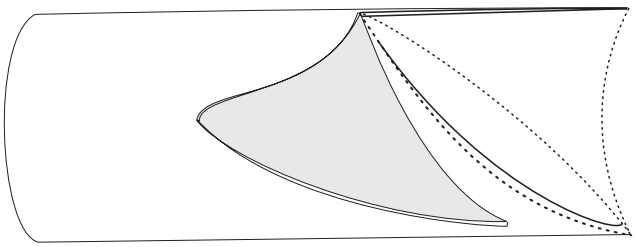
Incise the vessel along the posterior aspect.



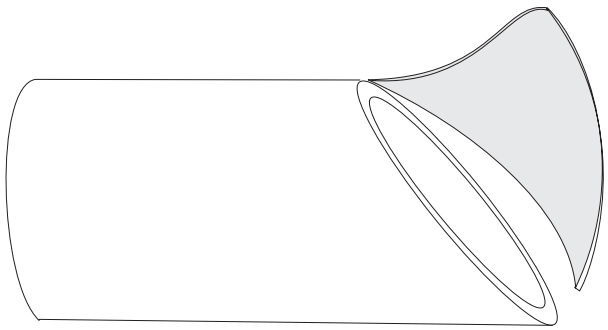


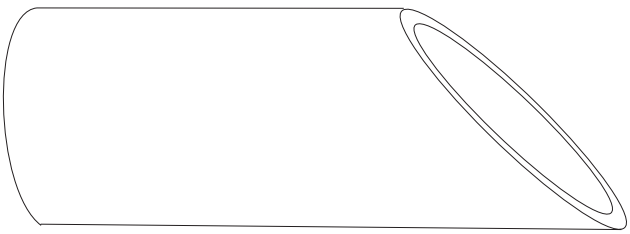
You may cut a wedge of the graft on one side.





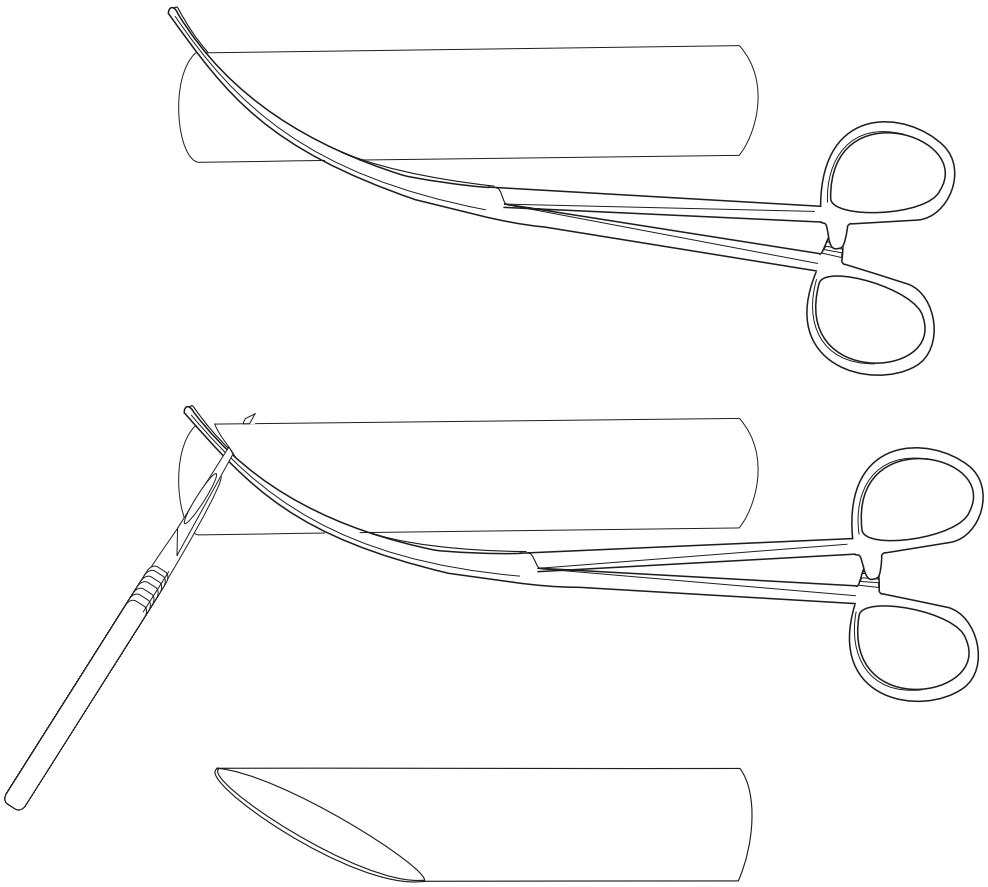
Cut the remaining wedge on the other side.





Preparation of a Bypass

Another alternative would be to clamp the graft and then transect it using a new blade along the inner aspect of the clamp.



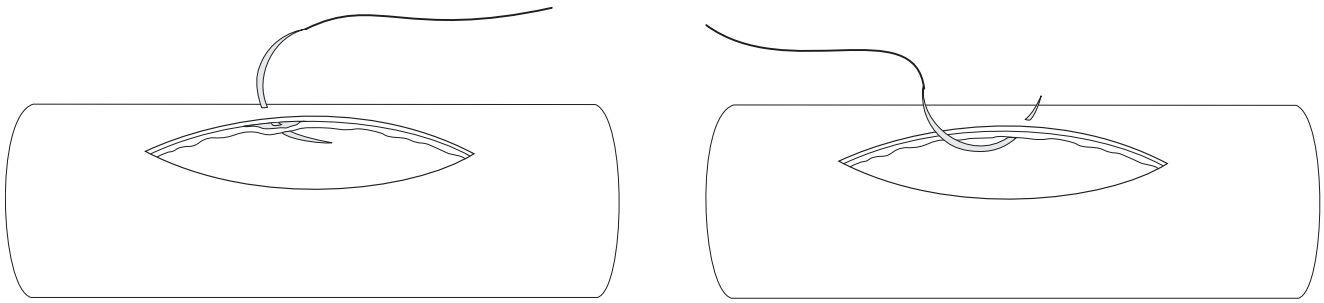
Before starting the suture line, the size of the opening in the bypass should be checked to match appropriately the length of incision in the blood vessel. If after starting the anastomosis the opening in the bypass is found to be larger than the vascular incision, the conduit can be trimmed or the arteriotomy can be lengthened. However, if the length of the arteriotomy is found to exceed the length of the opening in the graft, accommodating for the size discrepancy is more demanding.

CONSTRUCTION OF THE SUTURE LINE

The use of magnifying loupes is recommended, especially during the reconstruction of small vessels, such as in infrainguinal bypass procedures. Most surgeons will use 2.5–3.5 power loupe magnification. Illumination is as important as magnification. A headlamp may prove to be worth the headache it may cause.

INTRODUCTION OF THE NEEDLE

The needle should be passed through the vessel wall with minimal damage to the wall. In the presence of a plaque, introducing the needle from the adventitial side of the wall can result in separation of the plaque from the arterial wall. Creating a flap or a dissection can be avoided in calcified arteries, by always introducing the needle from the intimal side of the arterial wall.



In soft nondiseased arteries, the needle can be safely placed from the adventitial side of the wall. When placing sutures in veins or prosthetic grafts, the needles should be introduced in the simplest fashion that provide a forehand placement of the suture.

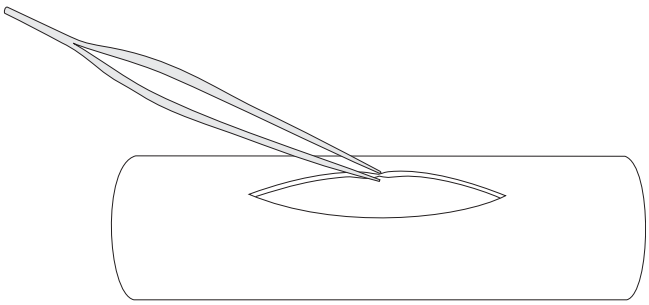
The needle should be introduced at a right angle to the vessel wall. The needle should be passed through the wall, while following the curvature with minimal movements, to avoid creating large needle holes.

Before pushing the needle through the wall, releasing the needle holder while maintaining control of the needle (unclick before you stick) will result in minimizing the amount of lateral movement of the needle while in the arterial wall. This maneuver will allow passage of the needle without creating large needle holes.

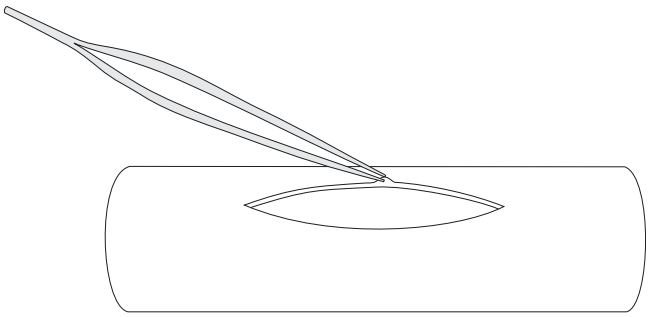
The temptation of holding the tip of the needle should be avoided, as this will result in blunting of the needle tip. Pushing the needle too far into the arterial wall also should be avoided, as it may result in pushing the tip of the needle holder into the arterial wall.

Construction of the Suture Line

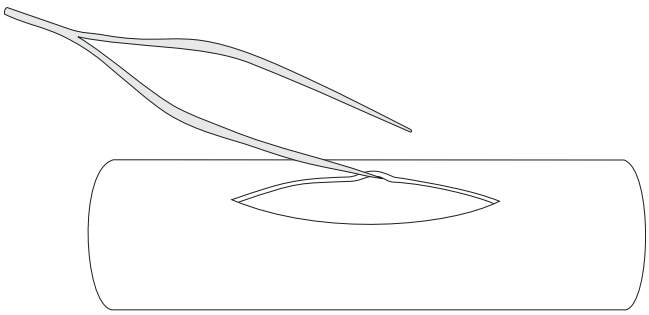
When placing sutures in autogenous vessels, the temptation of holding the entire thickness of the vessel wall with the forceps should be avoided.



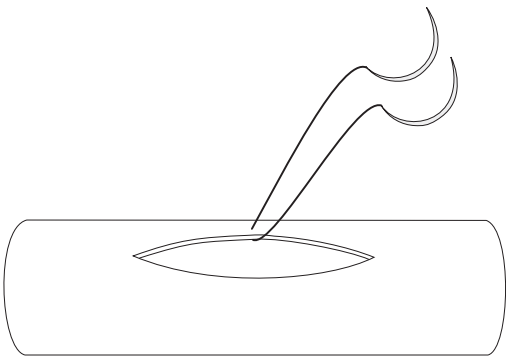
It is preferable to hold only the adventitia with the forceps, especially in small vessels. Even the softest "atraumatic" vascular forceps can cause intimal damage. The adventitia should be held carefully to avoid separating it from the rest of the vessel wall.



One option is to retract the vessel wall with one side of the forceps.



Another option is to place stay sutures to retract the vessel wall.



SIZE OF THE BITE

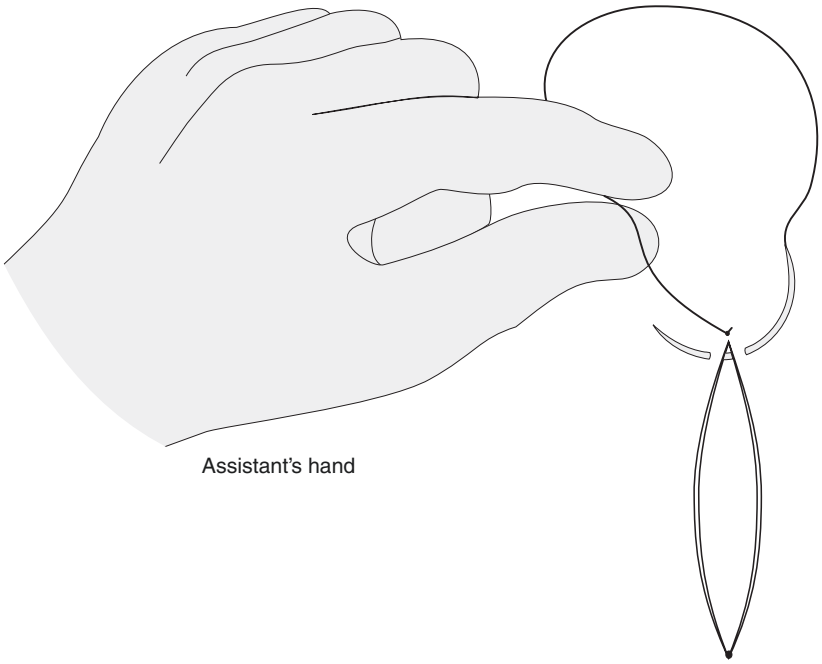
The size of the bite varies depending on the blood vessel being reconstructed. With aortic reconstructions, the bites are usually 3–4 mm deep and 2–3 mm apart. However, larger double-layer bites are recommended for the posterior wall of the aorta, especially when dealing with aneurysmal disease.

With infrainguinal reconstructions, the bites in the common femoral artery are usually 1–2 mm deep and 1 mm apart. In the popliteal artery, the bites are usually placed 1 mm deep, while, in the infrapopliteal vessels, the bites are usually 0.5–1 mm deep. Too few sutures with large advancement could result in bleeding between the sutures. Too many sutures are also not ideal.

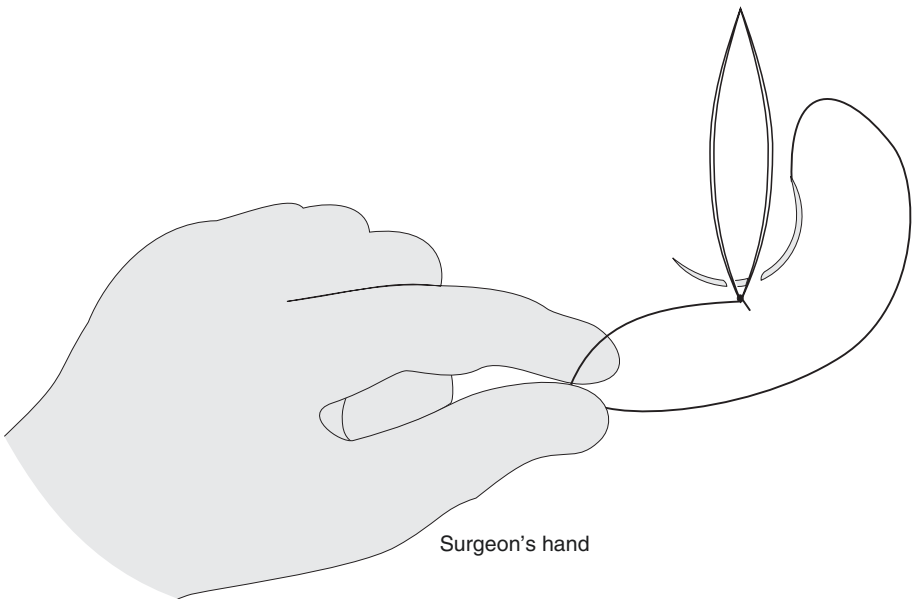
Construction of the Suture Line

The bites should result in intimal apposition, which is usually obtained when the suture line is everting. Adventitial strings should not be allowed to slip into the suture line, as they can be very thrombogenic.

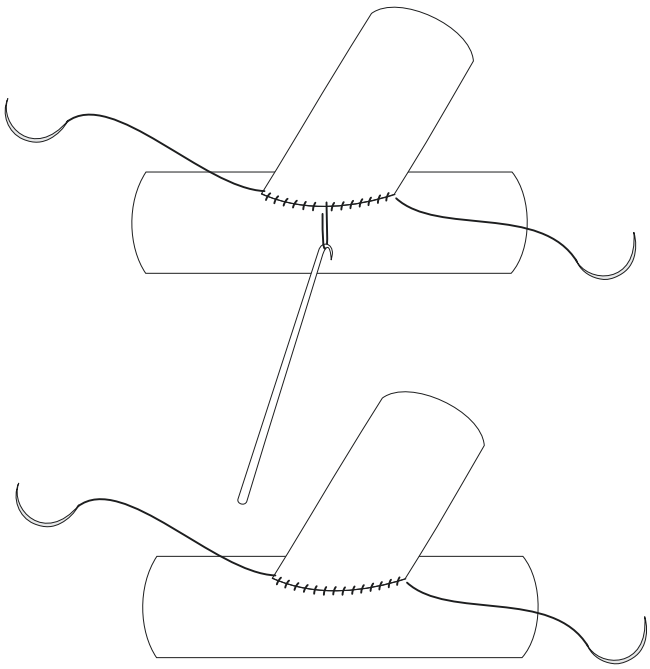
The assistant should follow the surgeon by maintaining tension on the suture line, while the surgeon is reloading the needle in the needle holder. Tension on the suture line is briefly released when the surgeon is ready to pull the suture through the vessel wall. The suture is pulled to appropriate tension by the surgeon, and the assistant regrasps the suture. When a continuous suture line is being used, the forceps can be used to guide the placement of the suture loop. The location of the suture loop is as important as the placement of the bites.



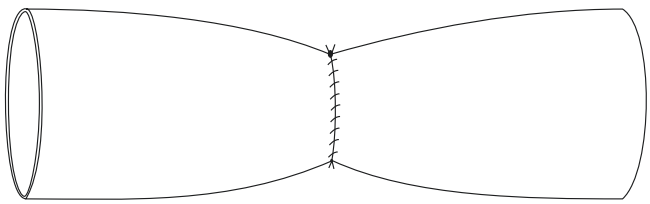
It is preferable to place the bites with a forehand rather than a backhand rotation of the needle. However, the surgeon should be comfortable with both forehand and backhand suturing techniques. When suturing away from the surgeon, the surgeon may follow himself/herself and grasps the suture line.



Construction of the Suture Line



The tension on the suture line should be maintained. If the suture line appears to be loose, a nerve hook can be used to engage a loop of the suture and readjust the tension.



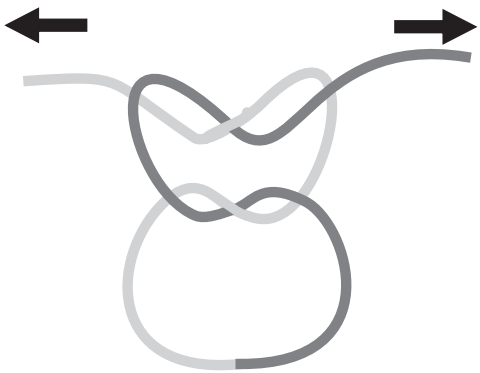
Excessive tension should be avoided, as it can cause a purse-string effect or puckering of the anastomosis.

TYING GUIDELINES

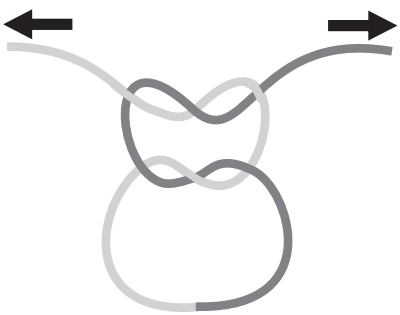
Surgeons should use the method with which they feel most comfortable. Crossing the hands while tying is necessary to achieve a square knot. A sliding knot can be helpful in reaching the desired amount of tension. A sliding knot can be created by placing two throws in the same direction without crossing the hands. Even if the first throw was flat, so long as the hands do not cross with the second throw, the knot will slide. Crossing the hands with the third and following throws is necessary to achieve square knots and prevent unraveling of the suture.

A square knot is started with a flat throw.

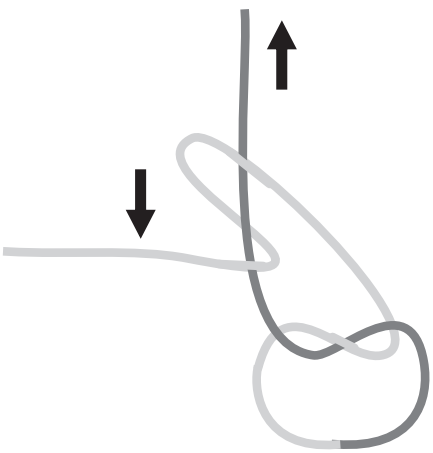
Crossing the hands with the second throw will result in a square knot.



When both throws are placed in the same direction, a granny knot is formed. This knot is not secure and can slip.



A slip knot can also be achieved by changing the direction of the tension applied on the strings while tying. This slip knot can be secured by adding multiple square knots.



Securing Hemostasis

SECURING HEMOSTASIS

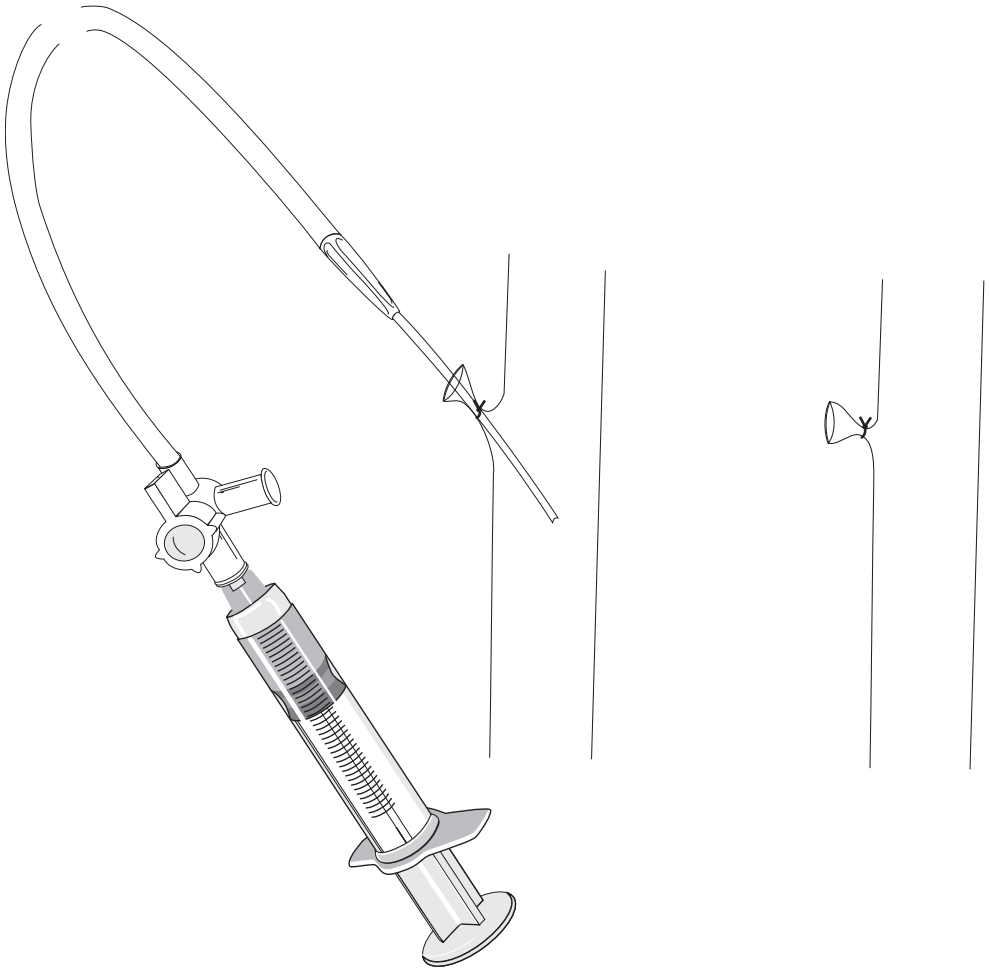
Before tying the suture line, the vessel lumen is irrigated with heparinized saline to flush out any debris. Forward and backward bleeding should also be rechecked before completing the suture line. The distal clamps are released first. The proximal clamps are then partially released to identify obvious leaks. In that situation, the clamps are reapplied and the defect repaired. In the presence of multiple outflow vessels, the circulation is usually first reestablished into the least critical outflow vessel, such as the external carotid artery during a carotid endarterectomy. This will allow any debris to travel into the nonvital circulation. After constructing the suture line, hemostasis is secured. In addition, the wound should be carefully checked for lymph leak. Hemostasis is reviewed in Chap. 5.

EVALUATING THE VASCULAR RECONSTRUCTION

After securing hemostasis, the vascular reconstruction is evaluated for patency or the presence of any technical abnormalities. Although the presence of a pulse distal to the reconstruction is very reassuring, most vascular surgeons rely on other methods to assess a newly completed vascular anastomosis. Noninvasive evaluation can be performed using a sterile handheld Doppler or duplex ultrasonography. The handheld Doppler is usually marched over the vascular reconstruction, as well as proximal and distal to the reconstruction site. The Doppler signal distal to an anastomosis should diminish with pinching the newly implanted bypass and re-augment with reestablishment of the blood flow. A high-pitched signal is suggestive of a stenotic pathology. Insonation over freshly implanted prosthetic grafts is usually unsuccessful. Duplex ultrasonography has also been used to evaluate vascular reconstruction intraoperatively. This method has been particularly useful for evaluating the carotid arteries following endarterectomy procedures. It has also been valuable following renal artery revascularization. However, its role in evaluating infrainguinal revascularization intraoperatively has not gained wide acceptance, as angiography continues to be the method of choice. This can be attributed to the superiority of the images obtained by angiography.

Intraoperative angiography is usually performed by inserting a 20-gauge angiocath or butterfly into the conduit and injecting 10–15 mL of diluted contrast. A side branch can be used as the entry site for the angiocath when a vein conduit is being used. After the angiogram is obtained, the angiocath is withdrawn, and the side branch is ligated. This avoids the need for placing a suture to control bleeding for the angiocath insertion site. Angioscopy was proposed for intraoperative assessment of infrainguinal revascularization. Although angioscopy was successfully used to monitor valvular disruption and the patency of vascular reconstructions, it remains infrequently performed. This can be attributed to concerns related to cost, fluid overload, and potential intimal injury to the conduit. Furthermore, angioscopy does not provide any information regarding the outflow vessel distal to the reconstruction.

Evaluating the Vascular Reconstruction



5

Hemostasis

Jamal J. Hoballah and Rakan Nasser Eldine

During a vascular reconstruction, standard surgical techniques are used for soft tissue hemostasis. The use of electrocautery should be limited near blood vessels to avoid inadvertent injury to the vessel wall or adjacent nerves. To achieve a desired vascular exposure, some blood vessels may need to be divided. Small vessels are usually double ligated in continuity and then transected, or oversewn.

SUTURE LIGATION

Suture ligation may be required when the transected vessel is expected to have a short stump. Examples include the common facial vein during the exposure of the carotid bifurcation or the lateral circumflex vein during the exposure of the profunda femoris artery. Suture ligation may also be needed to control bleeding from vascular orifices such as the backbleeding from the lumbar or inferior mesenteric arteries during abdominal aortic aneurysm replacement.

CLOSURE OF LARGE TRANSECTED ARTERY

When the transected vessel has a wide base, suture ligation may not be adequate. The edges of the transected end can be oversewn with a simple "over-and-over" continuous suture. This closure method may be adequate when the oversewn vessel has a low intraluminal pressure, such as a vein or the distal end of a transected artery. However, when dealing with the proximal end of a large transected artery, an additional suture line is often used to secure the closure. The first row of sutures is usually constructed with horizontal mattress sutures, placed proximal to the edges of the transected artery. The horizontal mattress sutures are placed using an interrupted or continuous technique. The second row of sutures will approximate the edges of the transected artery, usually with an "over-and-over" continuous suture. This method of closure is usually used to oversew the aortic stump after the removal of an infected aortic prosthesis.

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J. J. Hoballah, C. F. Bechara (eds.), *Vascular Reconstructions*, https://doi.org/10.1007/978-1-0716-1089-3_5

REPAIR OF LOOSE SUTURE LINE

After completing the vascular reconstruction, the suture line is inspected to ensure hemostasis. In general, the effect of heparin is allowed to wear off without reversal, especially with infrainguinal bypasses. Heparin can be reversed with protamine sulfate. The dose of protamine is estimated at 1 mg/100 U heparin, taking into consideration when heparin was administered and the decrease in heparin activity over time. Only one-half of the calculated dose of protamine should be given initially, as it can cause hypotension and bradycardia if given too quickly. The maximum rate of administration of protamine is 10 mg/min with a maximum of 50 mg in 10 min. A common safe practice is to administer protamine, at increments of 5-mg doses to be repeated, guided by an activated clotting time measurement. Most bleeding usually ceases after the administration of 10–15 mg of protamine.

Patience is essential when bleeding is noted from needle holes. Needle-hole bleeding will usually stop when the suture line is gently compressed with a dry gauze sponge. The control of needle-hole bleeding may be expedited by the topical application of hemostatic agents, such as oxidized cellulose or gel foam. The topical application of strips of gel foam soaked with thrombin is particularly helpful in controlling needle-hole bleeding from polytetrafluoroethylene (PTFE) grafts or patches. A list of topical hemostatic agents and sealants is outlined in Table 5.1.

Persistent diffuse bleeding from all the needle holes usually suggests a loose suture line. The tension of the suture line can be checked with a nerve hook by carefully engaging one loop in the suture line. Gentle tension on the loop will usually control the bleeding if it is caused by a loose suture line. In this situation, another suture is placed and tied next to the engaged loop. The loop and the new suture are then tied together.

REPAIR OF LONGITUDINAL TEARS

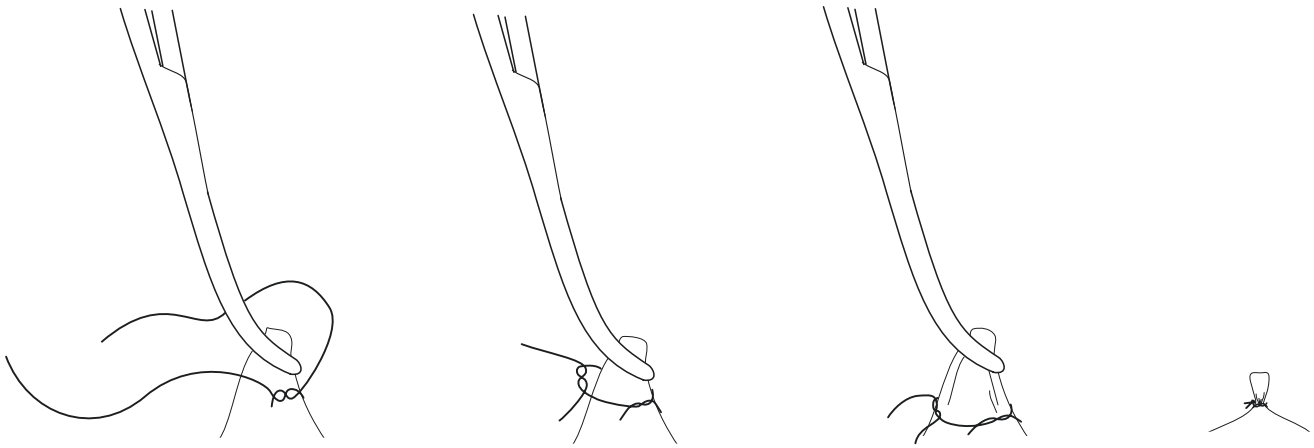
Occasionally, additional sutures may be required to achieve hemostasis. Bleeding from the suture line may also be caused by longitudinal tears in the vessel wall. This is usually controlled by sutures fortified with pledgets. When repairing a bleeding suture line, it is preferable to clamp the vessel proximally. This will avoid placing and tying sutures in a pulsating vessel with a high intraluminal pressure. Otherwise, additional tears in the vessel wall along the needle holes may occur.

Table 5.1 Topical hemostatic agents and sealants

Name	Manufacturer	Ingredients	How supplied
Hemostatic agent			
Arista absorbable hemostat	Bard (Davol)	Plant based Polysaccharide (starch)	Powder (microporous particles)
Surgicel	Johnson & Johnson Ethicon	Oxidized regenerated cellulose	powder, Sheet; (original, fibrillar, Knit)
Avitene; microfibrillar collagen hemostat (MCH)	Bard (Davol)	Partial hydrochloric acid salt of purified bovine corium collagen	Powder
Avitene syringe	Bard (Davol)	Partial hydrochloric acid salt of purified bovine corium collagen	Powder in a syringe
Avitene Sheet	Bard (Davol)	Partial hydrochloric acid salt of purified bovine corium collagen	Sheet
Avitene Ultrafoam	Bard (Davol)	Partial hydrochloric acid salt of purified bovine corium collagen	Sponge
Helistat	Integra Life Sciences corp	Bovine collagen (Achilles tendon)	Sponge
Helistat	Integra Life Sciences corp	Bovine collagen (Achilles tendon)	Fibrillar
Gelfoam	Upjohn/Pfizer	Purified porcine skin gelatin	Powder or sponge
Surgifoam	Johnson & Johnson and Ethicon	Porcine gelatin	Powder; sponge
Thrombin	GenTrac, Inc	Bovine thrombin	Vials and spray two syringes with a joining piece
Surgiflo	Johnson & Johnson and Ethicon	Flowable porcine gelatin and human thrombin	Dual syringes
Tissue sealants			
Evarrest	Johnson & Johnson Ethicon	Human fibrinogen and human thrombin embedded in a flexible composite patch	Patch
Evicel	Johnson & Johnson Ethicon	Fibrinogen and thrombin	Dual syringes with a common connector
Tisseel VH (fibrin sealant)	Baxter	Human thrombin; human sealer protein concentrate (fibrinogen cryoprecipitate); and bovine fibrinolysis inhibitor (aprotinin)	Dual syringes with a common connector
Floseal	Baxter	Gelatin and human thrombin	Dual syringes with a common connector
COSEAL	Baxter	Two synthetic biocompatible polyethylene glycol polymers	Dual syringes with a common connector
BioGlue	CryoLife	Albumin and glutaraldehyde	One applicator with syringe
PREVELEAK	Baxter	Purified bovine serum albumin and polyaldehyde	Dual syringes with a common connector

Suture Ligation
Small Vessels

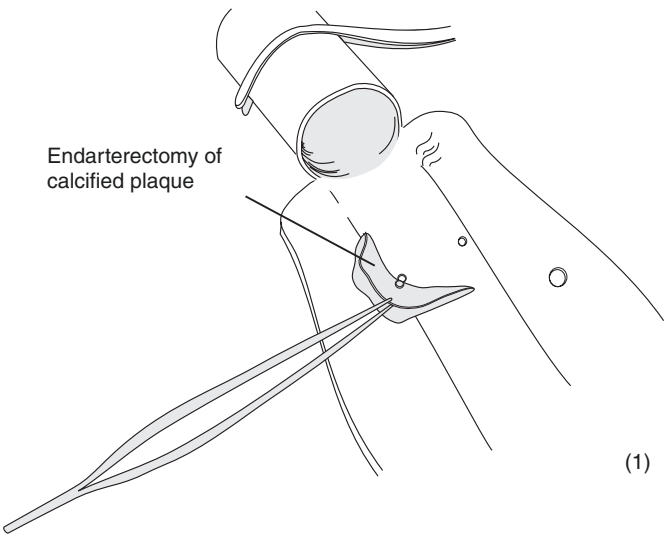
Place a suture in the vascular pedicle. Tie one throw.



Pass the thread around the clamp and tie the knot.

Suture Ligation
Lumbar Vessels

Bleeding lumbar vessels can be controlled by a simple figure-of-8 suture. In the presence of a calcified plaque, oversewing the orifice of the bleeding vessel will not achieve hemostasis, unless preceded by a localized endarterectomy.



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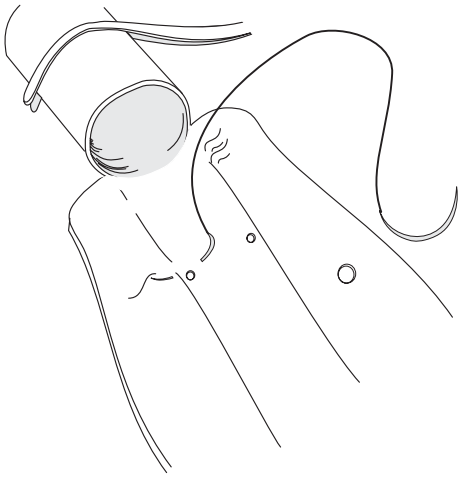

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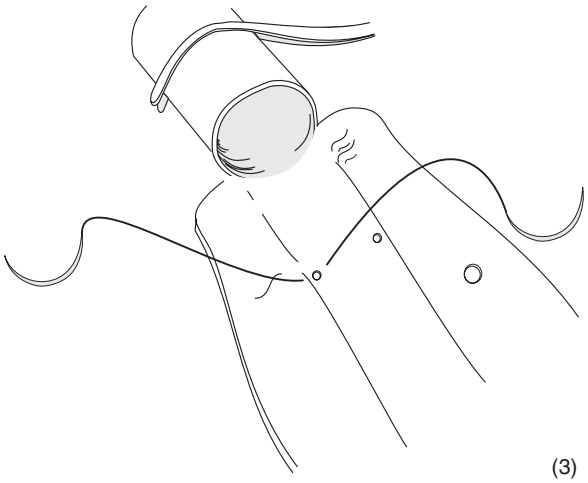

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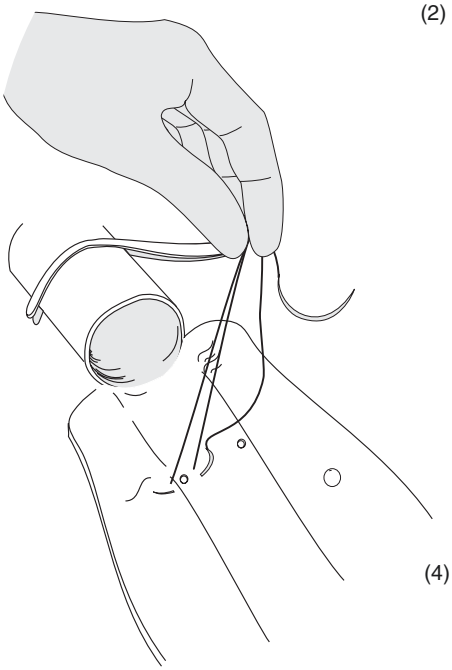

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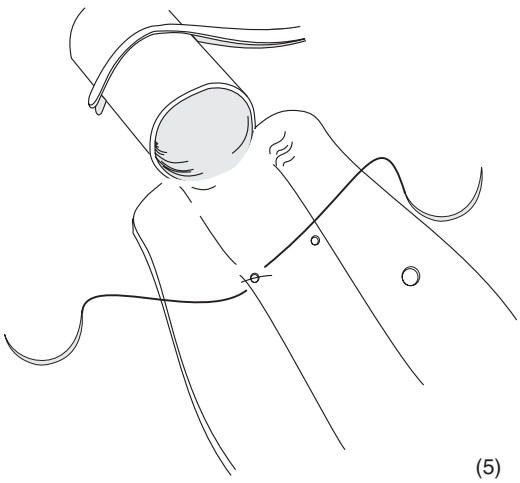

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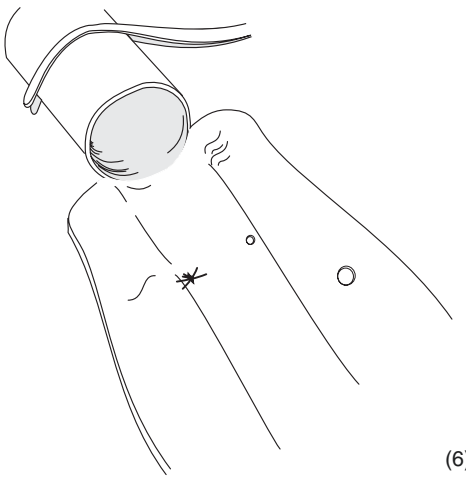

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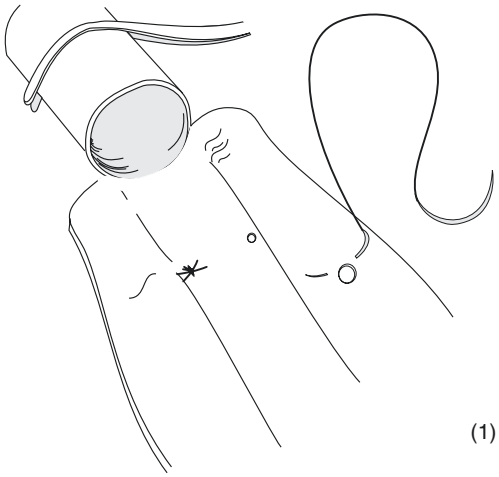
Suture Ligation
Inferior Mesenteric Artery

Blood vessels with large orifices, such as the inferior mesenteric artery, may need additional bites to secure hemostasis.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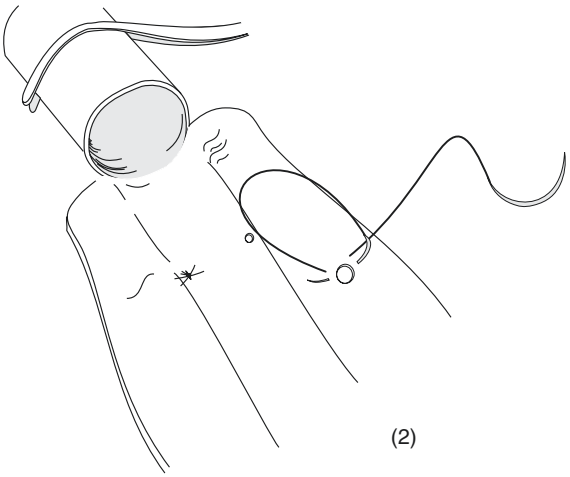
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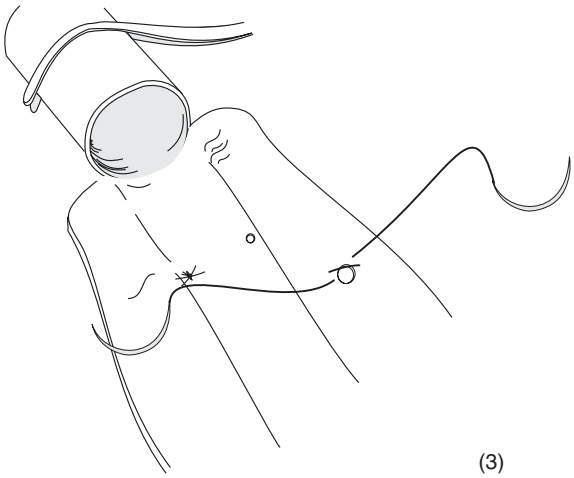
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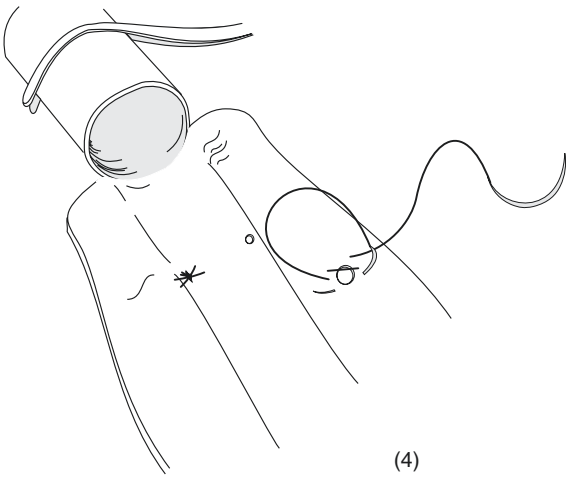
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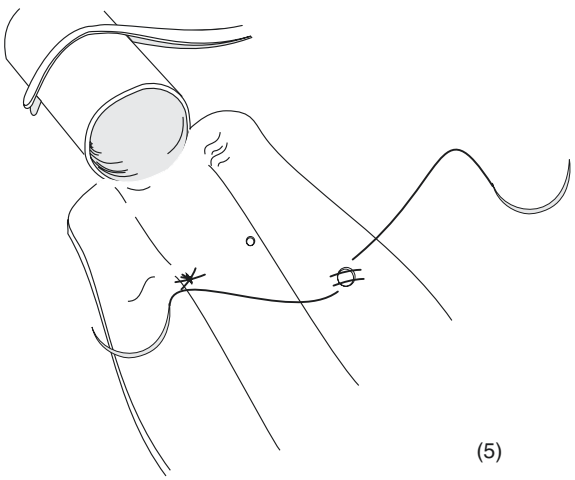
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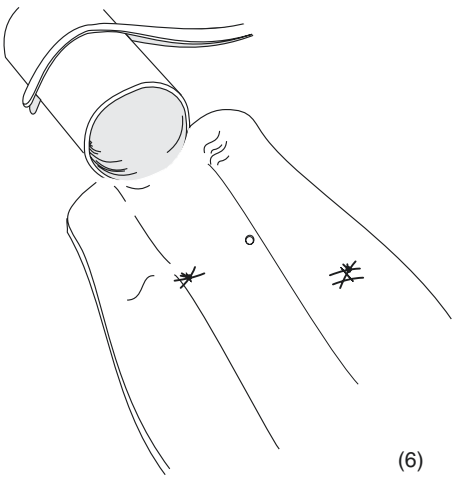
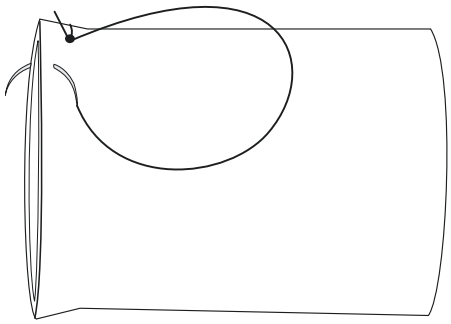

(6)

Closure of a Large Transected Artery

Start one suture at one end. Run the suture in a horizontal mattress technique, until you reach the opposite end.



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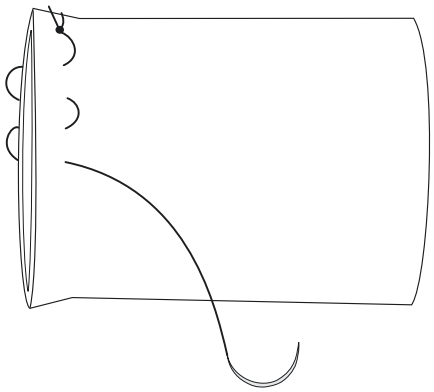
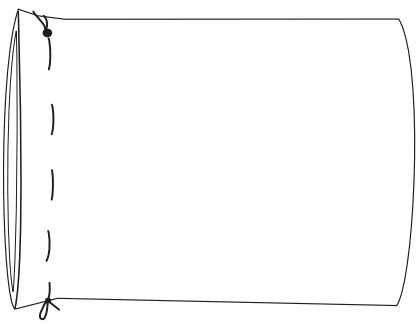


(2)

Tighten the suture line, and tie the suture to itself. Start another suture, and run it down using a simple continuous closure.



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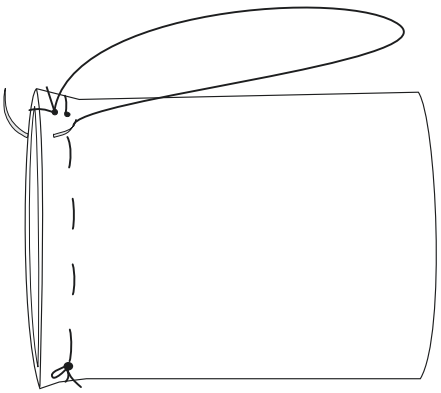
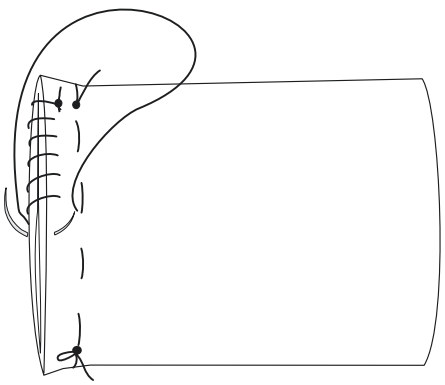


(4)

Place several sutures until you reach the opposite end. Tighten the suture line, and tie the suture to itself.



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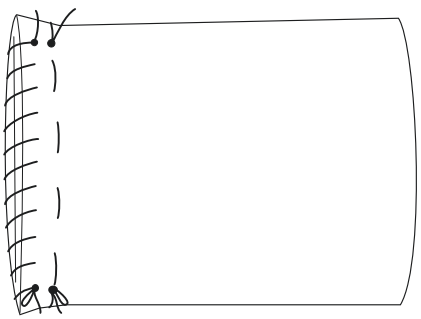
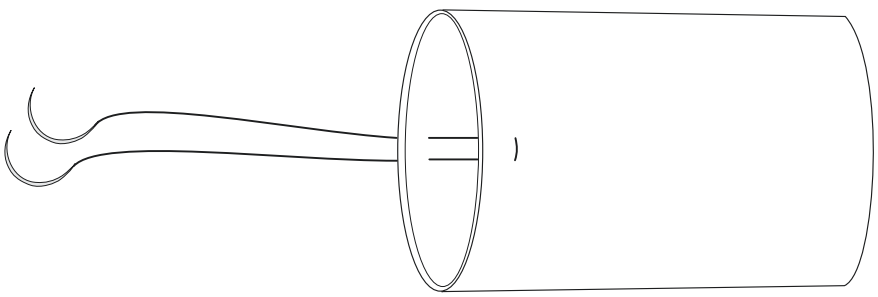


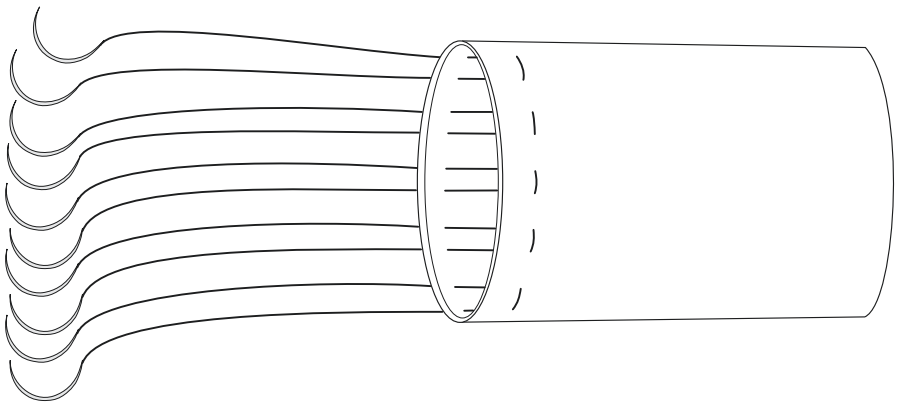
(6)

Alternatively, start by placing a horizontal mattress suture proximal to the edges of the transected end.

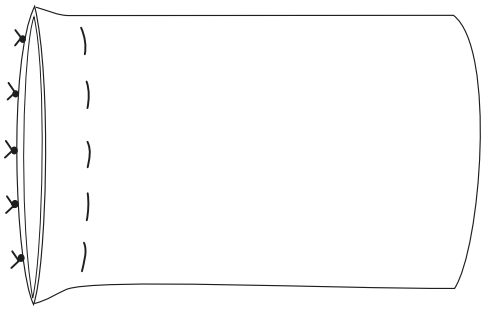


Closure of Large Transected Artery

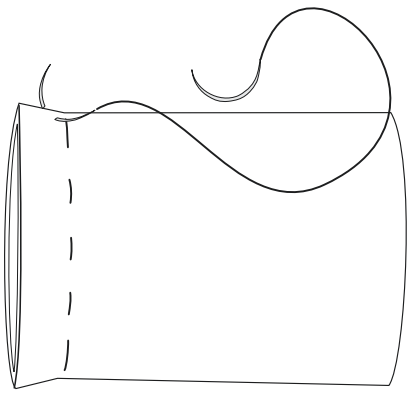
Place a row of sutures.



Tie the sutures.



Start another suture at one end. Tie the suture. You may run the suture to the other end, using a simple continuous closure.



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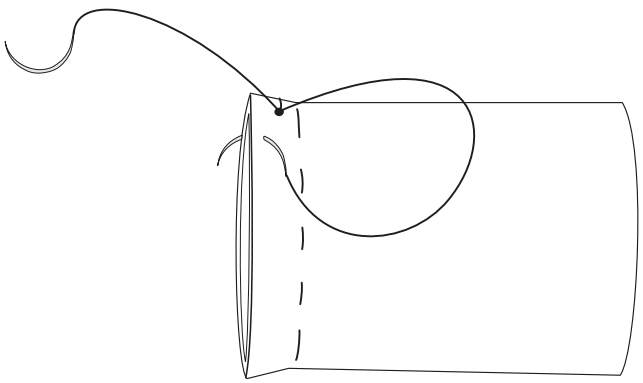
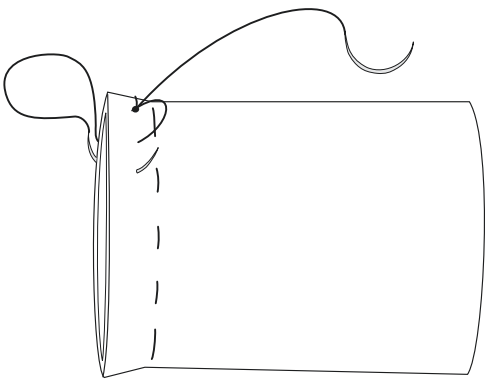


(2)

Alternatively, you may run the suture, using a horizontal mattress technique.



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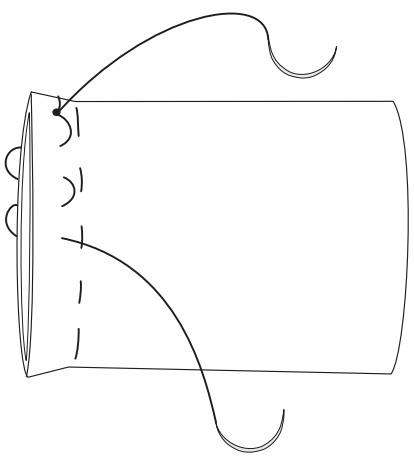
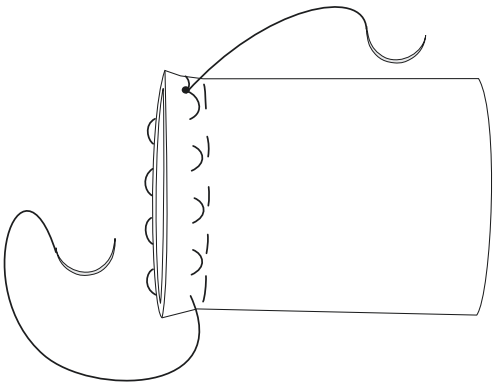


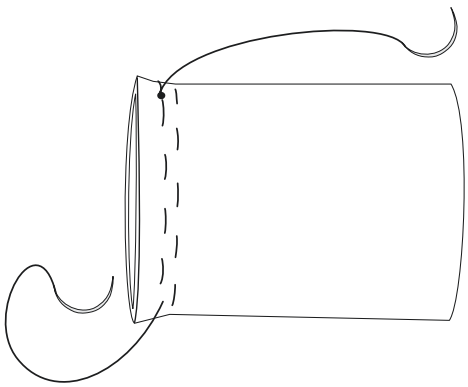
(4)

Closure of a Large Transected Artery

Continue until you reach the opposite end. Tighten the suture.

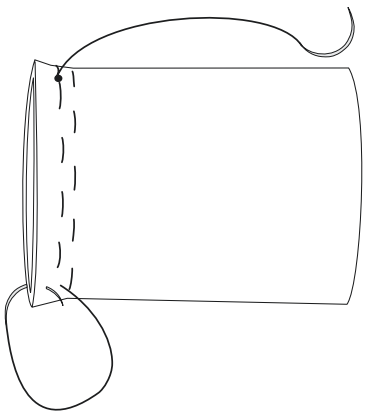


(5)



(6)

Run the suture back, using a simple continuous closure.



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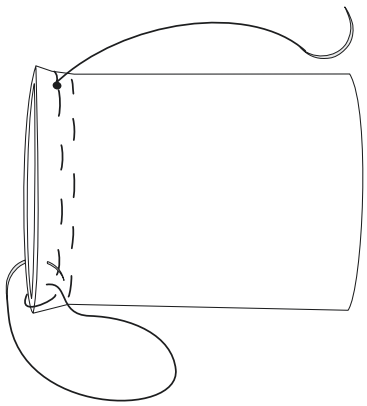
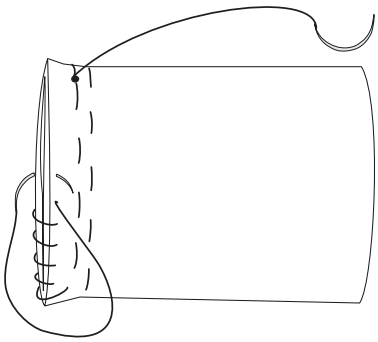
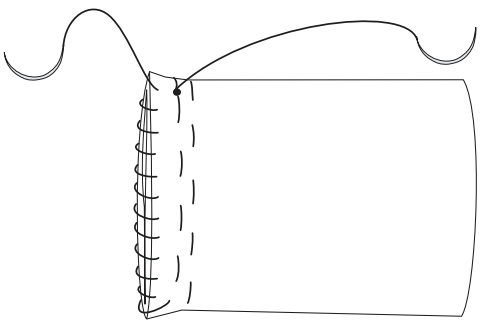


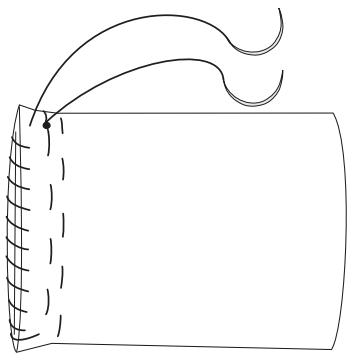
(8)

Place several sutures until you reach the opposite end.





Tighten the suture line, and tie both ends together.



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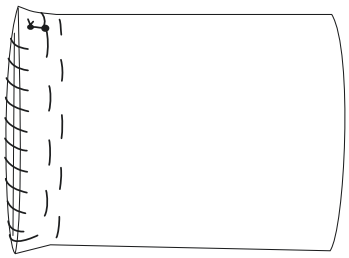
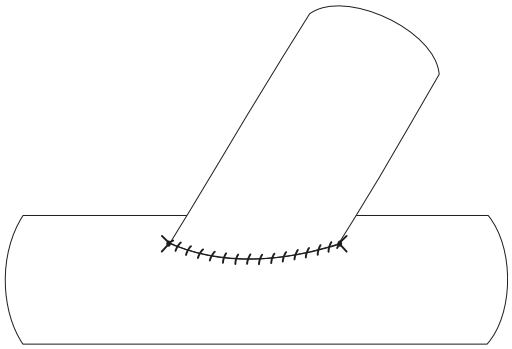


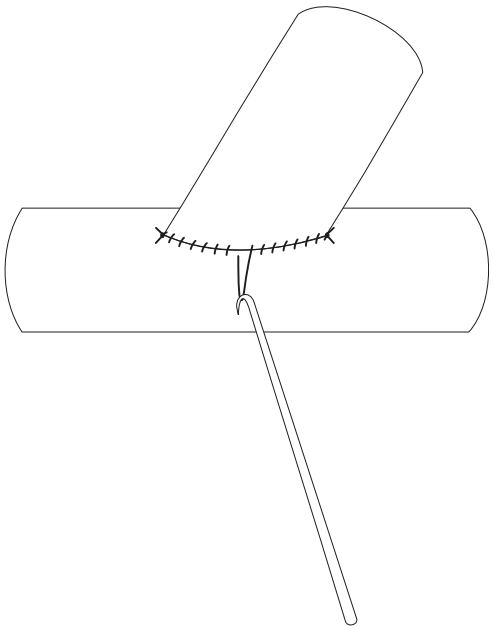
(12)

Repair of Loose Suture Line

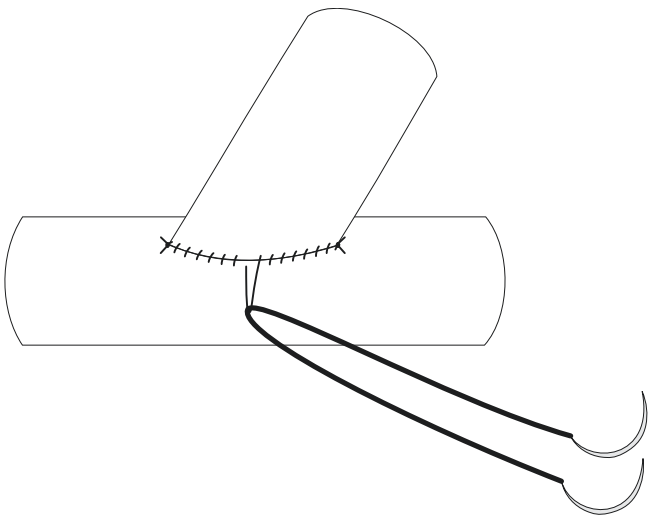
Excessive bleeding from the needle holes can occur when the anastomosis has been constructed without maintaining adequate tension on the suture line.



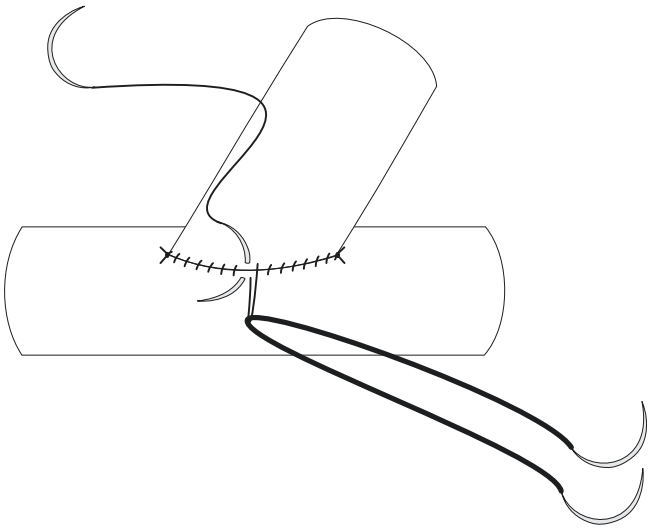
Using a nerve hook, a loop of the suture line is pulled with gentle tension.



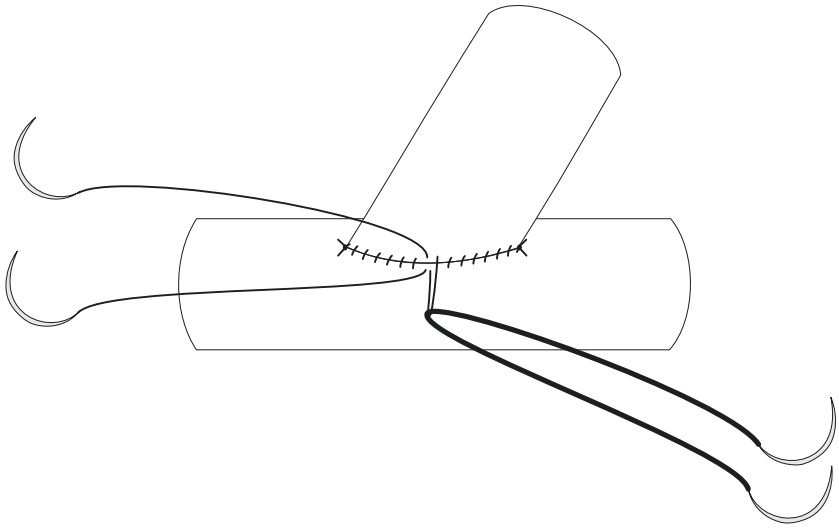
A suture of the same type is introduced through the loop. The loop can often be engaged with the needle without the nerve hook.



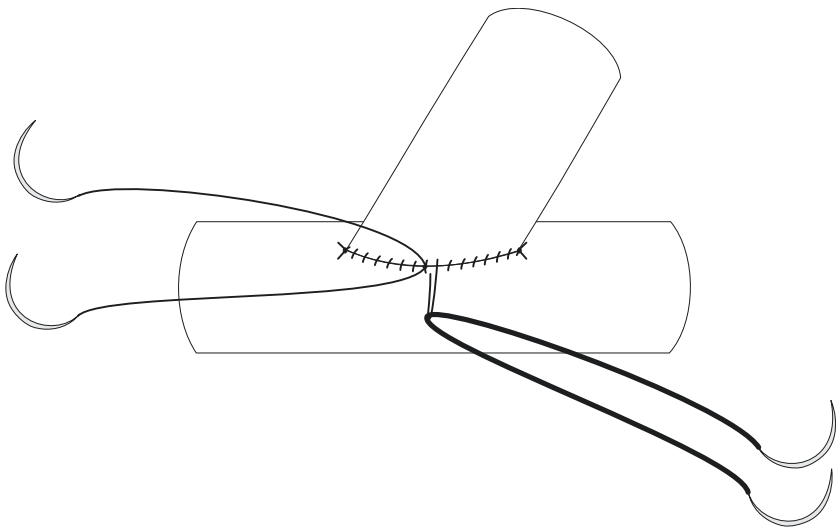
Repair of Loose Suture Line



A new suture is then placed close to the pulled loop.

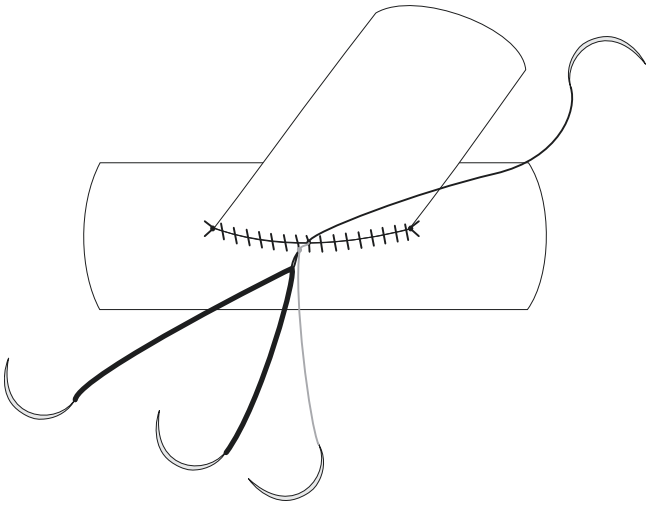


The new suture is then tied, while maintaining tension on the loop.

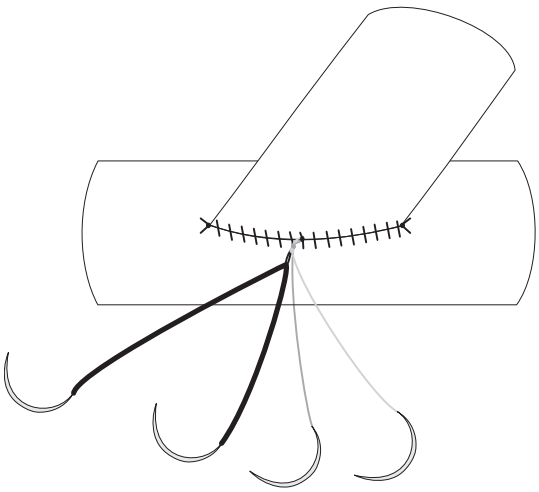


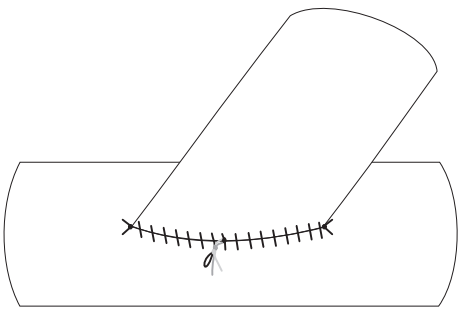
Repair of Loose Suture Line

Tie one end of the suture to the pulled loop.



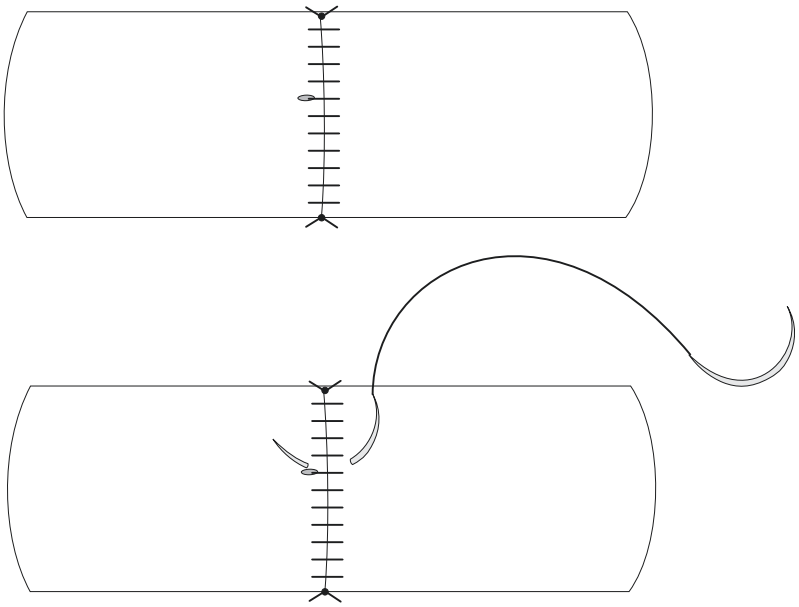
Tie the other end of the suture to the pulled loop.



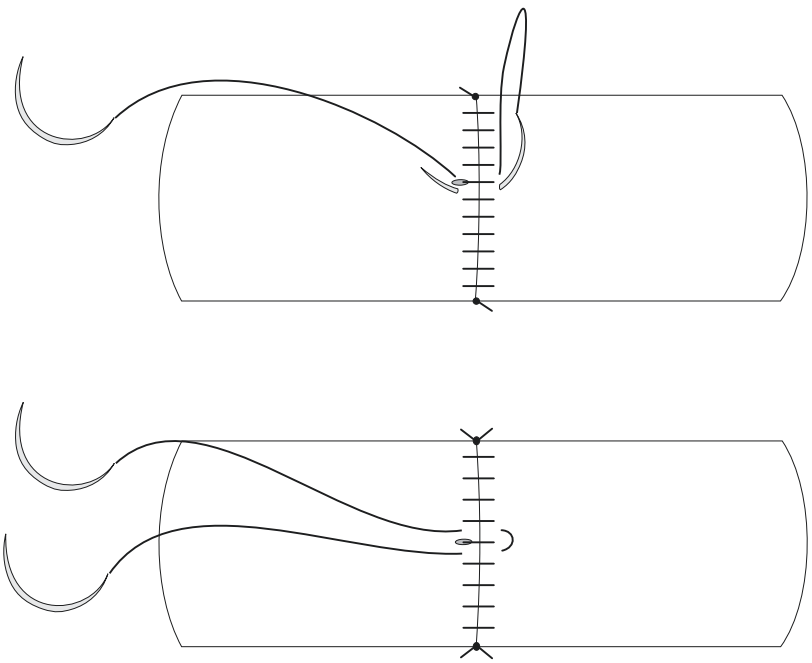


Repair of Longitudinal Tears

Bleeding from the suture line can be caused by a longitudinal tear along a needle hole.

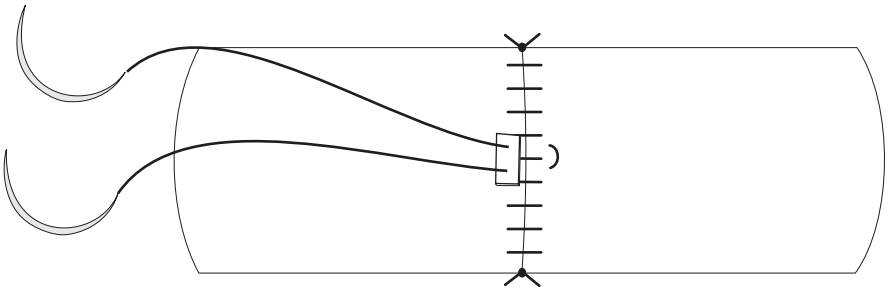


A horizontal mattress suture is placed around the tear.

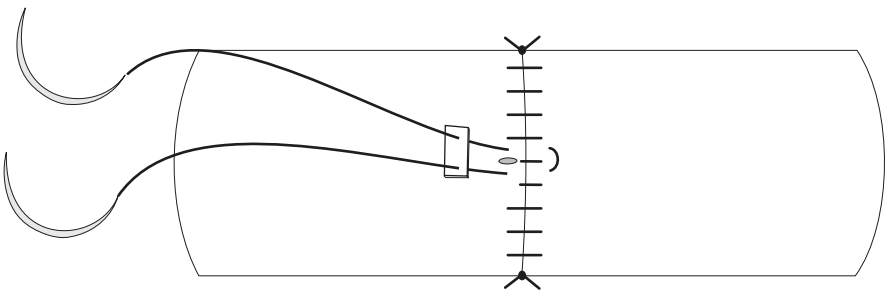


Repair of Longitudinal Tears

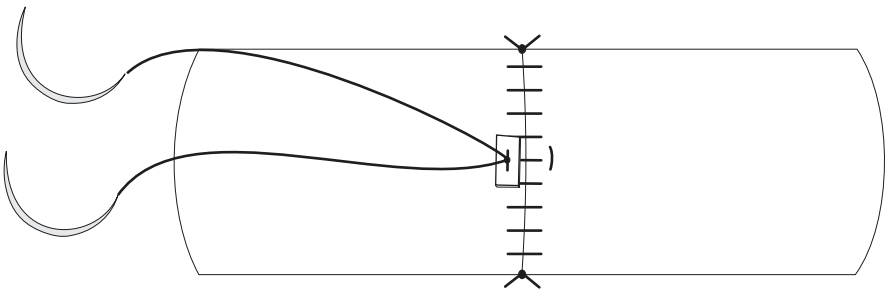
A pledget is then introduced.



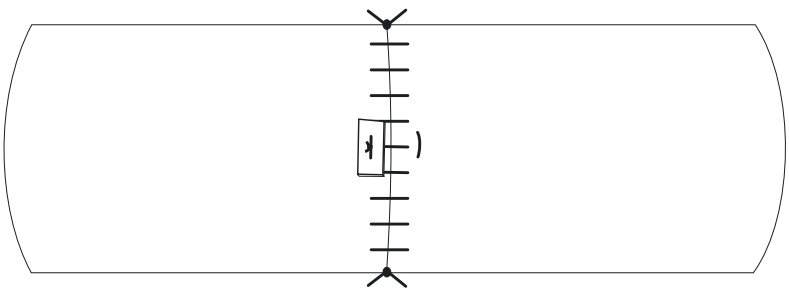
The pledget is advanced to cover the tear.



The suture is then tied over the pledget.



It is preferable to occlude the vessel proximally, before placing and tying the suture, to avoid additional tears from the repair suture.



6

Thrombectomy–Embolectomy

Jamal J. Hoballah

THROMBECTOMY–EMBOLECTOMY

Acute arterial occlusion can be caused by embolization or arterial thrombosis. Extractions of the embolus (embolectomy) or thrombus (thrombectomy) are frequently performed vascular procedures. Because thrombosis is very likely to occur distal to an embolization site, an embolectomy is often referred to as thrombo-embolectomy (TE). Several important considerations need to be addressed when performing these procedures. These include the type of blood vessel incision used to remove the thrombi, and the methods to minimize blood loss and blood vessel trauma during the procedure. Other important issues relate to the various methods used to achieve retrieval of all offending thrombi in addition to assessing the completeness and effectiveness of the clot extraction. Finally, the examination of the extracted thrombi can be very important, as it can provide insight into the etiology of the occlusive process.

INCISION TYPE

Thrombectomy or embolectomy can be performed through a transverse or a longitudinal incision in the vessel. It is important to ensure that the patient is adequately anticoagulated before occluding the vessels. When the occlusion is suspected to be due to embolization, a transverse incision may be most desirable. In this situation, a transverse incision can be closed primarily with relative ease and without causing any significant narrowing of the lumen. Embolization is usually suspected in a patient with arrythmias and intracardiac thrombi who lacks prior history of chronic arterial insufficiency and presents with acute arterial occlusion. In the presence of significant plaque in the artery or when the occlusion is suspected to be caused by thrombosis secondary to a stenotic pathology, a longitudinal arteriotomy will be most appropriate. Thrombosis secondary to a stenotic pathology is usually suspected when a patient presents with acute ischemia and has prior history of chronic arterial insufficiency in the absence of any cardiac arrythmias. A longitudinal arteriotomy will allow for inspection of the diseased area, as well as possible endarterectomy or repair with a patch. In addition, if TE proves to be inadequate, and a distal bypass

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becomes necessary, the incision can serve as the site of the proximal anastomosis of the bypass. The various methods used for closure of vascular incisions are discussed in Chap. 8.

MINIMIZING BLOOD LOSS

Blood loss during a TE can be significant. Most of the blood loss tends to occur when performing TE of the proximal segment of the vessel and reestablishing the arterial inflow. Blood loss may occur while passing the TE catheter beyond the thrombus and while retrieving the thrombus. To minimize blood loss, elastic loops are usually used to encircle and double loop the blood vessel. Gentle tension is then applied on the vessel loop when advancing or withdrawing the catheter. When dealing with a prosthetic graft or a large thickened artery, vessel loops may be inadequate to control bleeding around the TE catheter. In this situation, one option is to use "soft-jaw clamps" such as the Fogarty clamps to occlude the blood vessel. The soft jaws may be able to appose the blood vessel walls just enough to prevent bleeding and still allow the TE catheter to be advanced. The jaws are opened as the inflated TE catheter is being withdrawn. Another useful option is to pinch the vessel between the thumb and the index finger of one hand, while the other hand is manipulating the TE catheter.

AVOIDING VESSEL TRAUMA

Catheter manipulation during a TE can result in significant injury to the blood vessel [1, 2]. Vessel injury can be induced by the tip or the balloon of the TE catheter. The vascular trauma can occur during insertion, advancement, or withdrawal of the TE catheter. One type of injury occurs when the catheter is inadvertently introduced into a subintimal location. Thus, during insertion, it is very important to be sure that the catheter tip is actually going into the lumen of the vessel. If resistance is met and the catheter cannot be advanced any further with gentle manipulation, forceful advancement should be avoided. Forceful advancement can result in vessel perforation or can drive the catheter into a subintimal plane. The latter will result in intimal dissection. Furthermore, upon withdrawal of the inflated TE catheter, part of the intima may be stripped. It is also important to realize that every time an inflated catheter is withdrawn, intimal damage could occur. In fact, this is one of the techniques used in experimental animal models to harvest endothelial cells or to cause endothelial trauma for the evaluation of neointimal hyperplasia. Vessel injury can occur from excessive shear forces on the wall while retrieving the TE catheter, especially if the balloon is overinflated. Balloon overinflation can also result in vessel rupture.

Several steps can be helpful in avoiding vessel trauma during TE. First, it is important to select the appropriate size of the TE catheter. In general, a size 2 Fogarty catheter will be appropriate for vessels less than 2 mm in diameter, such as the pedal or hand vessels. A size 3 Fogarty catheter is usually most appropriate for vessels with diameters of 2–4 mm, such as the tibial vessels or the infrageniculate popliteal artery. A size 4 Fogarty catheter is usually most appropriate for vessels with diameters of 4–10 mm, such as the above-knee popliteal and superficial femoral arteries, as well as the common femoral artery. A size 4 Fogarty catheter can also be useful for the iliac arteries. A size 5 Fogarty catheter is most appropriate for vessels larger than 10 mm in diameter; it can be useful for TE of some relatively large iliac arteries. Other sizes available include size 6 and 7, which can also be used for thrombectomy of an aortic graft or a saddle aortic embolus. Before inserting the TE catheter, it is imperative to test the balloon and get a visual assessment of its size once fully inflated. It is a good practice to limit the amount of fluid used in the syringe to inflate the balloon to

the minimum volume needed for full inflation to avoid overexpansion and rupture of the balloon or the vessel. Another helpful step is to measure the distance from the arteriotomy to the area where the thrombus is expected to be lodged. This will help determine if the catheter has reached far enough to the desired location. In addition, this may help avoid pushing the catheter beyond the desired location unnecessarily, thus limiting the potential injury to the artery. Once the catheter has reached maximal advancement, gentle inflation, while pulling the catheter back, will allow feeling the friction between the balloon and the vessel wall. At that point, the balloon should not be inflated any further. The catheter should just be retrieved with that amount of tension. It is very important that the same individual withdrawing the catheter is also controlling the degree of balloon inflation. Similarly, slight deflation of the catheter may be necessary if the catheter is passing across a stenotic area. As the catheter is being pulled back, additional deflation or inflation may be necessary to accommodate for any change in the caliber of the vessel. With experience, you realize tactile feeling and resistance are important in achieving TE with minimal wall barotrauma.

ACHIEVING A COMPLETE THROMBECTOMY–EMBOLECTOMY

The ability to retrieve all clots and thrombi depends on getting the catheter into all the desired locations as well as the degree of adherence of the thrombi to the vessel wall. If the TE catheter does not reach the desired location, an angiogram can be very useful to delineate the anatomy. One useful approach is to perform the entire TE under fluoroscopic guidance. Half-strength contrast is used to inflate the balloon. The balloon is first tested under fluoroscopy to appreciate its shape when inflated and deflated. The balloon is then inserted and manipulated, based on the prethrombectomy angiogram. This step can be facilitated further if the fluoroscopy machine used has road-mapping capabilities. The fluoroscopy machine will also be used to follow the withdrawal of the catheter. Useful information can be gained from observing the movement of the catheter tip and the inflated balloon under fluoroscopy. First, better insight into the anatomical location of the catheter tip and the vessels that are being catheterized can be obtained. Furthermore, if the inflated catheter is passing across an area of stenosis, the balloon will be seen changing in shape and developing a "waist" at the level of the stenosis.

THROMBECTOMY–EMBOLECTOMY OF THE LOWER EXTREMITY VESSELS

During TE of the lower limb vessels, a Fogarty catheter introduced through the superficial femoral artery will tend to repeatedly travel into the peroneal artery. Thus, it is possible to perform a thrombectomy of the peroneal artery alone, leaving behind significant clots in the anterior and posterior tibial arteries. Several techniques can be used to guide the TE catheter selectively into the various tibial arteries. Prior to the use of intraoperative fluoroscopy, one helpful technique is to bend the tip of the TE catheter with the hope that at the level of the popliteal trifurcation, the bent tip will advance into the anterior or posterior tibial artery. Another technique is to perform the procedure using two TE catheters under fluoroscopic guidance. One TE catheter is placed at the origin of the tibioperoneal trunk, and the balloon is then inflated. Another TE catheter with a bent tip is advanced and manipulated under fluoroscopy to proceed into the anterior tibial artery. To catheterize the posterior tibial artery, the balloon of the first TE catheter is inflated at the level of the peroneal artery origin. The second

catheter is then advanced after flipping the tip by 180 degrees. Another option is to use special TE catheters that can be introduced over a wire (Fogarty Thru-Lumen Catheter; Baxter Healthcare Corp., Irvine, CA). The wire will be directed first into the desired vessels under fluoroscopic guidance, using an angled tip catheter. The TE catheter is then introduced over the wire, and TE is performed under fluoroscopy. This technique can also be useful when performing aortoiliac thrombectomy. A wire is introduced through each common femoral artery and the thrombo-embolectomy is performed over the wire, while maintaining wire access in case additional endovascular interventions are needed. It is often challenging to withdraw the catheter, while maintaining wire access and adjusting the balloon inflation at the same time, and, often, the wires are pulled out of the artery during the procedure, especially that the tibial TE catheter travels over a 0.018 wire.

An additional valuable technique, especially if the TE over the wire catheter is not available, is to catheterize the artery of interest with a regular 0.034 glide wire, and then introduce a long 6 French 65-cm Ansel sheath into the artery. The obturator is then removed and the 3 French TE catheter is introduced through the Ansel sheath to its desired location. The support provided by the sheath usually will allow the catheter to travel easily as far as it is needed. The inflated TE balloon catheter and the Ansel sheath are then withdrawn together out of the arteriotomy. Along the same principles, special aspiration catheters have been designed to be introduced instead of the traditional TE catheter and then activated, resulting in clot aspiration. These catheters come in various sizes and may allow for a percutaneous approach for retrieval of localized thrombi and small clot burdens. If despite all these maneuvers the desired vessels cannot be canalized, exposure of the popliteal trifurcation will be necessary. The TE catheter can be introduced into the orifice of each individual tibial vessel under direct vision. Occasionally, exposure of the tibial vessels at a more distal level, such as the ankle, may be necessary. This allows direct catheterization and TE of the individual tibial vessels.

One of the difficulties encountered with TE of prosthetic grafts is the excessive adherence of the clot to the graft wall. The usual Fogarty catheter may not be able to retrieve the clot, and other catheters can be used. These catheters have been designed especially for the purpose of recovering adherent thrombi. One of these catheters has a mesh over the balloon of the catheter, which theoretically helps in capturing and retrieving adherent clots (Latis Graft Cleaning Catheter; Applies Medical Resources, Laguana Hills, CA). Other catheters have a curved springy wire at the tip instead of the balloon. The curved wire will serve to strip the adherent thrombus from the vessel wall. (Fogarty Adherent Clot Catheter and Fogarty graft thrombectomy catheter; Baxter Healthcare Corp., Irvine, CA) These special catheters are intended to be used in prosthetic grafts. Their use in native vessels should be avoided.

EVALUATING THE COMPLETION AND RESULT OF THE THROMBECTOMY–EMBOLECTOMY

A thorough irrigation of the lumen with heparinized solution is performed. Angiography or angioscopy can be performed to check for residual clots. If the TE appears to be satisfactory, the arteriotomy is closed. One helpful maneuver is to tighten the suture line without tying of the suture and then allow for reperfusion of the limb. Blood flow distally is then assessed, using a Doppler probe or angiography. Should additional thrombectomy become necessary, tension is taken off the sutures, and the suture line is gently loosened and unraveled. The TE catheter insertion and withdrawal are repeated until no additional clots can

be retrieved on two consecutive withdrawals. In the presence of a clot that could not be retrieved, an attempt at suction aspiration of the residual clot can be tried, using a 60-cc syringe with negative pressure or an aspiration catheter device. Furthermore, an intraoperative injection of a thrombolytic agent (tPA 0.05 mg/kg) into the arterial bed harboring the clot can be helpful. If there is a spasm, you can inject 100–200 mcg of nitroglycerin or 30–60 mg of papaverine directly into the vessel; wait for a few minutes and repeat the angiogram. Notify anesthesia in case the systemic blood pressure drops. Finally, it is important to check for compartmental hypertension as a possible cause for poor distal Doppler signals despite what appears to be an adequate thrombectomy. The normal compartmental pressure should be less than 35 mmHg.

EXAMINATION OF RETRIEVED THROMBI

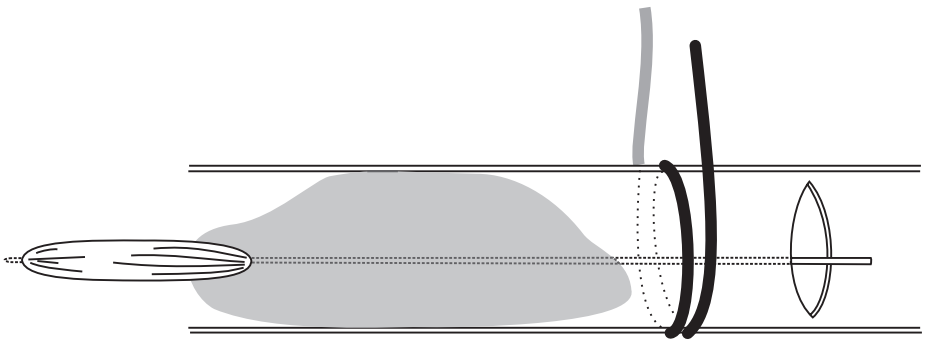
All retrieved clots and thrombi should be inspected. Inspection of the clots can be helpful in determining the etiology of the occlusion. Clots retrieved when thrombosis develops from low flow secondary to a tight stenosis are similar to coagulated blood. The presence of a grayish granular clot suggests platelet depositions. The presence of a darker or grayish organized clot at the end of the thrombus suggests embolization. An embolus from an atrial myxoma or tumor tends to be gelatinous with a grayish color. In this situation, microscopic examination of the thrombus is essential to delineating the source of the clot and establishing the diagnosis.

REFERENCES

1. Fogarty TJ, Cranley JJ, Krause RJ, et al. A method of extraction of arterial emboli and thrombi. Surg Gynecol Obstet. 1963;116:241.
2. Foster JH, Carter JW, Edwards WH, et al. Arterial injuries secondary to the use of the Fogarty catheter. Ann Surg. 1970;74:673.

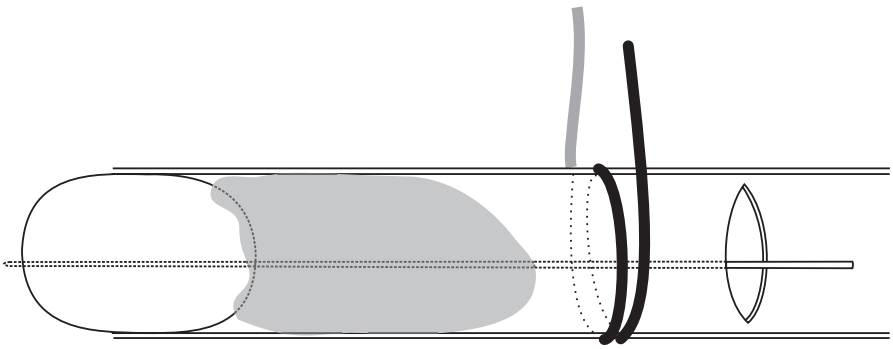
Thrombo–Embolectomy
Minimizing Blood Loss

Blood vessel control is achieved using elastic vessel loops. The embolectomy catheter is introduced carefully into the vessel lumen.

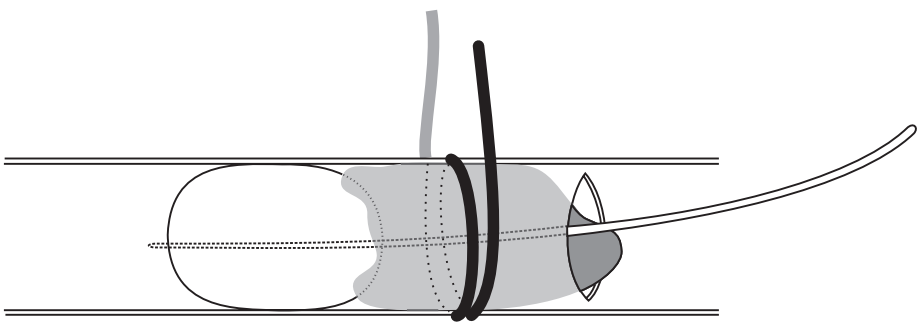


The catheter is advanced until it reaches the desired location. Forceful advancement of the catheter is to be avoided.

The balloon is gently inflated as the catheter is being pulled back slowly. This allows for feeling the friction between the balloon and the arterial wall. The catheter is withdrawn back, while maintaining the least amount of friction and tension.

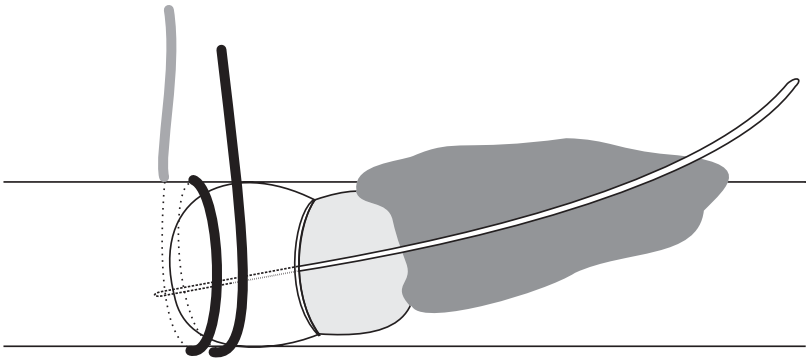


The vessel loop is kept loose, while the thrombus is being extruded out of the vessel.

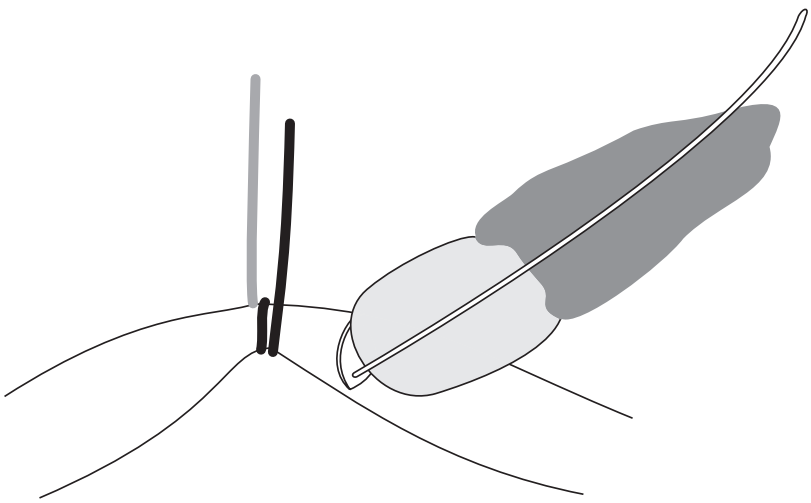


Thrombo–Embolectomy
Minimizing Blood Loss

Once the thrombus is retrieved, a gush of blood is allowed to flush out any remaining clot from the arteriotomy.

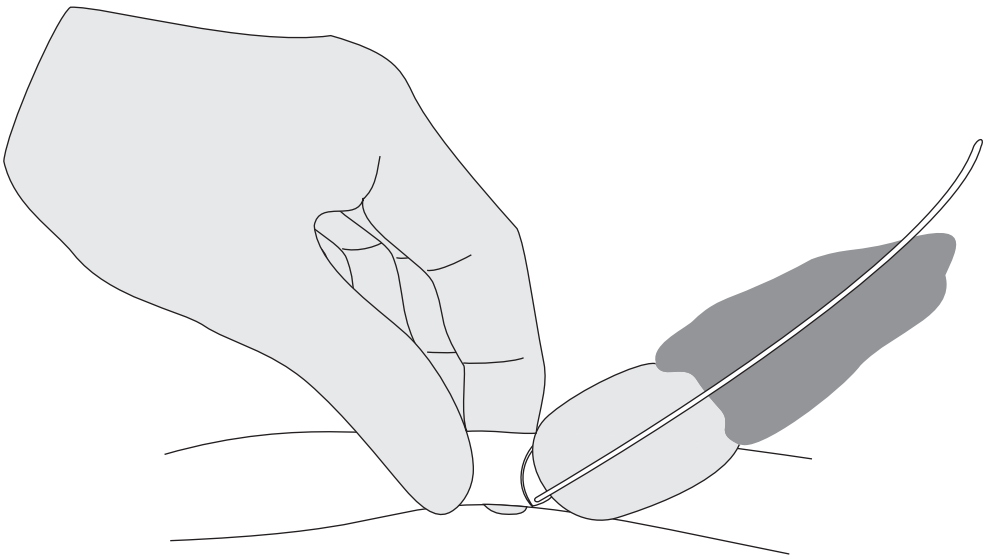


The vessel loop is then pulled to prevent further blood loss. The procedure is then repeated until no further clot is retrieved.



Thrombo–Embolectomy
Minimizing Blood Loss

When performing thrombectomy of a prosthetic conduit, the vessel loop may not be strong enough to compress the graft. Control of the proximal bleeding and the catheter can be achieved using Fogarty vascular clamps. Alternatively, the graft is pinched with the fingers, while advancing the embolectomy catheter to prevent excessive blood loss.

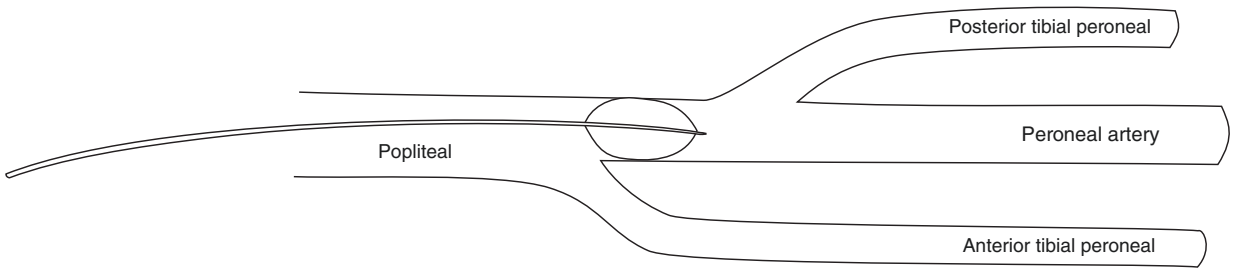


The thrombus is examined. The shape and form of the clot can provide an insight into the etiology of the occlusion. A stasis clot will have the shape of the vessel with the consistency of old clotted blood. A grayish granular thrombus is often seen with excessive platelet deposition. A whitish or darker piece of clot at the distal tip of the thrombus usually suggests an embolic process.

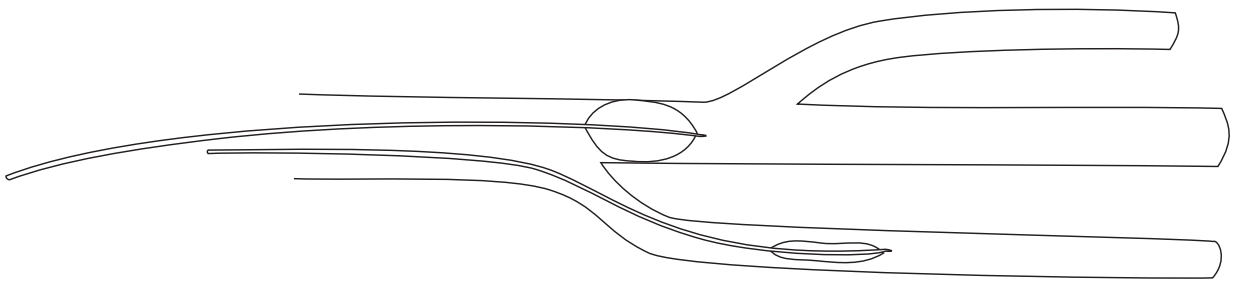
Thrombo–Embolectomy

Thrombo–Embolectomy of Lower Extremity Vessels

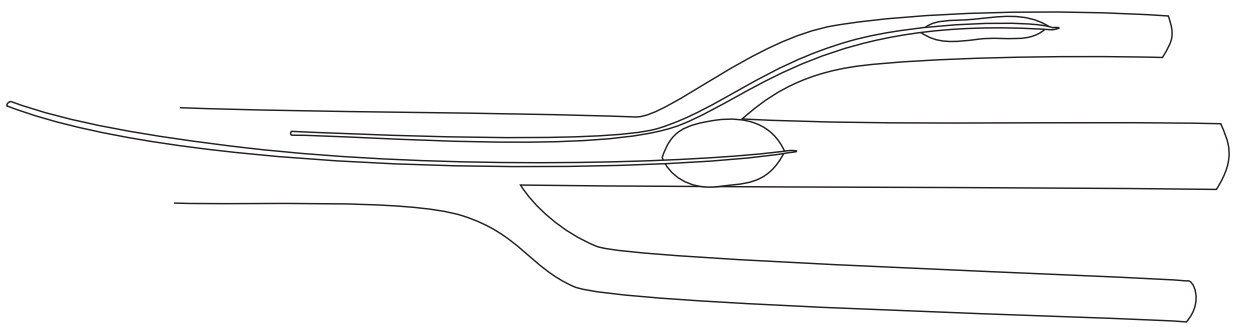
When performing a thrombo-embolectomy of the infrapopliteal vessels through a femoral arteriotomy, the catheter tends to repeatedly travel into the peroneal artery.



To introduce the catheter into the anterior tibial artery, introduce one Fogarty catheter. Under fluoroscopic guidance, place the catheter at the origin of the tibioperoneal trunk; inflate the balloon. Introduce another catheter, with the tip slightly bent.



To introduce the catheter into the posterior tibial artery, place the first Fogarty catheter at the suspected origin of the peroneal artery. Introduce the second catheter after rotating it 180°.



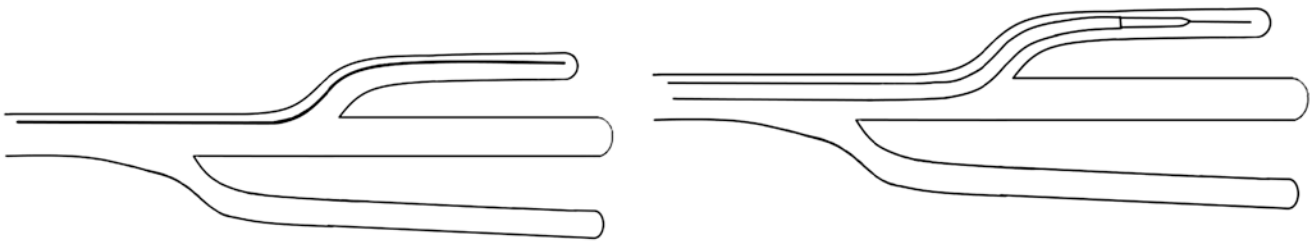
Thrombo–Embolectomy

Fluoroscopic-Guided Thrombo–Embolectomy of Lower Extremity Vessels

The superficial femoral artery is exposed few centimeters distal to its origin. An arteriotomy is performed and a short 5 French sheath is placed. An angiogram is performed directly through the sheath to identify the anatomy and the occluded tibial arteries.

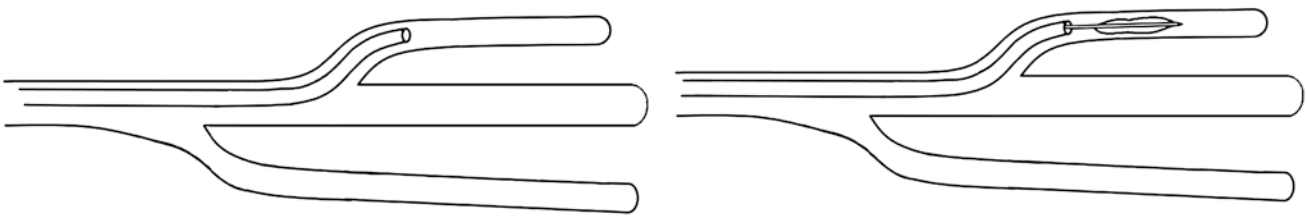
The wire is directed into the desired vessel.

The 5 French sheath is removed and a 65-cm-long 6 French sheath is advanced over the wire into the desired occluded artery.



The obturator is removed and the TE catheter inserted.

The balloon is then inflated, and the TE and sheath are removed together.



7

Endarterectomy

Jamal J. Hoballah

The histological examination of the cross section of the arterial wall will reveal three layers— the intima, the media, and the adventitia. The innermost layer is the intima, composed of the endothelium and the internal elastic lamina. The endothelium provides a smooth lining and has antithrombotic activity. The media is the inner layer of the arterial wall and is made of layers of smooth muscle cells oriented in longitudinal and circular directions. These layers are surrounded by basal lamina, collagen, and elastin fibers. The main role of the media is to regulate blood vessel resistance by constricting and controlling the vessel lumen. The adventitia is the outermost layer and contains the vasovasorum, which provides blood supply to the wall. In addition, it has a collagenous matrix that provides the artery's tensile strength. The purpose of an endarterectomy is to remove an obstructive atherosclerotic plaque from the arterial lumen. This usually results in removing the thickened intima and inner media, leaving behind the outer part of the media and the adventitia. The plaque can be removed by opening the vessel longitudinally and then separating the plaque from the vessel wall (Open Endarterectomy; section "Tacking the Endarterectomy Endpoint"). The plaque can also be removed by pushing and pulling the plaque, while everting the wall of the vessel (section "Eversion Endarterectomy"). Semiclosed endarterectomy refers to the procedure where an incision is performed proximally and distally in an artery. The plaque in the vessel segment between the arteriotomies is removed using special instruments known as plaque strippers. Currently, semiclosed endarterectomy is infrequently performed and will not be reviewed in this chapter.

Endarterectomy is ideal for treating focal atherosclerotic disease in medium- and large-sized arteries. Both open and eversion techniques can be utilized when conducting carotid endarterectomy, one of the most commonly performed vascular procedures. Aortoiliac endarterectomy, once a commonly performed procedure, is very infrequently performed, nowadays, with the availability of endovascular options. An aortobifemoral bypass is often selected over aortoiliac endarterectomy when endovascular interventions fail, as it tends to be a simpler operation. In the infrainguinal region, common femoral and profunda femoris endarterectomies continue to be performed in select cases as independent procedures or adjunctive procedures to infrainguinal bypasses. Below the knee endarterectomy is almost never performed and limited to very rare

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situations where the surgeon is forced to conduct an endarterectomy at the distal anastomotic bypass site, in order to place the anastomotic sutures.

OPEN ENDARTERECTOMY

When performing an open endarterectomy, being in the right plane is very important. Start by holding the edge of the adventitia with a pickup and pulling it away from the plaque. A plane will then develop. Using the Freer elevator, the adventitial wall is pushed away from the plaque. The endarterectomy plane is developed on each side of the vessel wall and advanced posteriorly until it becomes circumferential. On the proximal end, when a normal part of the artery is reached, the plaque is transected flush with the arterial wall without leaving any significant protruding ledge. On the distal end, if a normal segment of the artery is reached, an attempt is made to move the endarterectomy plane to a more superficial level. This usually allows terminating the endarterectomy with a smooth endpoint. Remaining circular fibers of the media can be gently and meticulously peeled off.

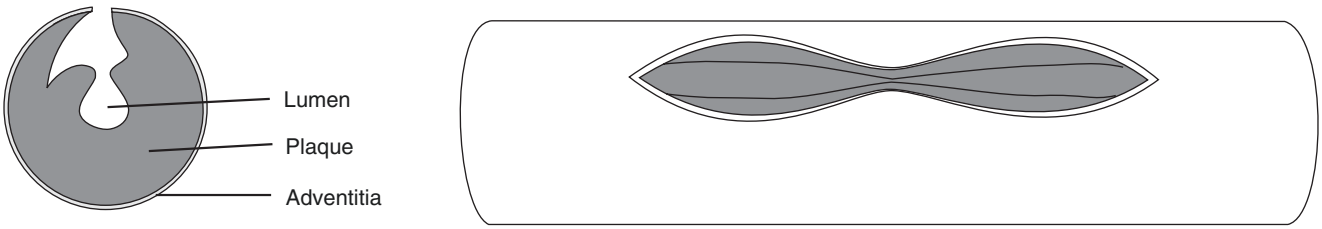
TACKING THE ENDARTERECTOMY ENDPOINT

If the disease extends beyond the level where the endarterectomy needs to end, transecting the plaque will create a shelf at the endpoint of the endarterectomy. When prograde flow is resumed, this shelf could lift up and create a dissection or an acute thrombosis. If a smooth transition cannot be achieved at the distal endarterectomy endpoint, the shelf of thickened intima or remaining plaque should be fixed to the vessel wall by "tacking" sutures (section "Tacking Sutures"). This is achieved by placing sutures in the endarterectomized and nonendarterectomized vessel wall segment to prevent separation of the adventitia from the remaining part of the arterial wall. Start by placing the suture 0.5–1 mm from the edge of the endarterectomy in the nonendarterectomized segment. This suture should always be placed from the inside of the intima toward the adventitial side to prevent separation of the intima. Place the other suture very close to the edge of the endarterectomy. This suture is also placed from the inside to the outside. Continue by placing several similar sutures almost 3–4 mm apart. Each suture is then tied separately. Great attention should be given to having the appropriate amount of tension on the sutures while tying. Excessive tension can result in tearing of the suture through the intima and media in the nonendarterectomized segment of the wall. Heparinized saline irrigation is then used to test the wall of the artery to check for any area that can still be at risk for lifting up, causing an intimal flap or dissection.

EVERSION ENDARTERECTOMY

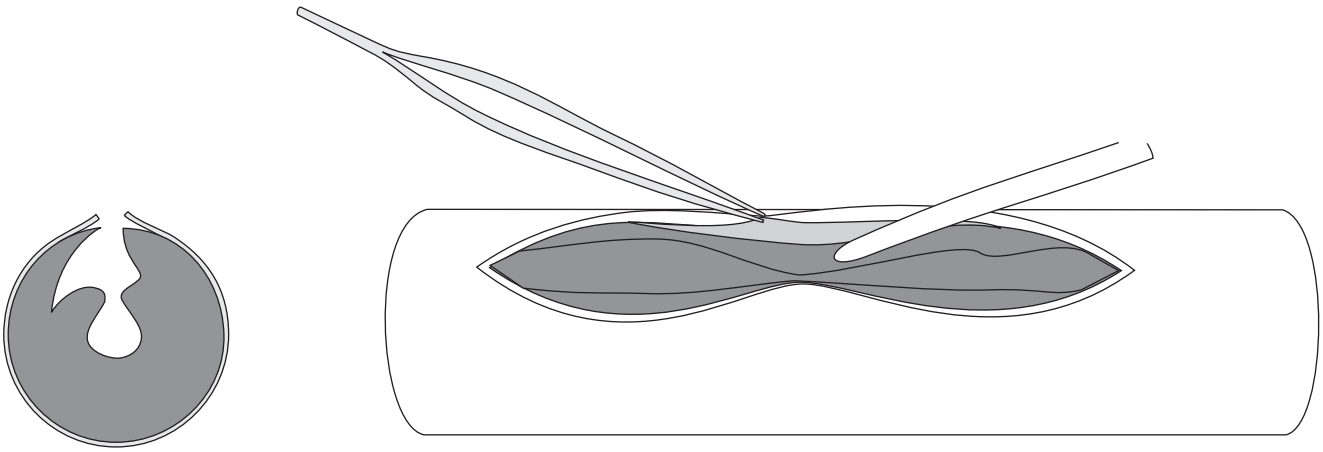
When the plaque is removed by everting the vessel wall and pushing the plaque out without opening the vessel longitudinally over the plaque, the procedure is called eversion endarterectomy (section "Eversion Endarterectomy"). It can be performed by transecting the artery and everting and rolling the adventitia away from the plaque as done is carotid eversion endarterectomy. It can also be performed without completely transecting the vessel as done with the external carotid artery during open carotid endarterectomy.

Open Endarterectomy

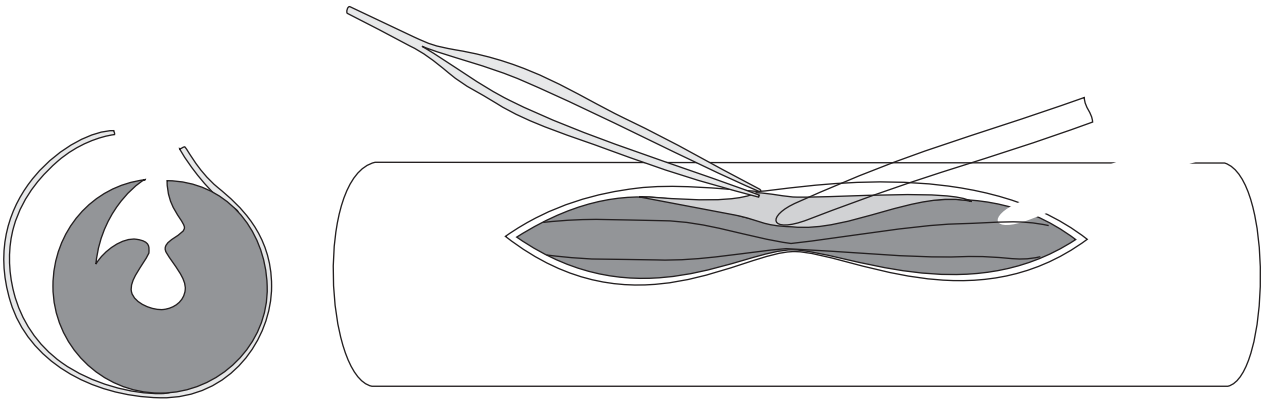


Cross Section

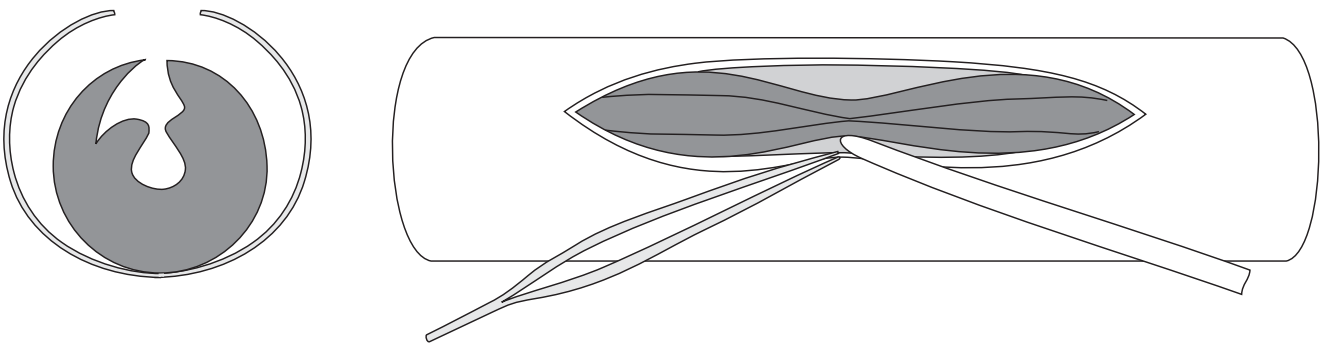
Incise the artery longitudinally through the plaque until a normal part of the artery is reached.



Hold the edge of the adventitia and gently lift it away from the plaque. Use the Freer elevator to identify the correct plane of endarterectomy.



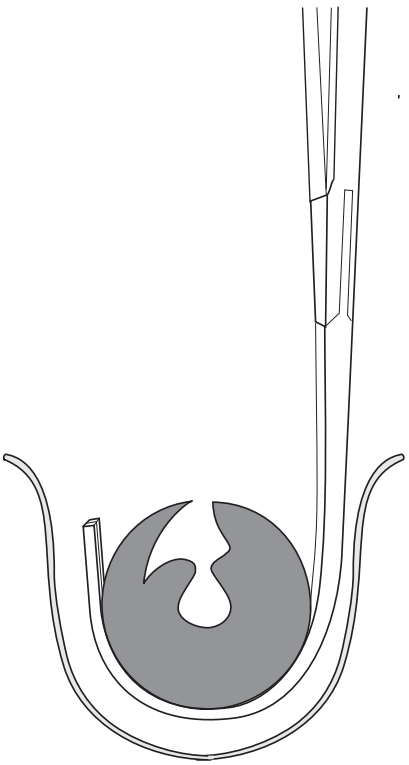
Continue separating the plaque from the adventitia by gently pushing the adventitial wall away from the plaque.

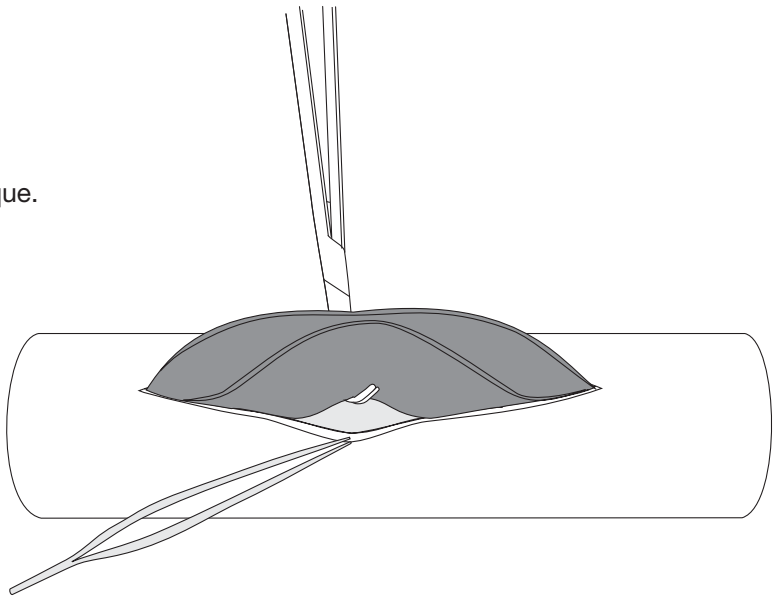


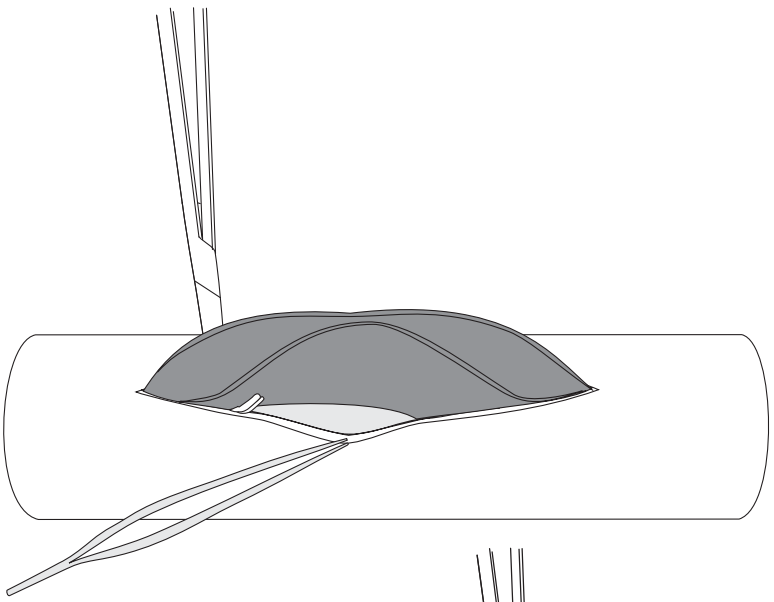
Repeat the same maneuver from the other side of the arteriotomy.

Open Endarterectomy

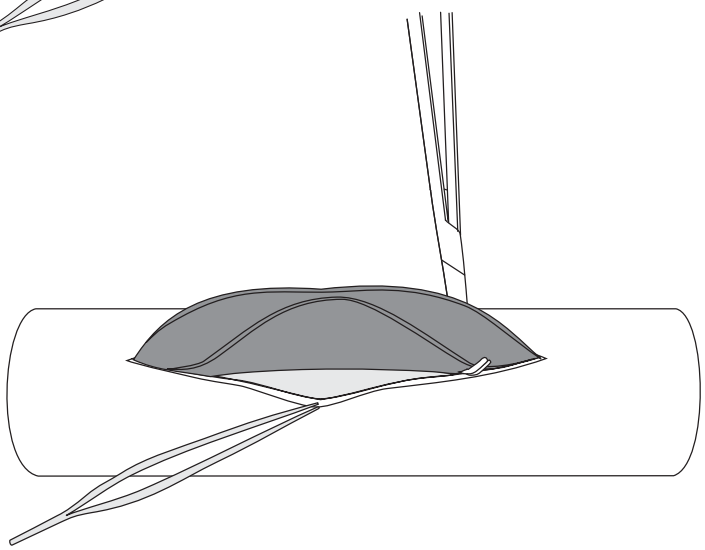
Pass a right-angle clamp underneath the plaque.







You may use the right-angle clamp to free the remainder of the plaque from the arterial wall by pushing the clamp toward each end of the arteriotomy.

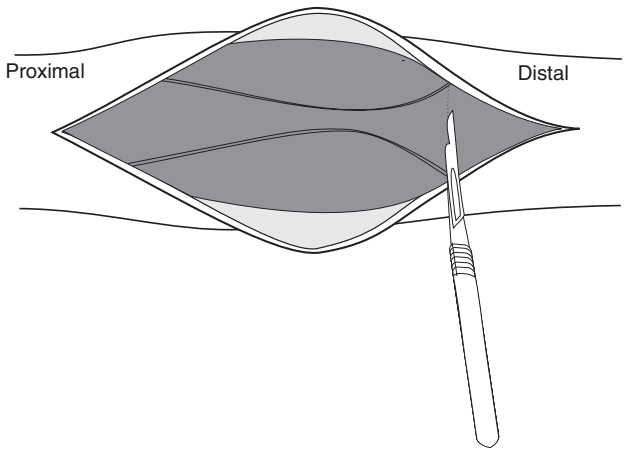


Open Endarterectomy
Tacking Sutures

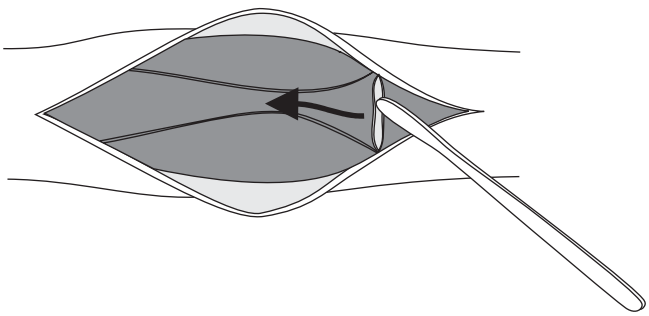
At the level of the distal endpoint, changing the endarterectomy plane into a more superficial one can help in providing a smooth, well-feathered endpoint.

A 15 blade may be used to transect the plaque.

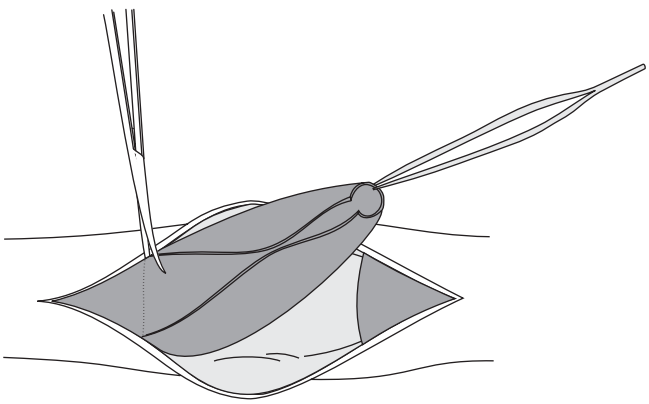
Start by carefully incising the intima at the desired level.



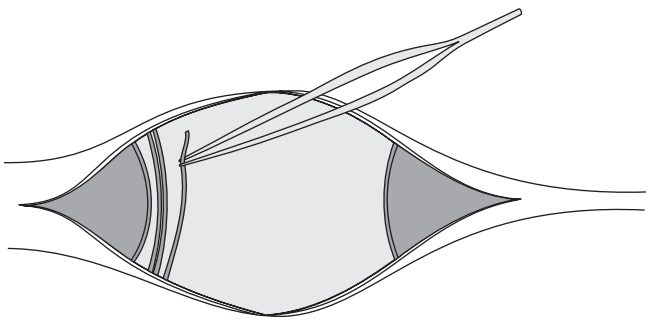
Use the Freer elevator to separate the plaque. Push with the Freer elevator using a sweeping motion toward the proximal endpoint.



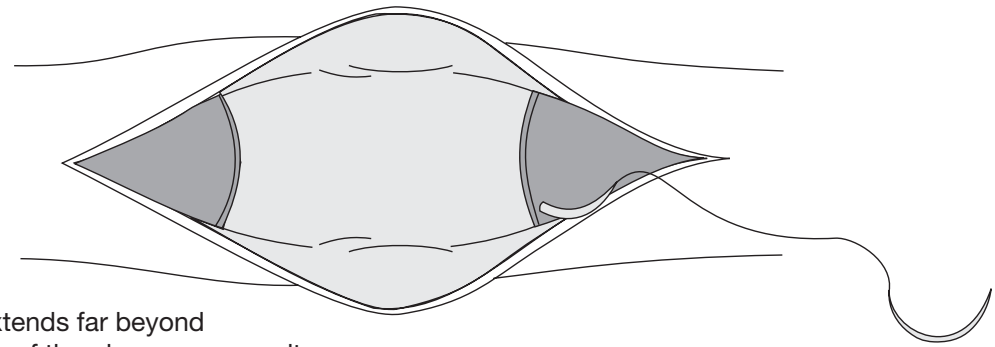
Alternatively, you may use the scissors to transect the plaque. Care is taken to avoid leaving an edge of plaque protruding at the endpoint.



Remaining circular fibers are individually peeled off.

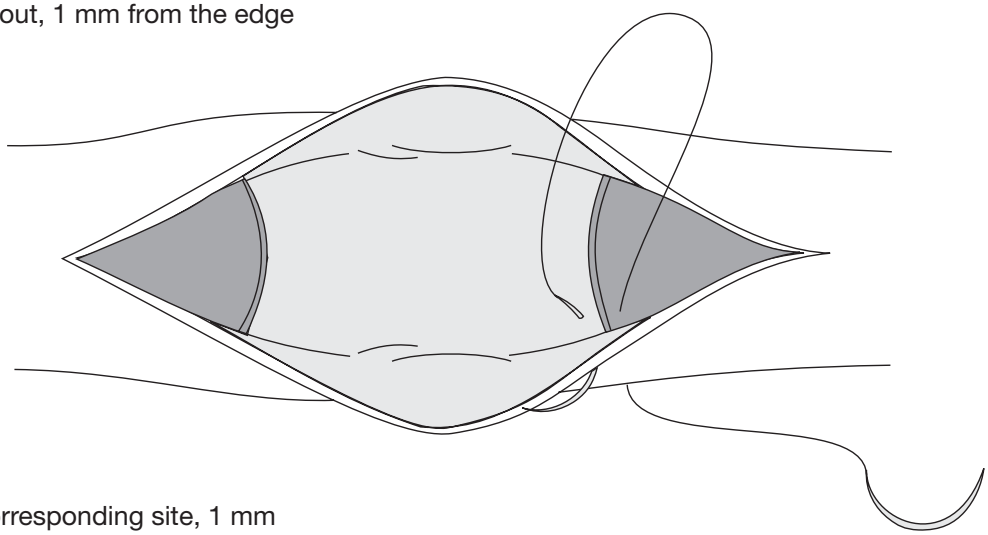


Open Endarterectomy
Tacking Sutures



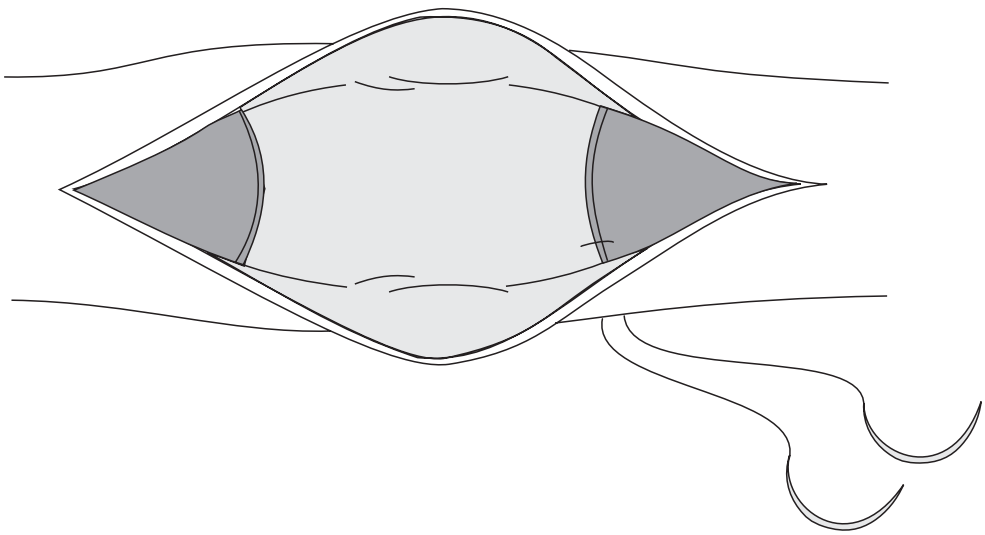
Occasionally, the plaque extends far beyond the arteriotomy. Transection of the plaque may result in an edge that could lift, causing dissection or thrombosis. Tacking the endarterectomy endpoint may be necessary.

Introduce the needle inside out, 1 mm from the edge of the endarterectomy.



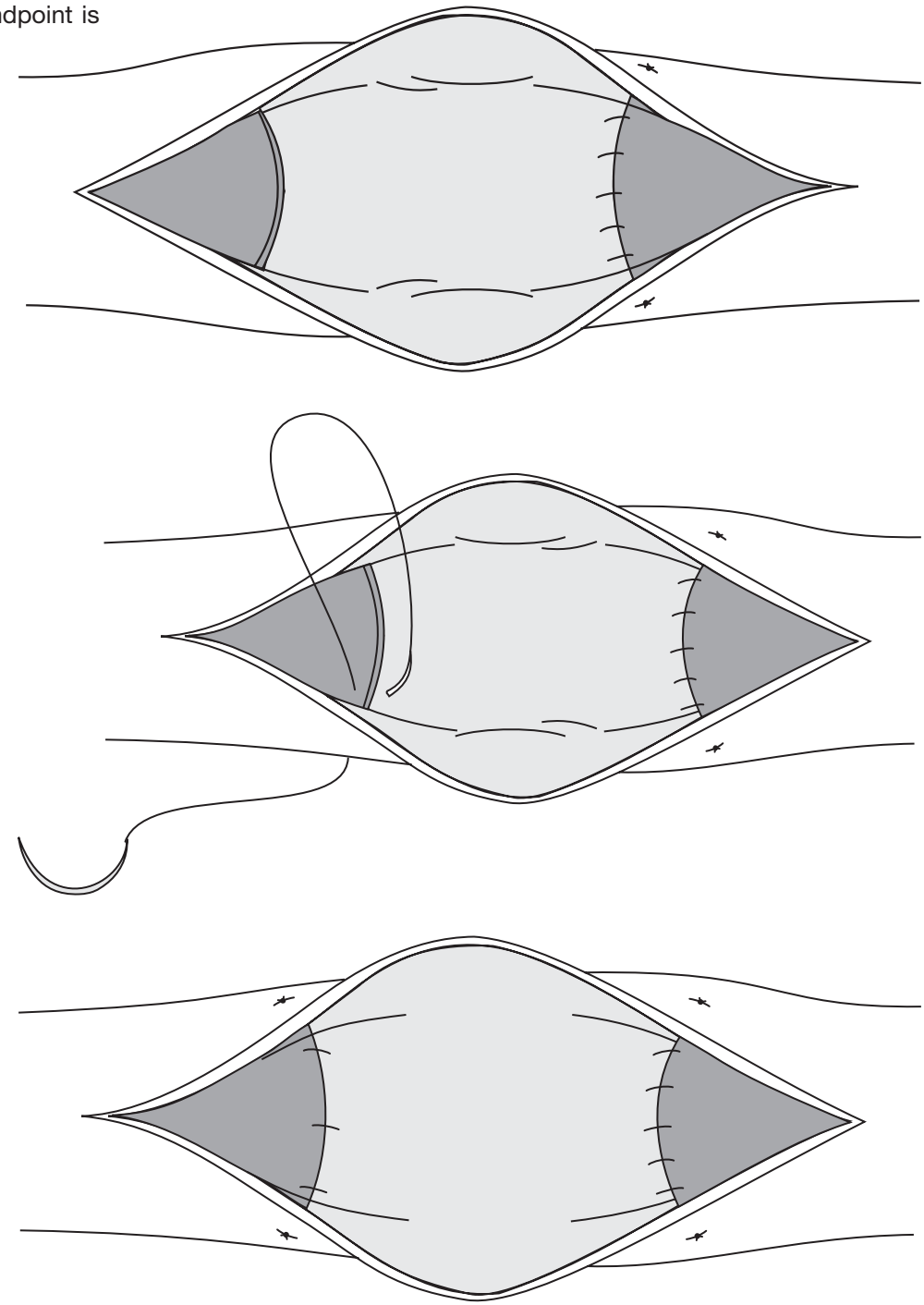
Introduce the needle in a corresponding site, 1 mm from the edge, again inside-out.

Place multiple sutures.

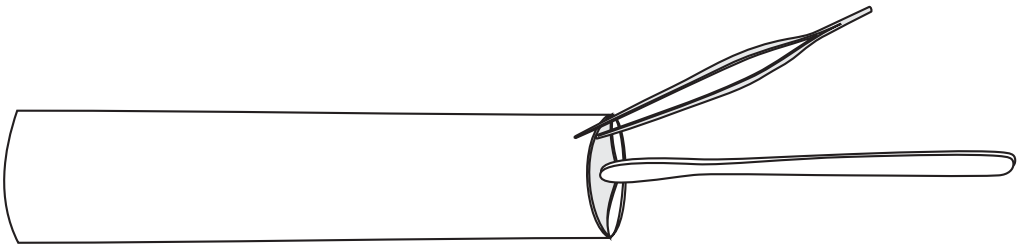


Open Endarterectomy
Tacking Sutures

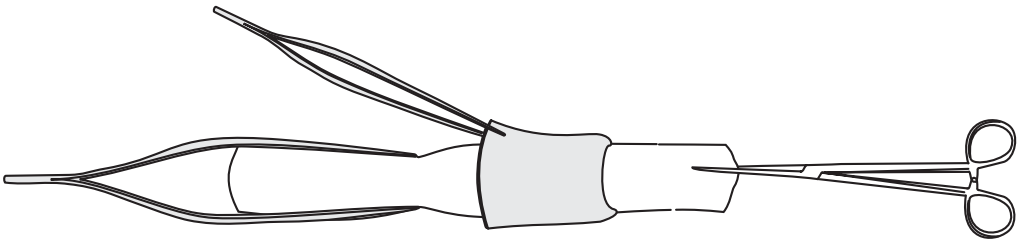
Tacking of the proximal endpoint is rarely needed.



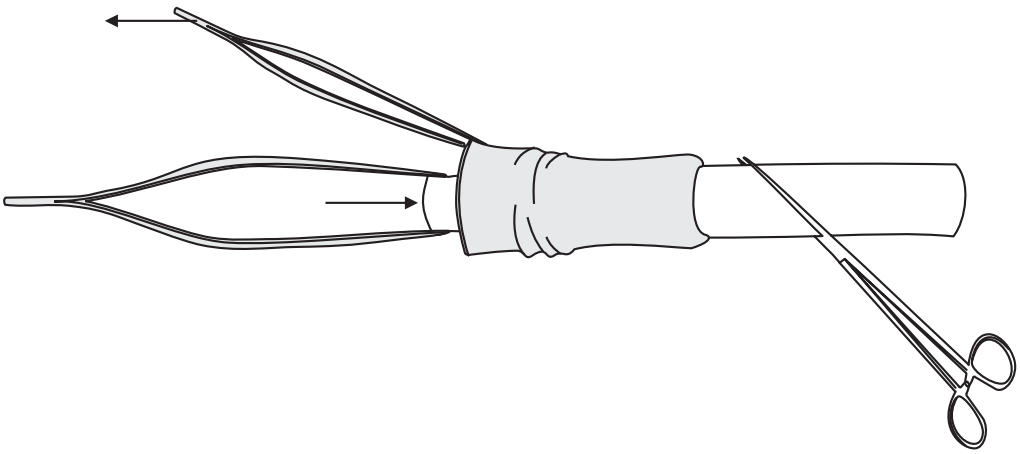
Eversion Endarterectomy



Hold the adventitia with a pickup and gently lift it away from the plaque. Use a Freer elevator to circumferentially dissect the plaque.



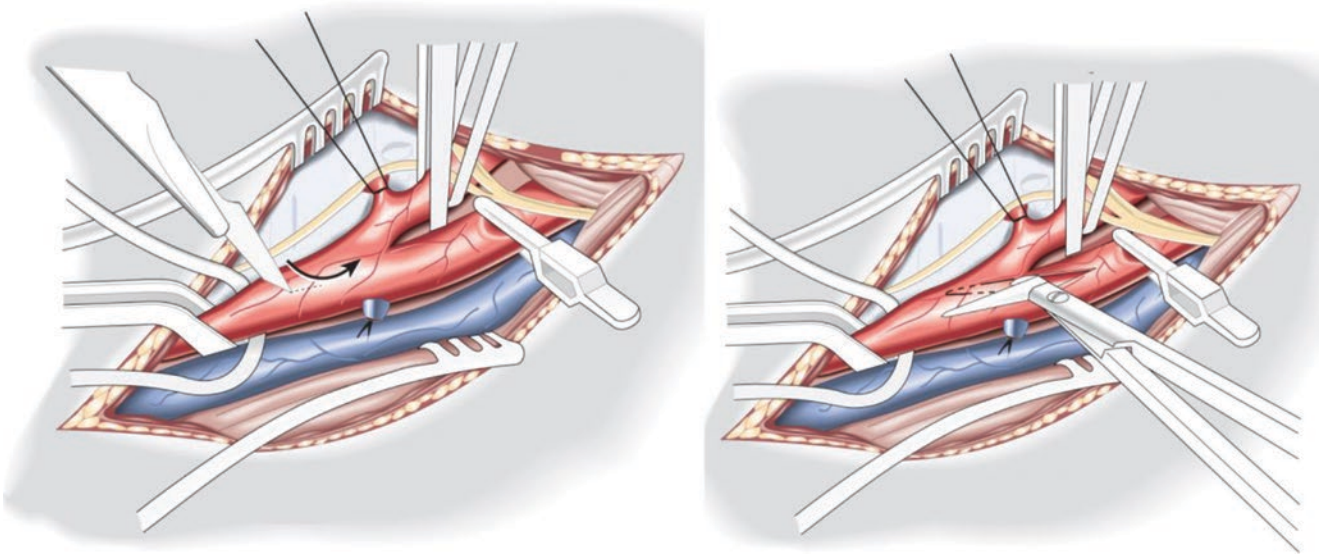
Hold the plaque with a clamp, and gently pull on the plaque while everting the adventitial wall in the opposite direction.



The eversion endarterectomy can be facilitated by pushing the entire artery with the forceps toward the clamp. This movement will help extrude the plaque from the artery.

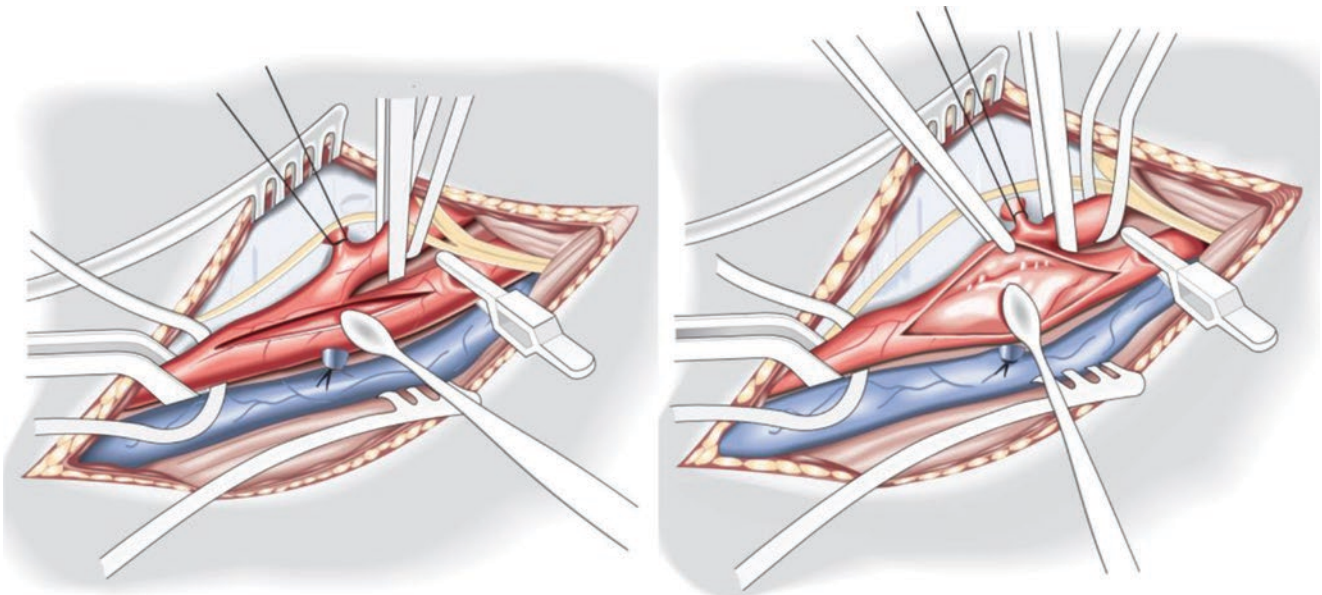
Carotid Endarterectomy

Carotid endarterectomy is the best example for endarterectomy whether performed via standard open technique or eversion technique will be illustrated here. (*Reproduced with permission from* Lumley JSP, Hoballah JJ. Vascular Surgery. Heidelberg: Springer; 2009.)



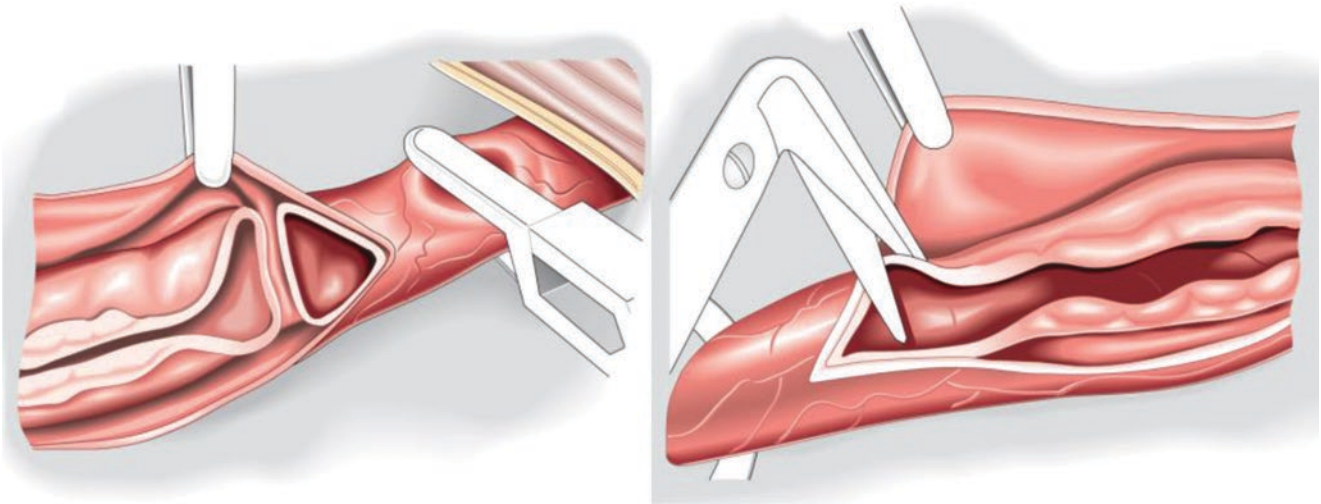
Carotid endarterectomy with vein patch angioplasty.

After controlling the common, external, and internal carotid arteries, an arteriotomy is started in the common carotid artery and extended with a Potts scissors.



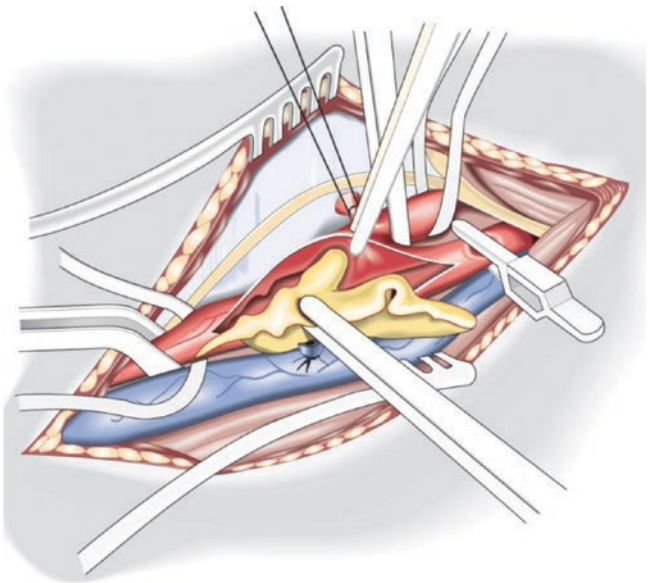
A plane is created between the adventitia and plaque and developed circumferentially.

Carotid Endarterectomy

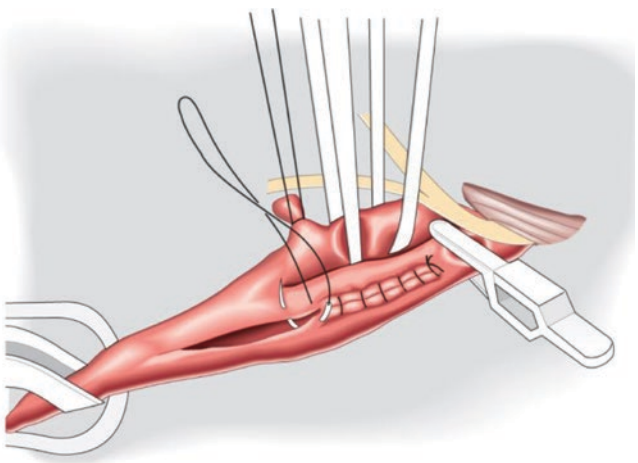


The plaque is then transected or feathered at the internal and common carotid arteries.

Eversion endarterectomy of the external carotid artery is performed and the plaque removed.

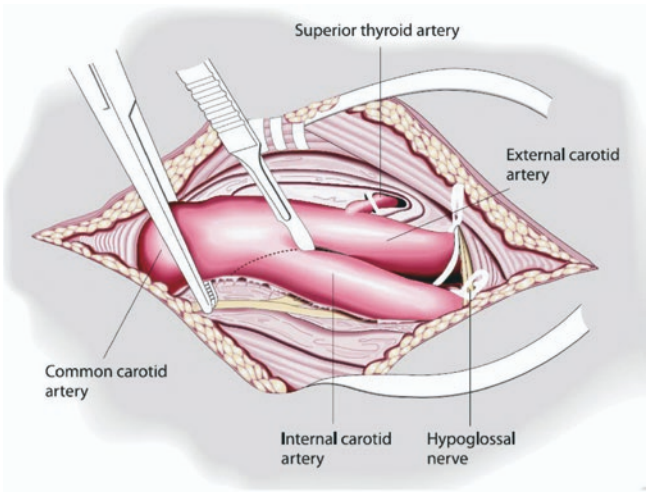


After making sure the endarterectomized surface is smooth and without any debris and removal of the circular smooth muscle fibers, the arteriotomy is typically closed with a patch although some surgeons will use primary closure if the internal carotid artery is larger than 5 mm as shown below.

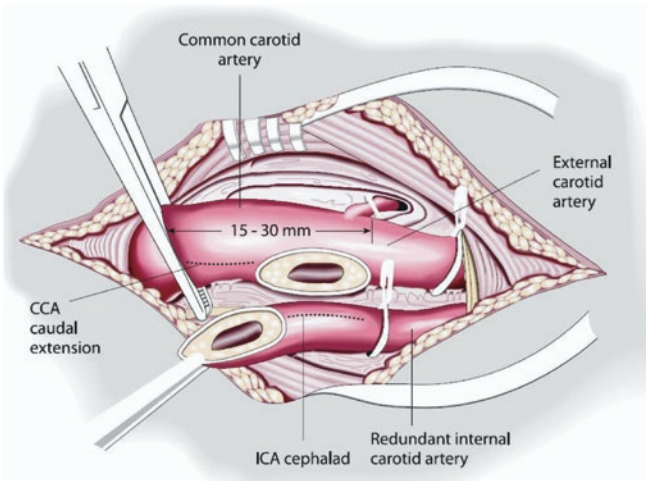


Eversion Carotid endarterectomy

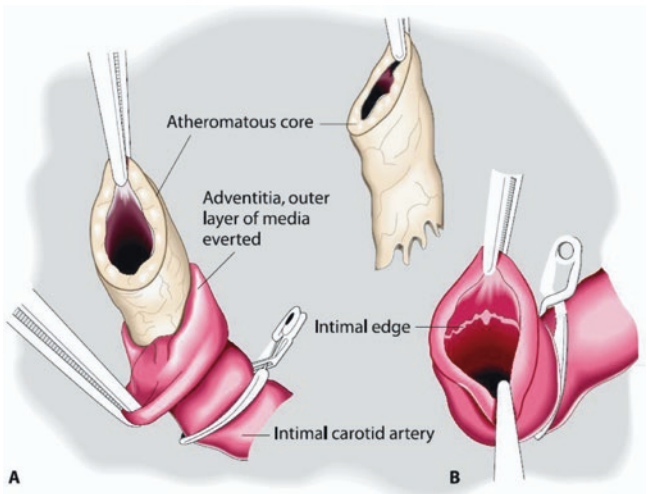
After controlling the common, external, and internal carotid arteries, the internal carotid artery is transected in an oblique manner at its origin.



The arteriotomy can be further extended caudally into the common carotid artery if needed.

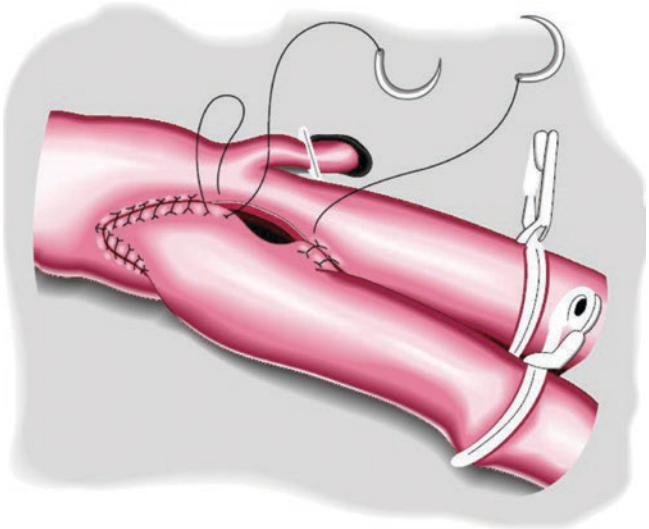


Eversion endarterectomy of the internal carotid artery is performed.



Eversion Carotid Endarterectomy

The internal carotid artery is sutured back on to the common carotid bifurcation.



Part II

Basic Vascular Reconstructions

8

Closure of an Arteriotomy

Jamal J. Hoballah

An incision in an artery (arteriotomy) can be closed either primarily or with a patch. In a primary closure, the edges of the arterial walls are approximated and sutured directly to each other. In a patch closure, also known as patch angioplasty, a patch is used to bridge the defect between the edges of the incision. The choice of the closure method depends on various factors. These factors include the size of the artery, the direction and the shape of the arteriotomy, and the presence of atherosclerotic plaque at the arteriotomy site.

PRIMARY CLOSURE OF A TRANSVERSE ARTERIOTOMY

Primary closure is a simple and expeditious method of closing an arteriotomy. Most transverse arteriotomies in nondiseased arteries can be closed primarily even in small arteries of 1.5–2.0-mm diameter such as the radial artery or the posterior tibial artery. Similarly, most longitudinal incisions in nondiseased arteries with a diameter greater than 5 mm such as the common carotid artery or the common femoral artery can be closed primarily. However, some degree of narrowing of the lumen is likely to occur with primary closure. Such narrowing could threaten the patency of the reconstruction, especially in longitudinal incisions. Thus, whenever there is concern that primary closure will compromise the lumen, patch closure should be considered.

Primary closure is usually performed, using a continuous running suture technique (Section "Continuous Sutures"). The needle is first introduced from the adventitial surface of one wall and then from the intimal surface of the opposite wall. It is important that the arterial wall at the incision site be free of plaque. Otherwise, as the needle is being passed from the adventitial surface, the needle tip can push the plaque away from the arterial wall and create a nidus for thrombus formation or dissection. Thus, primary closure with continuous sutures is most suitable in normal or minimally diseased arteries. Other applications for primary closure include veins, vein bypasses, prosthetic bypasses, and endarterectomized arteries. The depth and advancement of the bites should be even throughout the length of the suture line. Bites placed inappropriately deep could result in a focal narrowing of the lumen.

Even in the presence of significant plaque at an arteriotomy site, primary closure may still be possible without causing plaque separation from the arterial wall. This

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may be achieved by using an interrupted suture technique (Section "Interrupted Sutures"). This technique will allow introducing all the needles from the intimal surface of each wall of the incision, thus pinning the thickened intima to the arterial wall. Placement of deep bites may be necessary to penetrate the arterial wall.

PATCH CLOSURE OF A LONGITUDINAL ARTERIOTOMY

Patch closure is usually utilized in situations where primary closure is likely to cause luminal narrowing or thrombosis [1]. These situations are determined by both technical and nontechnical factors. The technical factors include a jagged incision, a very tortuous artery, a longitudinal incision in an artery smaller than 5 mm in diameter, and the presence of calcified plaque at the arteriotomy site. If the edges of the vessel wall cannot be approximated because of scarring or the presence of a large defect in the vessel wall secondary to trauma or debridement, a patch closure becomes necessary. Furthermore, obstructing pathology that cannot be excised from the vessel wall, such as neointimal hyperplasia or residual plaque, requires closure with a patch. Nontechnical factors suggesting the need for patch closure include uncontrollable risk factors for atherosclerosis such as hyperlipidemia, heavy smoking, female gender, and a history of recurrent stenosis. In patch closure, the needle can be introduced constantly from the adventitial aspect of the patch and then from the intimal aspect of the arterial wall. This avoids the possibility of pushing a plaque fragment into the lumen and precipitating thrombosis or dissection. Patch closure will allow placing good-sized bites in the patch and in the artery without compromising the lumen. However, careful bite placement is still required, especially at the apices where improperly placed bites can cause undesirable luminal narrowing. Furthermore, with patch closure, the width of the patch should be well selected. Aneurysmal dilatation at the reconstruction site could occur when the width of the patch significantly exceeds the diameter of the vessel to be repaired.

Patch closure is performed using either an anchor technique or a parachute technique. In the anchor technique, the initial suture is tied down, thus anchoring and stabilizing the patch for the placement of the remaining bites (Section "Anchor Technique"). The simplest method is to start an anchoring suture at one apex and to place another anchoring suture at the other apex after trimming the patch to the appropriate length. The anchoring suture can be a simple or horizontal mattress suture. The horizontal mattress suture helps to evert the suture line. In small- and medium-sized vessels, it is prudent to avoid placing wide horizontal mattress sutures at the apex to avoid narrowing the lumen.

In the parachute technique, several bites are initially placed without pulling down the suture (Section "Parachute Technique"). This technique is particularly helpful when the arteriotomy is in a deep location. The patch is held a few centimeters away from the artery. After placing five or six bites in the patch and in the artery, each end of the suture will be pulled simultaneously, while the patch is brought down toward the incision like a parachute. Gentle tension should be applied to each end of the suture because rough handling could result in the suture line cutting through the arterial wall, especially in thin vessels. The starting suture in the parachute technique is usually a horizontal mattress suture. The suture line can be started at the apex, a few bites off the apex, or a combination of both (Section "Parachute Technique").

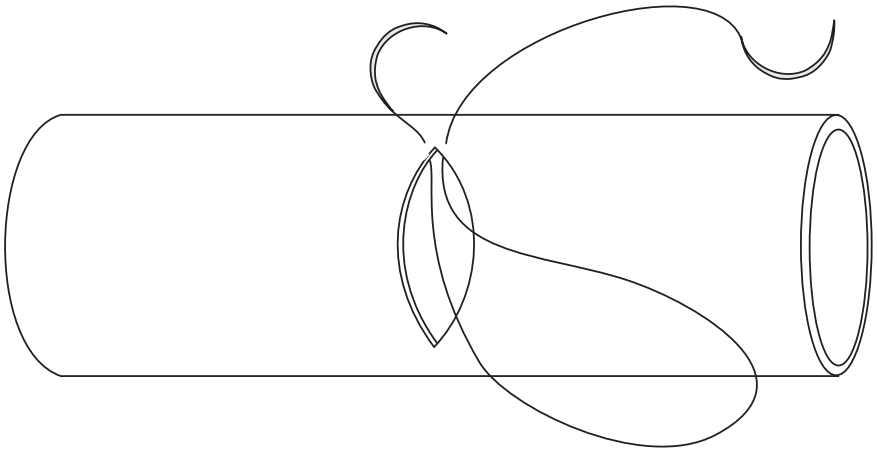
REFERENCE

1. De Bakey ME, Crawford ES, Morris GC, Cooley DA. Patch graft angioplasty in vascular surgery. J Cardiovasc Surg. 1976;131:452.

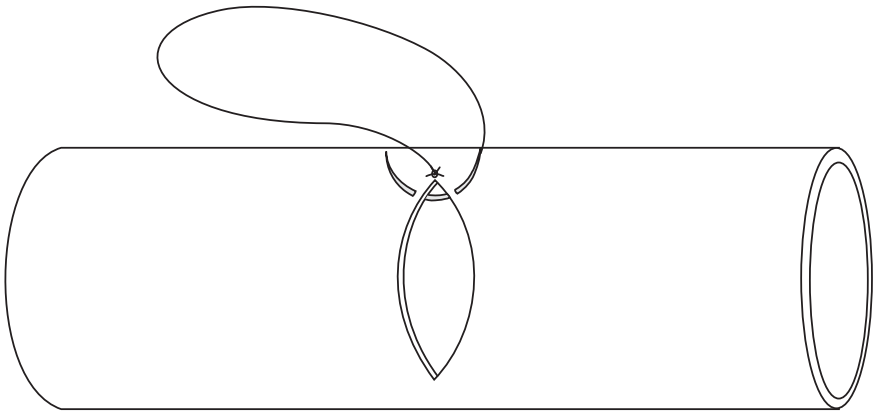
Primary Closure of a Transverse Arteriotomy

Continuous Sutures

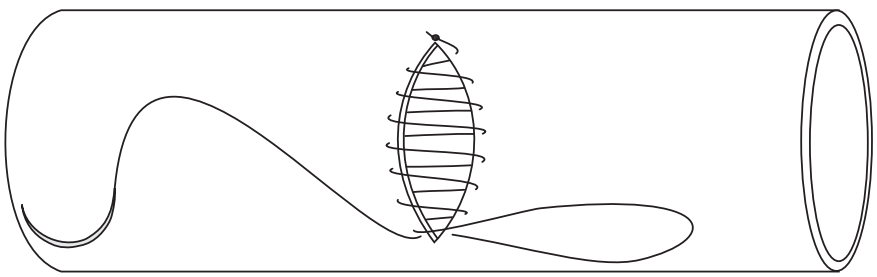
Introduce the needle from the intimal side of the arterial wall.



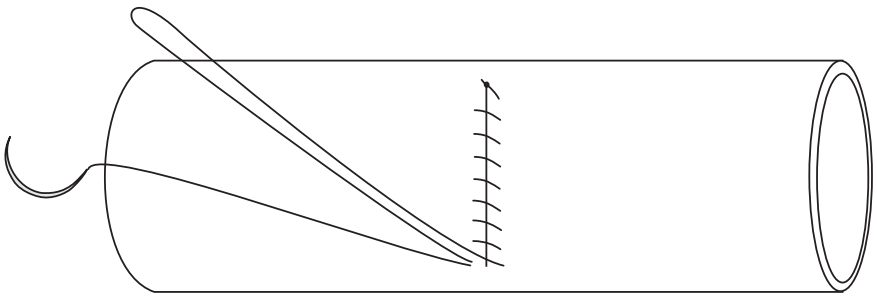
Tie the suture and cut one end.



Start running the suture toward all the way toward the end of the arteriotomy.



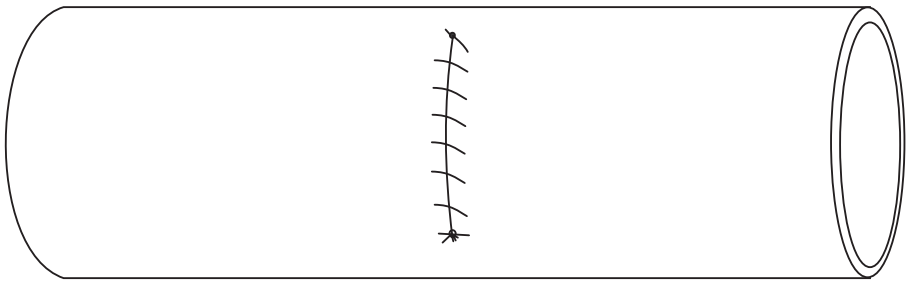
Place the last two bites closely spaced.



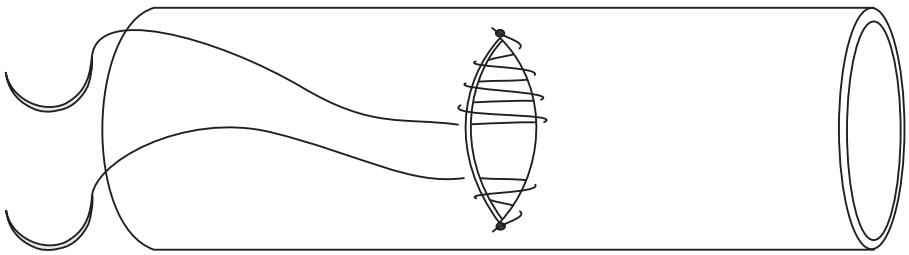
Primary Closure of a Transverse Arteriotomy

Continuous Sutures

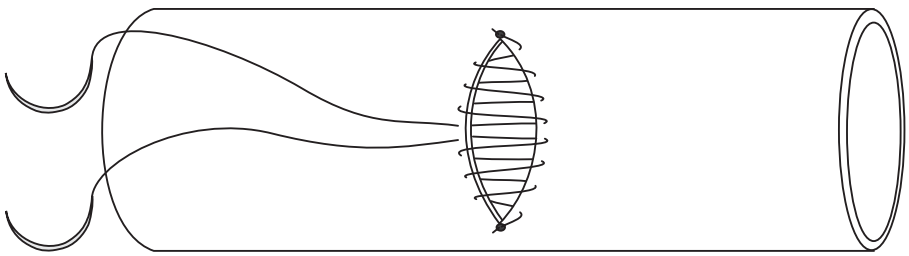
Pull the suture and tie it to itself.



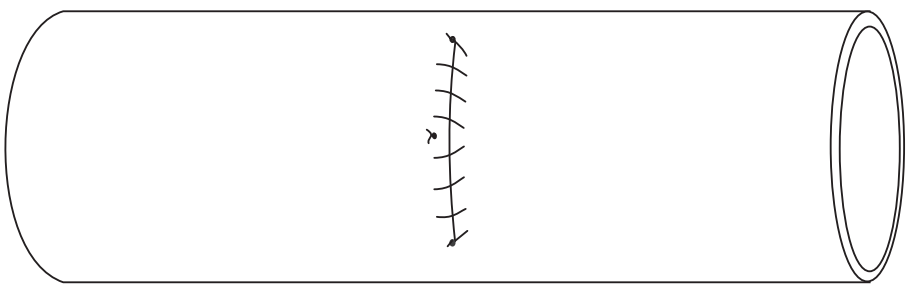
Alternatively, start running the suture toward the midpoint of the arteriotomy.
Start another suture at the other end of the arteriotomy to avoid the need to tie the suture to itself.



Run the second suture toward the midpoint of the arteriotomy.

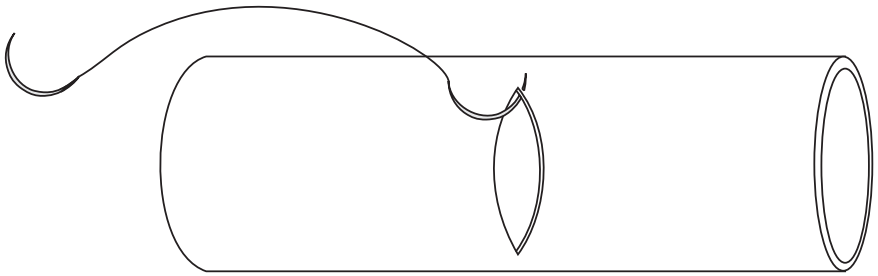


Tie both sutures.

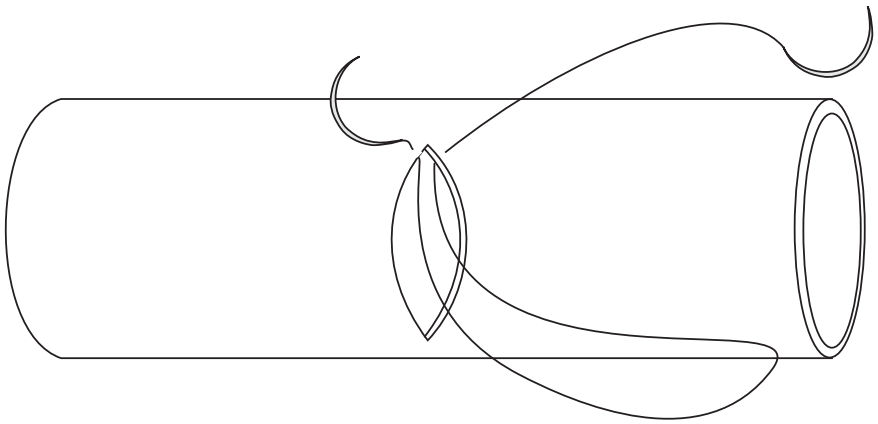


Primary Closure of a Transverse Arteriotomy

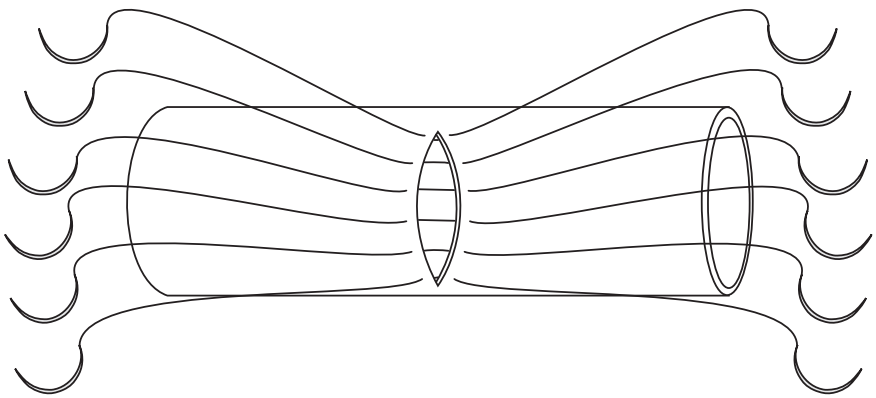
Interrupted Sutures



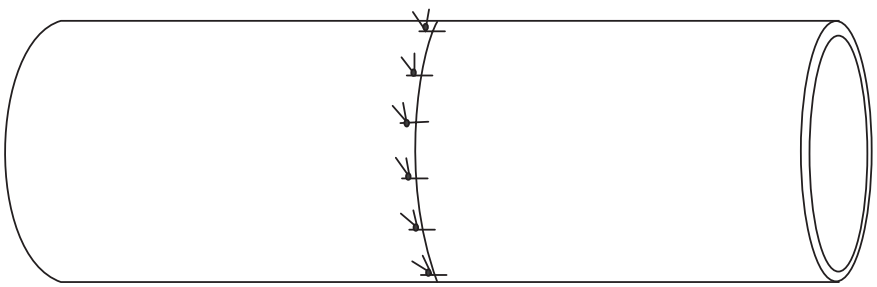
Introduce the needles from the intimal side of the arterial wall to avoid dissection of the plaque.



Place all the sutures under direct vision.



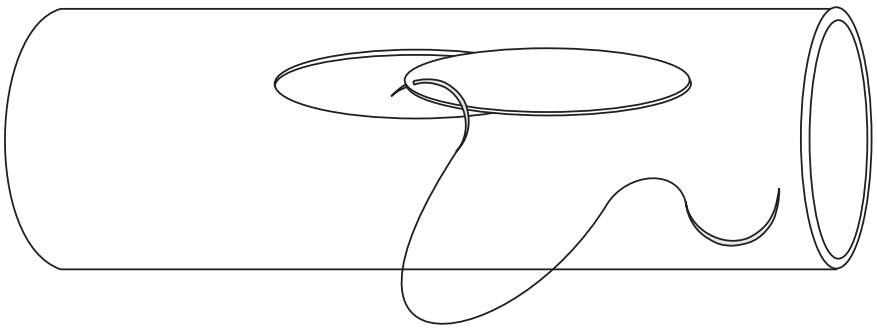
Pull and tie the sutures.



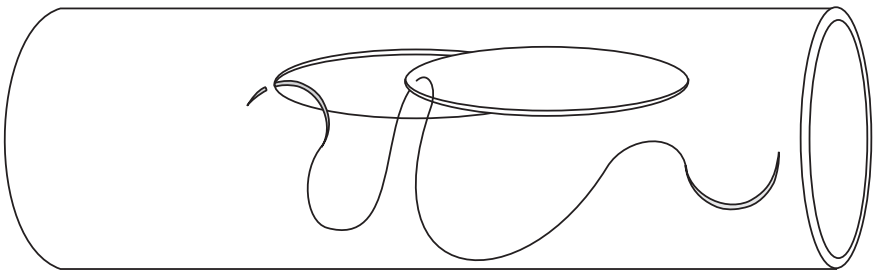
Patch Closure of a Longitudinal Arteriotomy

Anchor Technique

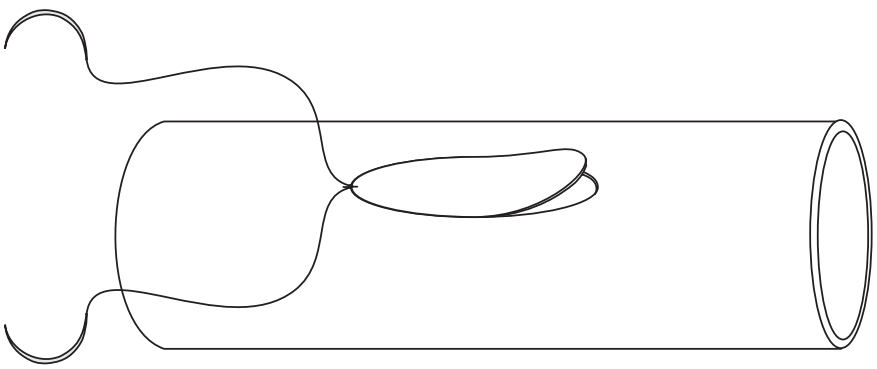
Start by placing a suture at the apex. This suture may be a horizontal mattress or a simple suture as shown here.



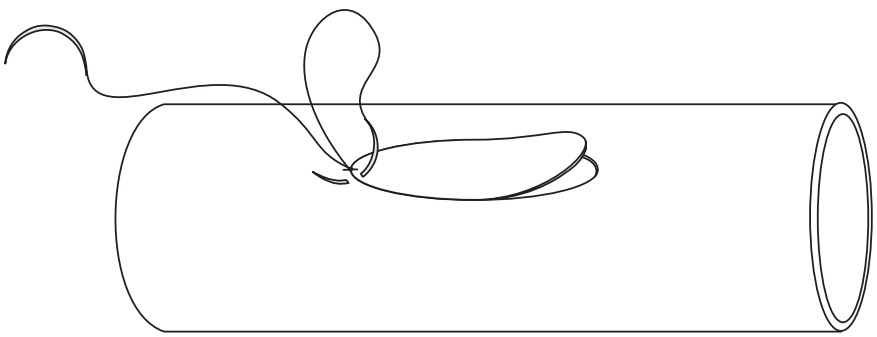
The needle should be introduced from the adventitial side of the patch and from the intimal side of the artery.



After ensuring that both sides are of equal length, tie the suture. Three throws are usually sufficient.



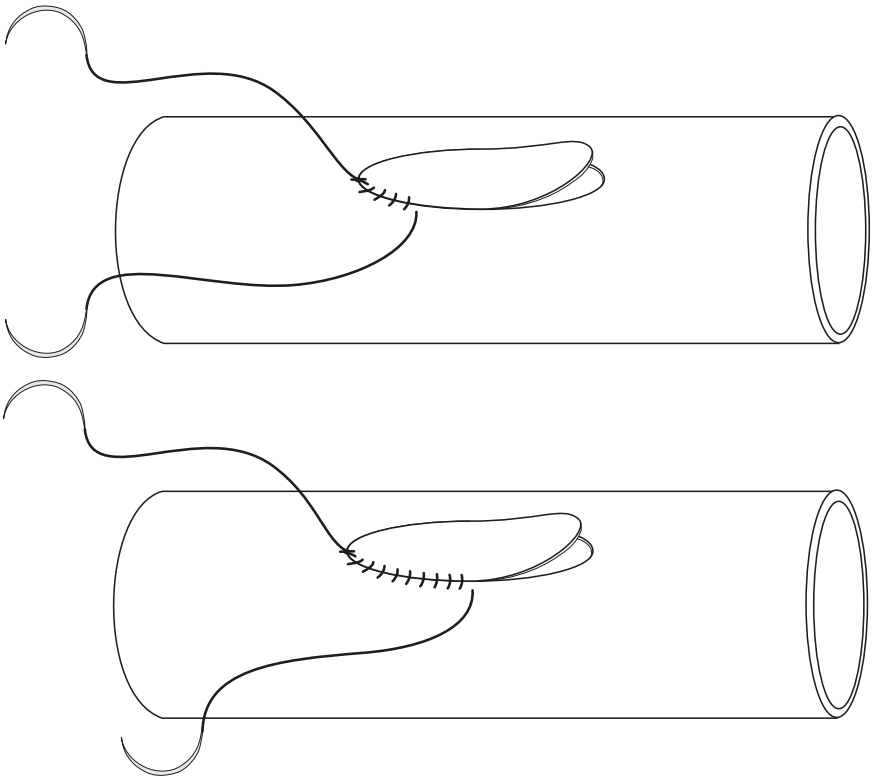
Start suturing with one end. The needle should penetrate from the adventitial side of the patch and then from the intimal side of the artery.



Patch Closure of a Longitudinal Arteriotomy

Anchor Technique

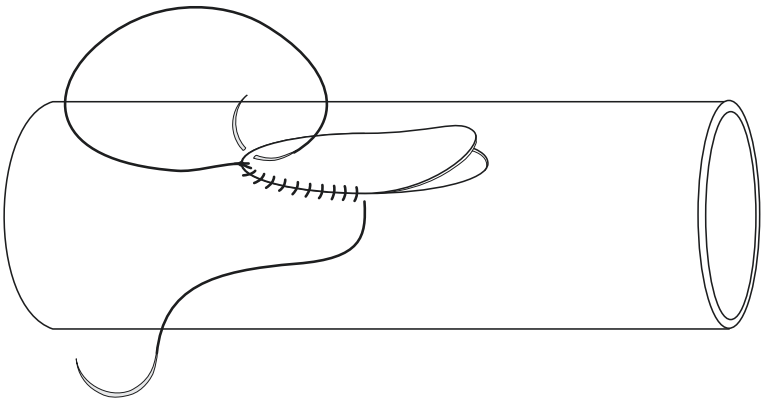
Run the suture to the midpoint of the arteriotomy.



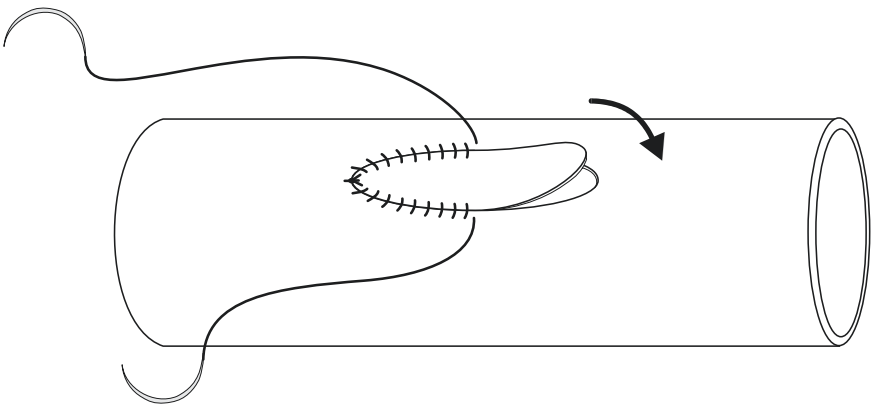
Patch Closure of a Longitudinal Arteriotomy

Anchor Technique

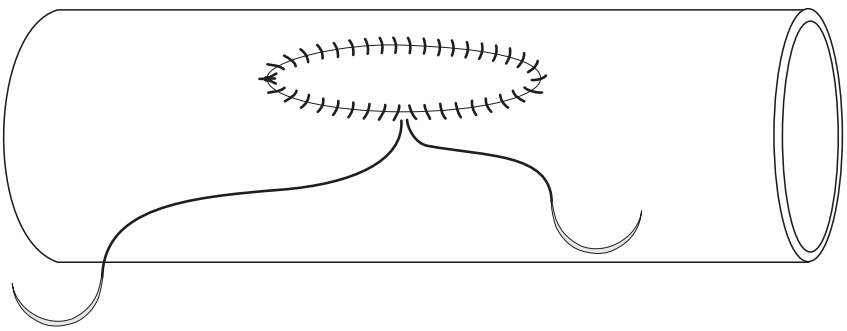
Similarly, run the other end of the suture to the midpoint of the arteriotomy.



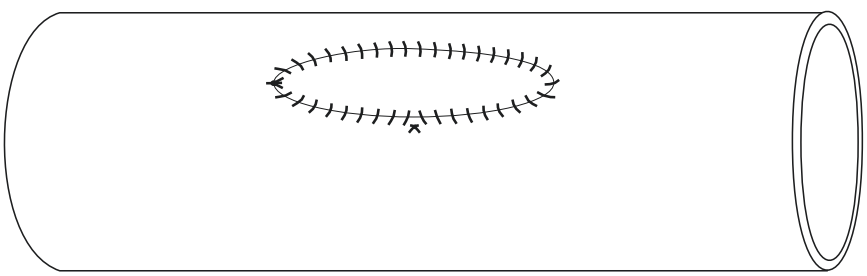
Again, the needle should penetrate outside-inside in the patch and inside-outside in the artery.



You may continue running this suture until you reach the other end.



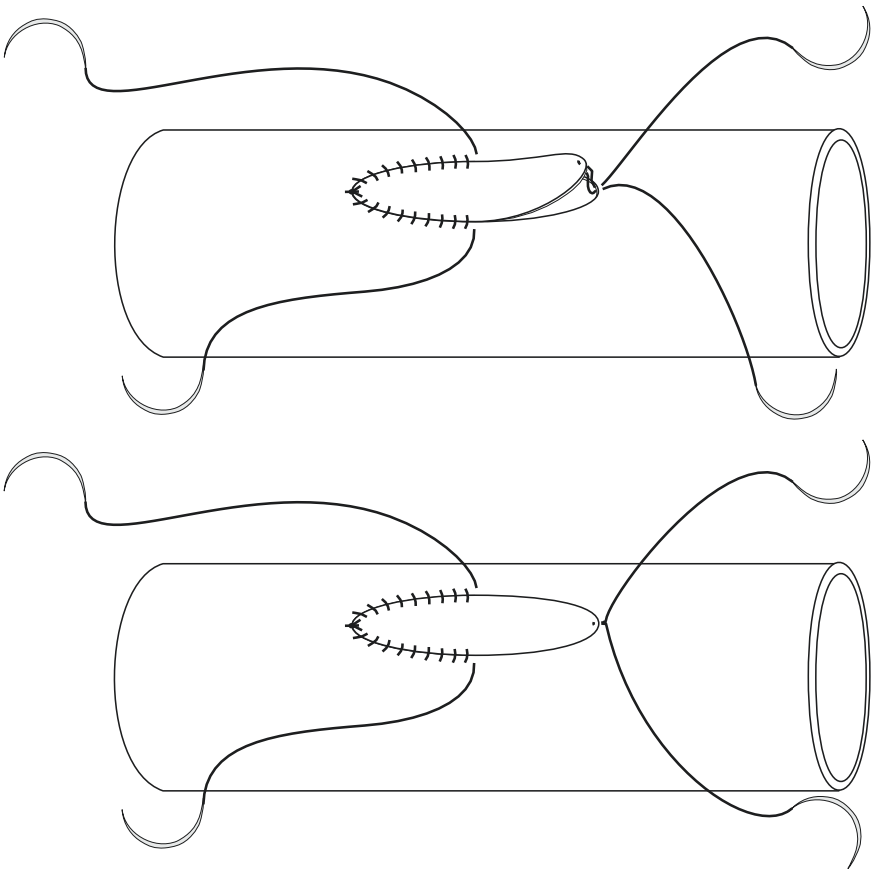
Tie both ends.



Patch Closure of a Longitudinal Arteriotomy

Anchor Technique

Alternatively, after suturing one-half of the patch, you may start another suture at the opposite end. This suture may be a simple or a horizontal mattress suture as shown here.



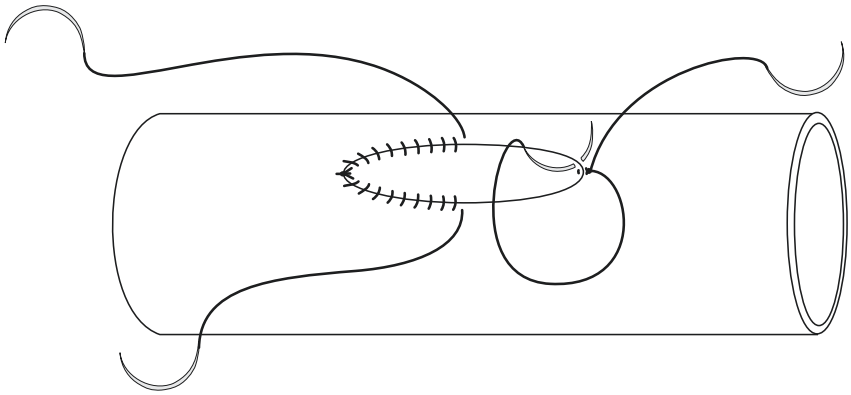
Tie the suture.

In small vessels, it is preferable not to place a wide horizontal mattress suture at the apex to avoid puckering or narrowing the lumen at the apex.

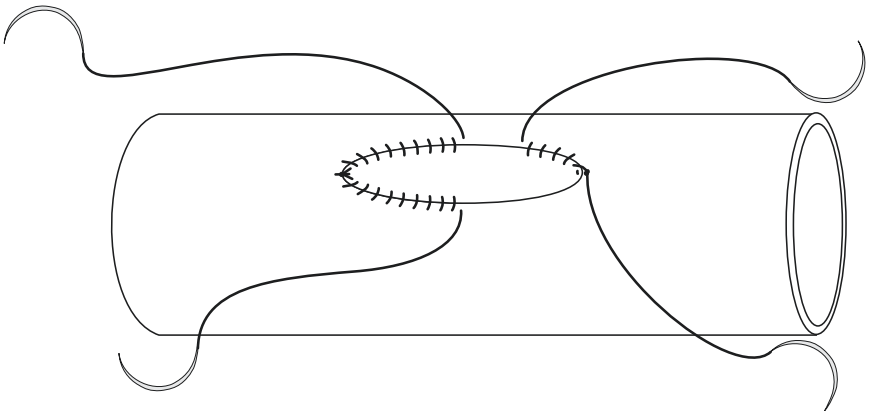
Patch Closure of a Longitudinal Arteriotomy

Anchor Technique

Begin suturing with one end. Again, outside-inside in the patch, inside-outside in the artery.



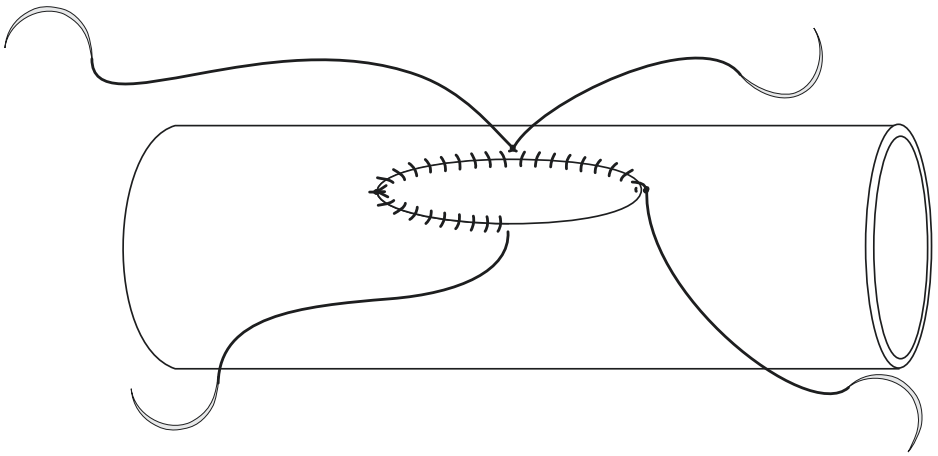
Run one end of the suture to the midpoint of the patch.



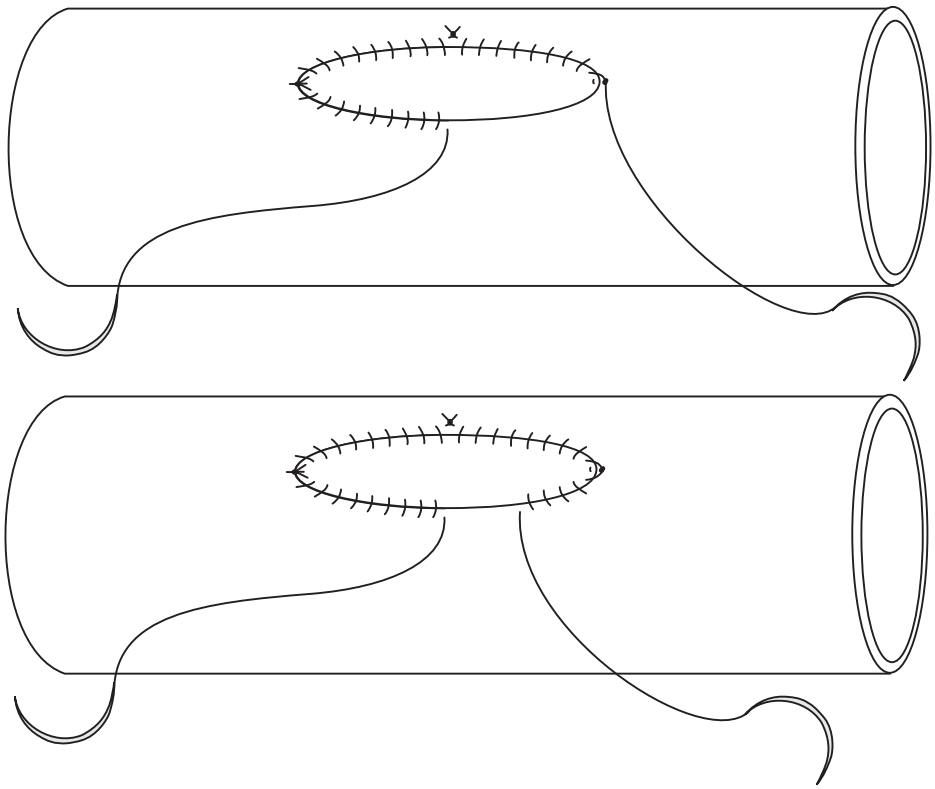
Patch Closure of a Longitudinal Arteriotomy

Anchor Technique

Tie both sutures.



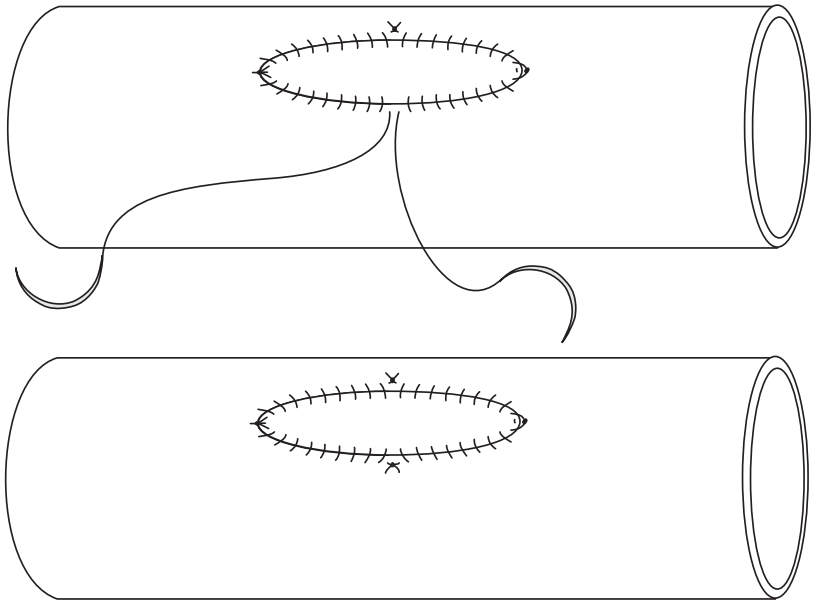
Run the other end of the suture in the other direction to the midpoint of the arteriotomy.



Patch Closure of a Longitudinal Arteriotomy

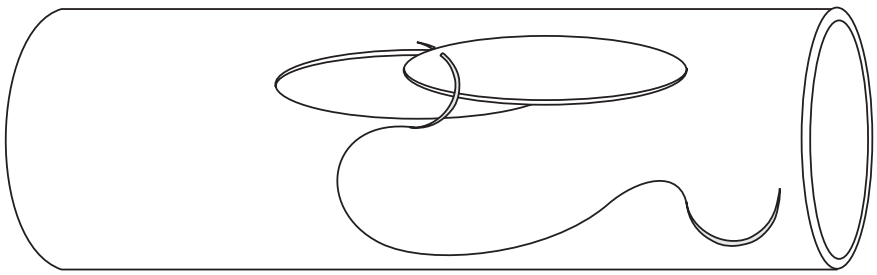
Anchor Technique

Tie both sutures.



You may start at the apex or a few bites off the apex, as shown here.

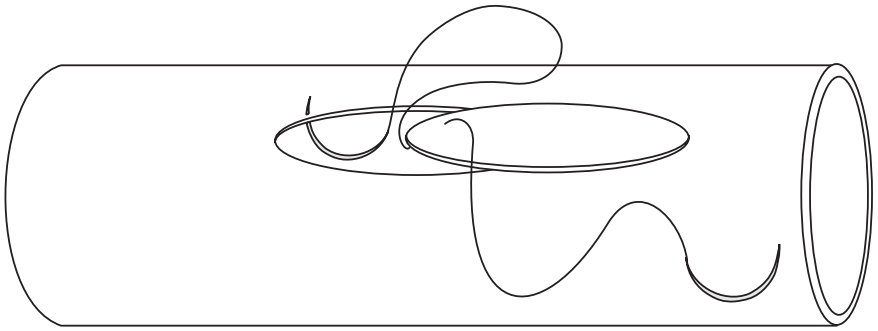
Introduce the needle in the patch three bites away from the apex, outside-inside in the patch.



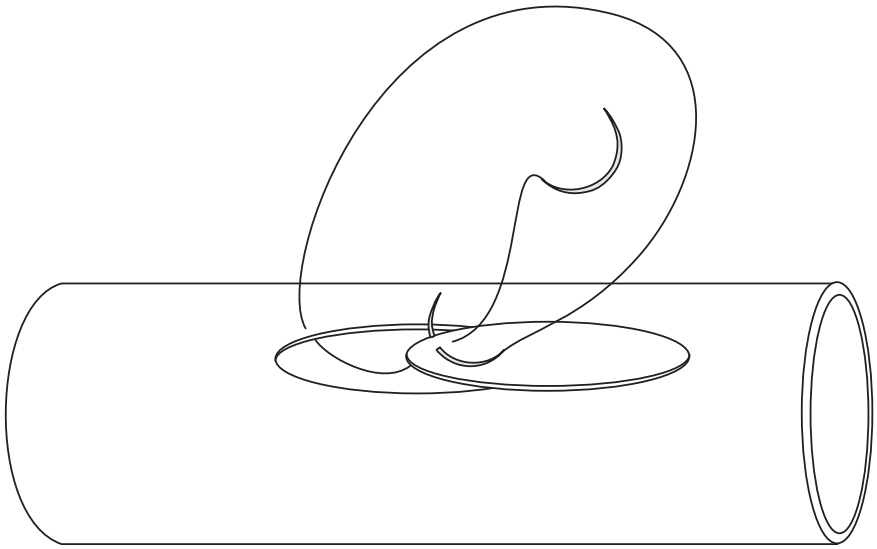
Patch Closure of a Longitudinal Arteriotomy

Parachute Technique

Introduce the needle in a corresponding location inside-outside in the artery.

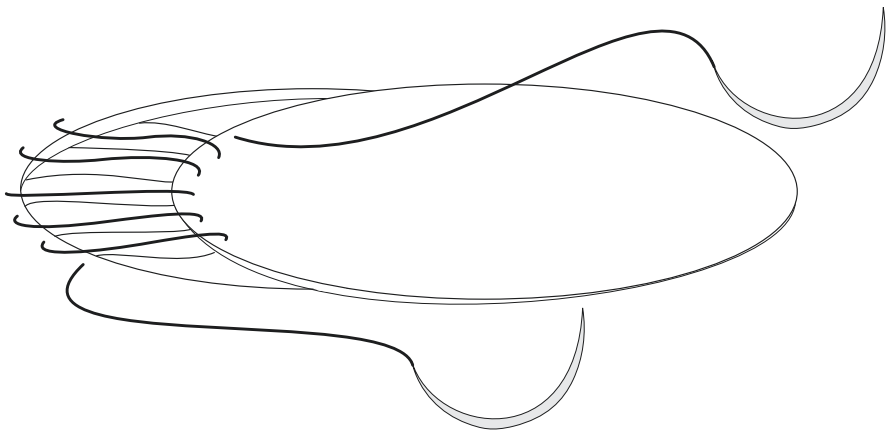


Continue suturing until you have placed three bites past the apex.



Pull down the suture and the patch.

Placing more than three bites on each side of the apex could create difficulty in pulling and tightening the suture line.

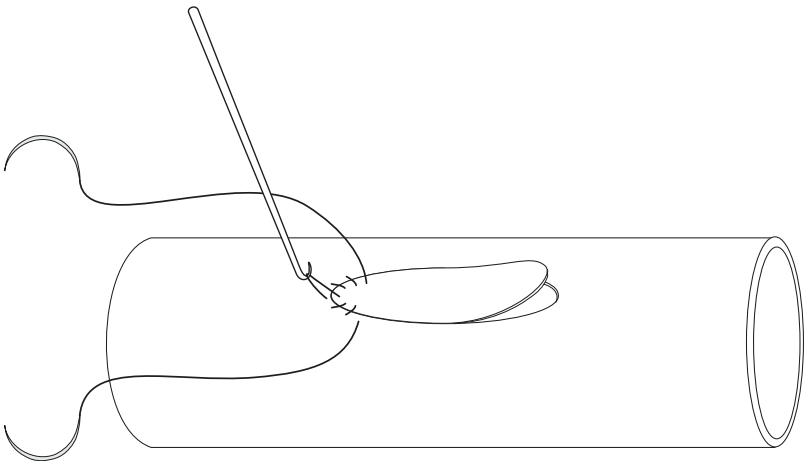


Enlarged view of the suture line before being pulled.

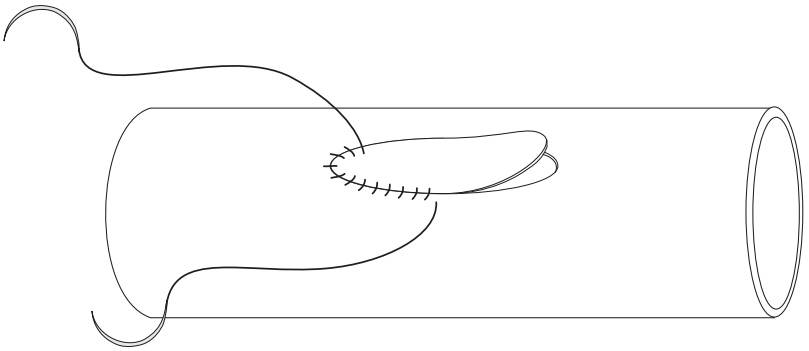
Patch Closure of a Longitudinal Arteriotomy

Parachute Technique

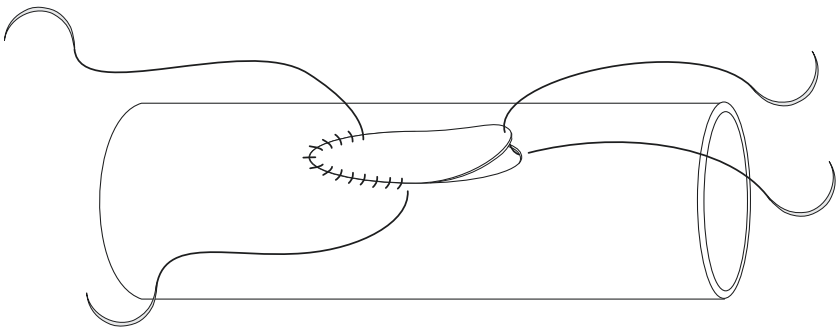
Pulling the loop at the center of the apex with a nerve, the hook could facilitate tightening the suture line.



Continue suturing until you reach the middle of the arteriotomy.



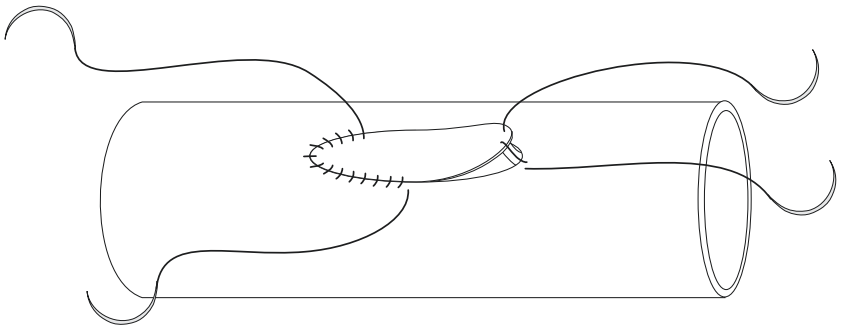
The next suture can be started a few bites off the apex or at the apex as shown here.



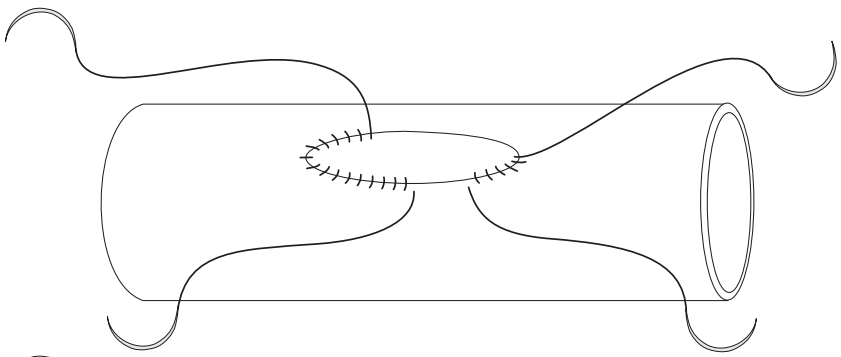
Patch Closure of a Longitudinal Arteriotomy

Parachute Technique

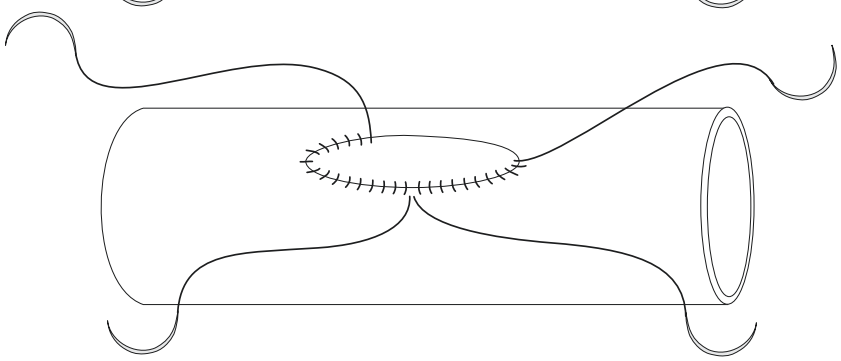
Again, introduce the needle outside-inside in the patch, inside-outside in the artery.



Run the suture on one side until it meets the previous suture.



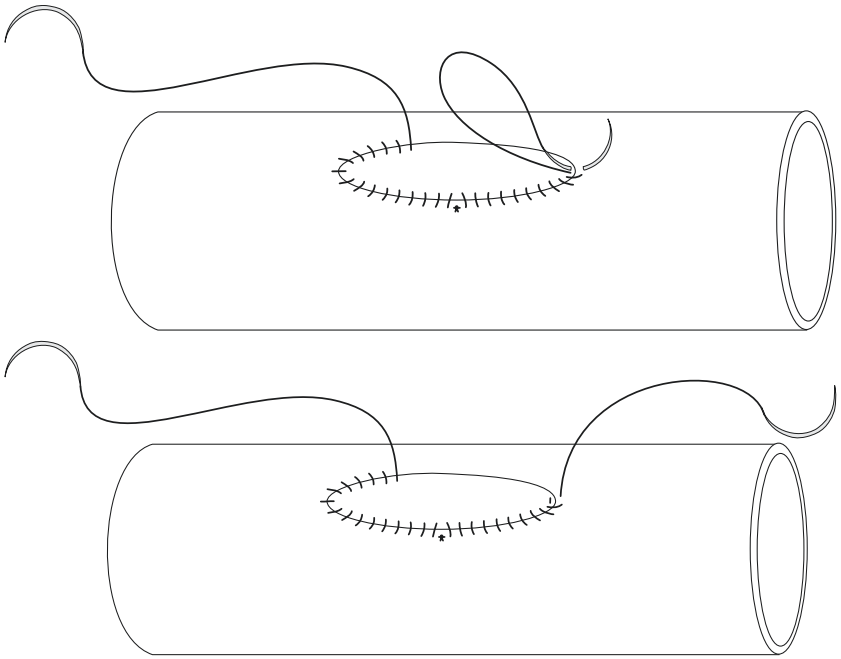
Tie both sutures.



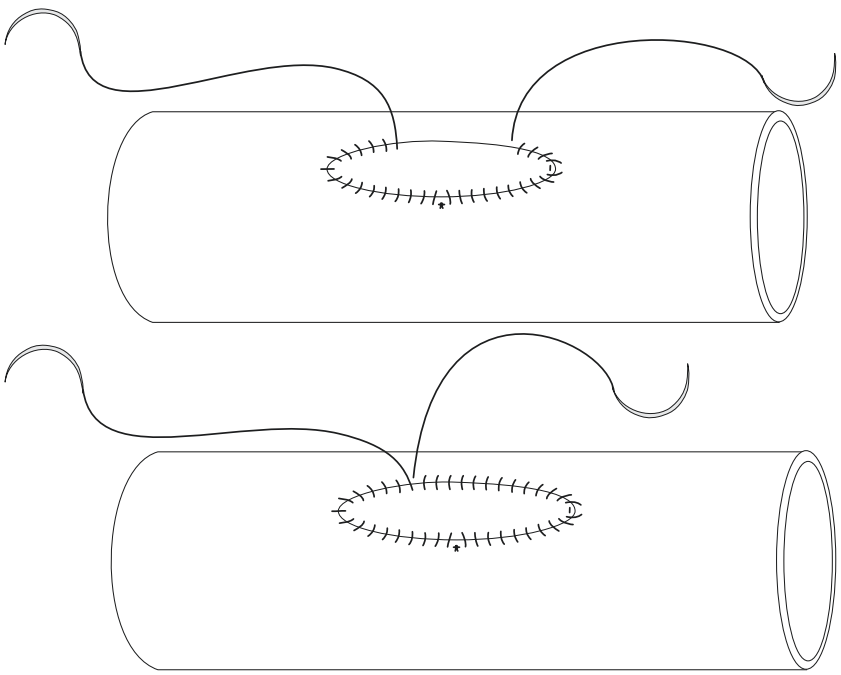
Patch Closure of a Longitudinal Arteriotomy

Parachute Technique

Start suturing with the other end. The needle is first introduced outside-inside in the patch, and then inside-outside in the artery. This first suture should be placed very close to the previous one, as it will become a horizontal mattress suture.



Continue suturing toward the remaining suture.



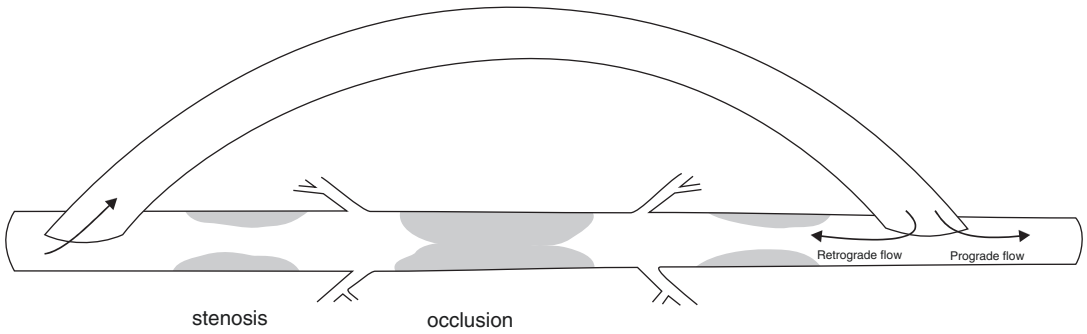
Tie both sutures.

9

End-to-Side Anastomosis

Jamal J. Hoballah

In most bypasses performed for occlusive disease, the proximal and distal anastomoses are constructed in an end-to-side fashion. Such a configuration allows for constructing the proximal anastomosis in the least diseased area of the inflow vessel while maintaining the original circulation. The distal anastomosis is constructed distal to any occlusive pathology and provides both antegrade and retrograde blood flow. The revascularization provided by the end-to-side configuration protects the limb from ischemia between the proximal and distal anastomoses. This condition, often referred to as "interval ischemia," is more likely to occur when both anastomoses are constructed using an end-to-end configuration.



GEOMETRY OF AN END-TO-SIDE ANASTOMOSIS

The geometry of an end-to-side anastomosis depends on the diameters of the bypass and the artery and the length of the anastomosis, which will influence the angle of transection of the bypass. The ideal dimensions of an end-to-side anastomosis are ill defined as is the optimal length of an anastomosis. Because the diameter of the recipient artery cannot be changed, the geometry of an end-to-side anastomosis depends greatly on the length of the arteriotomy.

The length of the proximal anastomosis of an infrainguinal bypass usually varies from 1 cm to 2 cm. Some surgeons recommend that the length of the distal anastomosis should be twice the bypass diameter [3]. Others recommend an arteriotomy greater than 2 cm [4] or creation of an arteriotomy 2–4 times the diameter of the recipient popliteal artery and 10–20 times the diameter of the recipient

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infrapopliteal artery [5]. Other surgeons prefer creating a relatively short arteriotomy 1–1.5 cm in length to avoid having to sew a long anastomotic suture line, especially in a diseased small-diameter tibial artery [1]. A short arteriotomy 4–6 mm in length is usually recommended for a coronary artery vein bypass [2]. In a vein bypass, technical imperfections may be more responsible than the geometry of the anastomosis for the development of distal anastomotic stenotic pathology [1]. The end-to-side reconstruction can be carried using either an anchor technique (Section "End-to-Side Anastomosis: Anchor Technique") or a parachute technique (Section "End-to-Side Anastomosis: Parachute Technique").

END-TO-SIDE ANASTOMOSIS: ANCHOR TECHNIQUE

In the anchor technique, the anastomosis is usually constructed by first placing a suture at the heel. The suture is tied down, anchoring and stabilizing the bypass. The suture is then run in a continuous manner on either side of the heel. Frequently, another suture is then started at the apex and tied. The apical suture is run in a continuous manner on either side of the apex to complete the anastomosis. This technique can be ideal for large vessels, especially if they are not in deep locations.

An end-to-side anastomosis can have numerous variations. When the anchor technique is used, the sutures at the apex and the heel can be simple (Section "Simple Anchoring Sutures") or horizontal mattress sutures (Section "Horizontal Mattress Anchoring Sutures"). The horizontal mattress sutures may help in everting the suture line. However, in small vessels, wide horizontal mattress sutures at the apex or the heel can cause narrowing of the lumen.

Another variation in the anchor technique relates to the apical part of the anastomosis where interrupted sutures are used instead of a continuous suture (Section "Construction of the Apex with Interrupted Sutures"). This variation may have some theoretical advantages in very small vessels by allowing the anastomosis to stretch with arterial pulsations and not be limited by the length of the continuous suture.

Another variation in the anchor technique relates to the location of the initial anchoring suture, which usually depends on the surgeon's preference. In this variation, instead of placing the anchoring suture at the center of the heel, the suture is started mid distance between the apex and the heel (Section "Anchoring Suture Starting Mid Distance Between the Apex and the Heel"). In this method, suturing around the heel may be technically demanding. In addition, it is important in this variation that the distance from the heel to the anchoring suture is well matched between the bypass and the arteriotomy to prevent any torsion at the heel of the anastomosis.

Another variation in the anchor technique utilizes staples for constructing the anastomosis (Section 1e). The role of this evolving technology is yet undetermined. This technique may offer some advantages with respect to expediency and minimizing the bleeding from needle holes, especially with polytetrafluoroethylene grafts. However, when dealing with small veins and arteries, the precision achieved with suturing cannot yet be duplicated with the current generation of staples available.

END-TO-SIDE ANASTOMOSIS: PARACHUTE TECHNIQUE

The parachute technique differs from the anchor technique, in that the sutures at the heel and the apex are not pulled down initially. Thus, the bypass is still a few centimeters away from the arteriotomy and should not obscure the placement of the heel and apical sutures. Several bites are first placed in the bypass and the arteriotomy. Tension is then gently applied on either end of the suture. The bypass is advanced toward the arteriotomy, as the suture line is tightened at each end in a seesaw fashion. It is important to note that if more than five

bites are placed before "parachuting" the bypass, pulling on each end of the suture may not result in a tight suture line. A useful maneuver in this situation is the use of a nerve hook to pull up on the loop at the center of the heel. Tension on either side of the suture will then successfully tighten the suture line. Excessive tension and rough manipulation of the suture line could result in cutting of the suture line through the vessel wall.

The parachute technique is especially useful if the vessels are small or in a deep location. In such situations, visualization of the first few bites at the apex and the heel may be suboptimal. Better visualization and placement of the sutures at the heel and the apex can be facilitated by the use of the parachute technique. Furthermore, if an autogenous bypass is in spasm following transection, the anastomosis may be initially under slight tension. In this situation and especially in thin small vessels, using a parachute technique could distribute the tension over several bites and prevent the possibility of the suture tearing through the vessel wall.

In the parachute technique, the main variation relates to the site where the suture is started. The suture may be started exactly at the center of the heel or a few bites off the center of the heel. Starting the suture at the center of the heel and the apex (Section "Starting at the Center of the Heel") is the simpler method and may allow for a better appreciation of the size match between the arteriotomy and the transected vessel. In addition, it may avoid the possibility of uneven advancement between the different sides of the anastomosis.

Starting a few bites away from the center of the heel (Section "Starting a Few Bites from the Center of the Heel") may be more challenging when first learning the technique, with possible entanglement of the suture line. However, once past the learning curve, this technique could facilitate the placement of the difficult heel sutures in a continuous forward movement. Infrequently, the graft is in a location that does not allow flipping the graft around the heel. In this situation, constructing the entire posterior wall of the anastomosis first may be necessary (Section "Starting at the Center of the Apex").

Additional variations in the end-to-side anastomosis include using an anchor technique for the heel portion and a parachute technique for the apical portion, or vice versa. These variations are usually dictated by individual circumstances. For example, the exposure may be such that the heel portion of the anastomosis is more suitable for reconstruction with a parachute technique, while the apical portion of the anastomosis is more amenable to construction with an anchor technique, or vice versa.

When constructing an anastomosis to a heavily calcified vessel, the needle tip may become dull from repeated impacts against the calcified plaque. Starting new sutures may be necessary to provide a sharp needle point that can penetrate the calcified plaque without tearing the vessel wall.

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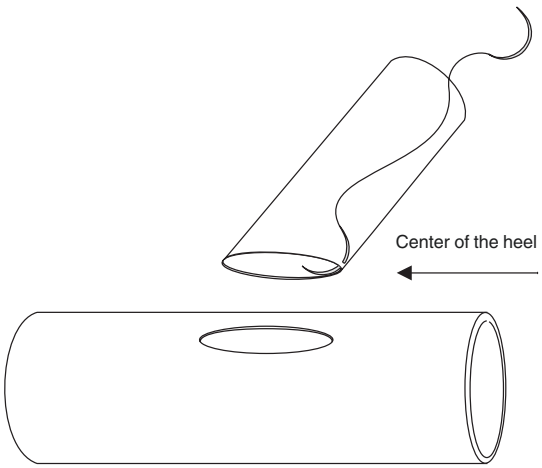
5. Taylor LM, Porter JM. Technique of reversed vein bypass to distal leg arteries. In: Bergan JJ, Yao JST, editors. Techniques in arterial surgery. Philadelphia: Saunders; 1990. p. 109–21.

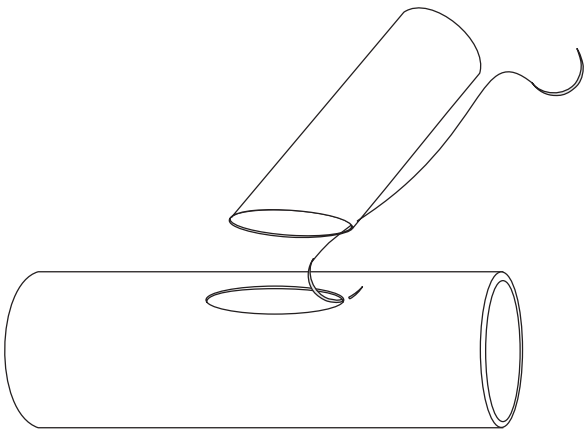
Anchor Technique
Simple Anchoring Sutures

Create an incision in the artery. Transect the graft in a beveled fashion to match the size of the arteriotomy.

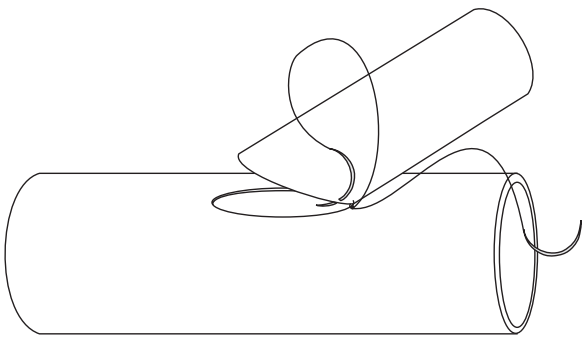


Start at the center of the heel. Introduce the needle outside-inside in the graft.

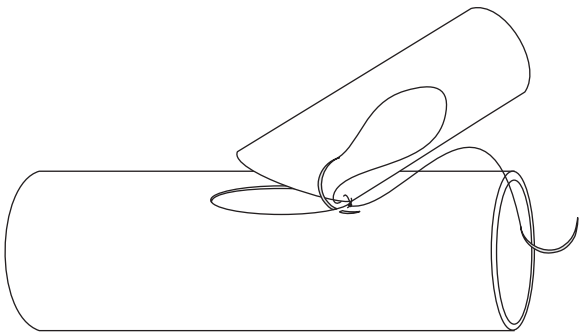
Introduce the needle in a matching location in the artery (inside-outside). This suture may be a horizontal mattress suture or a simple suture as shown here.



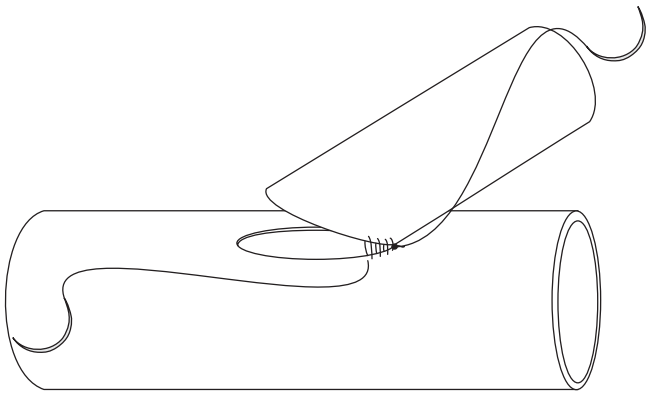
Tie the suture. Three throws are usually sufficient.



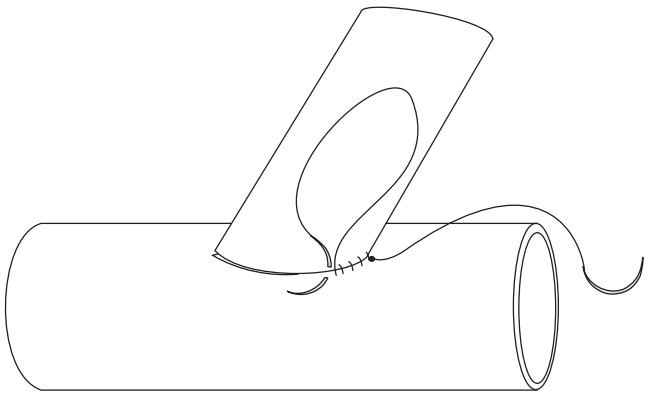
Continue with one end of the suture, and introduce the needle in the graft.



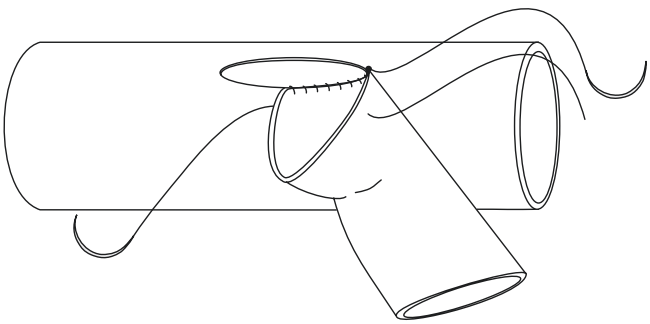
Anchor Technique
Simple Anchoring Sutures



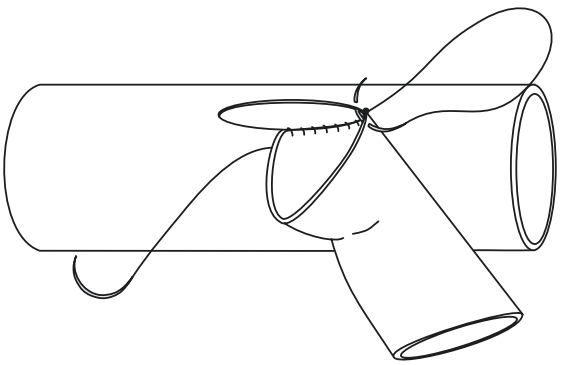
Introduce the needle in the artery: very often the first few bites after tying down the suture will need to be placed separately in the graft and then in the artery to ensure ideal placement.



Place several sutures on one side. Tighten the sutures. At this stage, you may be able to suture the graft and the artery together in a single bite.



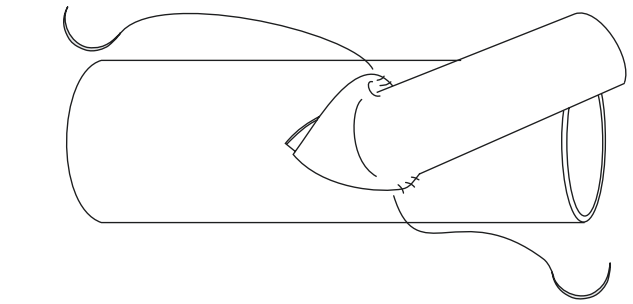
Flip the graft to the other side.



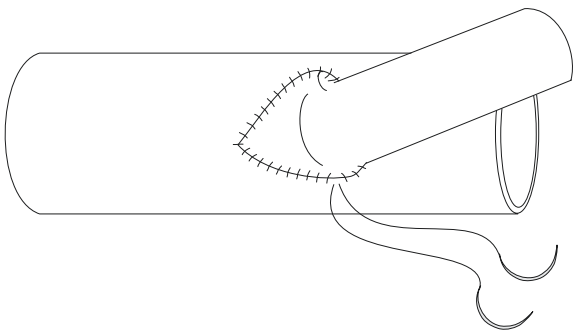
Start suturing on this side. Again, introduce the needle from the adventitial side of the graft and then from the intimal side of the artery.

Anchor Technique
Simple Anchoring Sutures

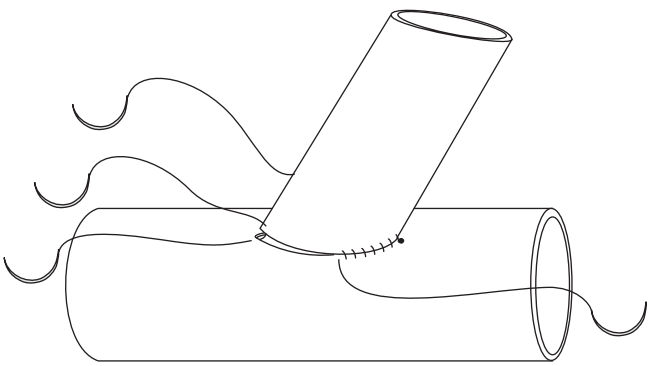
Place several bites.



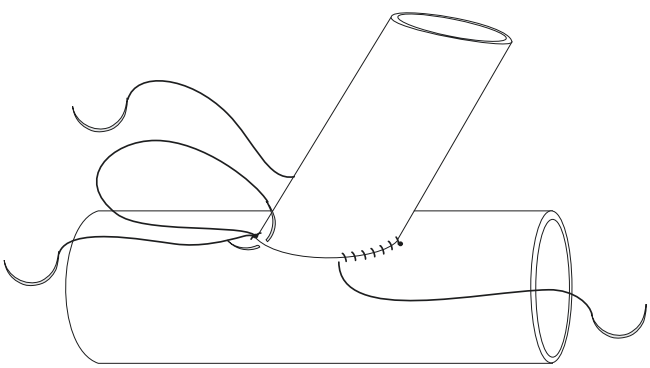
You may continue with the upper suture and run it around the apex until it meets the other end.



Alternatively, you may start a new suture at the apex. The new suture may be a horizontal mattress or a simple suture as shown here.



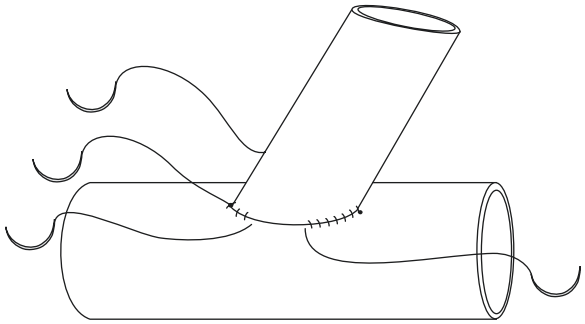
Tie the suture. Introduce the needle from the adventitial side of the graft and the intimal side of the artery.



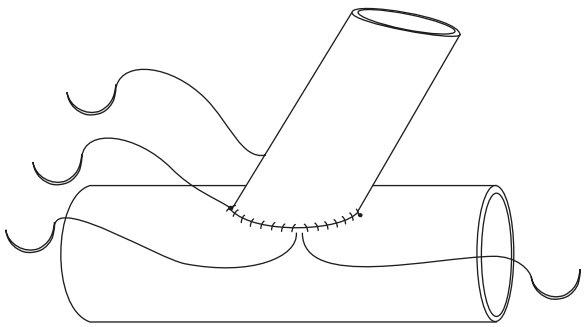
Anchor Technique

Simple Anchoring Sutures

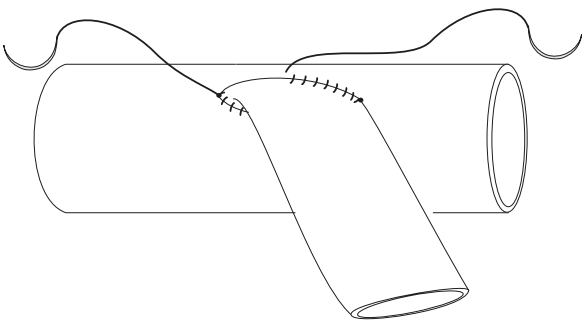
Place several more bites. Run the suture line toward the heel until it meets the other suture.



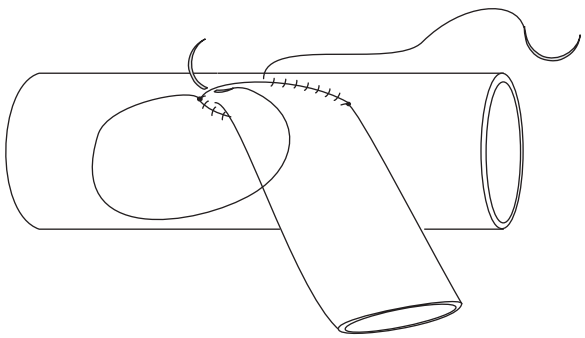
Tie both sutures together.



Flip the graft to the other side.

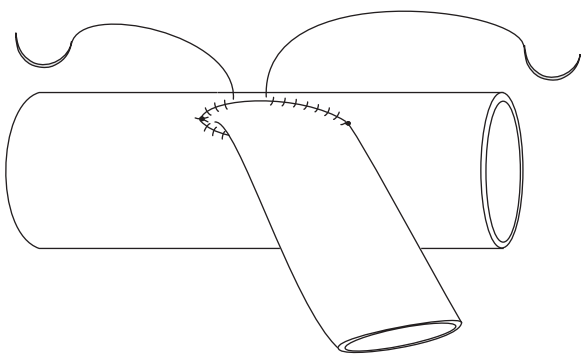


Again, introduce the needle from the adventitial side of the graft and the intimal side of the artery.



Place several more bites.

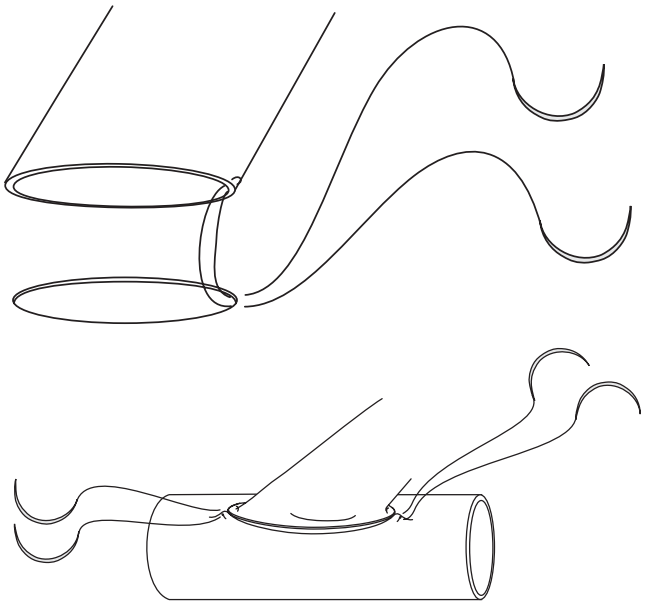
Run the suture line toward the heel until it meets the other suture. Tie the sutures.



Anchor Technique Horizontal Mattress Anchoring Sutures

These mattress sutures may help fold the graft and the artery to achieve an everted suture line with an ideal intima-to-intima opposition. In small vessels, it is important to avoid taking wide horizontal mattress sutures at the toe or the heel, as they may cause puckering or narrowing of the lumen.

In this variation, the fixing sutures are horizontal mattress sutures.

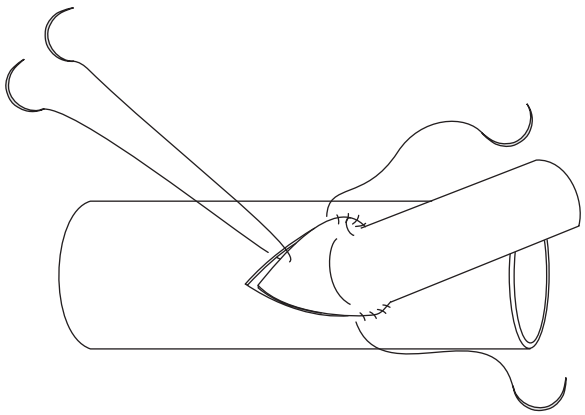


Anchor Technique

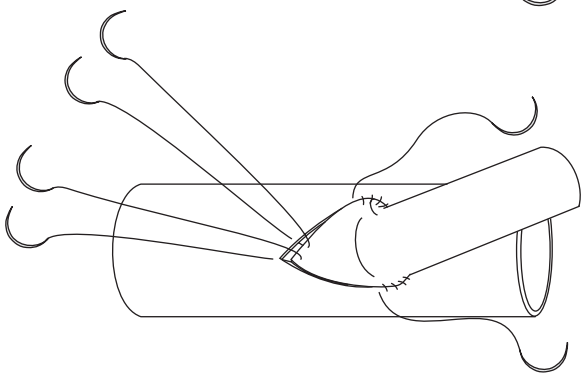
Construction of the Apex with Interrupted Sutures

Another variation is in the construction of the toe portion of the anastomosis. In very small vessels, interrupted sutures may be used to construct the toe of the anastomosis. The interrupted sutures at the anastomosis may allow for expansion of the anastomosis with arterial pulsations.

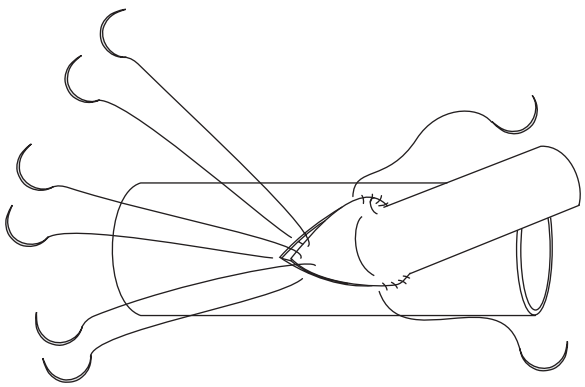
Construct the heel as previously described. Place one suture just proximal to the apex. Again, outside-inside in the graft, and inside-outside in the artery.



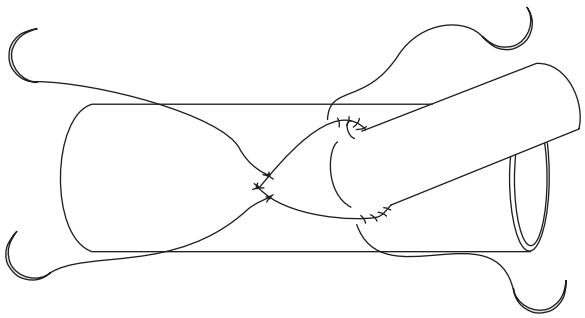
Place another suture at the apex.



Usually, three sutures are sufficient; however, additional interrupted sutures may be placed if deemed necessary.

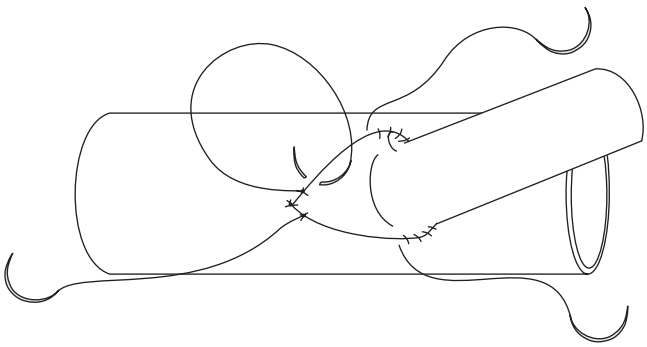


Tie the sutures.

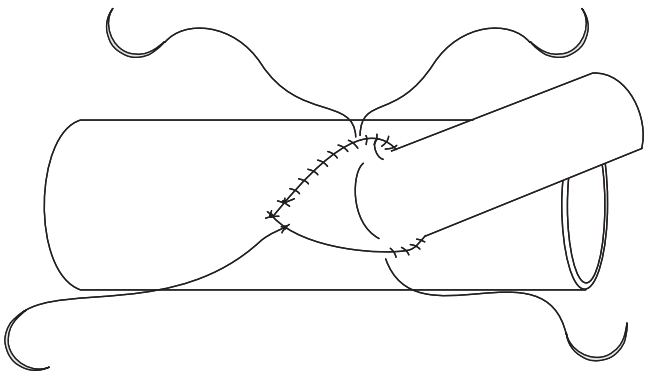


Anchor Technique Construction of the Apex with Interrupted Sutures

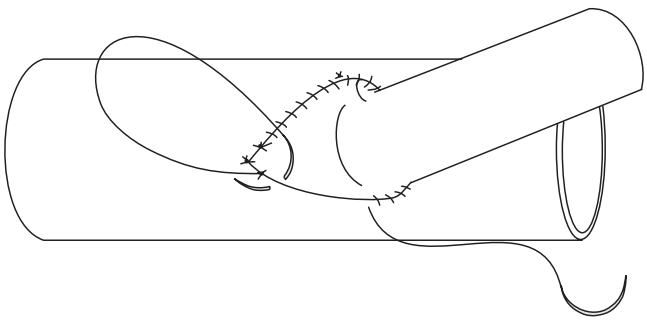
Start suturing with one end.



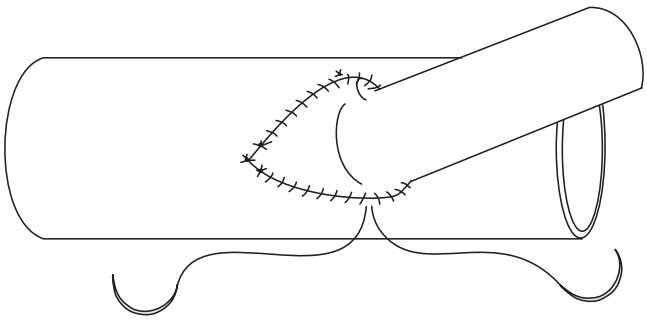
Run the suture until it reaches the heel suture.



Start suturing with the other end.

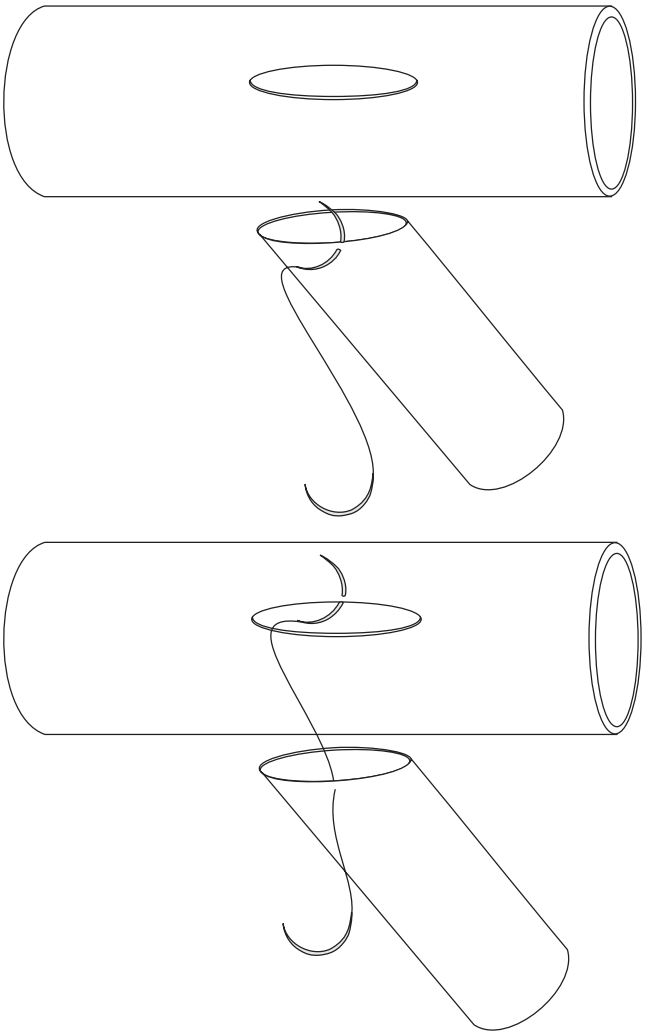


Run the suture toward the heel.



Anchor Technique

Anchoring Suture Starting Mid Distance Between the Apex and the Heel



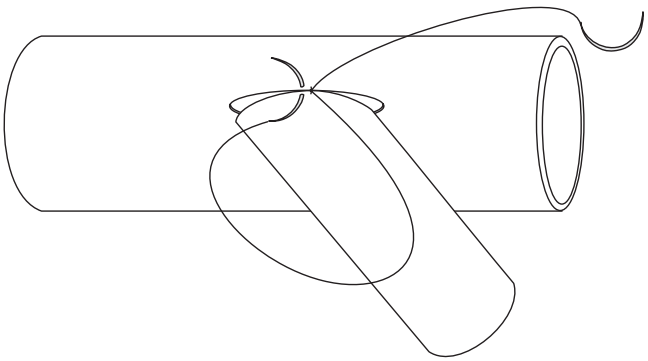
Introduce the needle outside-inside in the graft mid distance between the apex and the heel.

Introduce the needle in a corresponding site inside-outside in the artery.

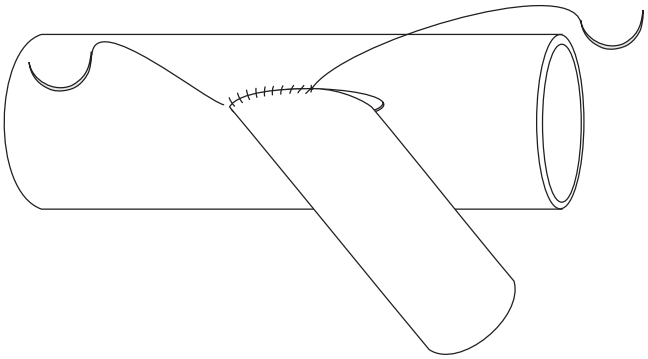
Anchor Technique

Anchoring Suture Starting Mid Distance Between the Apex and the Heel

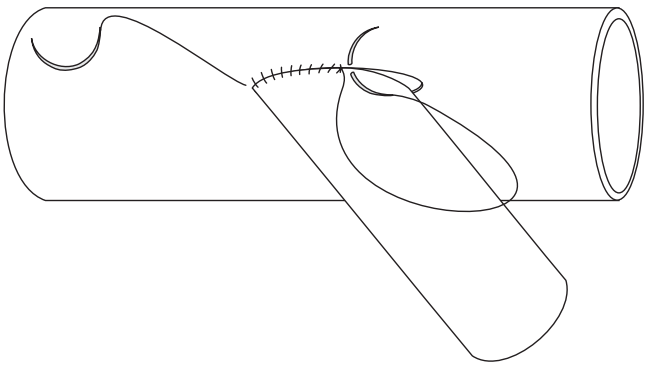
Tie the suture.



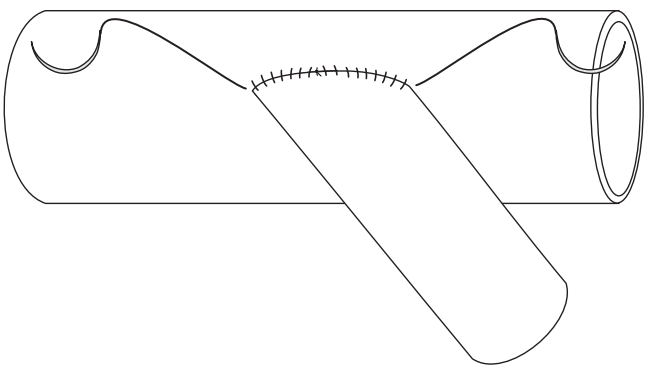
Run one end of the suture toward the apex.



The needle should penetrate from the adventitial side of the graft and the intimal side of the artery.

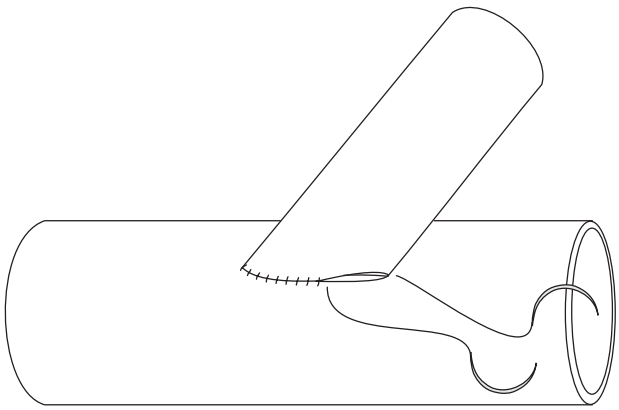


Run the other end toward the heel.

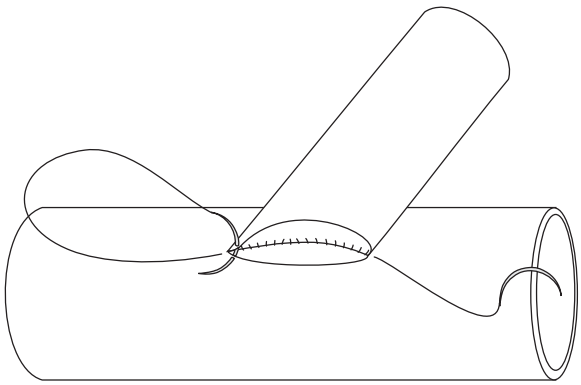


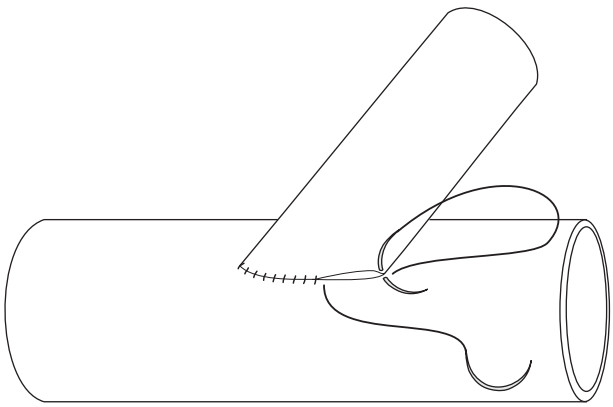
Anchor Technique

Anchoring Suture Starting Mid Distance Between the Apex and the Heel

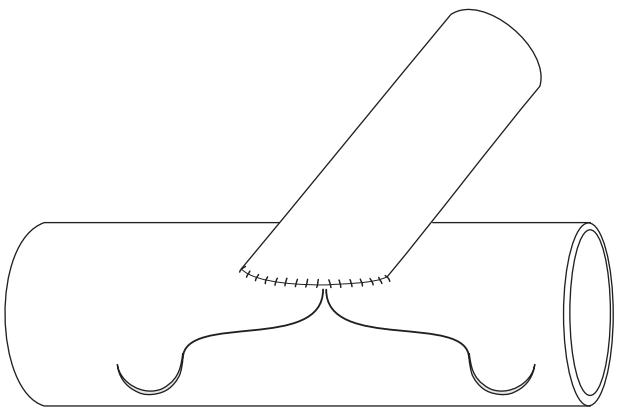


Flip the graft. Continue running the suture from the apex toward the heel.



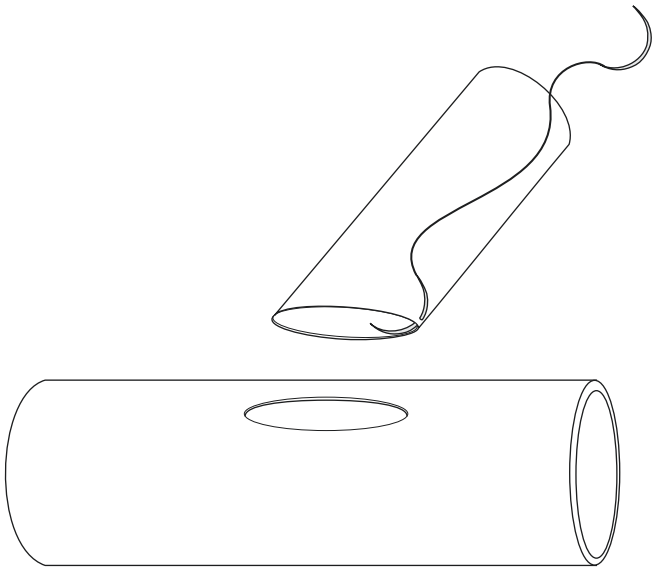


Resume suturing with the other end of the suture from the heel toward the apex.

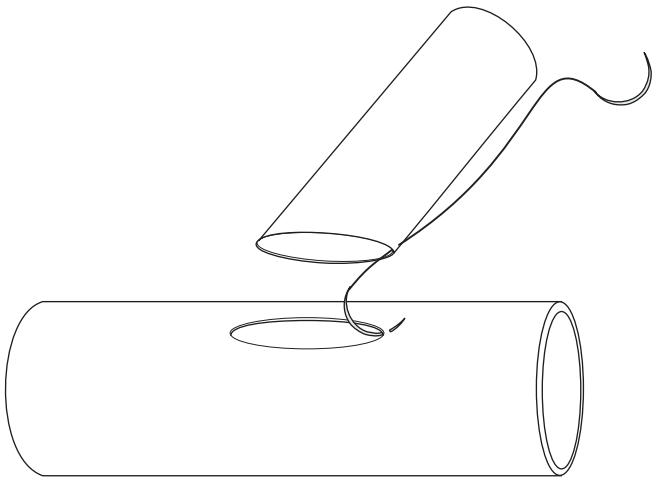


Parachute Technique
Starting at the Center of the Heel

Start the suture at the center of the heel. Introduce the needle in the graft (outside-inside).

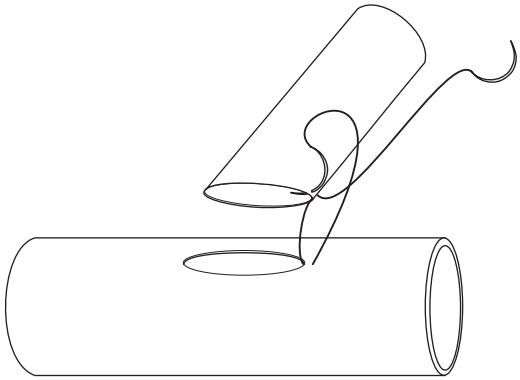


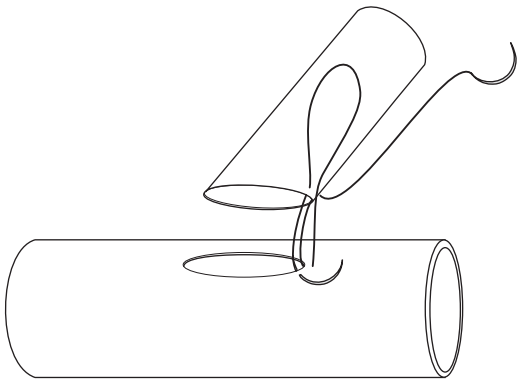
Introduce the needle in a matching location in the artery (inside-outside).



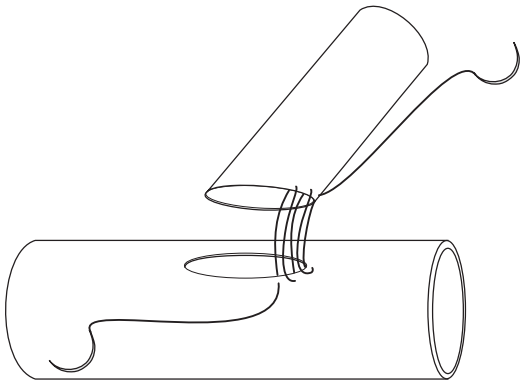
Parachute Technique
Starting at the Center of the Heel

Progress with the suturing toward the apex.

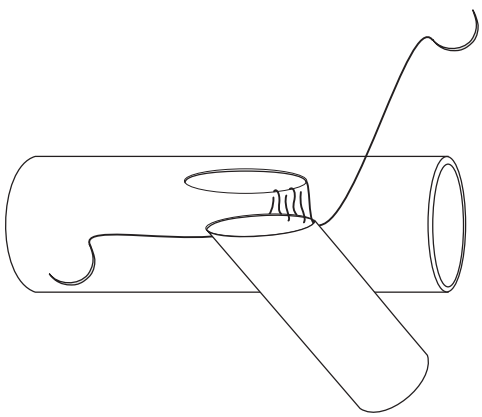




Continue suturing toward the apex for a few bites.

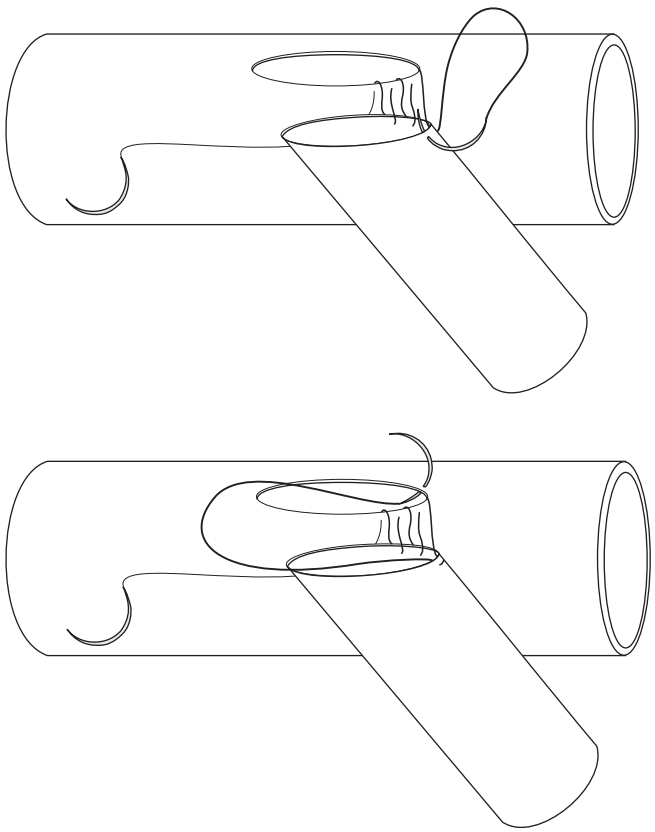


Flip the graft.

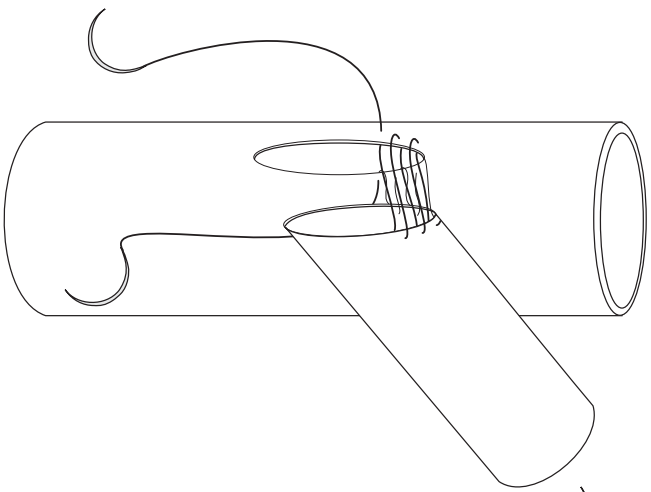


Parachute Technique
Starting at the Center of the Heel

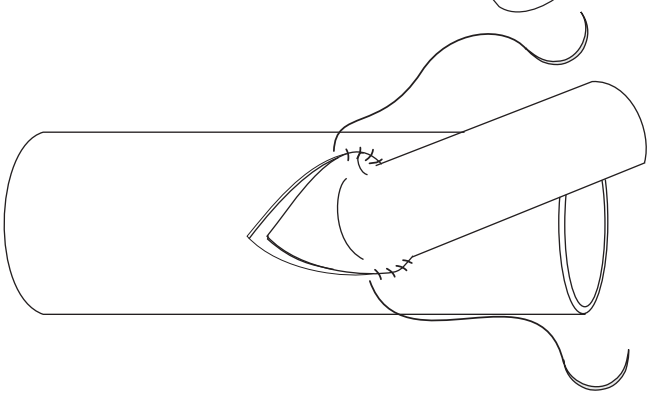
Resume suturing at the center of the heel. Introduce the needle (outside-inside) in the graft. This suture will be a horizontal mattress suture. Introduce the needle in a matching location in the artery.



Progress with the suturing forward toward the apex for a few bites.

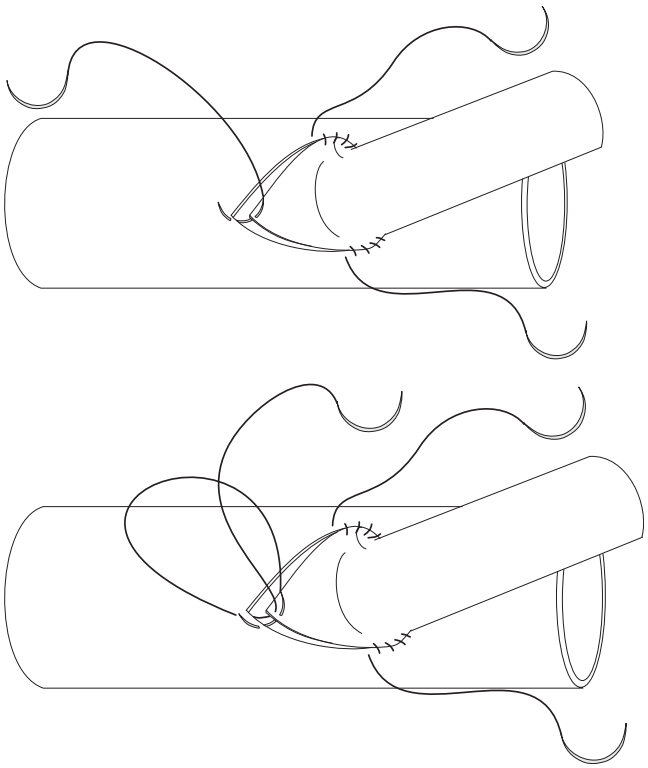


Pull and tighten the suture line.

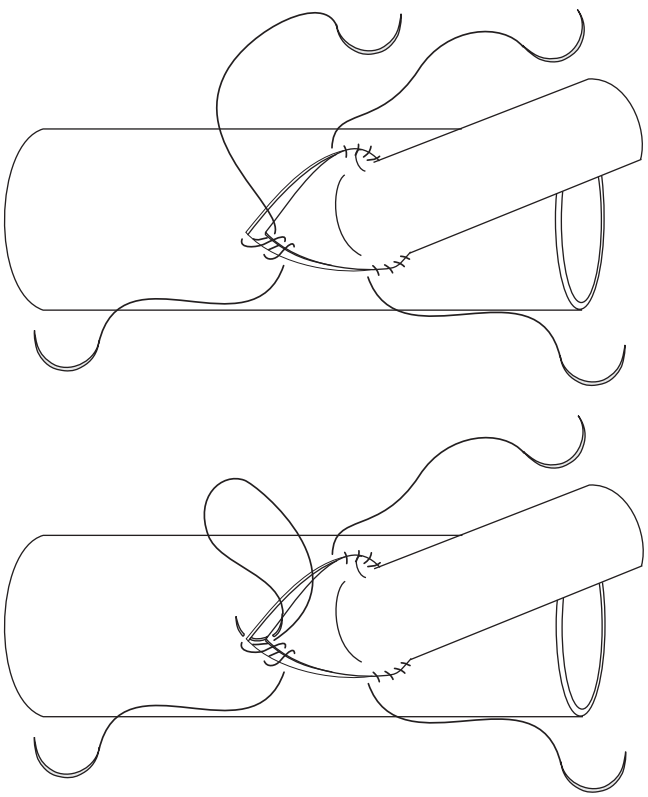


Parachute Technique
Starting at the Center of the Heel

Start another suture at the apex—outside-inside in the graft and inside-outside in the artery.

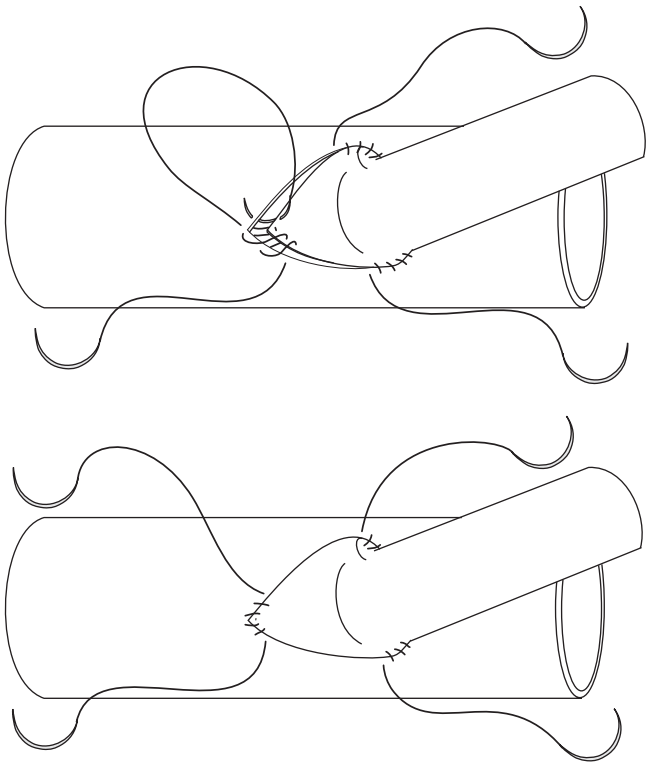


Progress with the suturing toward the heel for a few bites. Resume suturing with the other end of the apical suture. This suture will become a horizontal mattress suture.

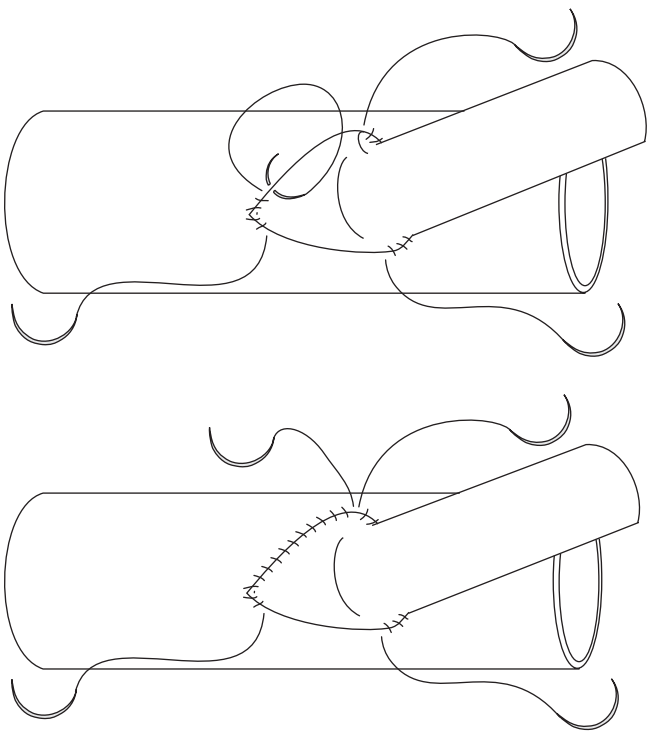


Parachute Technique
Starting at the Center of the Heel

Progress with the suturing toward the heel for a few bites. Pull and tighten the suture line.

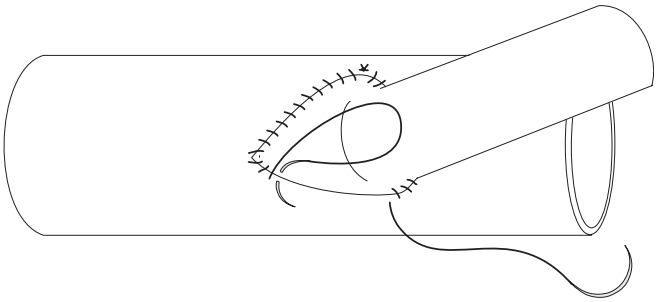


Progress with the suturing toward the heel. Tie the sutures.

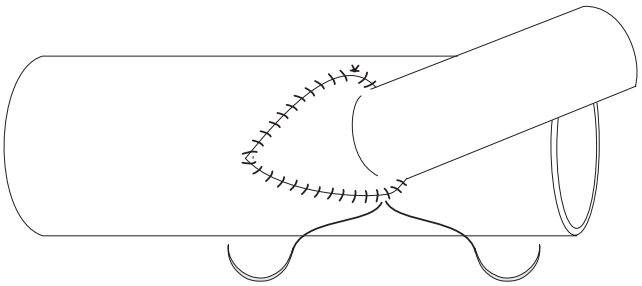


Parachute Technique
Starting at the Center of the Heel

Resume suturing with the other end of the apical suture toward the heel.

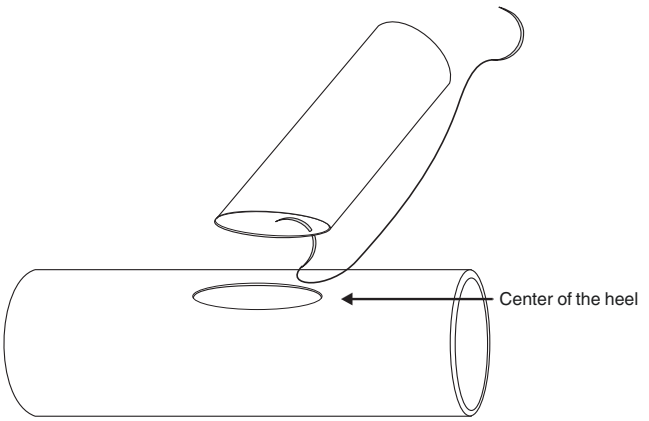


Tie the sutures.

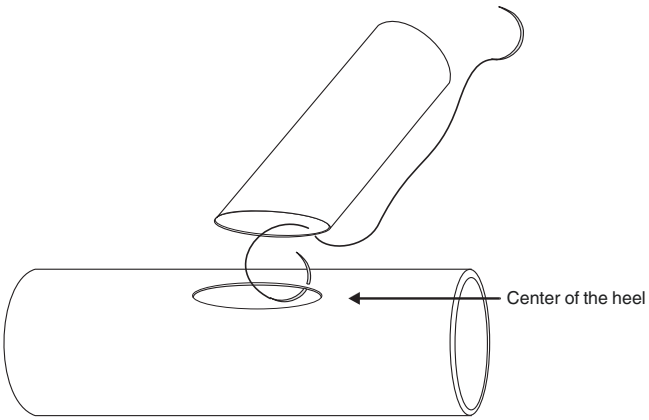


Parachute Technique Starting a Few Bites from the Center of the Heel

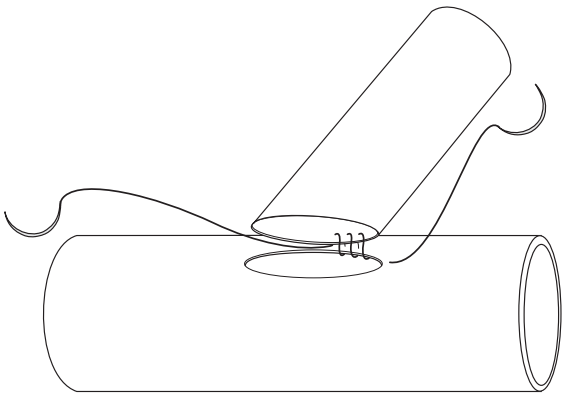
Start by introducing the needle through the adventitial side of the graft, a few bites away from the center of the heel.

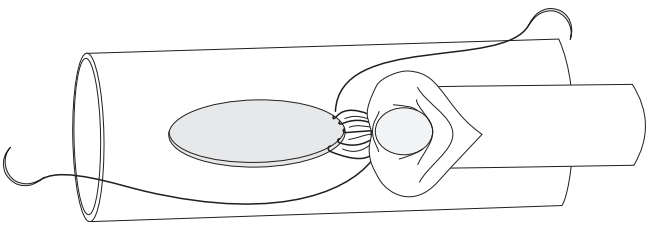


Introduce the needle in a corresponding site through the intimal side of the artery, a few bites away from the center of the heel.



Place several more sutures. Continue until you have placed a few bites past the center of the heel.

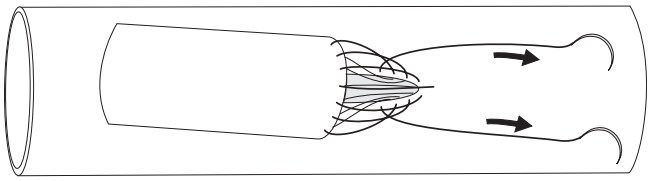




Parachute Technique

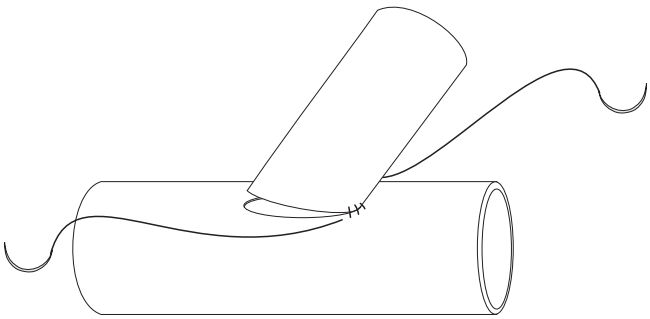
Starting a Few Bites from the Center of the Heel

Pull the ends of the sutures and parachute the graft down toward the artery.



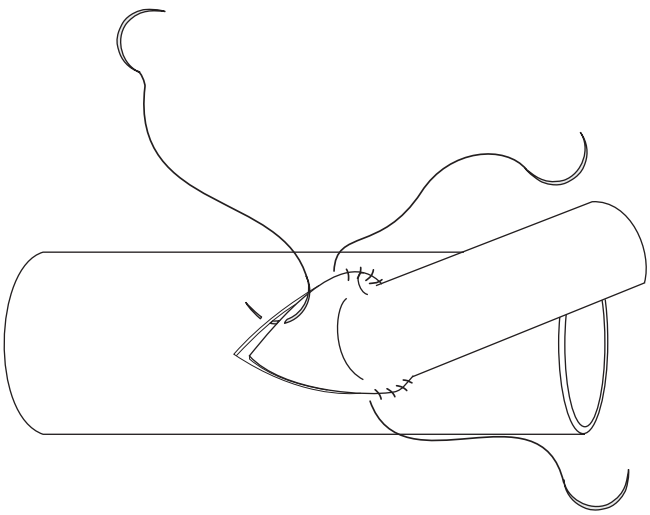
Posterior appearance of the suture line.

Tighten the suture line.



Start another suture a few bites away from the apex.

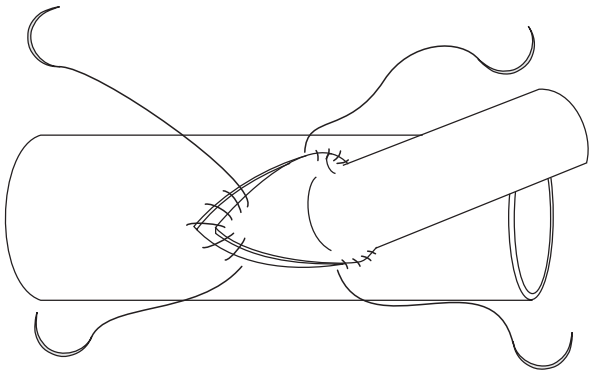
Introduce the needle from the adventitial side of the graft and the intimal side of the artery.



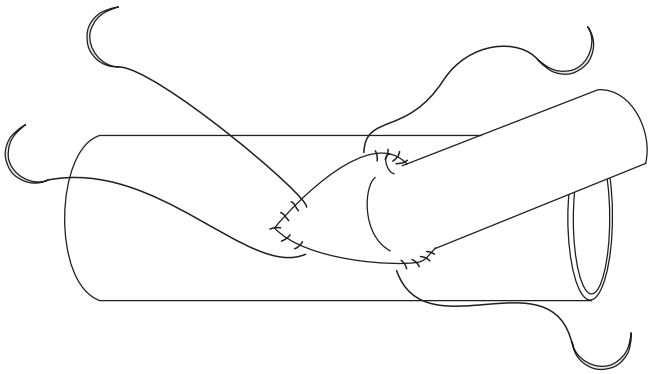
Parachute Technique

Starting a Few Bites from the Center of the Heel

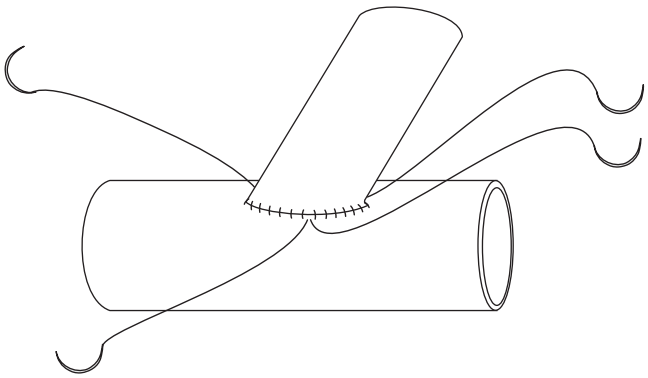
Continue the suture line until you have placed a few bites past the apex.



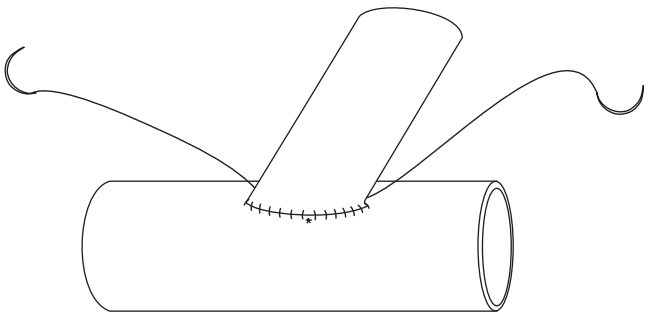
Tighten the suture line and pull down the graft.



Continue suturing with one end until the heel suture is met.



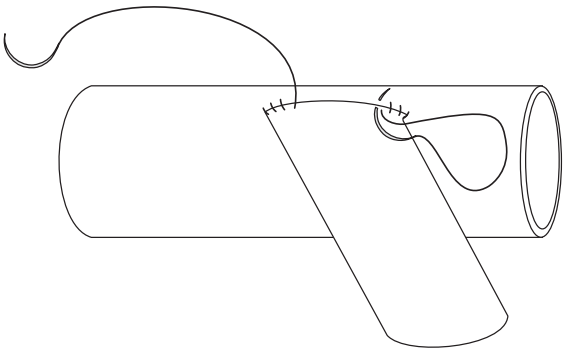
Tie both ends.



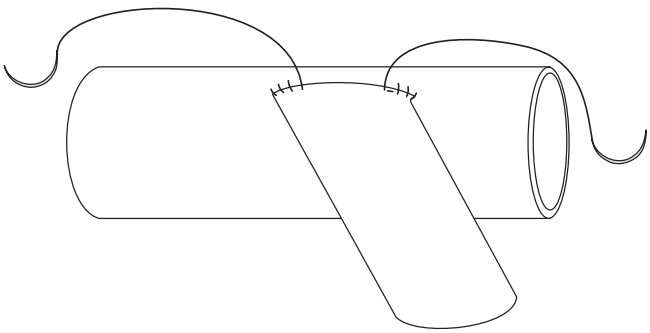
Parachute Technique

Starting a Few Bites from the Center of the Heel

Flip the graft and continue suturing with the other end. Again, start by introducing the needle from the adventitial side of the graft.

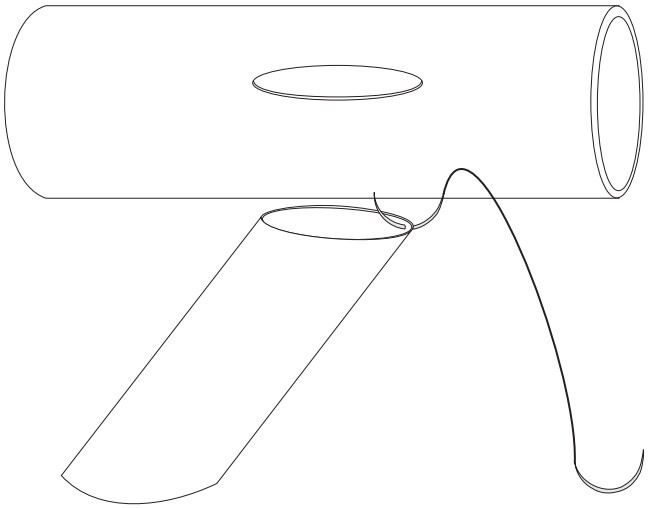


Run the suture toward the apex until it meets the other suture.

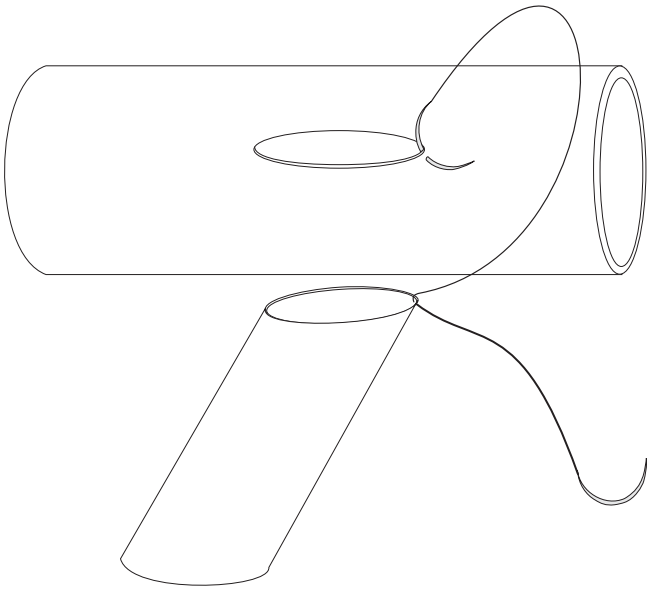


Parachute Technique: Starting at the Center of the Apex
Initial Completion of the Posterior Wall.

Start at the center of the apex.



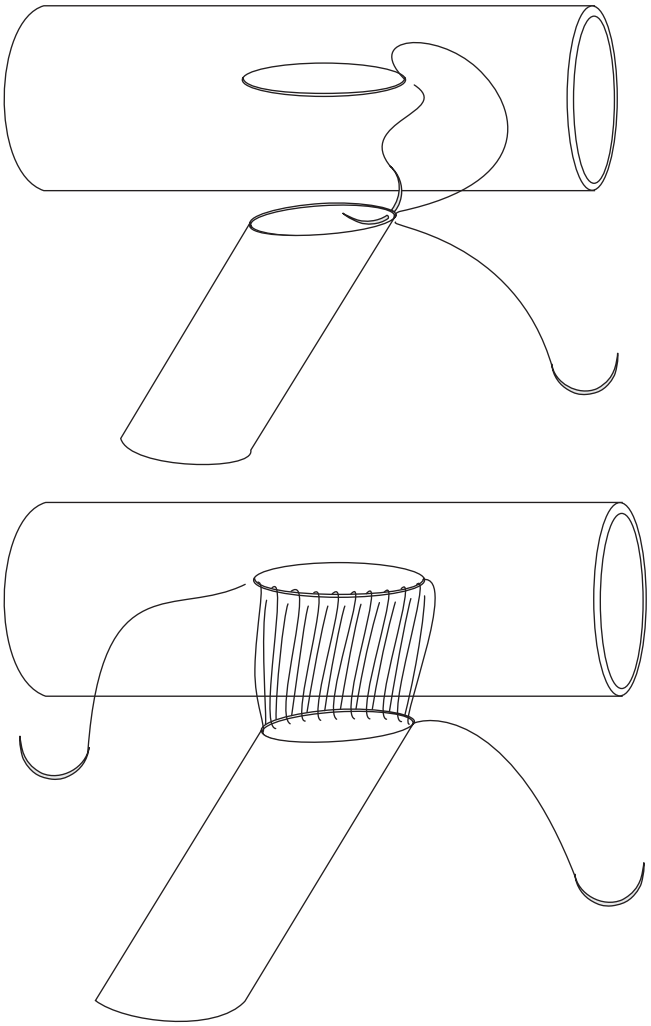
Introduce the needle in the graft (outside-inside). Introduce the needle in a matching location in the artery (inside-outside).



Parachute Technique: Starting at the Center of the Apex

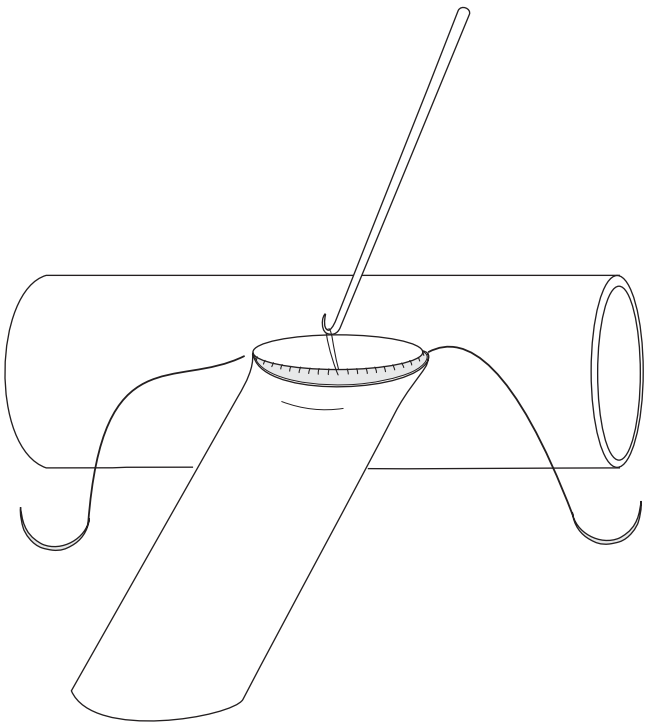
Initial Completion of the Posterior Wall.

Run the suture along the posterior part of the anastomosis. Continue running the suture along the heel.

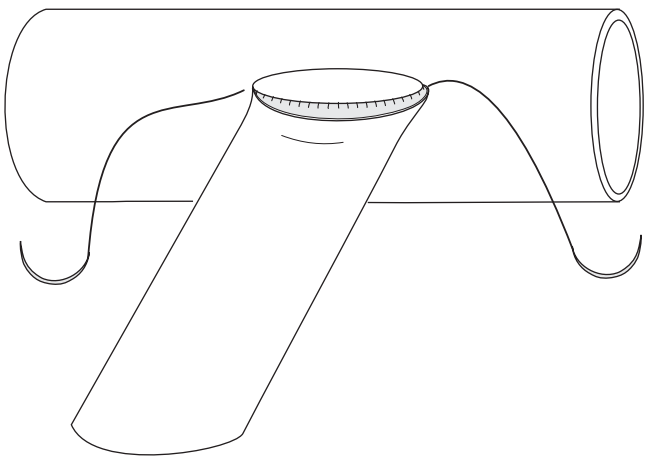


Parachute Technique: Starting at the Center of the Apex
Initial Completion of the Posterior Wall.

Use a nerve hook to facilitate tightening the suture line.

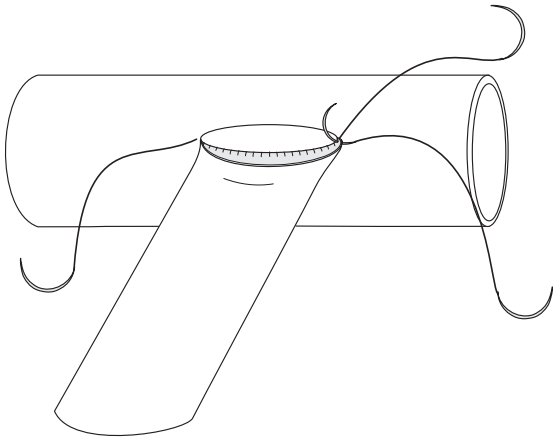


Pull and tighten the suture line. You may continue with the apical suture along the anterior wall to complete the anastomosis.

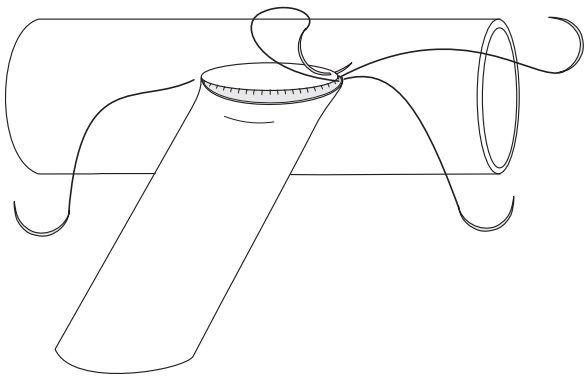


Parachute Technique: Starting at the Center of the Apex
Initial Completion of the Posterior Wall.

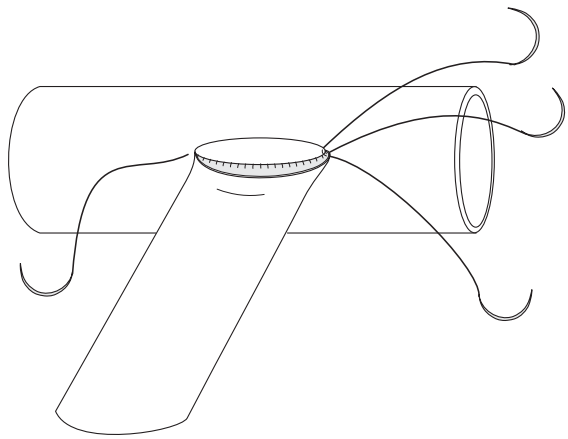
Alternatively, you may start another suture at the apex as shown here.



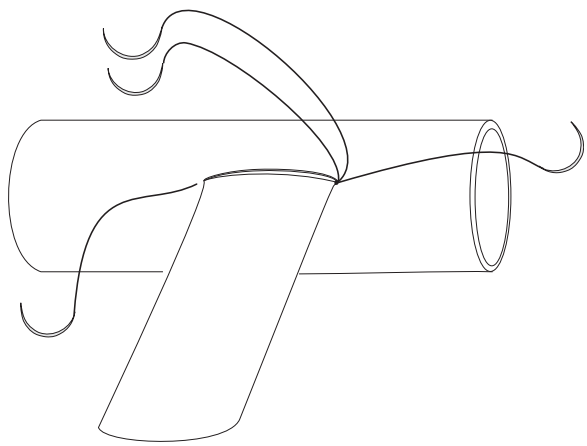
Start the new suture at the apex very close to the starting point of the previous suture. Again, introduce the needle outside-inside in the graft and inside-outside in the artery.



Tie the new apical suture. Three throws are usually sufficient.

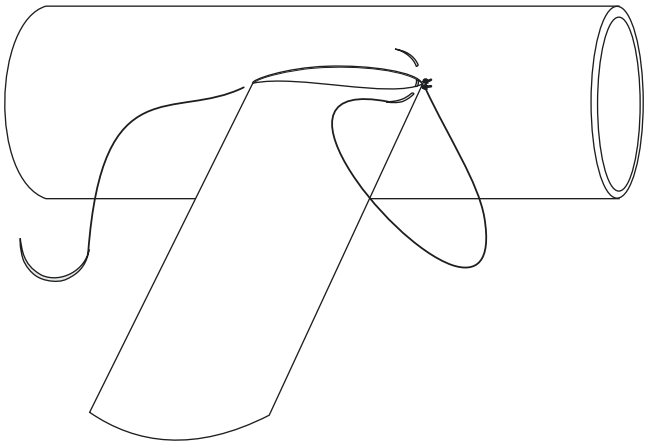


Tie one end to the first suture.

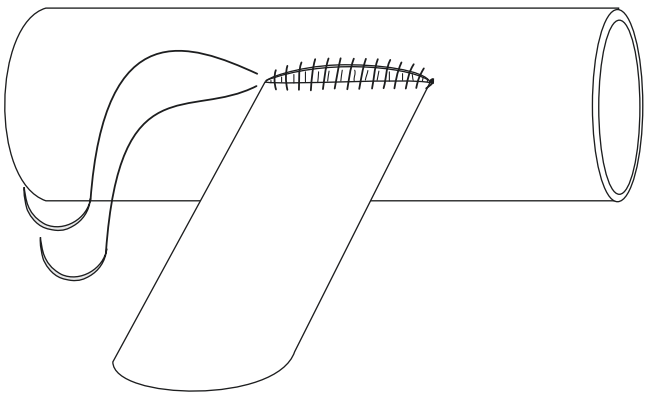


Parachute Technique: Starting at the Center of the Apex
Initial Completion of the Posterior Wall.

Start suturing the anterior wall—outside-inside in the graft and inside-outside in the artery. Progress with the suturing until you reach the heel suture.



Pull and tighten the suture line and tie the sutures.



10

End-to-End Anastomosis

Jamal J. Hoballah

An end-to-end anastomosis is usually performed in trauma or for aneurysmal disease to replace an injured or aneurysmal vessel. An end-to-end anastomosis is also used when constructing a composite bypass or when replacing a diseased segment of a bypass. Furthermore, an end-to-end configuration may be chosen when preservation of retrograde flow is not essential, such as in a renal or celiac artery bypass.

Numerous methods are available for constructing an end-to-end anastomosis. The choice of the method will depend on several factors. These factors include the diameter of the vessels to be anastomosed, their mobility, and their ability to be rotated along their long axis. End-to-end anastomoses are usually performed with a continuous running suture technique. A continuous suture line can be started using an anchor technique, a parachute technique, or a combination of both. When a combination of both techniques is used, an anchor technique may be utilized for the posterior part of the anastomosis and a parachute technique for the anterior part or vice versa. In very rare situations, such as in children, the whole anastomosis or a portion of it is constructed with interrupted sutures to accommodate for future growth of the vessel.

END-TO-END ANASTOMOSIS IN LARGE VESSELS OF COMPARABLE DIAMETER (8 mm or Greater in Diameter)

When constructing an end-to-end anastomosis between two large vessels of comparable diameters, the vessel transection and the anastomotic suture line are usually in a plane perpendicular to the long axis of the vessels. If both segments are freely movable, one simple technique involves dividing the anastomosis into an anterior and a posterior part by placing two diametrically opposed sutures (section "Large Vessels, Freely Movable: Transection Perpendicular to the Longitudinal Axis"). The sutures are tied and the anterior part of the anastomosis is constructed first. The vessels are then flipped 180°degrees, placing the posterior walls in an anterior location for completion of the anastomosis. One modification of this technique is the triangulation technique first described by Alexis Carrel (section "Large Vessels, Freely Movable: Transection Perpendicular to the Longitudinal Axis"). In this method, the anastomosis is

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divided into three parts. The vessels are joined by three individual sutures, placed and tied one-third of the circumference of the anastomosis apart. This approach may help to prevent uneven advancements between the sutures on either side of the vessels, especially when dealing with large vessels of comparable but unequal diameters. When the vessel segments are not freely movable and will not allow for rotating the anastomosis 180°, the posterior walls are sutured first. This can be performed using a parachute technique (section "Large Vessels, Fixed: Transection Perpendicular to the Longitudinal Axis") or an anchor technique. In either technique, the suture may be started in the center or at one end of the posterior wall.

END-TO-END ANASTOMOSIS IN SMALL VESSELS OF COMPARABLE DIAMETER (6 mm or Smaller in Diameter)

When constructing an end-to-end anastomosis between two small vessels, a beveled or spatulated anastomosis is necessary to avoid compromising the lumen (section "Small Vessels: Beveled Transection"). A simple method is to start one anchoring suture at the heel and then progress with the suturing on each side of the heel toward the apex. Another suture is then started at the apex after ensuring that the size of the vessels match appropriately. The anchoring sutures may be simple or horizontal mattress sutures. The anchoring sutures will stabilize the graft for the placement of the remaining bites. Once well apposed, both walls may be sutured together with a single passage of the needle. However, at the apex and the heel, it is preferable to pass the needle separately in each vessel wall to ensure optimal placement of the bites.

Autogenous vessels may contract and shorten transiently after transection. Approximation of the shortened vessels may place the anastomosis under slight tension. If the vessels are thin, the anchoring suture may tear through the vessel wall, especially if a simple suture was used. In this situation, using a parachute technique may be helpful. The parachute technique will spread the tension over several bites in the posterior wall rather than confining the tension to the area of a single anchoring suture. The parachute technique in spatulated vessels is similar to that shown in section "Large Vessels, Fixed: Transection Perpendicular to the Longitudinal Axis."

One useful additional technique that is used infrequently is the end-to-end anastomosis with anterior patch angioplasty [2]. This technique is useful when the debrided ends of an injured artery can only be approximated together if the anastomosis is constructed without beveling or spatulation. In this situation, the length of the arterial segments is not sufficient to allow for spatulation despite maximal mobilization. This technique involves creating an anterior arteriotomy in both vessel segments. The ends of the vessels are sutured together after aligning the anterior arteriotomies. The anastomosis is completed by covering the anterior defect using a vein patch angioplasty (section "Small Vessels: Transection Perpendicular to the Longitudinal Axis"). The main advantage of this technique is avoiding the placement of a very short interposition graft.

END-TO-END ANASTOMOSIS BETWEEN VESSELS OF UNEQUAL CALIBER

Several methods have been described to facilitate the construction of an end-to-end anastomosis between two vessels of unequal calibers. In such reconstructions, it is helpful to minimize trimming the smaller caliber vessel and to create a long spatulated anastomosis. This can help in providing a smooth transition

between the anastomosed structures and may prevent an acute angulation caused by the diameter mismatch (section "Vessels of Unequal Diameter; Beveled Transection").

If an undesirable angulation is likely to develop following an end-to-end anastomosis between unequal-sized vessels, a patch angioplasty may be necessary to correct the deformity. The technique of end-to-end anastomosis with anterior patch angioplasty described in section "Small Vessels: Transection Perpendicular to the Longitudinal Axis" can be used to create an anastomosis between two relatively small vessels of unequal calibers. The patch is tailored to accommodate for the diameter mismatch.

When the size discrepancy is so large that an end-to-end anastomosis cannot be constructed, the options available become limited. One alternative involves oversewing the transected end of the larger diameter vessel. This is followed by connecting the end of the smaller diameter vessel to the side of the larger diameter vessel. The resulting configuration is an end-to-side anastomosis, which is a functional end-to-end anastomosis (section "Vessels of Unequal Diameter").

Another alternative is to consider other reconstructive alternatives. One such example is the composite vein graft, which is usually constructed by joining two vein segments together. If there is a notable size discrepancy, the large end of one segment will need to be anastomosed to the small end of the other segment. This difficult anastomosis can be avoided if one segment of vein is used in a reversed manner [1] while the other is used in a nonreversed manner. The change in the orientation of one vein segment will allow suturing the larger ends of the veins together. The valves in the nonreversed segment are then disrupted after arterializing the graft (section "Two Vessels of Unequal Diameter").

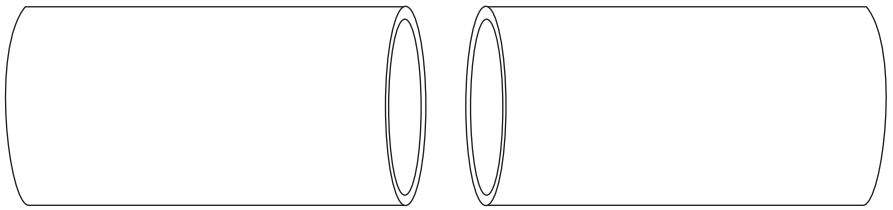
REFERENCES

1. Hoballah JJ, Chalmers RTA, Sharp WJ, Corson JD. Composite vein bypass: a simple technique for venovenous anastomosis. Ann Vasc Surg. 1994;8(4):400–2.
2. Reiner JAM, Van Dongen MD. End to end anastomosis with anterior patch angioplasty. In: Reconstructive arterial surgery. New York, Springer; 1970. p. 11.

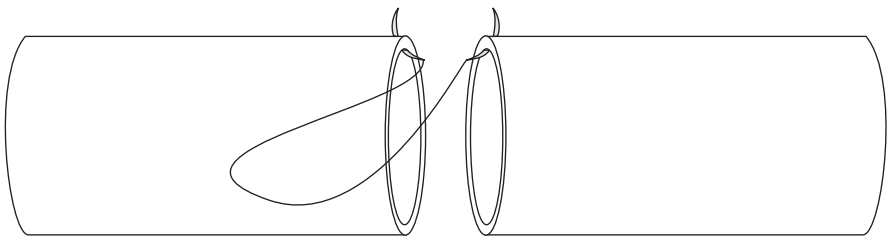
Large Vessels, Freely Movable: Transection Perpendicular to the Longitudinal Axis

Anchor Technique

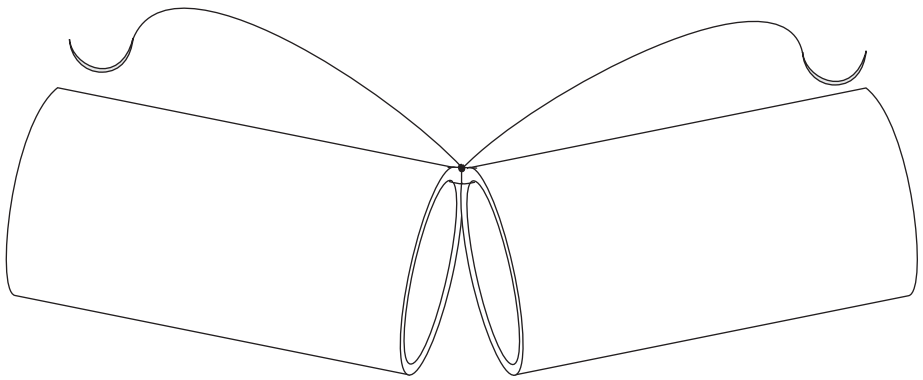
Transect the vessels at a right angle to their longitudinal axis.



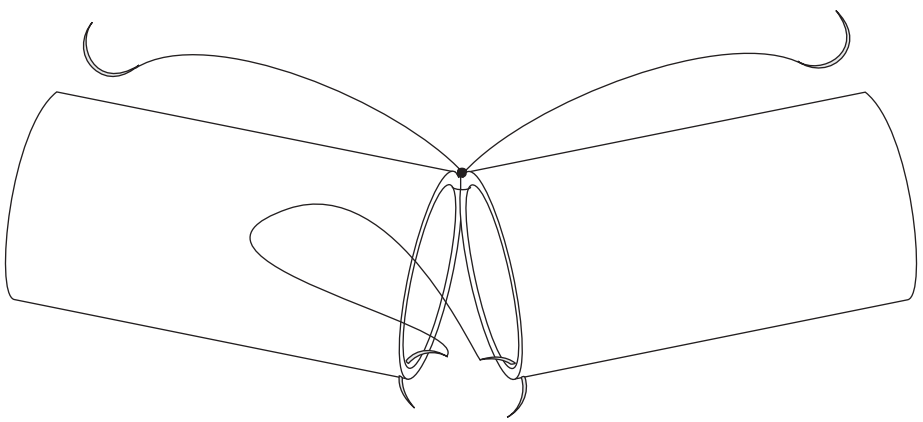
Start by placing one suture at the base of each vessel.



Tie the suture.



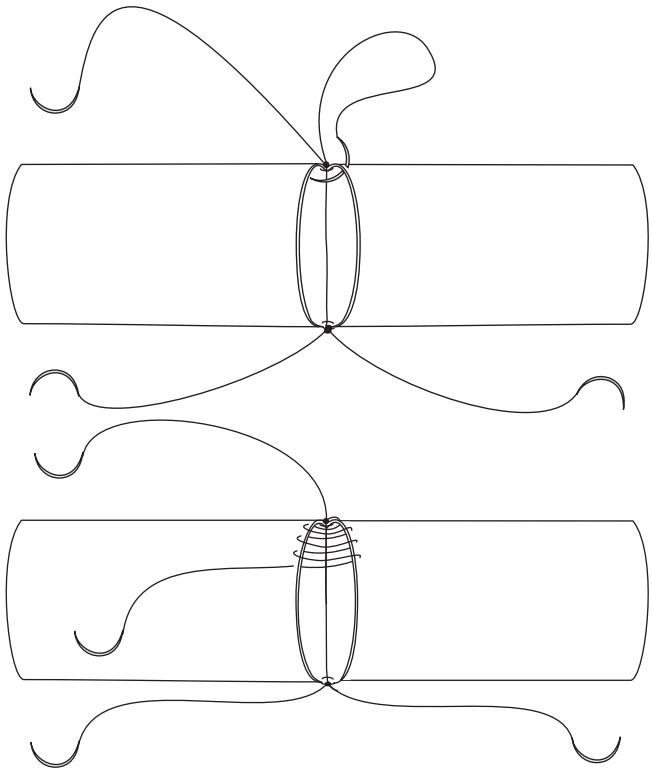
Place an identical suture diametrically opposite to the first suture.



Large Vessels, Freely Movable: Transection Perpendicular to the Longitudinal Axis

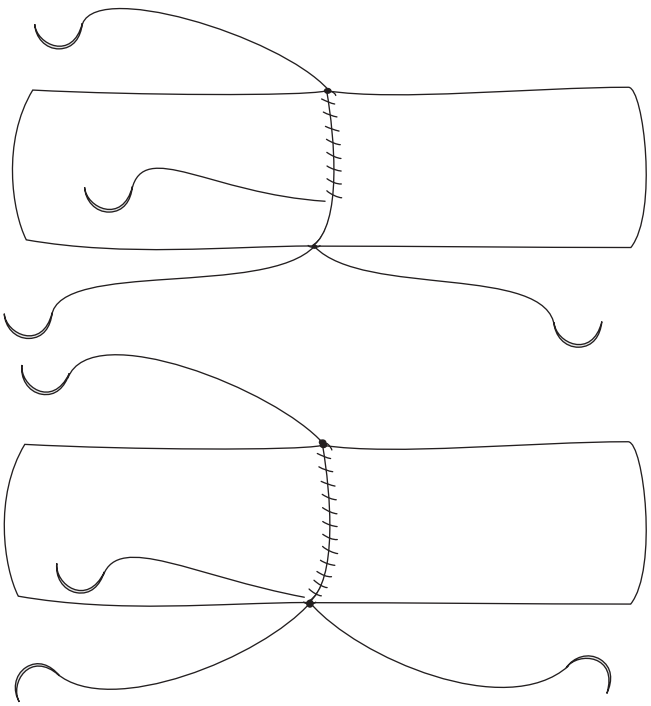
Anchor Technique

Start suturing on the anterior wall.



Run the suture along the anterior wall until it meets the inferior suture.

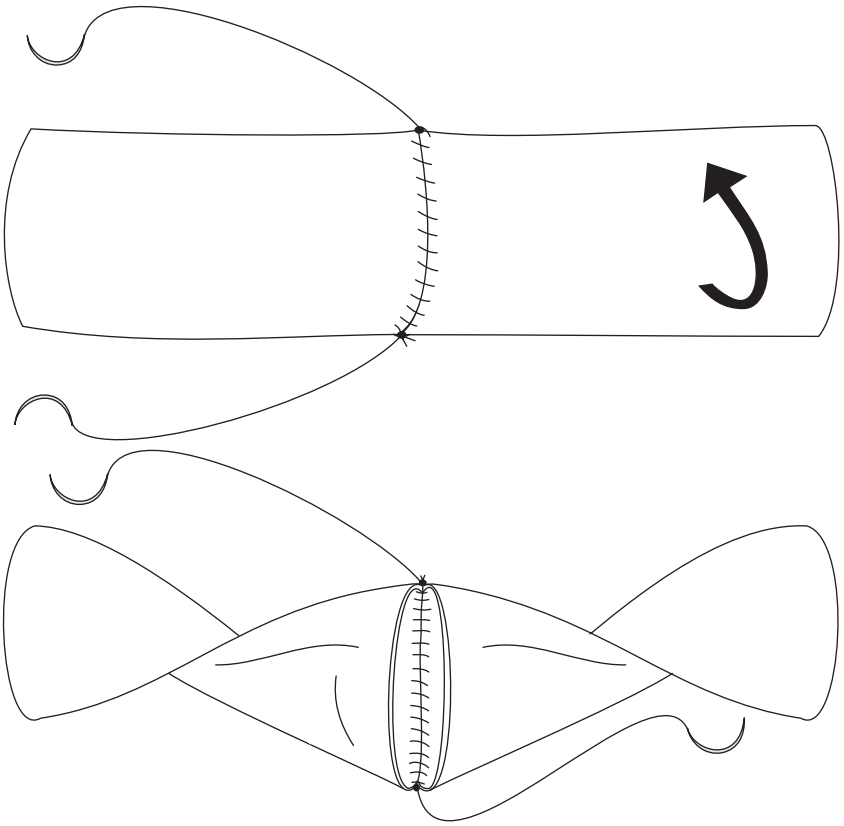
Tie the sutures.



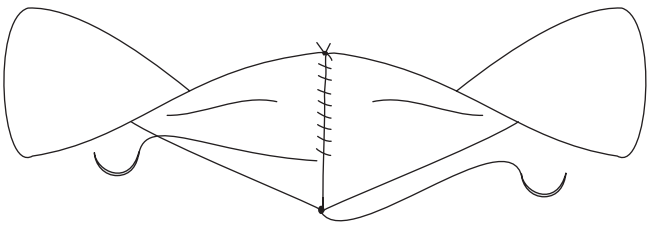
Large Vessels, Freely Movable: Transection Perpendicular to the Longitudinal Axis

Anchor Technique

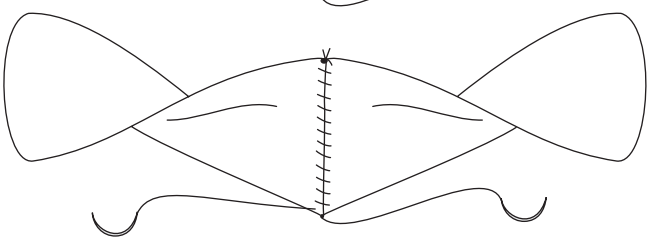
Flip the graft 180°, bringing the posterior wall to an anterior location.



Run the remaining end of the superior suture toward the inferior suture. You may



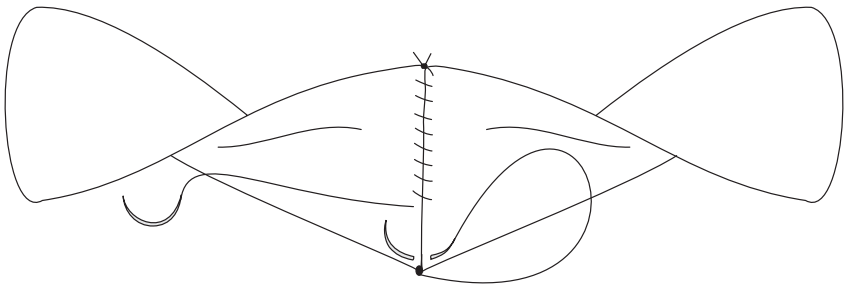
continue with the superior suture until it meets the inferior suture.



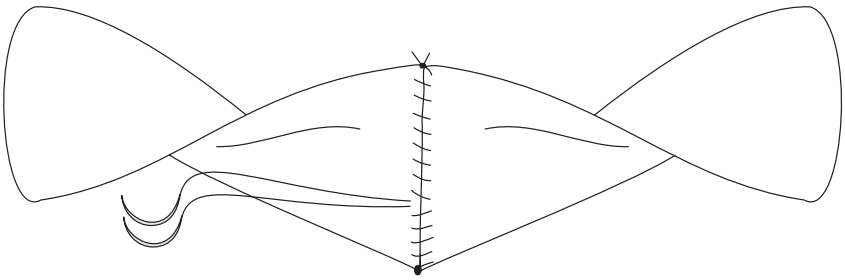
Large Vessels, Freely Movable: Transection Perpendicular to the Longitudinal Axis

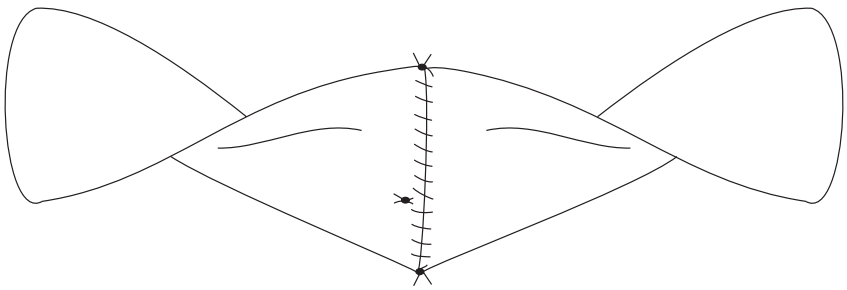
Anchor Technique

Alternatively, you may start suturing with the lower suture toward the upper suture.

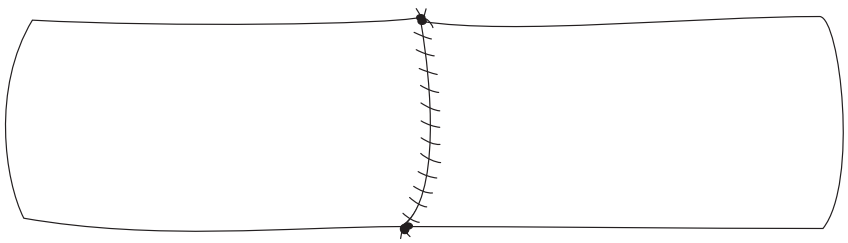


This variation will avoid the need to tie to a suture that already has a knot at its base, which could result in a bulky knot.





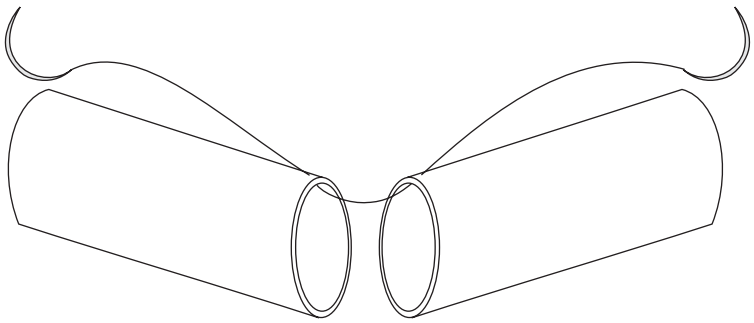
Tie the sutures and flip the graft back to its original position.



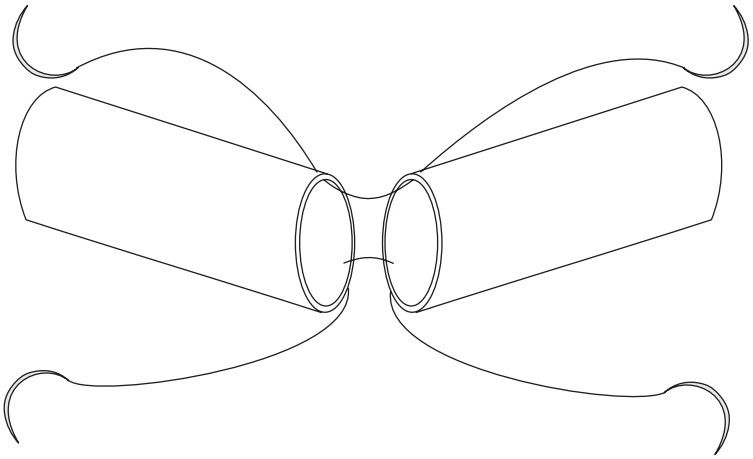
Large Vessels, Freely Movable: Transection Perpendicular to the Longitudinal Axis

Triangulation Technique

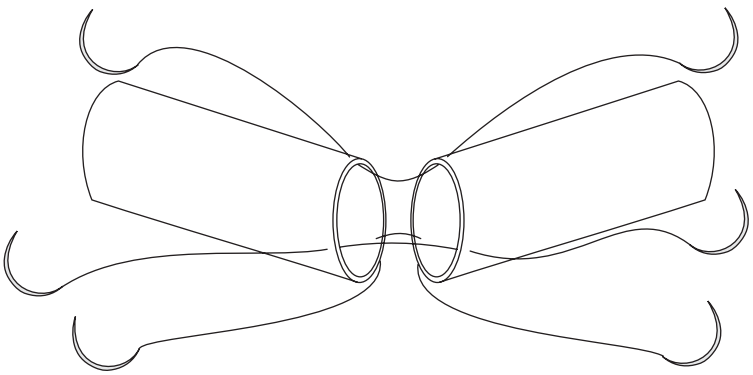
Place the first suture at the apex.



Place the next suture one-third the circumference away from the first suture.



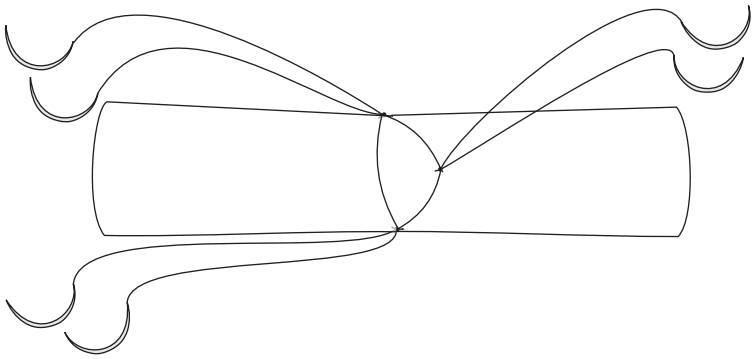
Place the third suture one-third the circumference away from the second suture.



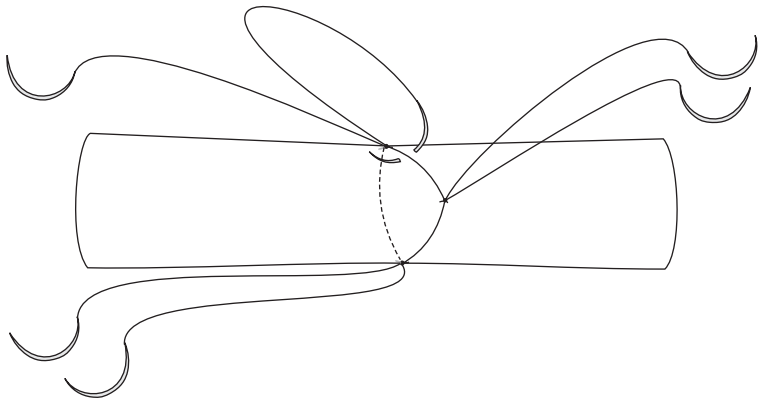
Large Vessels, Freely Movable: Transection Perpendicular to the Longitudinal Axis

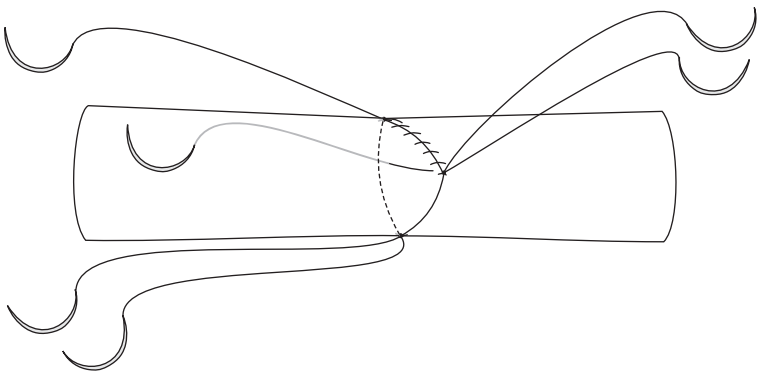
Triangulation Technique

Tie all the sutures. The suture line will now resemble an equilateral triangle.



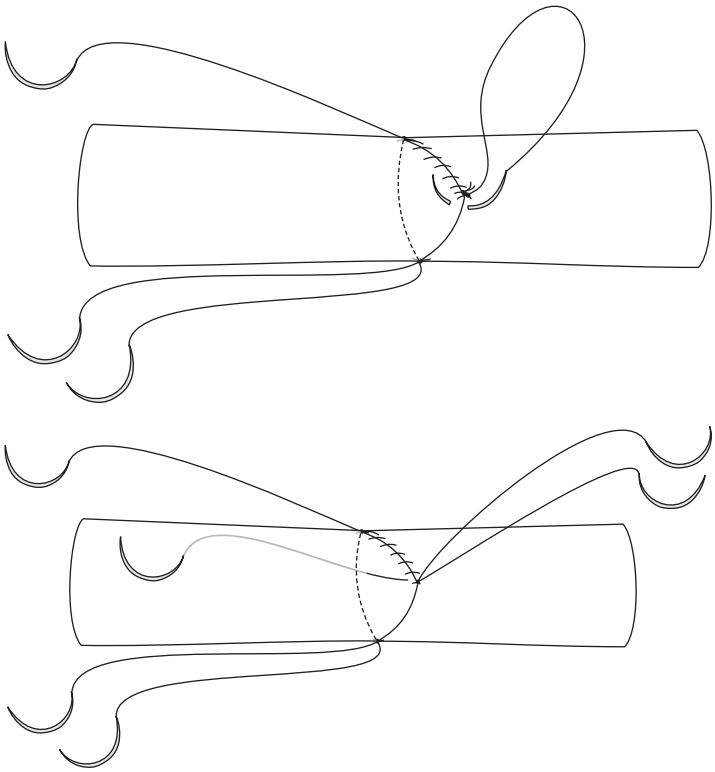
Start running one end of the apical suture toward the next suture. Tie the sutures to one end of the middle suture.





Large Vessels, Freely Movable: Transection Perpendicular to the Longitudinal Axis

Triangulation Method

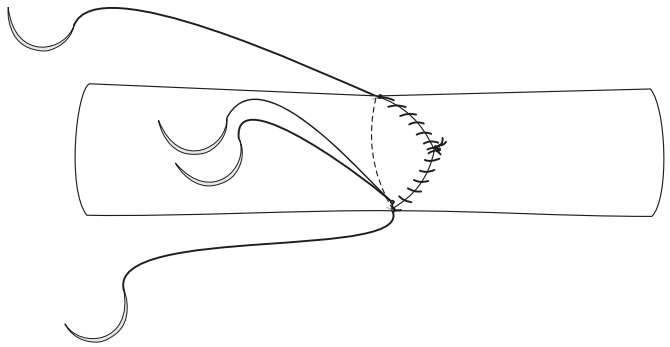


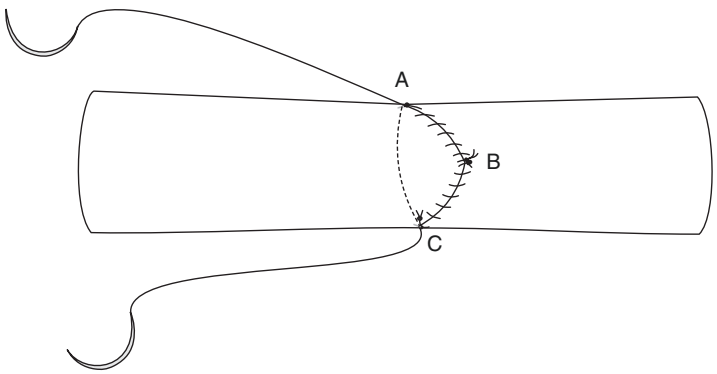
Run the remaining end toward the inferior suture.

Large Vessels, Freely Movable: Transection Perpendicular to the Longitudinal Axis

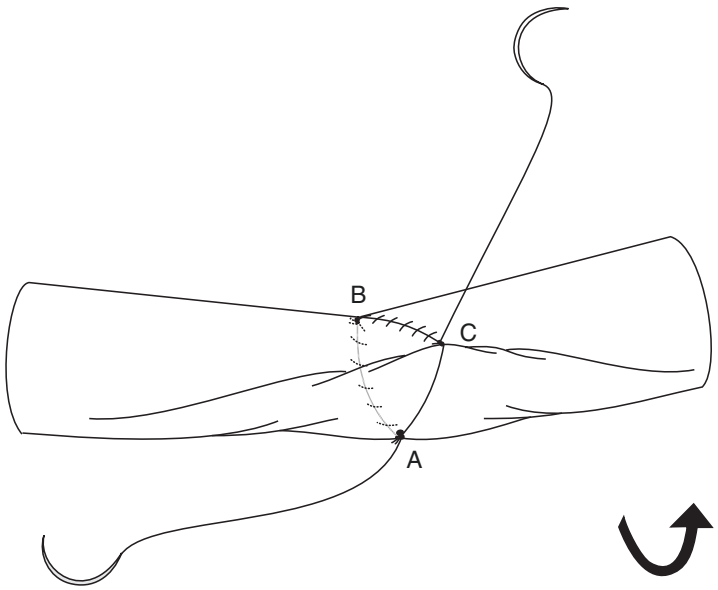
Triangulation Technique

Tie the suture to one end of the inferior suture.





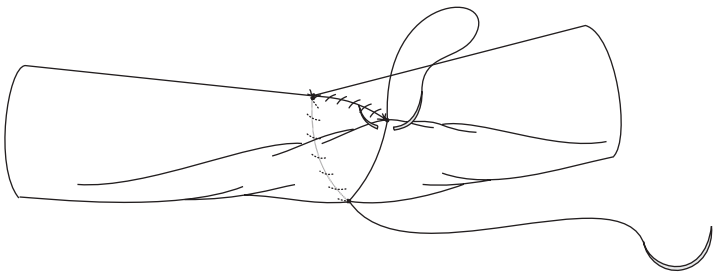
Flip the vessels 180°.

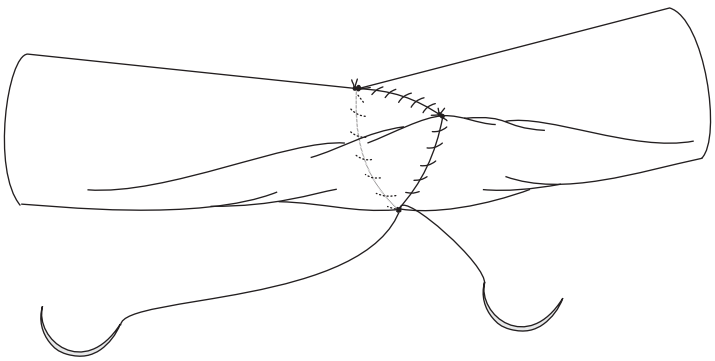


Large Vessels, Freely Movable: Transection Perpendicular to the Longitudinal Axis

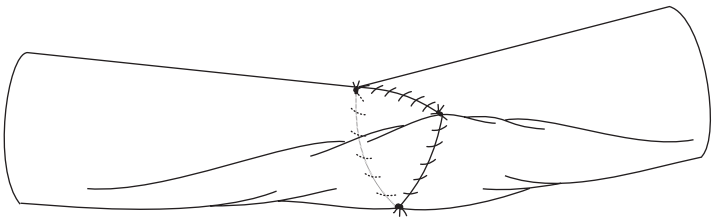
Triangulation Technique

Run the upper suture toward the lower suture.





Tie both sutures.

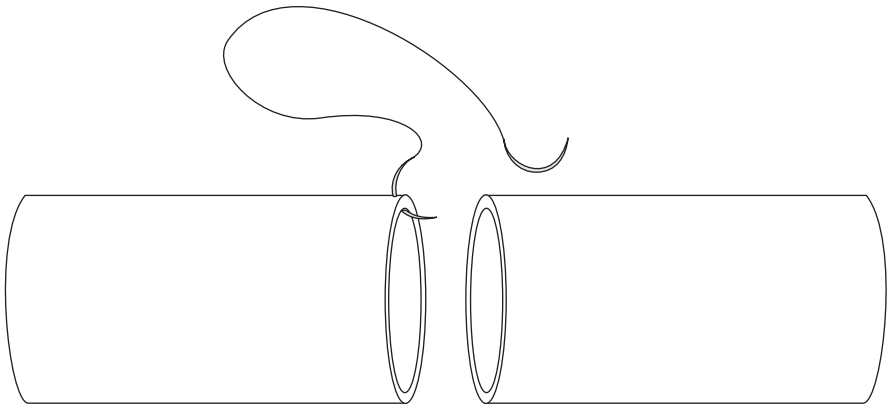


Large Vessels, Fixed: Transection Perpendicular to the Longitudinal Axis

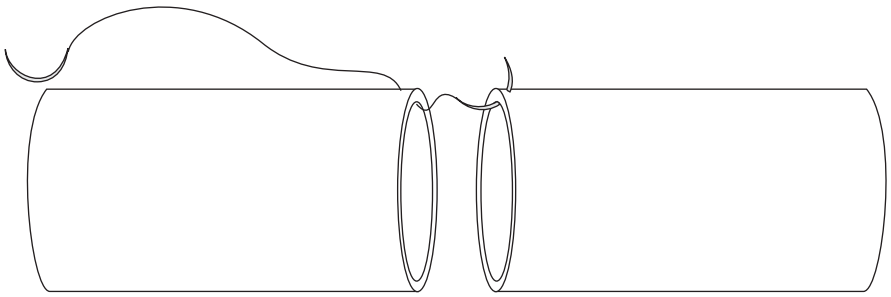
Parachute Technique

When the vessels cannot be rotated 180°, the back wall will have to be sutured first.

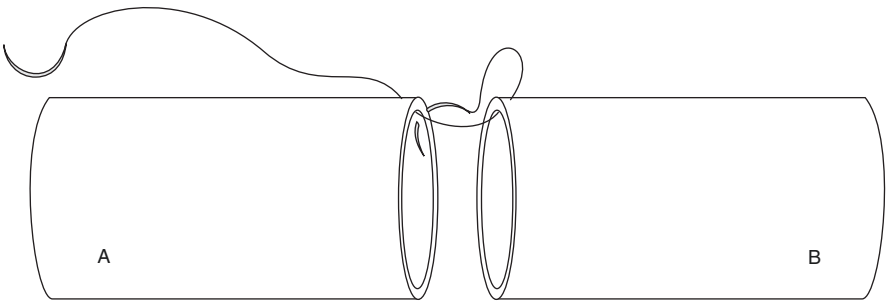
Start by placing one suture at the base of each vessel.

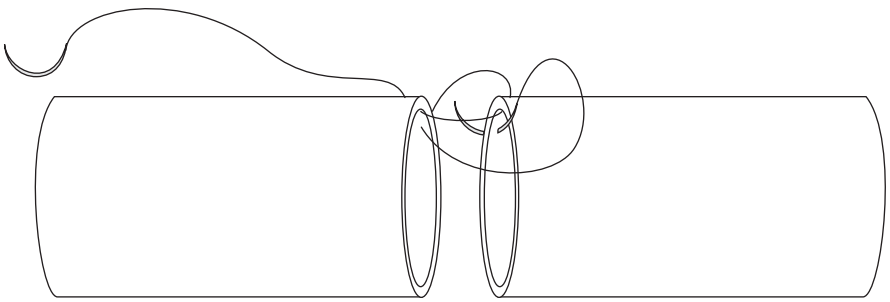


You may tie the suture or continue suturing the back wall without tying, as illustrated here.



The needle will be introduced from the adventitial side of vessel A and the intimal side of vessel B, thus allowing the suturing to be performed in a forehand manner.

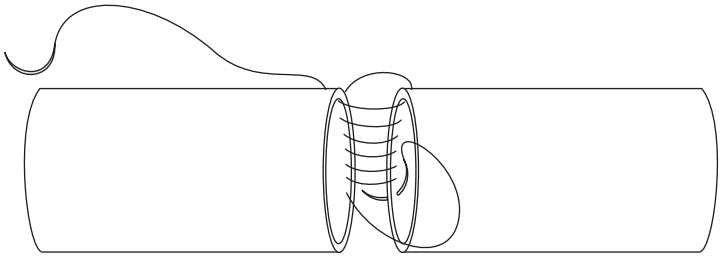




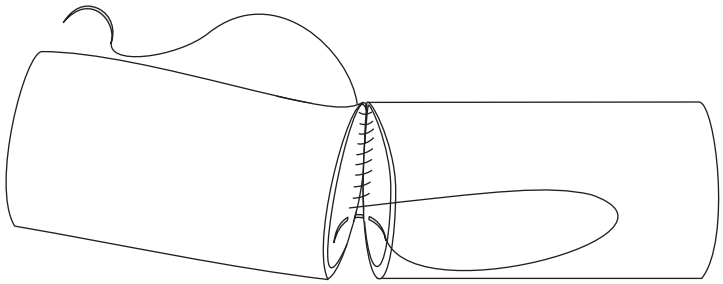
Large Vessels, Fixed: Transection Perpendicular to the Longitudinal Axis

Parachute Technique

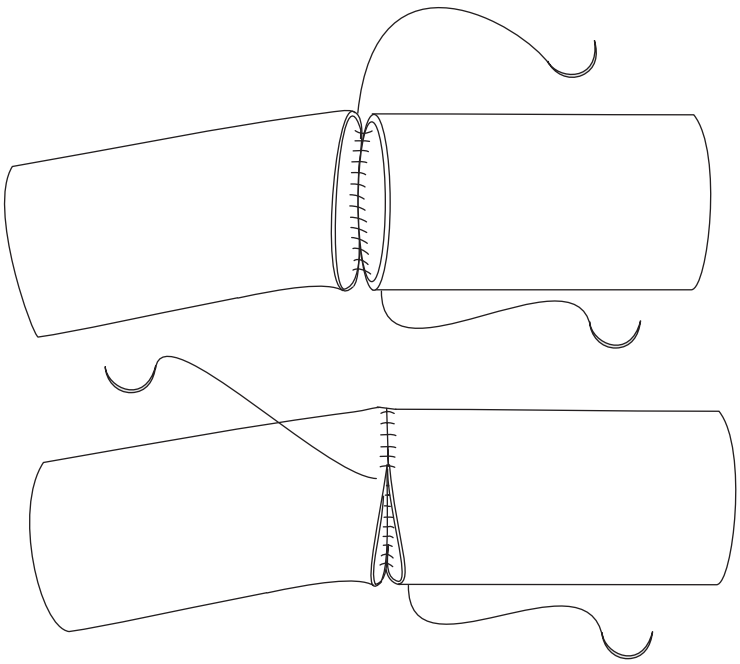
Continue placing the sutures until the posterior suture line is completed.



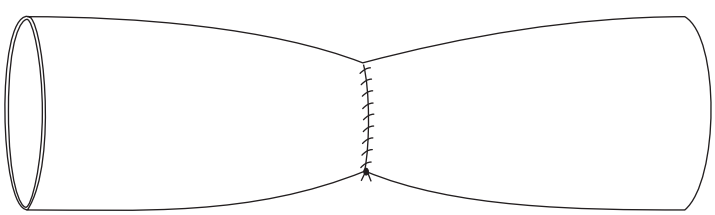
Tighten the suture line.



You may continue with the upper suture until it meets the other end. Avoid excessive tension on the suture line.



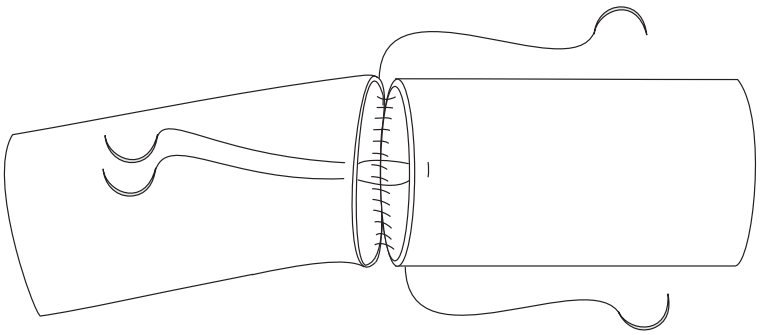
A waist or purse-string effect can occur at the anastomosis if excessive tension is applied to the suture line.



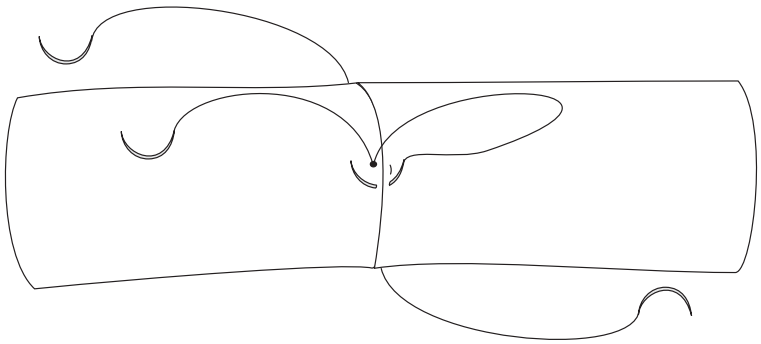
Large Vessels, Fixed: Transection Perpendicular to the Longitudinal Axis

Parachute Technique

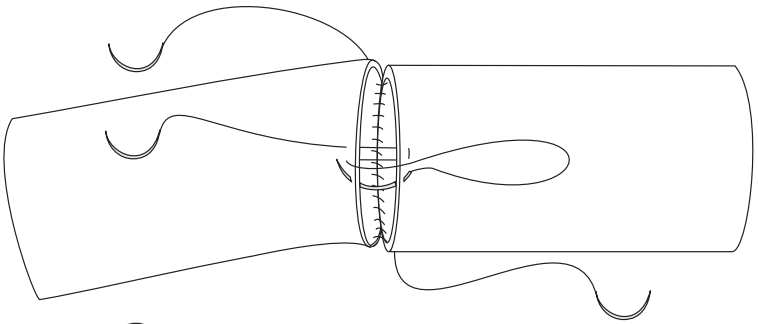
Alternatively, you may start another suture. This suture may be a simple or a mattress suture as shown here.



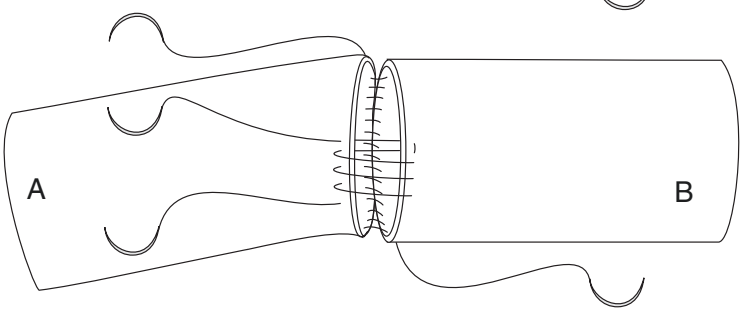
You may tie the suture and continue running the suture line.



Alternatively, you may continue suturing without tying, as shown here.



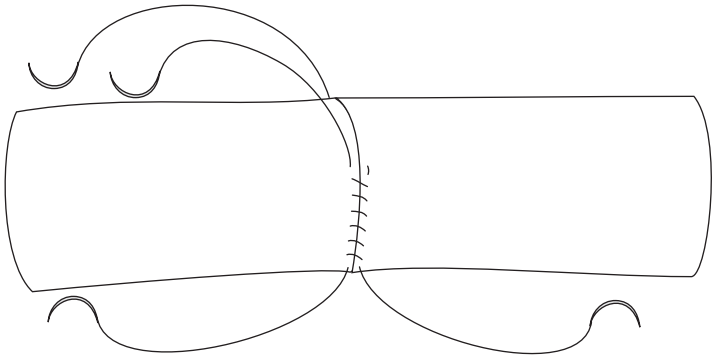
Introduce the needle on the adventitial side of vessel B and on the intimal side of vessel A.



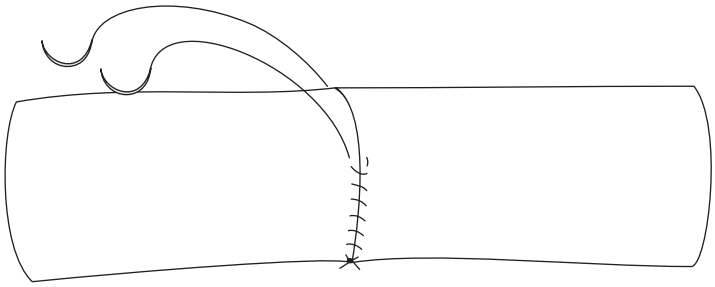
Large Vessels, Fixed: Transection Perpendicular to the Longitudinal Axis

Parachute Technique

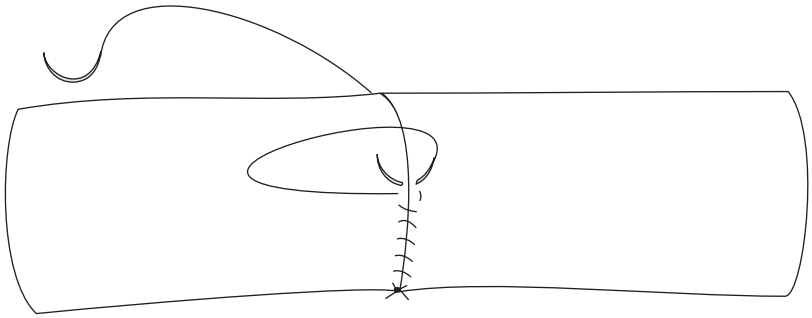
Continue suturing until you reach the inferior suture.



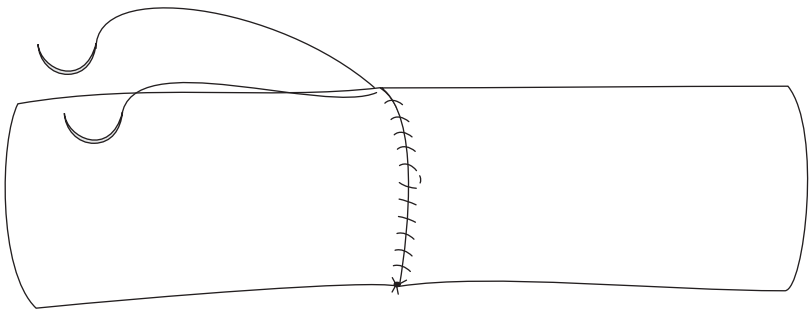
Tie the sutures.



Start suturing toward the superior suture.



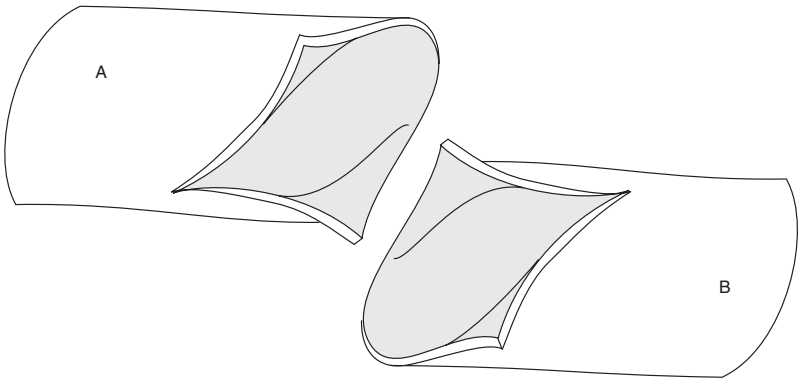
Tie the sutures.



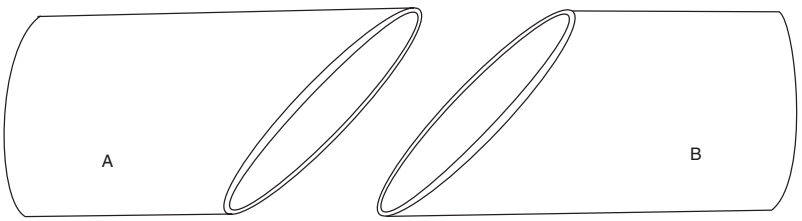
Small Vessels: Beveled Transection

Anchor Technique

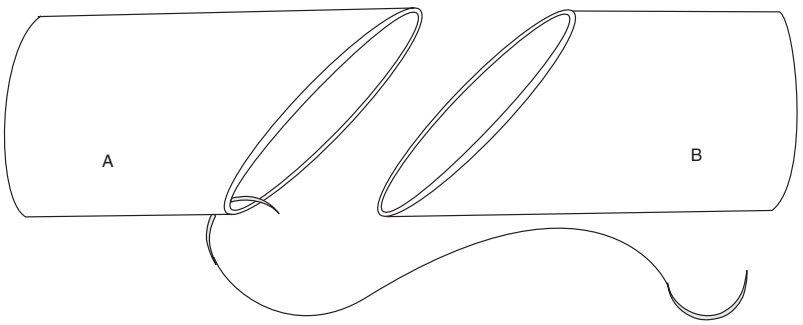
This section depicts an end-to-end anastomosis between a graft (A) and an artery (B).



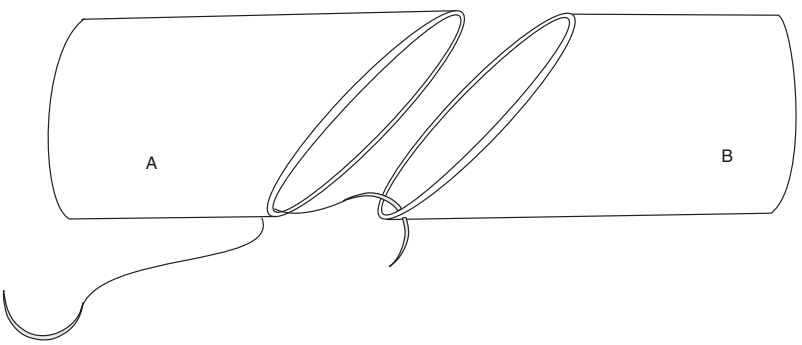
The vessels are beveled as previously described. In small vessels, spatulation may be helpful. The edges can be trimmed as necessary.



Start the suture at the center of the heel.



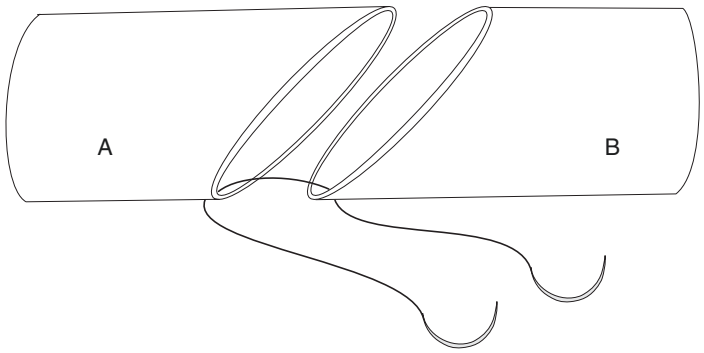
Introduce the needle from the adventitial side of the graft and the intimal side of the artery.



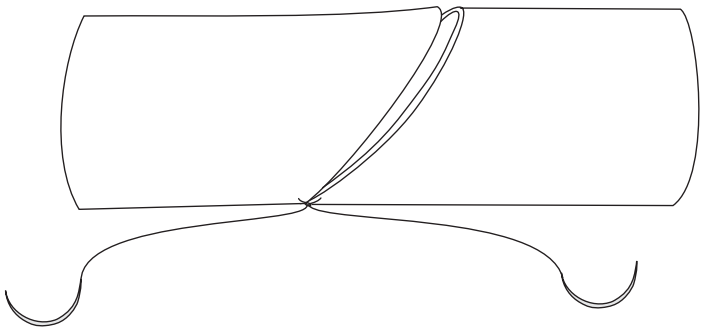
Small Vessels: Beveled Transection

Anchor Technique

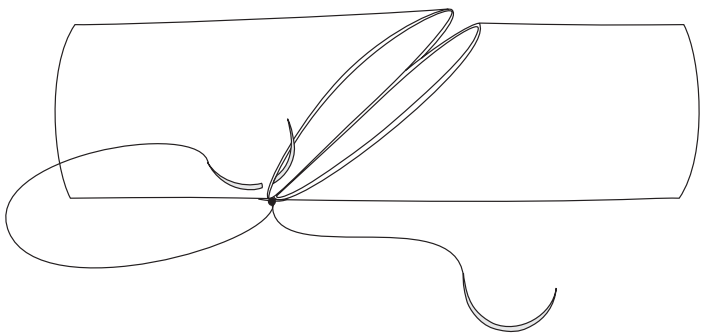
This suture may be a horizontal mattress or a simple suture as shown here.



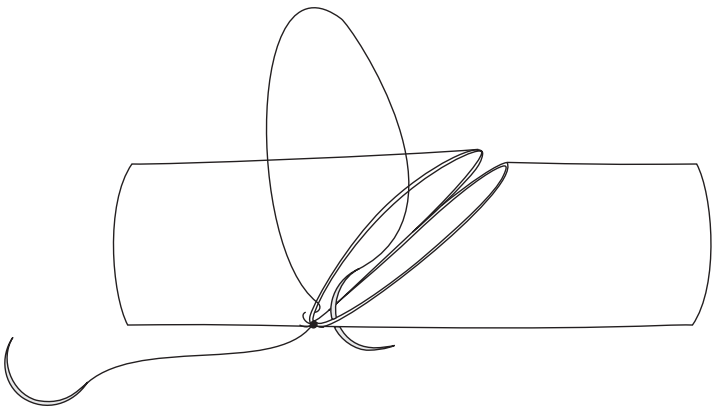
Tie the suture.



Introduce the needle from the adventitial side of the graft.



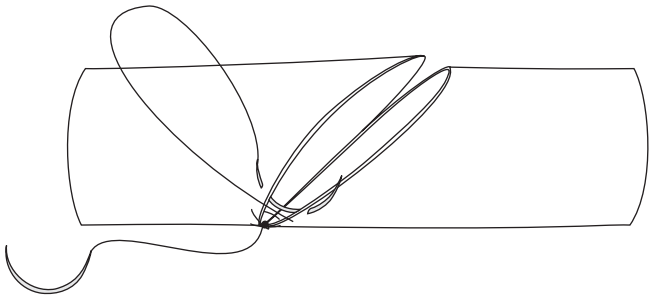
Introduce the needle from the intimal side of the artery.



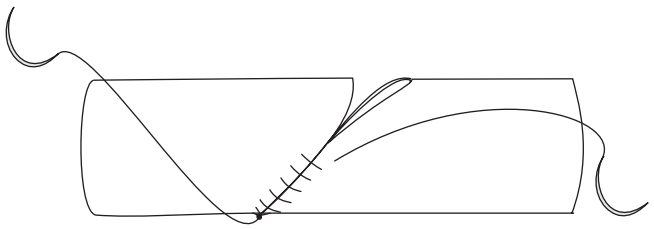
Small Vessels: Beveled Transection

Anchor Technique

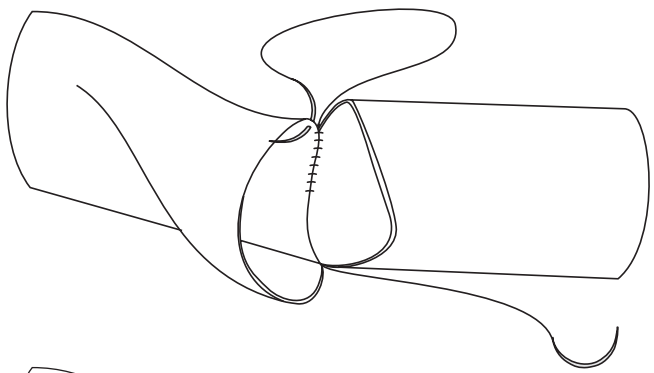
Run the suture toward the apex.



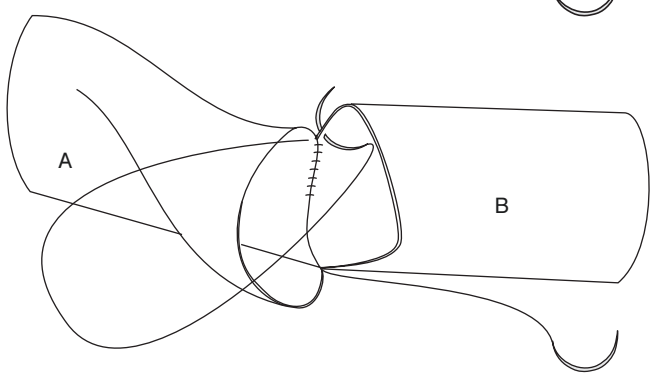
Tighten the suture line.



Flip the graft and start suturing with the other end of the suture.



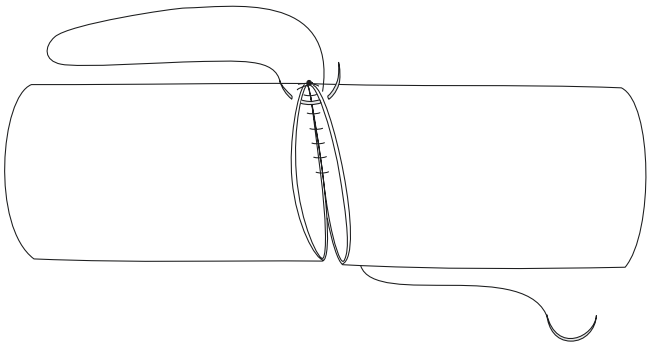
Again, introduce the needle from the adventitial side of the graft (A) and the intimal side of the artery (B).



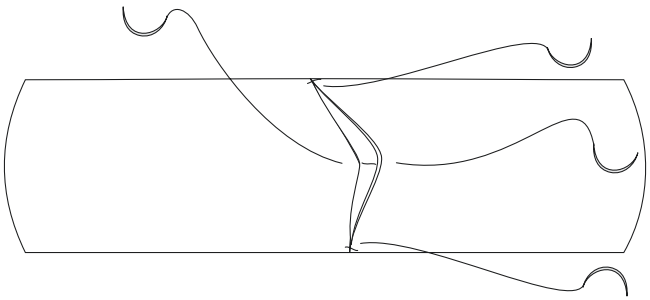
Small Vessels: Beveled Transection

Anchor Technique

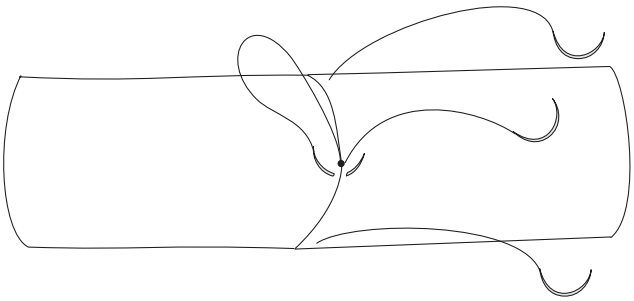
Run the suture until it reaches mid-distance to the apex.



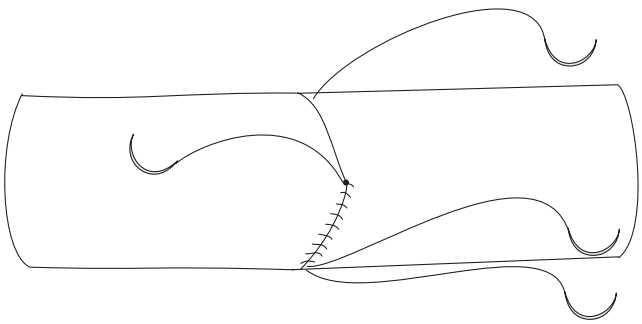
Start another suture at the apex. This suture may be a horizontal mattress suture or a simple suture as shown here.



Tie the suture.



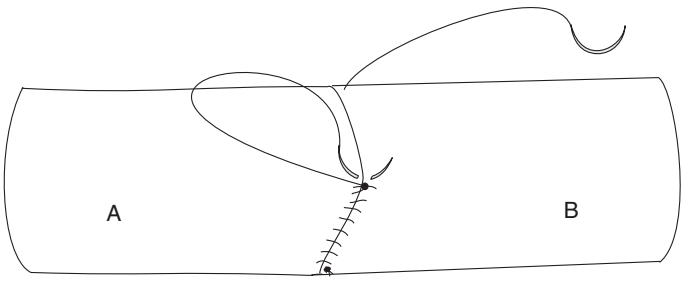
Run one end of the suture toward the heel until it meets the other suture. Tie the sutures.



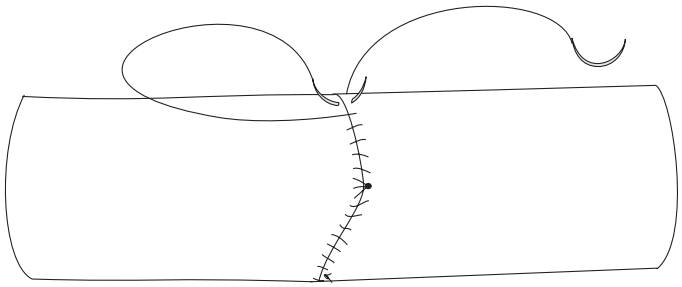
Small Vessels: Beveled Transection

Anchor Technique

Start suturing toward the superior suture. (Again, outside-inside in the graft [A], inside-outside in the artery [B]).



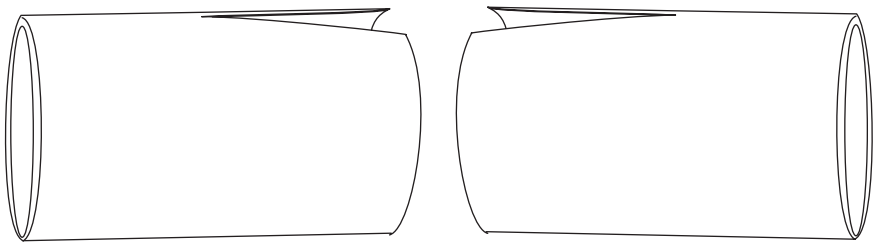
Tie the sutures.



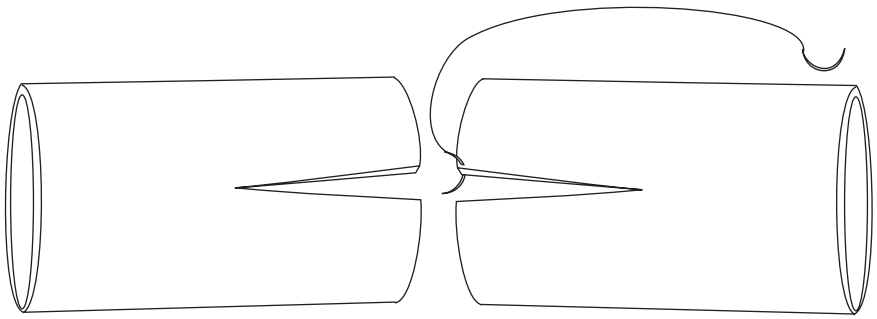
Small Vessels: Transection Perpendicular to the Longitudinal Axis

End-to-End Anastomosis with Anterior Patch Angioplasty

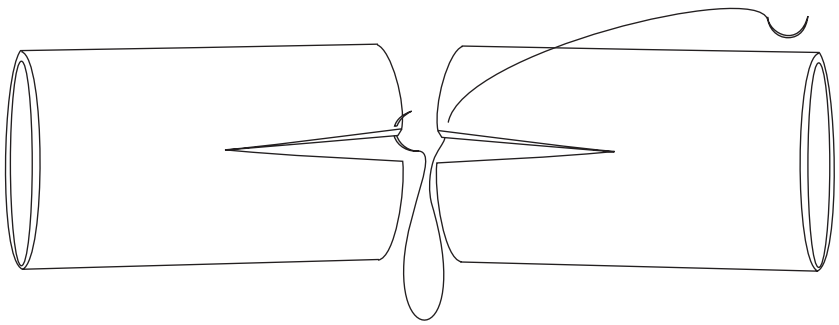
Incise the vessels along the anterior surface.



Introduce the needle on one side of the anterior surface.



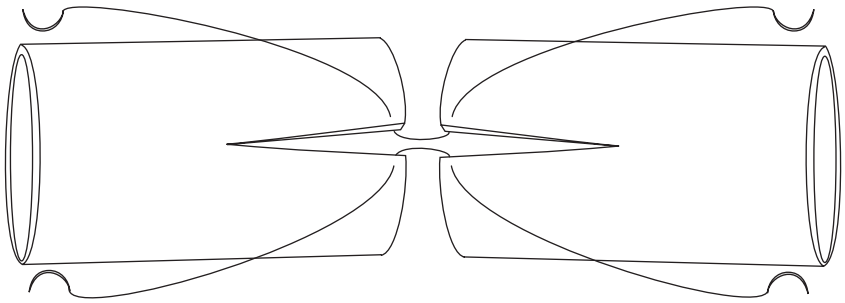
Introduce the needle in a corresponding site in the other vessel.



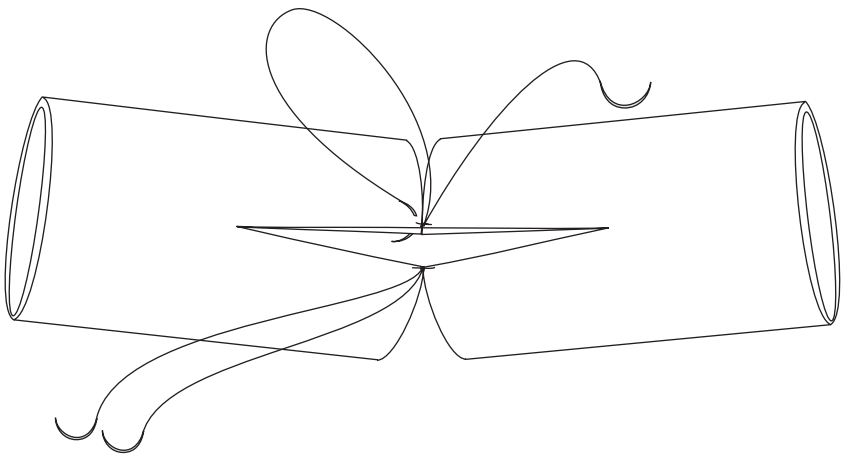
SMALL VESSELS: TRANSECTION PERPEndicular to the Longitudinal Axis

End-to-End Anastomosis with Anterior Patch Angioplasty

Place an identical suture in the other edge of the anterior incision.



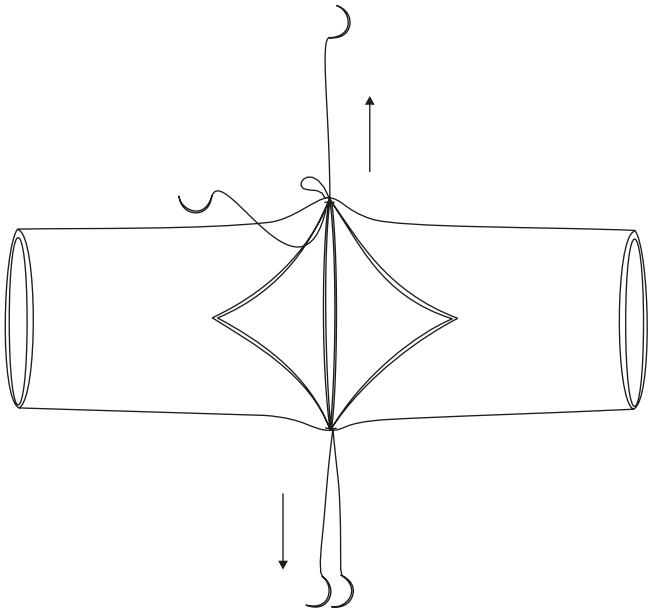
Tie the sutures. Introduce the needle (outside-inside) closely spaced to the starting point. This will allow suturing the posterior wall from within the lumen.



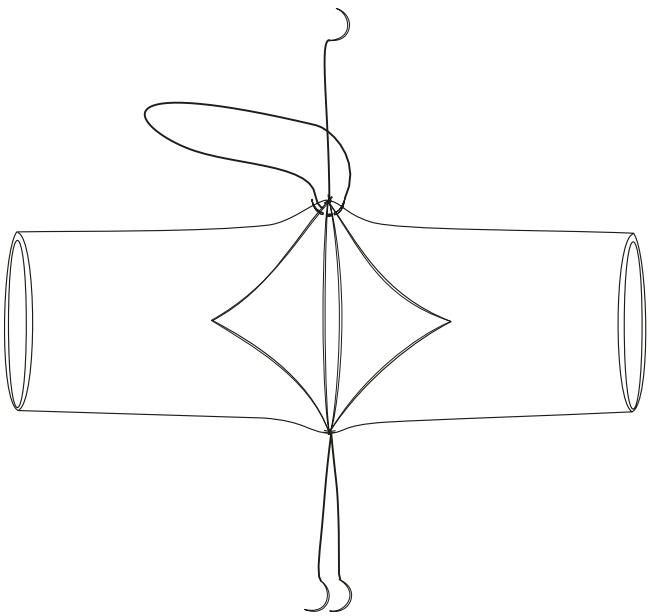
Small Vessels: Transection Perpendicular to the Longitudinal Axis

End-to-End Anastomosis with Anterior Patch Angioplasty

Apply traction on each suture in opposite directions.



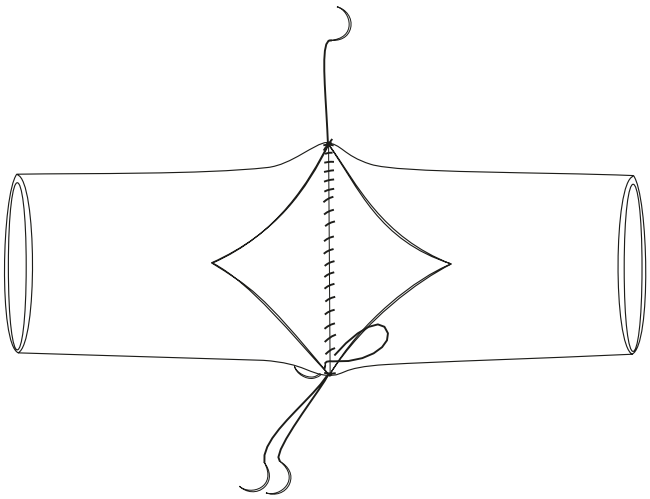
Start suturing the posterior wall from within. Keep running the superior suture toward the inferior suture.



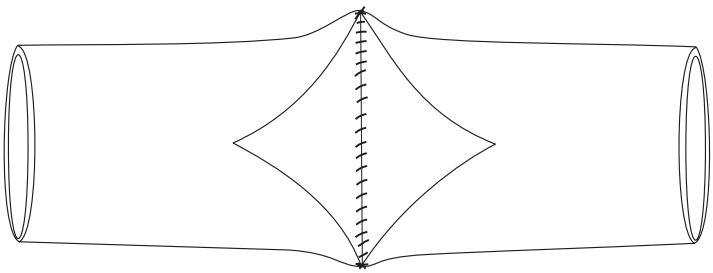
Small Vessels: Transection Perpendicular to the Longitudinal Axis

End-to-End Anastomosis with Anterior Patch Angioplasty

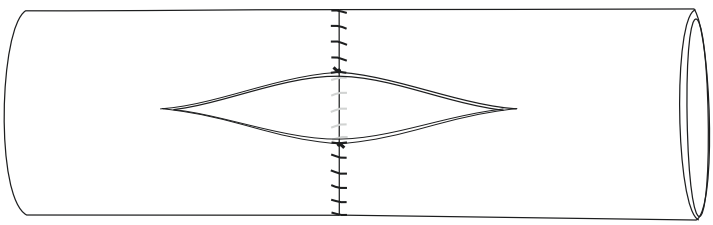
Introduce the needle (inside-outside) to bring the suture back to the anterior surface.



Tie the sutures.



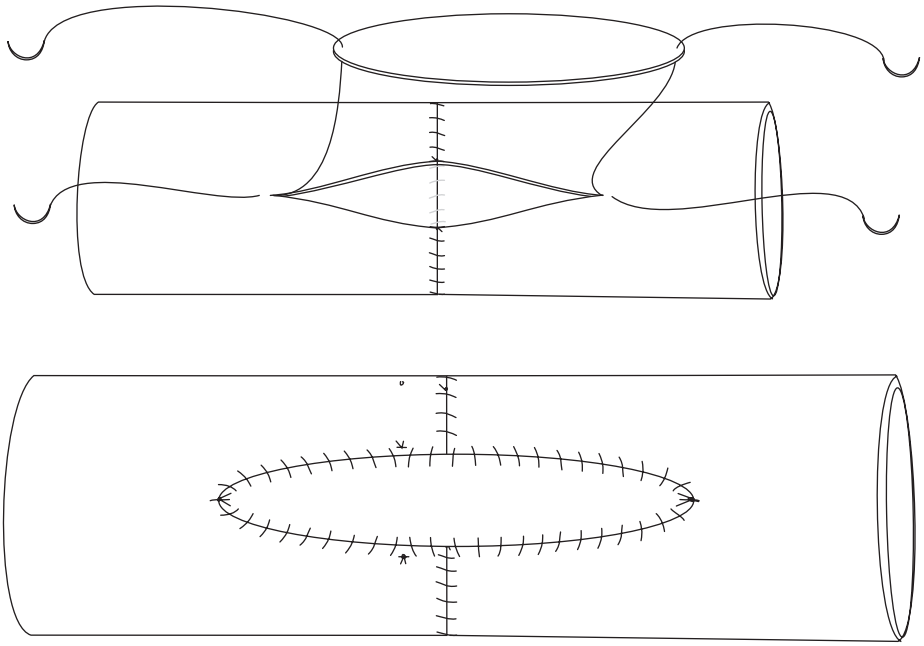
Appearance of the joined vessels after the tension on the stay sutures is removed.



Small Vessels: Transection Perpendicular to the Longitudinal Axis

End-to-End Anastomosis with Anterior Patch Angioplasty

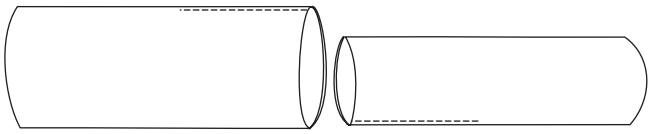
Close the anterior defect in the joined vessels with a patch as previously described.

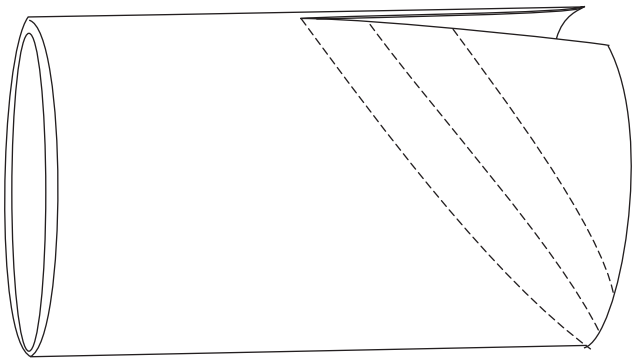


Vessels of Unequal Diameter: Beveled Transection

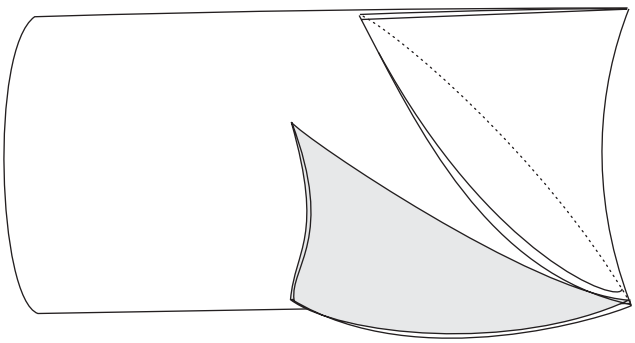
Combined Technique: Anchor Heel, Parachute Apex

Transect each vessel at a right angle to the longitudinal axis. Make an anterior slit in the larger vessel and a posterior slit in the smaller vessel.

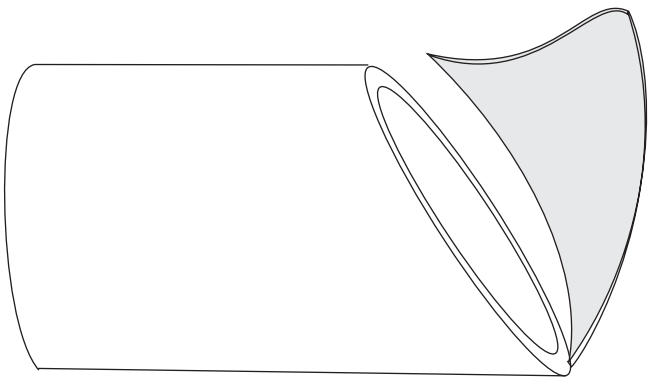




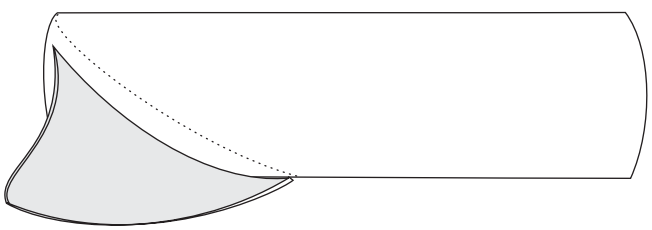
Cut a wedge of the vessel on one side.



Cut the remaining wedge on the other side.



Use the length of the excised wedge to determine the approximate length to which the smaller vessel should be trimmed.

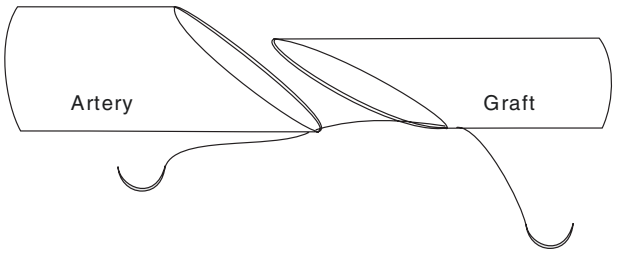


Vessels of Unequal Diameter: Beveled Transection

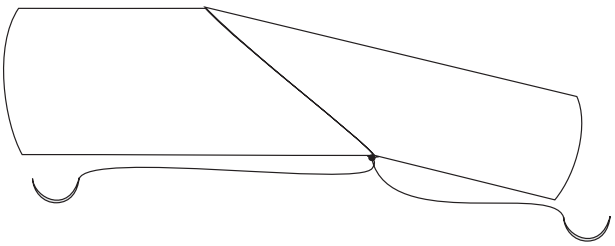
Combined Technique: Anchor Heel, Parachute Apex

This section describes an end-to-end anastomosis between a small diameter graft and a larger artery. To illustrate the various possible alternatives, the heel suture will be started using an anchor technique. The apical suture will be constructed using a parachute technique.

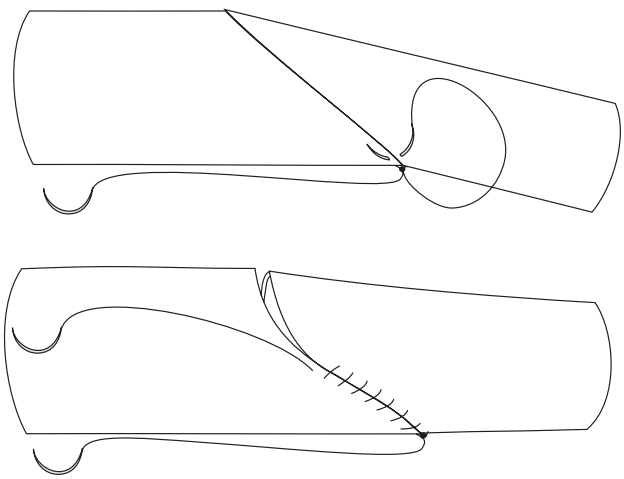
Start a heel suture penetrating from the adventitial side of the graft and then penetrating from the intimal side of the artery.



This suture may be a horizontal mattress or a simple suture as shown here. Tie the suture.



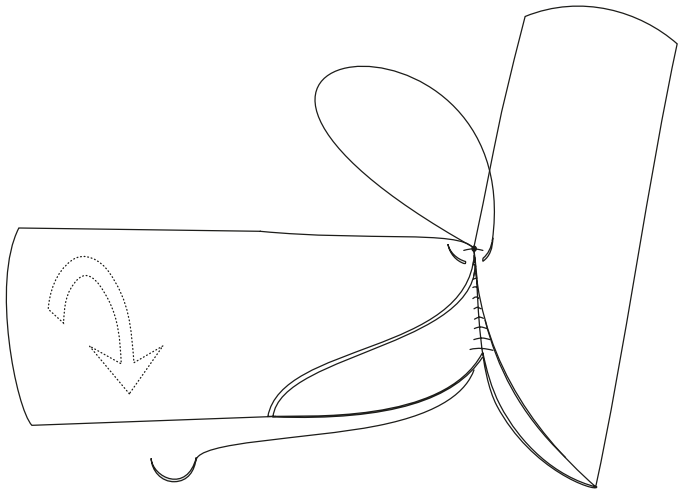
Start running the suture on one side until you have reached mid-distance to the apex.



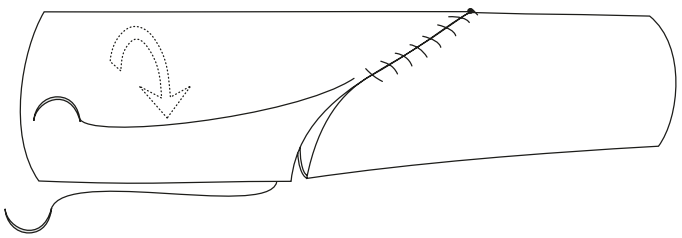
Vessels of Unequal Diameter: Beveled Transection

Combined Technique: Anchor Heel, Parachute Apex

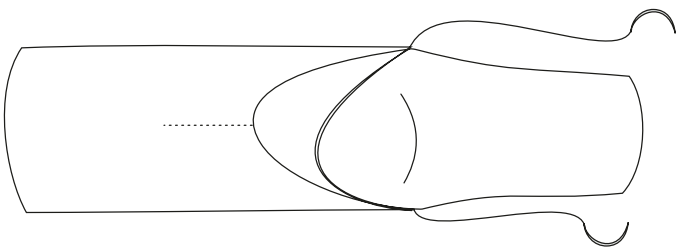
Flip the graft. Introduce the needle from the adventitial side of the graft and through the intimal side of the artery.



Run the suture until you reach mid-distance to the apex.



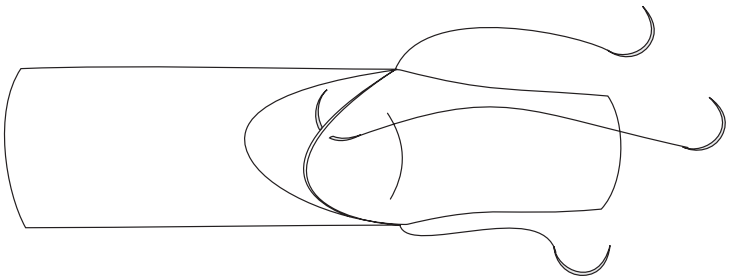
Check that the length of the arteriotomy matches the length of the graft. If the graft is too long for the arteriotomy, you may have to trim the graft or extend the arteriotomy along the dotted line.



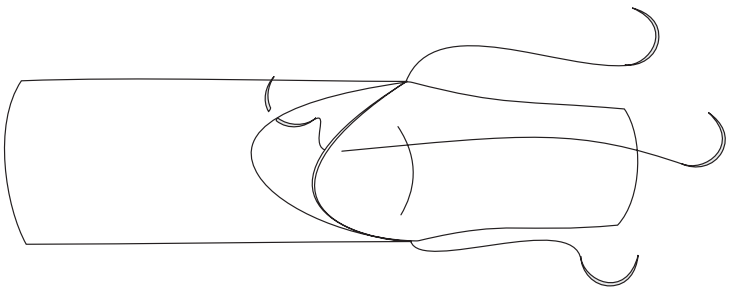
Vessels of Unequal Diameter: Beveled Transection

Combined Technique: Anchor Heel, Parachute Apex

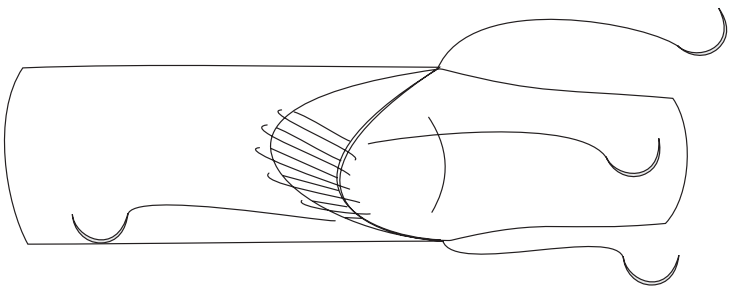
Start the apical suture two bites away from the center of the apex.



Again, the suture should penetrate on the adventitial side of the graft and then through the intimal side of the artery.



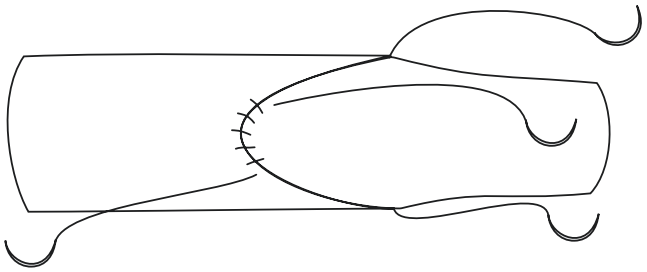
Continue placing the sutures until you have placed two bites past the center of the apex.



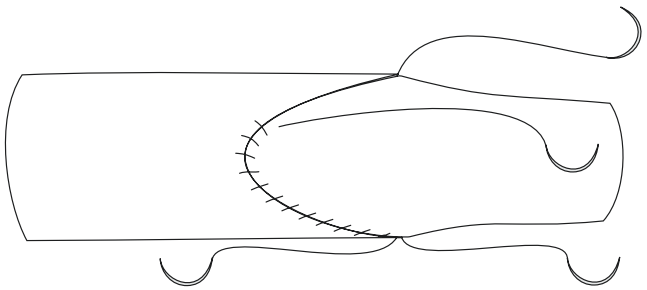
Vessels of Unequal Diameter: Beveled Transection

Combined Technique: Anchor Heel, Parachute Apex

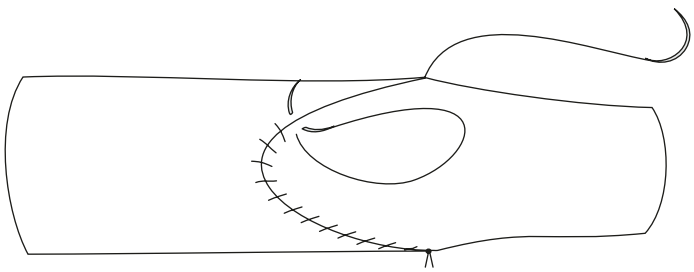
Tighten the suture line and pull down the apex of the graft.



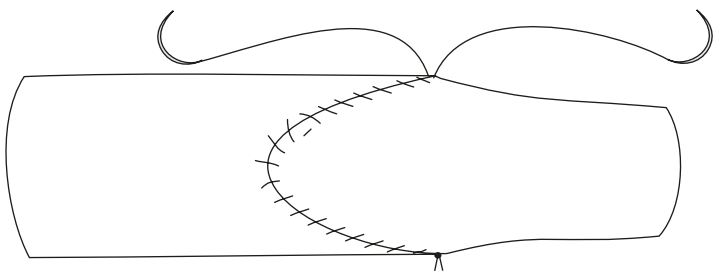
Continue running the suture until it meets the heel suture.



Repeat the same process with the other end of the suture.



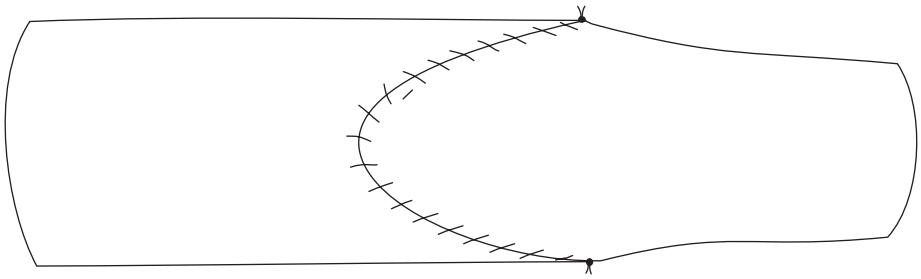
RTie both sutures together.



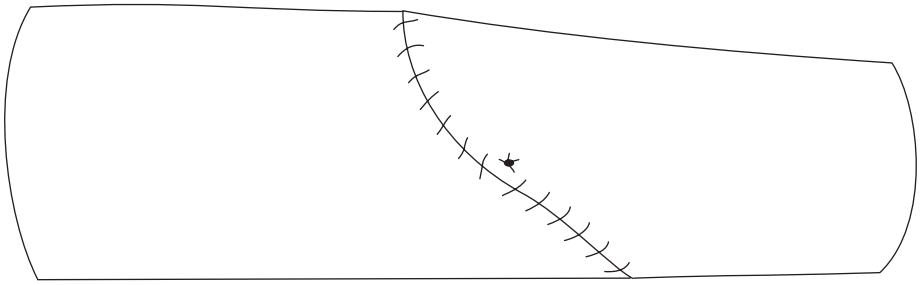
Vessels of Unequal Diameter: Beveled Transection

Combined Technique: Anchor Heel, Parachute Apex

Top view of anastomosis.



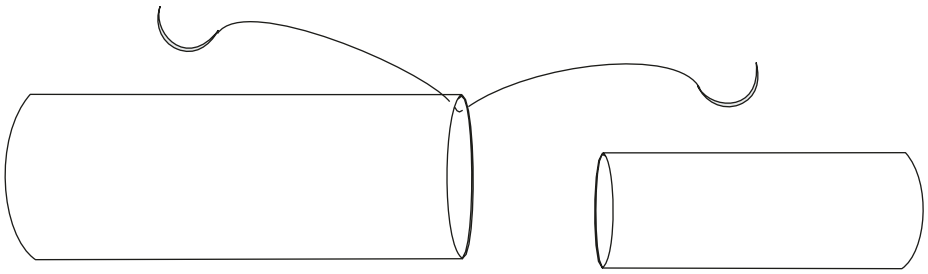
Side view of anastomosis.



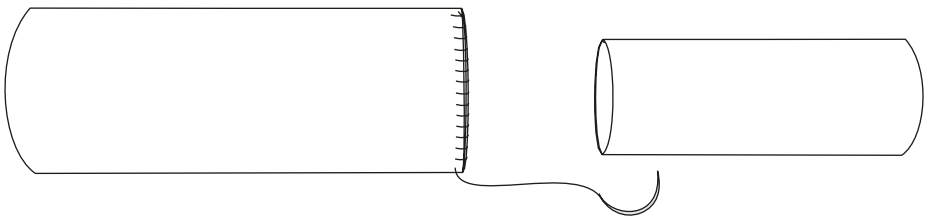
Vessels of Unequal Diameter

End-to-Side: Functional End-to-End

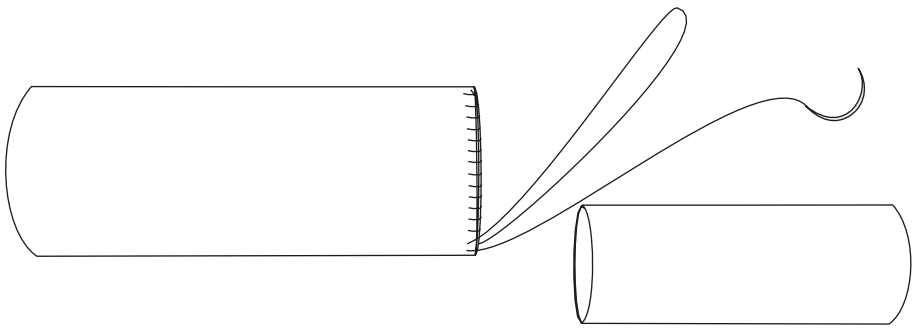
Start one suture in the upper part of the transected vessel.



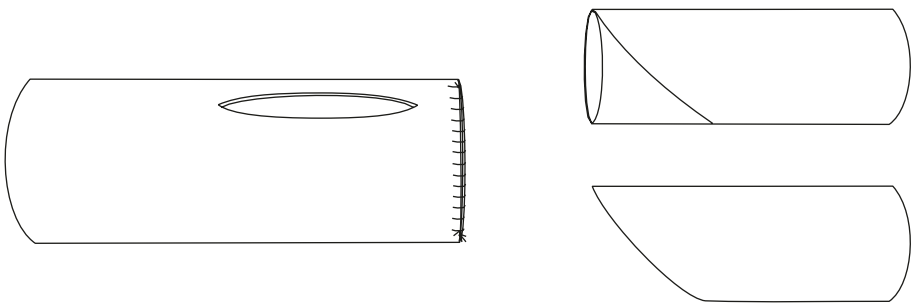
Run the suture toward the base of the vessel.



Tie the suture to itself.



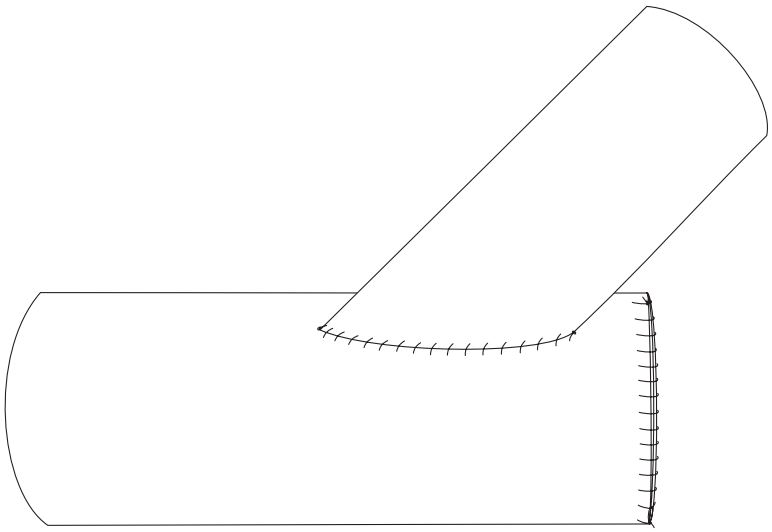
TCreate an incision in the large vessel and transect the smaller vessel to match the incision site.



Vessels of Unequal Diameter

End-to-Side: Functional End-to-End

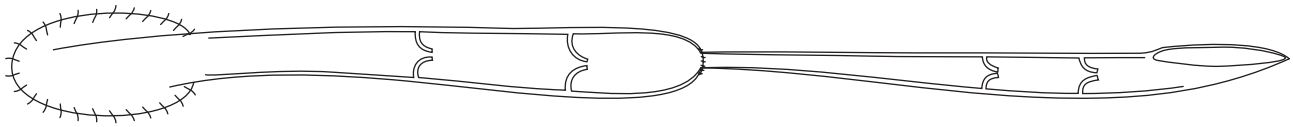
Construct an end-to-side anastomosis as described in Chap. 9.



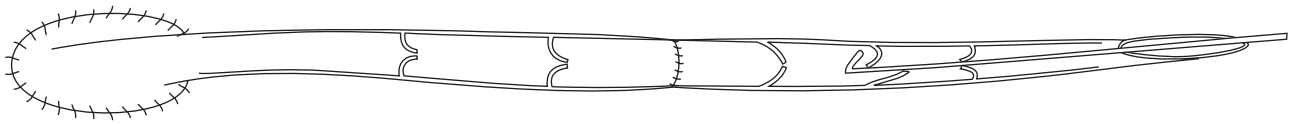
Two VesSELS of Unequal Diameter

Composite Vein Bypass

When two vein segments of unequal diameters are joined in a reversed manner, the larger end of one segment will be anastomosed to the smaller end of the other vein segment. This anastomosis may be technically challenging and may result in the configuration shown below.



To avoid constructing an anastomosis between two vein segments of unequal diameter, the first segment is attached to the artery in a reversed fashion. The second segment is used in a nonreversed fashion, which allows the construction of an anastomosis between the larger ends of the vein segments. The valves in the nonreversed vein segment are disrupted with a valvulotome.



11

Side-to-Side Anastomosis

Jamal J. Hoballah

The conditions in which a side-to-side anastomosis is used include the creation of a side-to-side portocaval shunt in portal hypertension, the creation of a side-to-side radiocephalic arteriovenous fistula for chronic hemodialysis, and the creation of a side-to-side arteriovenous fistula distal to an infrainguinal prosthetic bypass as an adjunctive procedure to decrease the outflow resistance. The side-to-side configuration is also used in the construction of the second anastomosis of a sequential bypass when multiple segments of a limb require revascularization.

A side-to-side anastomosis is infrequently performed because the need for such a reconstruction is rare. Mesocaval interposition shunts are frequently used instead of the side-to-side portocaval shunts because they are considered to be technically less demanding. In addition, these shunts do not violate the hepatic hilum, which could increase the difficulty of future liver transplantation. An end-to-side rather than a side-to-side configuration is usually used when creating an arteriovenous fistula for chronic hemodialysis. The end-to-side radiocephalic fistula requires less mobilization of the cephalic vein and the radial artery than the side-to-side configuration, which does not offer in this situation any advantage over the end-to-side reconstruction. The role of an arteriovenous fistula distal to an infrainguinal prosthetic bypass remains controversial, and frequently an end-to-side rather than a side-to-side reconstruction is used.

When a side-to-side anastomosis is being constructed, the vessels are dissected and mobilized to lie adjacent to each other with minimal tension. The anastomosis is created on the part of the vessels where the walls are in direct contact. The posterior part of the anastomosis is constructed first. The anastomosis can be constructed using "anchor technique" (section "Anchor Technique") or "parachute technique" (section "Parachute Technique"). The suture line can be started at the midpoint of the incision in the vessel (section "Anchor Technique") or at either end (section "Parachute Technique").

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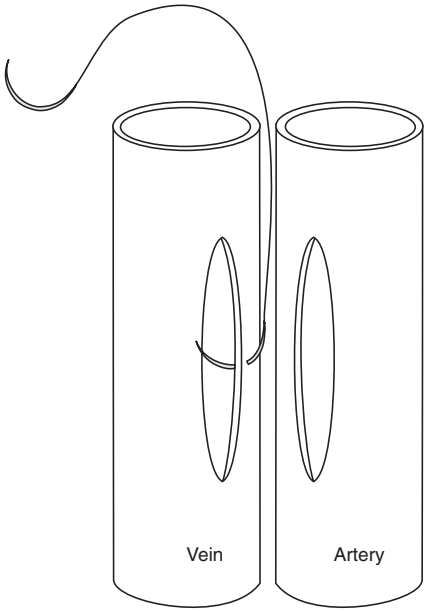
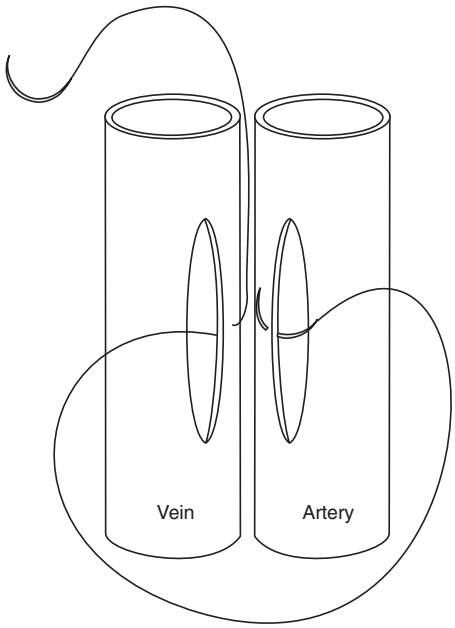
J. J. Hoballah, C. F. Bechara (eds.), *Vascular Reconstructions*, https://doi.org/10.1007/978-1-0716-1089-3_11

Anchor Technique

Start by placing one suture at the midpoint of the venotomy (outside-inside).

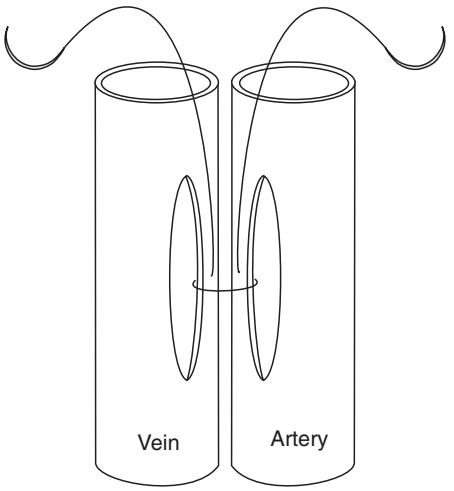


Introduce the needle in a corresponding point in the arteriotomy (inside-outside).

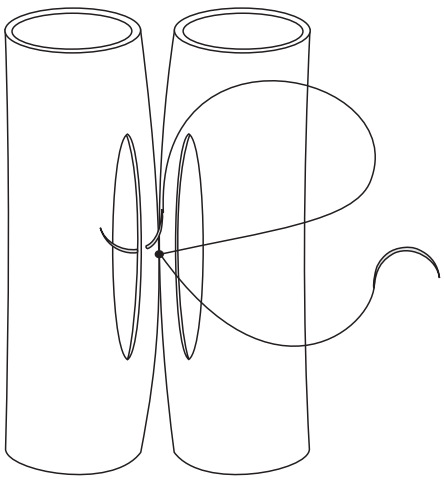


Anchor Technique

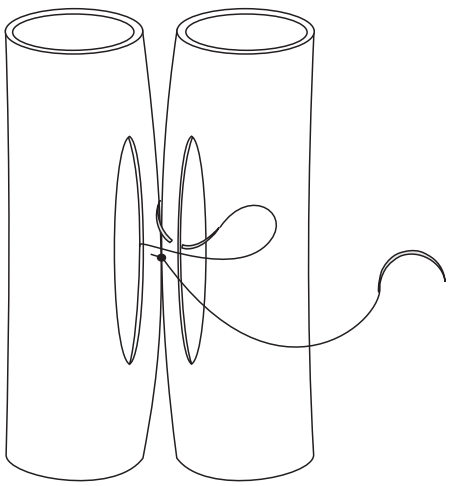
Tie down the suture.



The needle is introduced from the adventitial side of the vein and the intimal side of the artery.

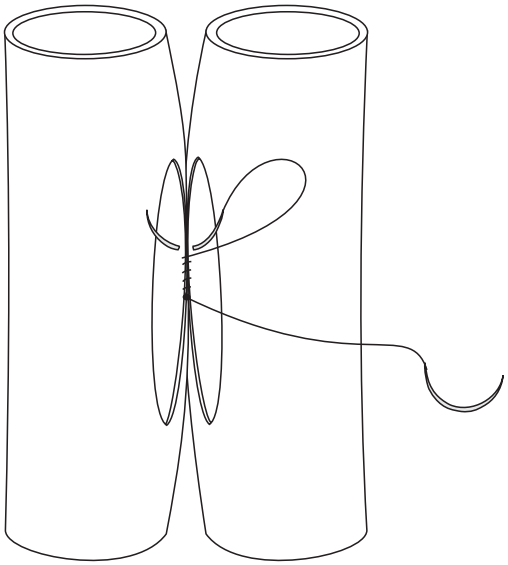


Continue suturing the back wall on one side of the suture.

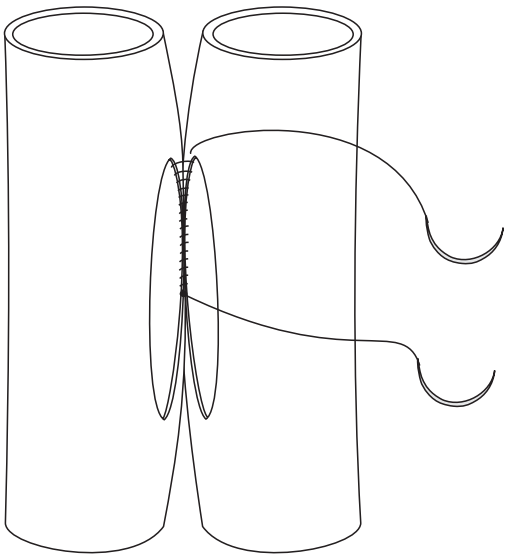


Anchor Technique

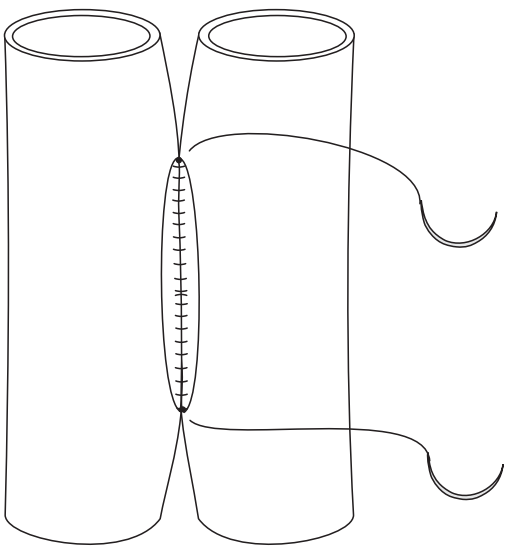
Complete the back wall of the anastomosis on one side of the suture.



Complete the back wall on the other side of the suture in a similar manner.

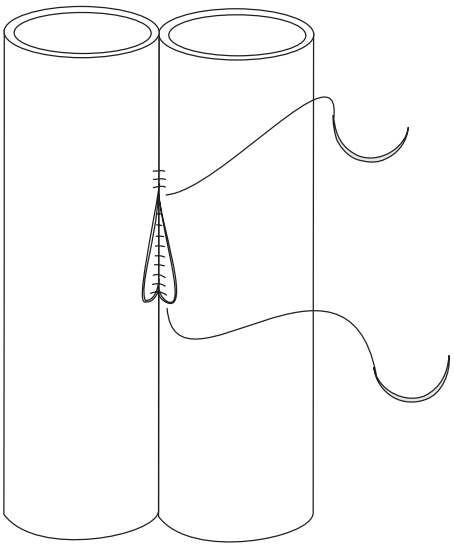


Resume suturing along the anterior wall. Introduce the needle inside-outside in the artery.

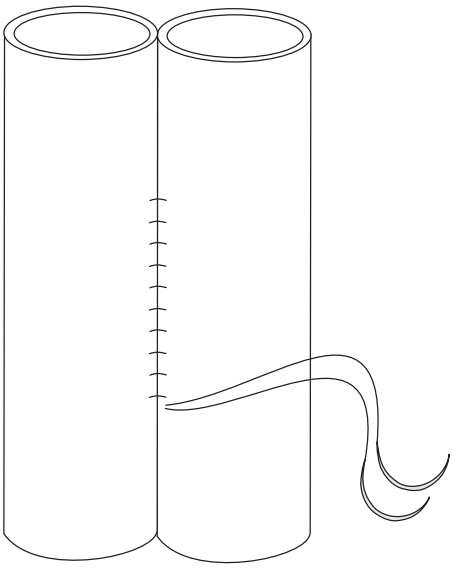


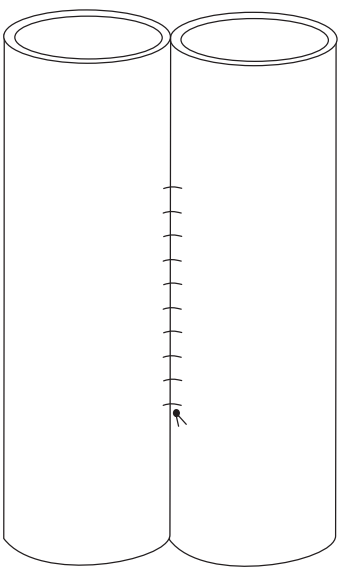
Anchor Technique

Continue running the suture toward the lower suture.



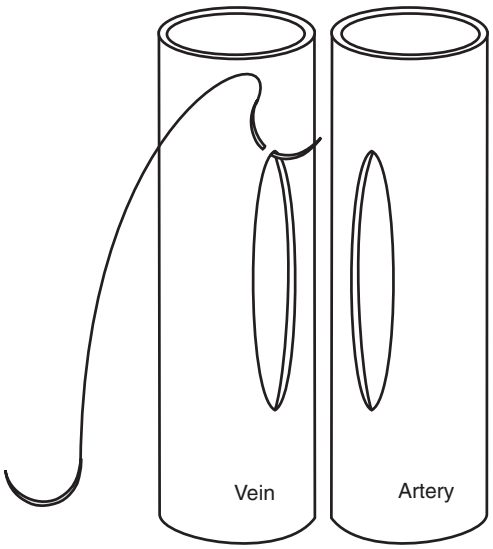
Tie the suture.



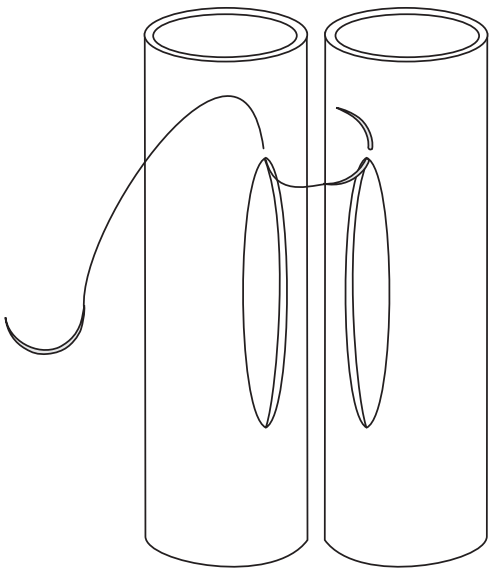


Parachute Technique

Start by placing one suture at the apex of the venotomy (outside-inside).

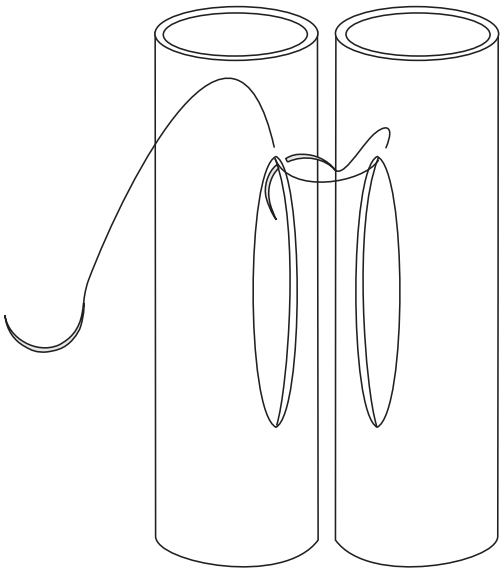


Introduce the needle in the apex of the arteriotomy (inside-outside).

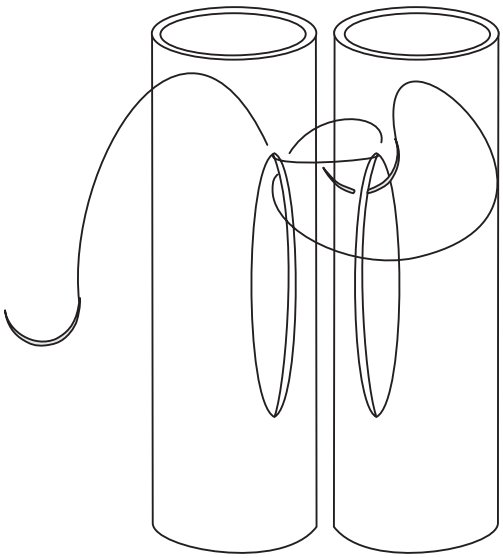


Parachute Technique

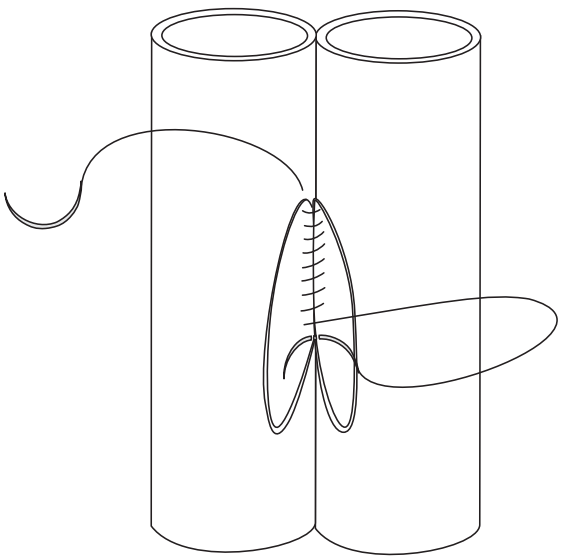
The needle is introduced from the adventitial side of the vein and the intimal side of the artery.



Continue suturing the back wall without tying.

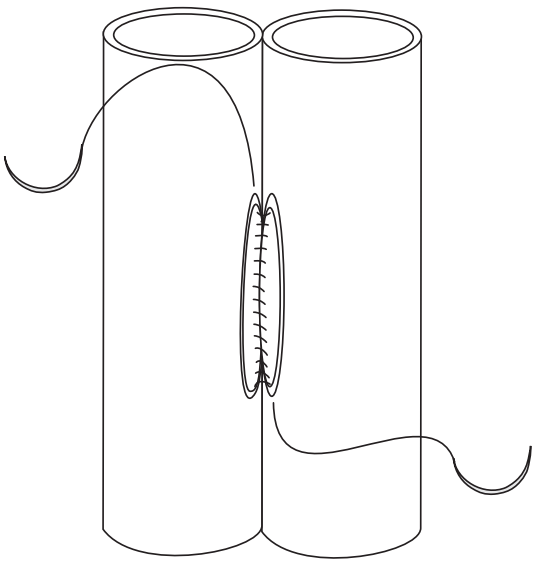


Tighten the suture.

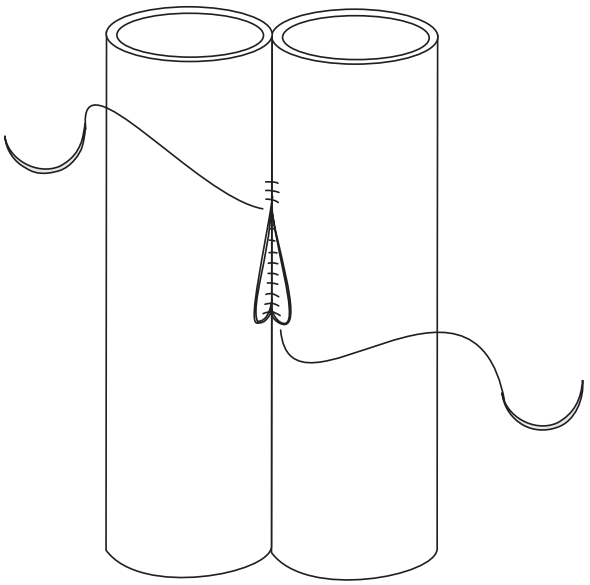


Parachute Technique

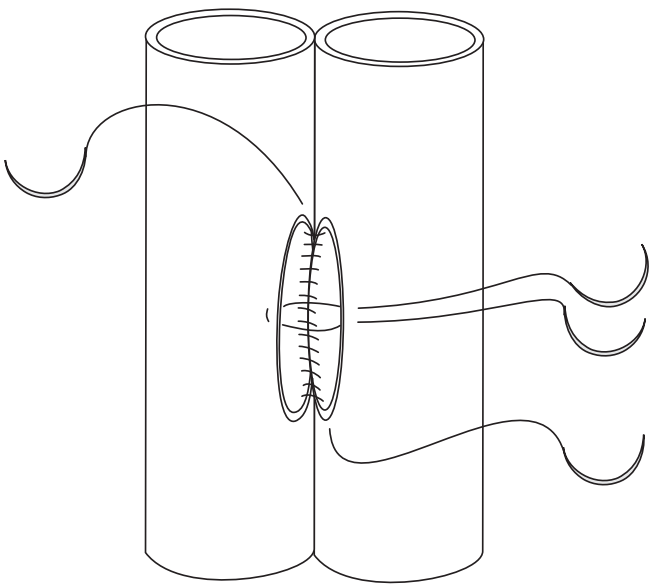
Continue placing the sutures until the posterior part of the anastomosis is completed.



You may continue with the upper suture until it meets the other end.

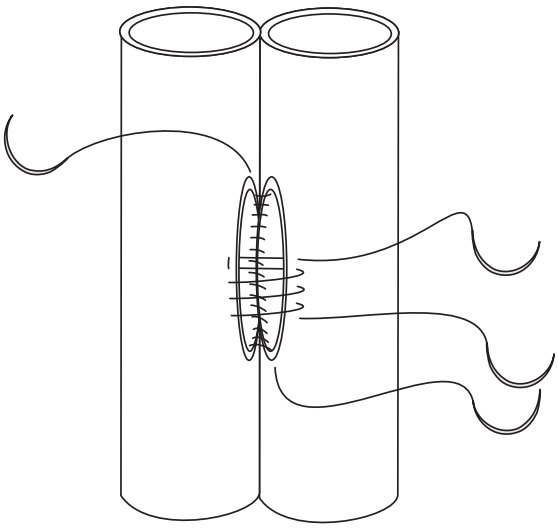


Alternatively, you may start another suture.

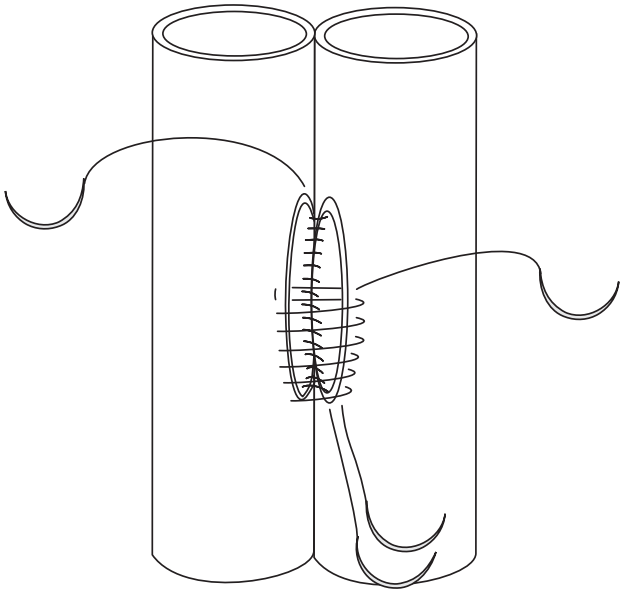


Parachute Technique

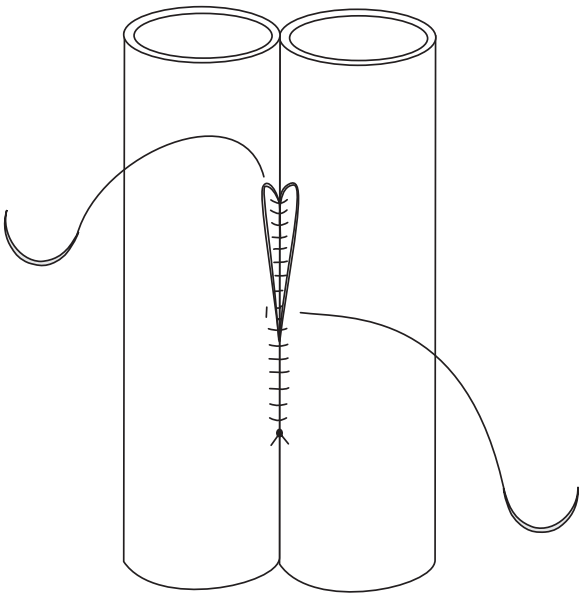
Again, introduce the needle inside-outside in the vein and outside-inside in the artery.



Continue placing the sutures until you reach the inferior apex.

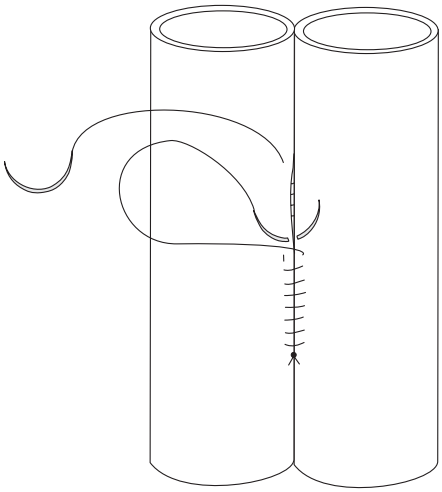


Tie the sutures.

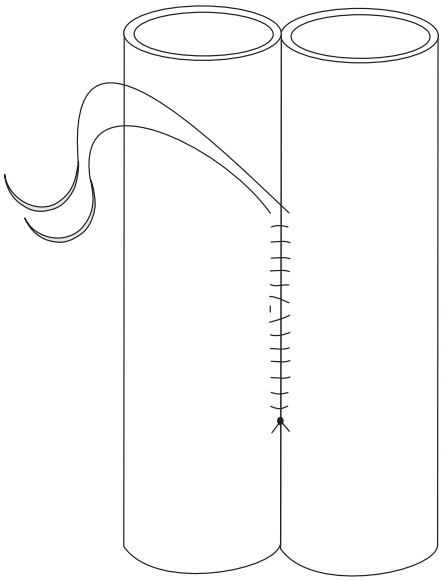


Parachute Technique

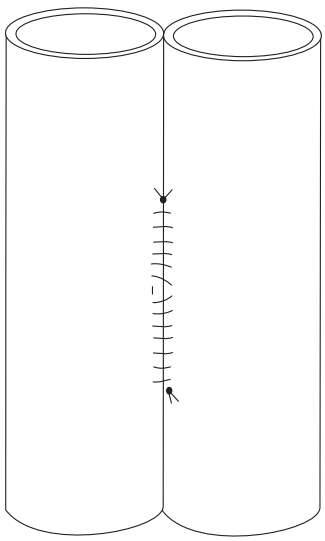
Resume suturing with the other end.



Run the suture toward the upper apex.



Tie the sutures.



Part III

Infrainguinal Bypass Surgery

12

Adjunctive Techniques: Proximal Anastomosis of an Infrainguinal Bypass

Jamal J. Hoballah

The main principles of constructing a bypass for infrainguinal occlusive disease include:

4. Identifying a soft arterial segment proximal to the occlusive disease to serve as an inflow source
5. Identifying a soft arterial segment distal to the occlusive disease to serve as a suitable outflow vessel
6. Connecting these two arterial segments with a conduit, preferably a single segment of autogenous great saphenous vein

The artery to be used as the inflow vessel is usually selected on the basis of the preoperative angiogram. The inflow vessel may be found to be diseased upon its exposure. The pathology that may be encountered includes a heavily calcified plaque or severe thickening of the wall, especially in redo procedures. If dissecting a more proximal segment of the artery is not possible or reveals a similar pathology, constructing an anastomosis to a diseased inflow vessel may become unavoidable. In this situation, the proximal anastomosis could become very challenging. Proximal and distal vascular control can be accomplished by occluding the vessels from within using balloon occluding catheters. Even in the presence of heavy calcifications, a soft area in the artery may still be identified and used as the arteriotomy site. If that is not possible, a localized endarterectomy may become necessary. In that situation, it is important to perform the endarterectomy without creating a distal dissection and disrupting valuable collaterals. In addition, because the atherosclerotic disease usually extends distally for a long segment, ending the endarterectomy often requires transecting the plaque and leaving a shelf. Consequently, tacking of the endarterectomy endpoint is often necessary.

SAPHENOFEMORAL JUNCTION WITH FEMORAL VEIN CUFF

When constructing an anastomosis to an artery with thickened walls, narrowing of the bypass could occur just distal to the heel, especially if the conduit has a small caliber such as with a reversed vein bypass graft. If a prosthetic conduit

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J. J. Hoballah, C. F. Bechara (eds.), *Vascular Reconstructions*, https://doi.org/10.1007/978-1-0716-1089-3_12

is to be used, an 8-mm graft can be selected and the hood can be fashioned to accommodate for the thickening in the arterial wall. If the conduit used is the greater saphenous vein, this narrowing must be avoided. One option is to perform an in situ or a nonreversed free vein bypass. The saphenofemoral junction is used as the hood of the bypass (section "Saphenofemoral Junction with Femoral Vein Cuff"). The saphenofemoral junction is dissected freely. A Cooley clamp is applied to the femoral vein in a partially occluding manner. The saphenous vein is transected to include a 1-mm rim of the femoral vein. The venotomy in the femoral vein is then closed with a 5-0 Prolene running suture. The leaflets of the valve at the saphenofemoral junction are excised under direct vision. The hood created will be able to accommodate for the thickening in the arterial wall.

T-JUNCTION

If the saphenofemoral junction is not available, several techniques could be used to assist in performing the proximal anastomosis without creating a narrowing in the bypass. One option involves using the segment of vein with the largest diameter and an associated side branch. The vein is slit along the posterior wall in a fashion to incorporate the side branch [2, 3, 5]. The shape of the segment of the vein that will be used for the anastomosis will appear as a "T". Consequently, this technique is referred to as the "T-junction technique" (section "T-Junction"). The T-junction technique can help prevent the narrowing that could develop just distal to the heel. In addition, it can also be used in the distal anastomosis to prevent undesirable angulation in the bypass [4]. The length of the T-junction can be modified according to the size of the arteriotomy and the length of the side branch.

PATCH ANGIOPLASTY OF THE INFLOW VESSEL

Another option is to perform a vein patch angioplasty of the arteriotomy. An incision is then performed in the patch and used as the new site for constructing the proximal anastomosis [2]. In this technique, the vein bypass is sutured to the soft and thin wall of the vein patch, which could prevent the proximal anastomotic stenosis (section "Patch Angioplasty of the Inflow Vessel").

PATCH ANGIOPLASTY OF THE HOOD OF THE BYPASS

Another option is to carry out the anastomosis in the usual fashion and then perform a vein patch angioplasty if the bypass appears stenotic. The vein patch angioplasty is started in the hood of the graft and may be extended into the bypass as needed (section "Patch Angioplasty of the Hood of the Bypass").

INCORPORATION OF PROFUNDAPLASTY

In the presence of occlusive disease at the orifice of the profunda femoris artery, a profundaplasty may be performed in conjunction with the distal bypass. The arteriotomy in the common femoral artery is extended into the profunda femoris artery. Following the endarterectomy, a vein patch closure of the arteriotomy may be performed. The proximal anastomosis can be carried out as described in the section "Patch Angioplasty of the Inflow Vessel." Alternatively,

the arteriotomy used for the endarterectomy is incorporated in the proximal anastomosis, with the hood of the bypass serving as a patch (Section "Incorporation of Profundaplasty").

SARTORIUS MUSCLE FLAP

The subcutaneous tissues are the only layers separating a femoral anastomosis from the skin. If a wound problem develops, wound debridement can result in exposing the graft and the anastomotic suture line. In this situation, one treatment option is to perform a muscle flap to cover the graft and the anastomosis with vascularized tissue. This can allow adequate debridement without the risk of exposing the graft. The sartorius muscle is readily accessible for use as a rotational muscle flap (section "Sartorius Muscle Flap") [1]. It can also be used prophylactically in high-risk wounds.

Gracilis Muscle Flap

The gracilis muscle is the most superficial muscle on the medial side of the thigh and can serve as a reliable muscle flap to cover groin wounds. Unlike the sartorius muscle flap, it will require a separate incision over the medial thigh. A separate incision can also be made at the knee to incise the insertion into the medial condyle. While the leg is in the frog position, a 10–20-cm-long incision is made.

The blood supply to the gracilis muscle is via the medial femoral circumflex, a branch off the profunda artery.

Once mobilized and transected at the knee, it is retroflexed below the fascia into the groin. Few interrupted 2-0 vicryl sutures are placed to tack the muscle to the inguinal ligament and surrounding tissue. The wound can be closed in layers over a drain.

Website with pics (https://www.microsurgeon.org/gracilismuscle)

Youtube: (https://www.youtube.com/watch?v=FngQbkHtrrE)

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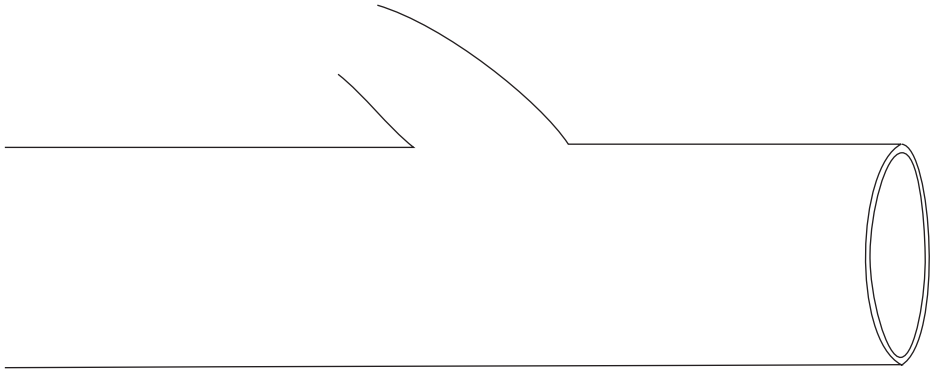
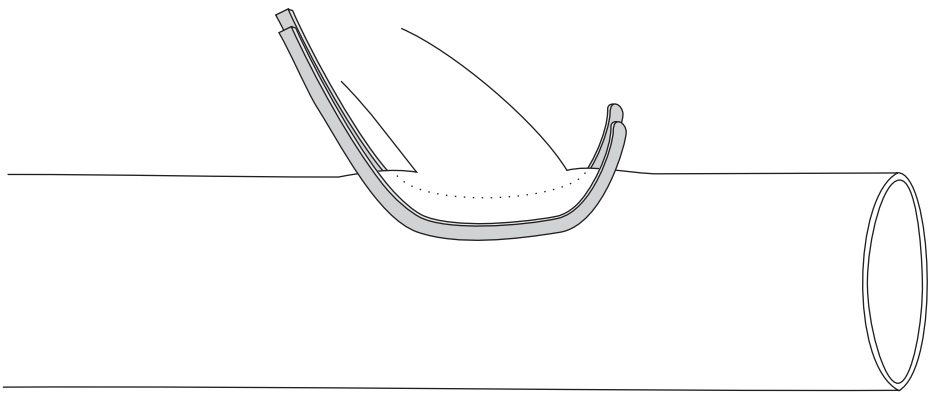
Saphenofemoral Junction with Femoral Vein Cuff

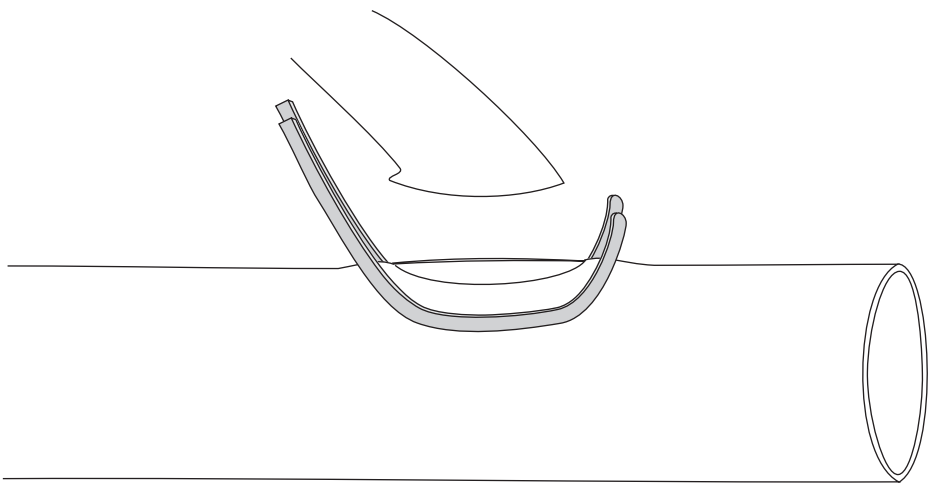
Dissect the saphenofemoral junction.



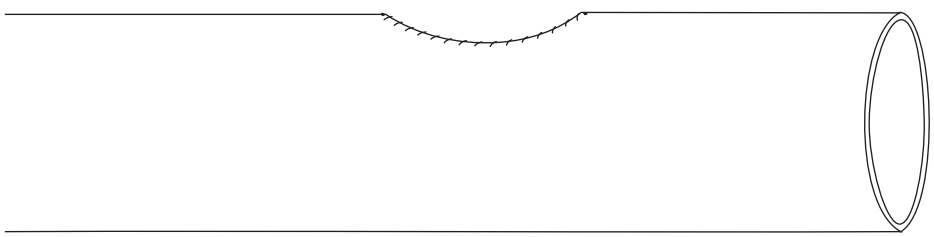
Apply a partial occluding clamp on the common femoral vein.



Transect the saphenous vein, including a 1-mm rim of the femoral vein.

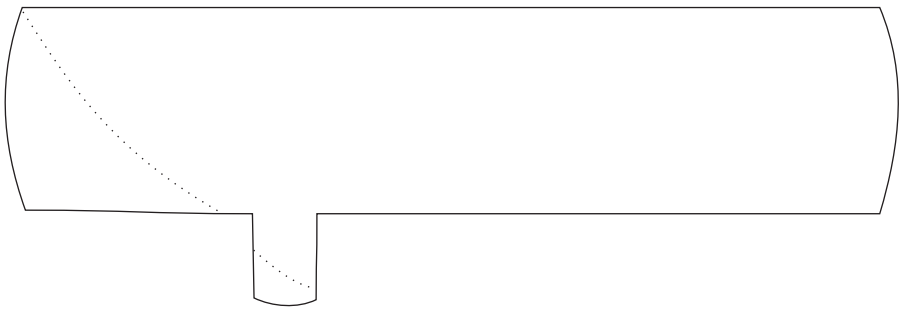


Close the femoral vein with a running suture.

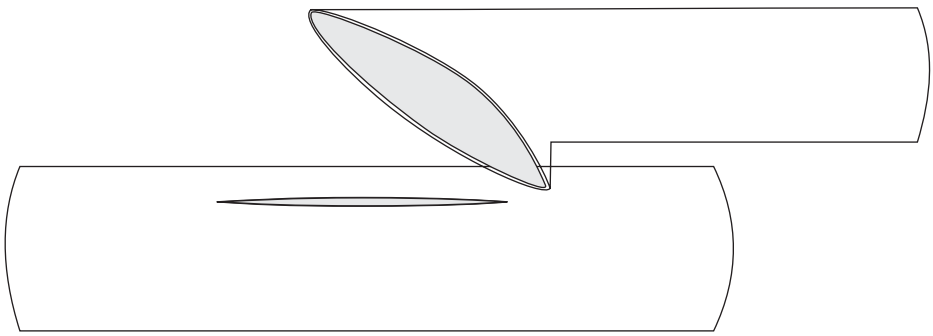


T-Junction

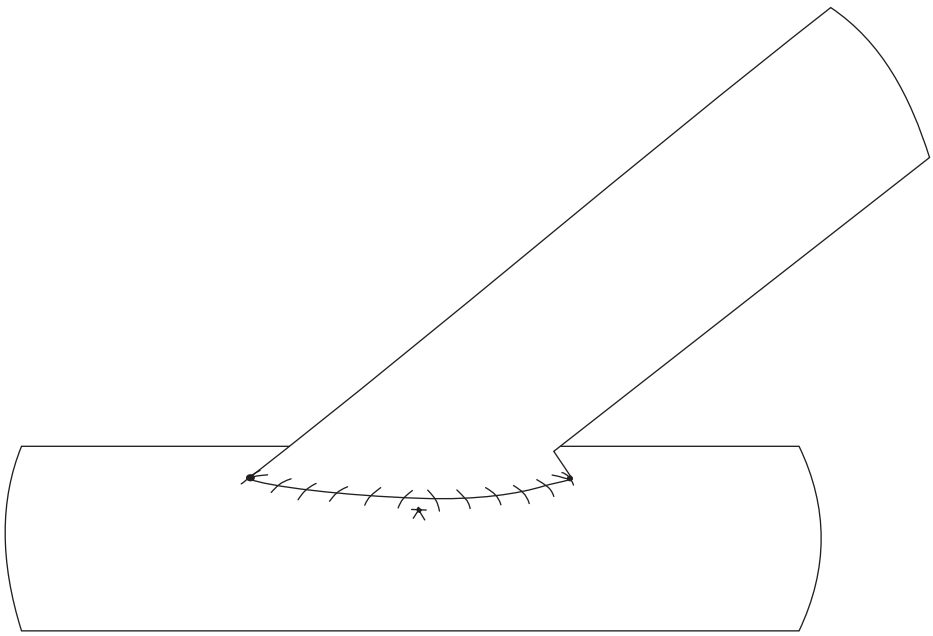
The vein is harvested with a branch segment, 4-mm in length.



The vein is incised along its posterior aspect toward the branch. The side branch should not be made too long; otherwise, the vein will pivot along its heel.

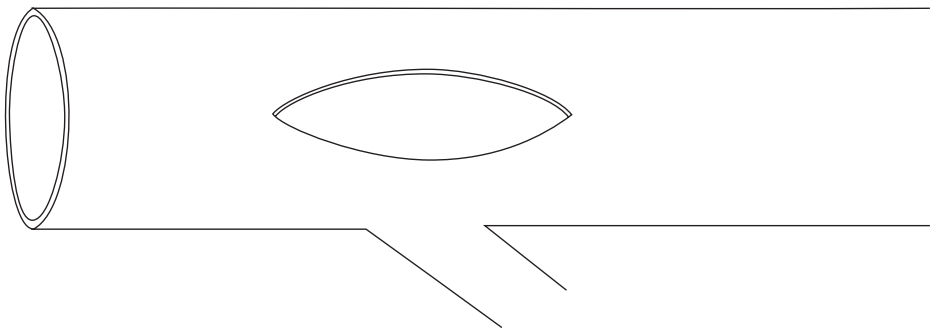


The anastomosis is completed.

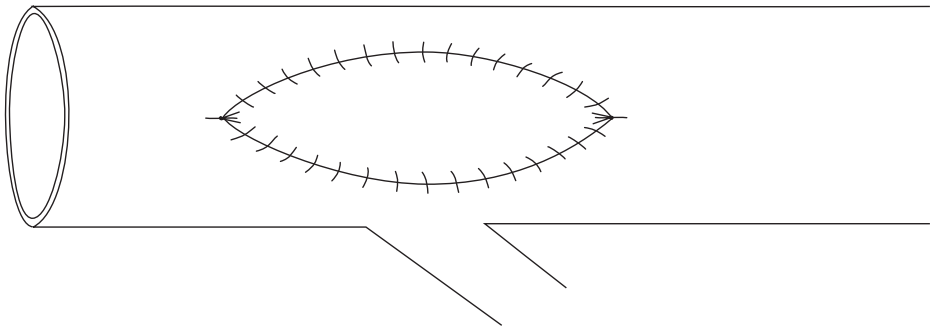


Patch Angioplasty of the Inflow Vessel

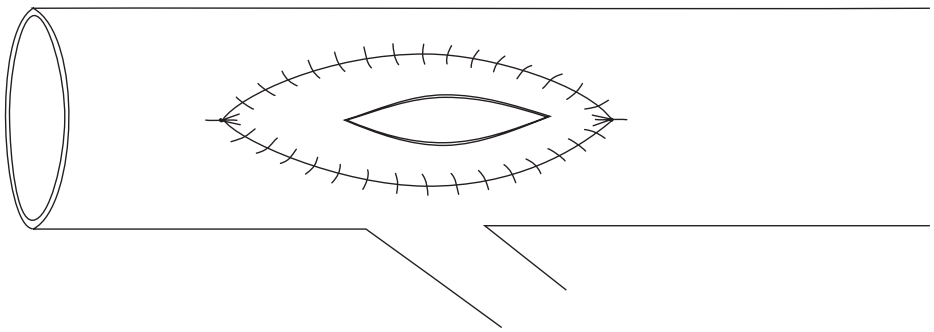
Create an arteriotomy in the desired location.



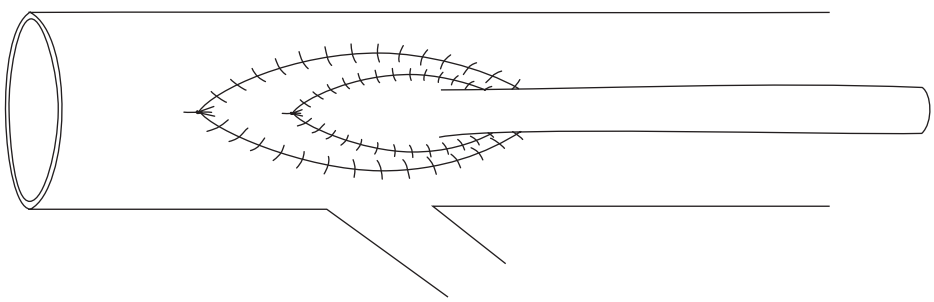
Close the arteriotomy with a vein patch.



Create a venotomy in the patch.

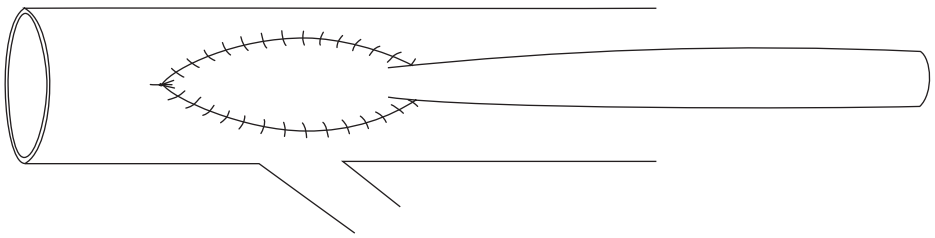


Construct the proximal anastomosis between the bypass and the venotomy.

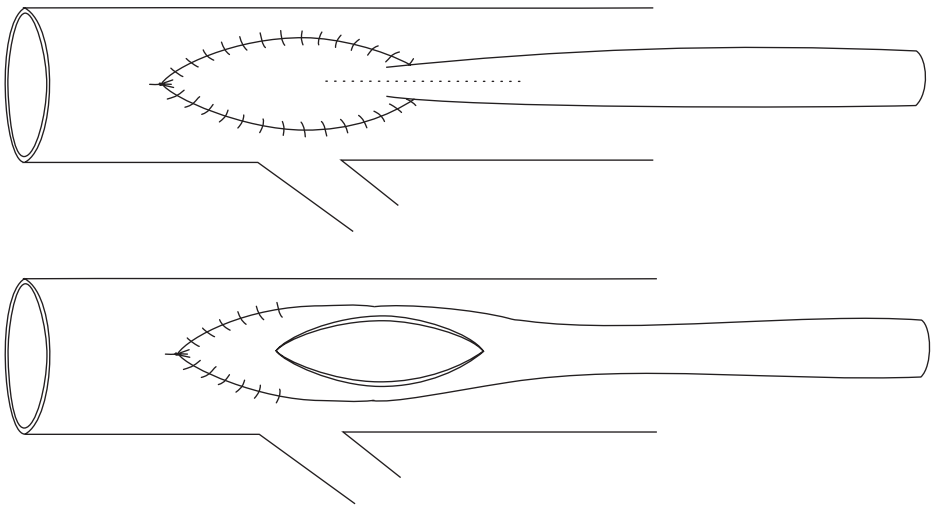


Patch Angioplasty of the Hood of the Bypass

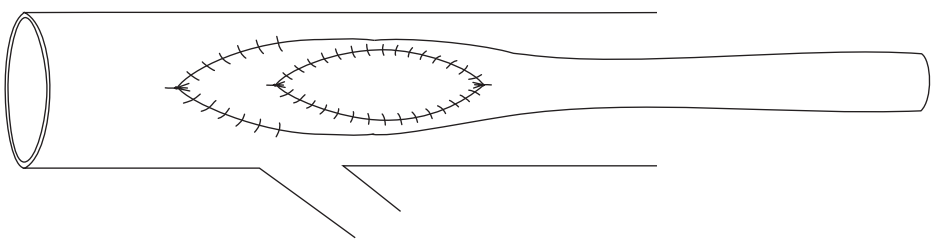
Construct the proximal anastomosis.



Create an incision in the narrowed segment of the bypass.

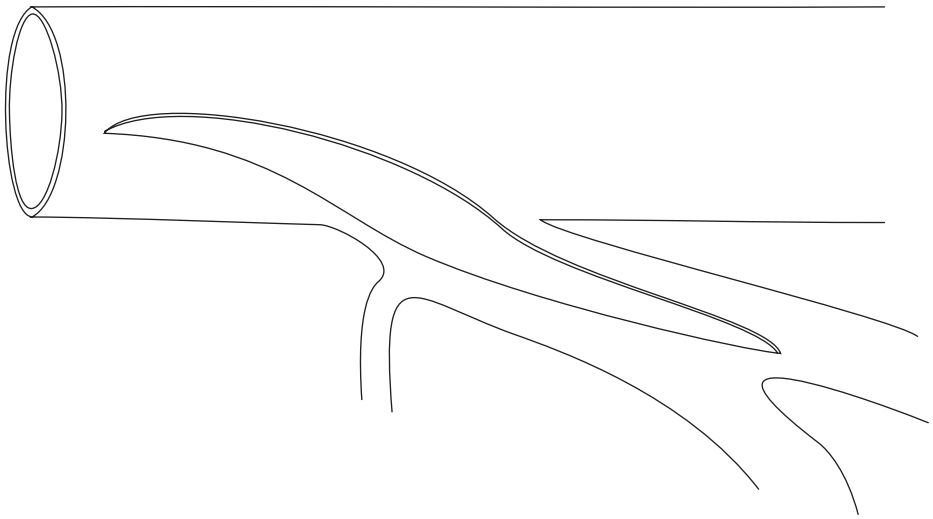


Perform a vein patch angioplasty of the proximal segment of the graft.

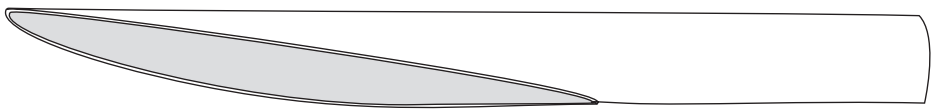


Incorporation of Profundaplasty in the Proximal Anastomosis

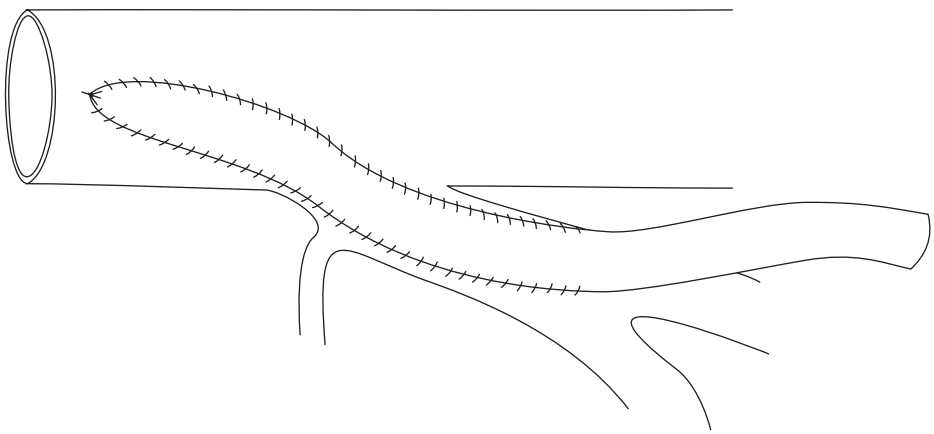
Create an arteriotomy starting in the common femoral artery and extending into the profunda femoris artery.



The vein is incised along its posterior aspect to match the length of the arteriotomy.



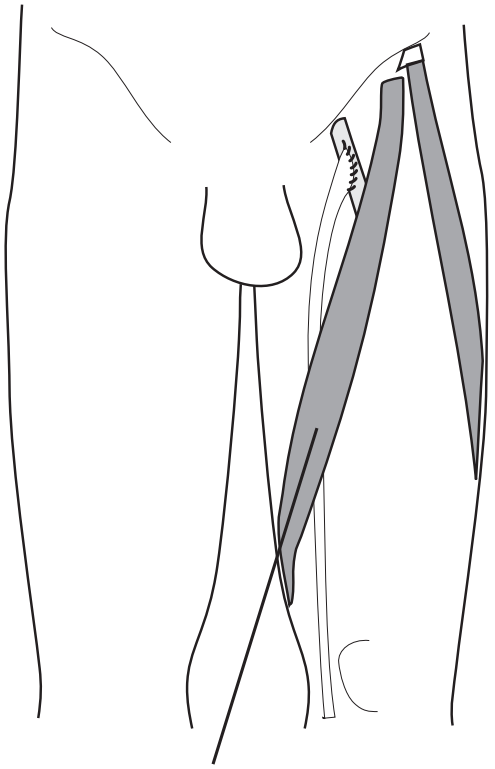
The anastomosis completed, with the hood of the bypass serving as a patch.



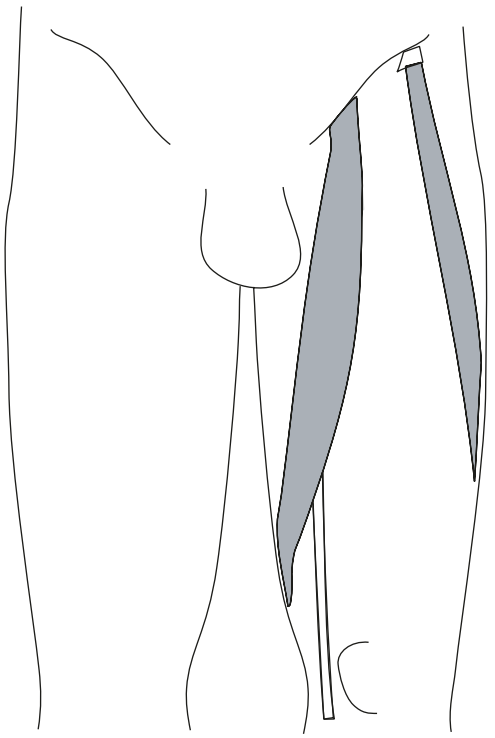
Sartorius Muscle Flap

The skin incision can be extended toward the anterior superior iliac spine. The origin of the sartorius muscle is identified and divided.

The proximal part of the sartorius muscle is mobilized. This often necessitates division of one or two segmental arterial branches supplying the muscle. The number of transected branches should be kept to a minimum because the blood supply to the sartorius muscle is segmental rather than longitudinal. This is necessary to prevent ischemia of the mobilized muscle segment.

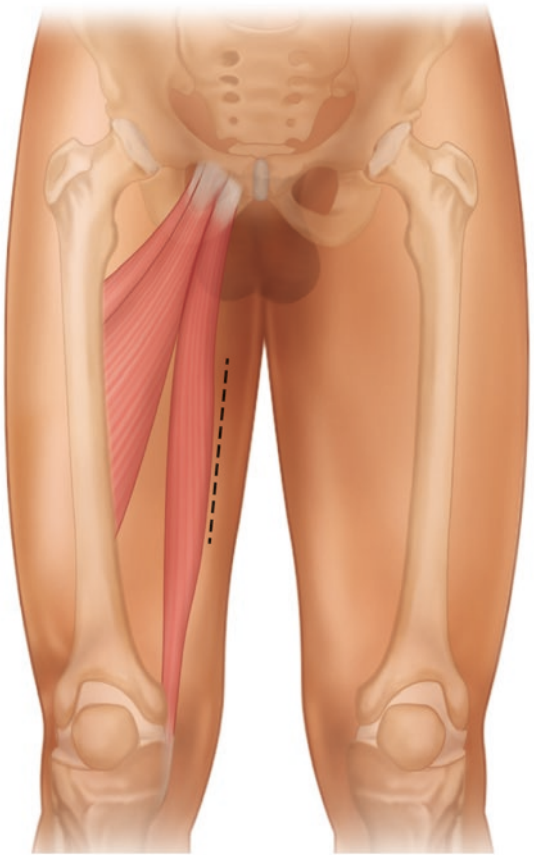


The mobilized sartorius muscle is rotated to cover the anastomosis. The sartorius muscle can be secured to the inguinal ligament and the surrounding tissues with nonabsorbable sutures.



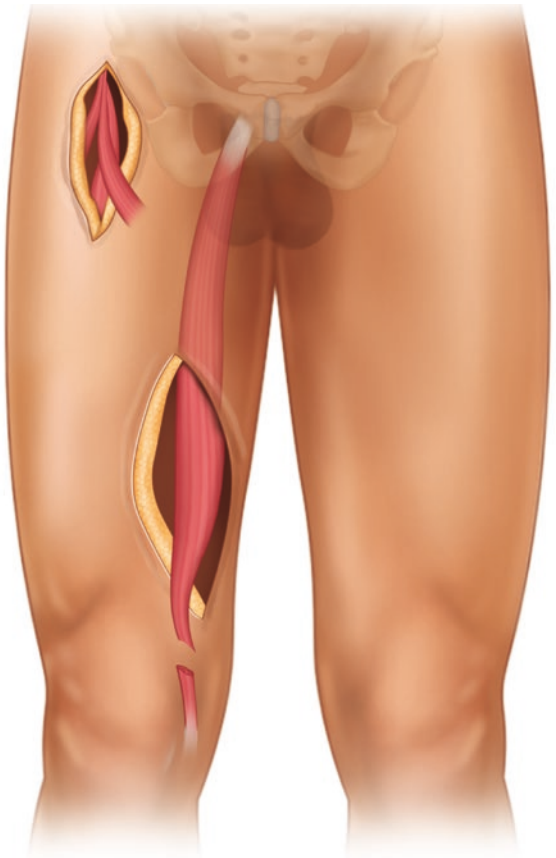
Gracilis Muscle Flap

An incision is made on the medial aspect of the thigh over the anticipated anatomic location of the gracilis muscle



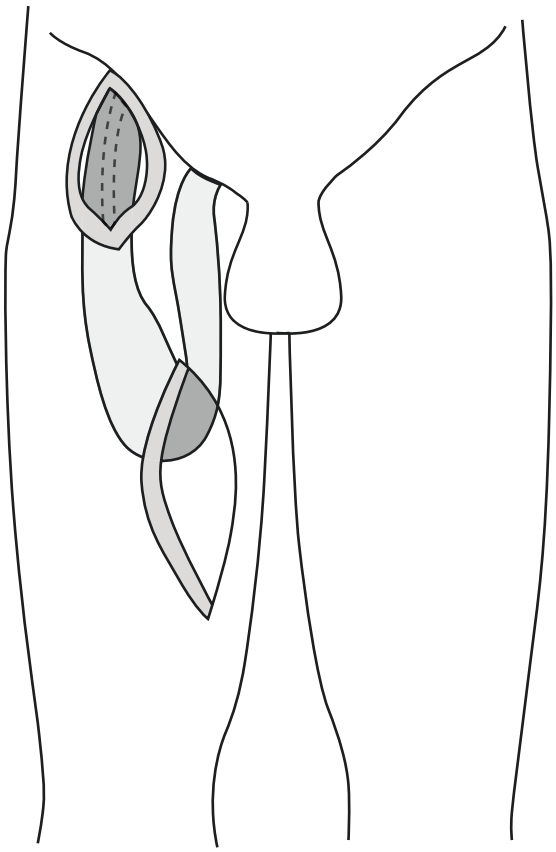
Gracilis Muscle Flap

After incising the deep fascia, the gracilis muscle is identified inferior and deep to the adductor muscle. The gracilis muscle is freed completely toward its tendinous insertion at the knee, which is divided



Gracilis Muscle Flap

A wide tunnel is created between the groin and the thigh incisions. The gracilis muscle is retroflexed and passed through the tunnel to cover the exposed femoral vessels or grafts



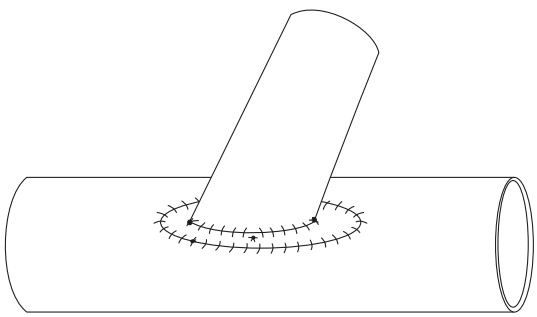
13

Adjunctive Techniques: Distal Anastomosis of an Infrainguinal Prosthetic Bypass

Jamal J. Hoballah

VEIN PATCHES AND CUFFS

Neointimal hyperplasia is a leading cause of bypass failure in the intermediate postoperative period (2–24 months). In prosthetic bypasses, neointimal hyperplasia is most likely to develop at the level of the distal anastomosis. Several techniques have been developed in an attempt to improve the patency of infrainguinal prosthetic bypasses [1, 2, 5, 6, 7, 8, 9, 10]. These techniques involve incorporating a segment of vein between the prosthetic bypass and the recipient artery. The theory behind these techniques is that the interposition of the vein segment may ameliorate the future development of neointimal hyperplasia at the level of the distal anastomosis. In addition, incorporating the vein segment could facilitate the construction of the distal anastomosis and improve bypass patency in the immediate postoperative period. Although these techniques were often used, there are very few prospective randomized trials to date that show their efficacy [1, 2, 3]. Furthermore, there are no prospective randomized trials that compare these various techniques in an attempt to identify which technique is best. With the advancement of endovascular technology and the availability of aggressive infrainguinal and infrapopliteal revascularization options, including retrograde pedal and popliteal access, tibial prosthetic bypasses are rarely performed nowadays. Nevertheless, when used as a last resort prior to an amputation, adjunctive techniques may be useful.



Linton's Patch

LINTON PATCH

In one technique (section "Linton Patch"), a vein patch angioplasty is initially performed at the site selected for the distal anastomosis. An incision is created in the patch and used as the new site for constructing the anastomosis. The graft is then sutured to the vein patch. This technique is often referred to as the "Linton patch" technique [1, 3, 4]. It is relatively simple to perform and can facilitate the construction of the anastomosis, especially in a heavily calcified vessel.

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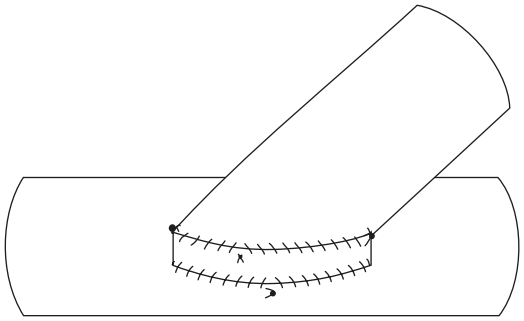
MILLER CUFF

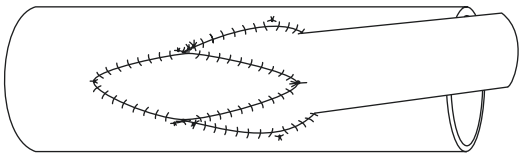
Another technique involves suturing a segment of vein to the arteriotomy at the site selected for the distal anastomosis as a collar or a cuff. The graft is then sutured to the vein cuff. This technique originally described by Siegman is usually referred to as the "Miller cuff technique" [5, 7]. Several modifications of this technique have been described. The simplest method to perform is illustrated in section "Miller Cuff." St. Mary's boot, another modification of the Miller cuff, is also described in section "Miller Cuff" [5].



Miller's Cuff

TAYLOR PATCH

Another technique involves constructing the distal anastomosis directly between the graft and the artery. An incision is then created in the graft at the level of the distal anastomosis and extended through the apex for 1–2 cm into the outflow artery. A vein patch angioplasty of the incision is then performed. This method is referred to as the "Taylor patch" (section "Taylor Patch") [9]. This technique can be technically demanding and requires mobilization of a long segment of artery in order to construct the anastomosis.



Taylor's Patch

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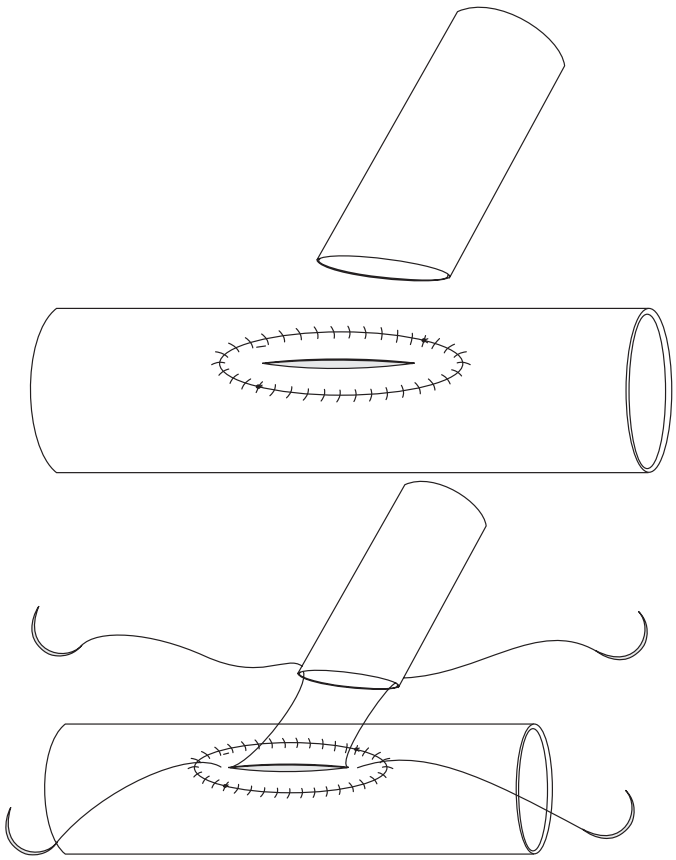
Vein Patches and Cuffs
Linton Patch

Create an arteriotomy measuring 1.5–2.0 cm. Suture a vein patch to the arteriotomy as shown in Chap. 8.

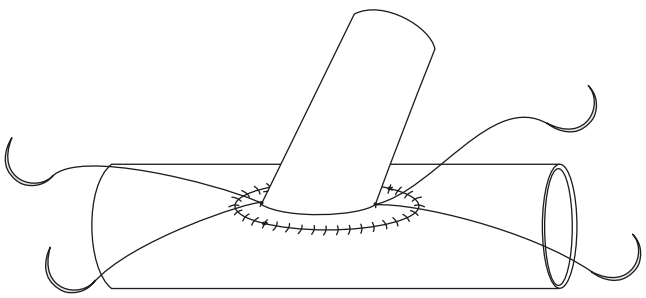
Perform an incision in the center of the patch.

Transect the prosthetic graft in a beveled manner to match the incision in the vein patch.

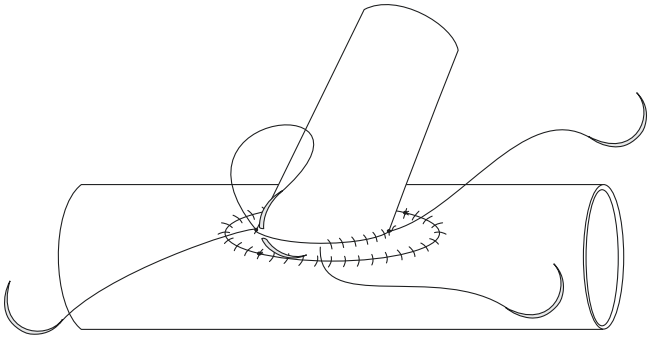


Start one suture at the heel the graft (outside-inside), and then through the intimal part of the vein patch. place a similar suture at the apex.

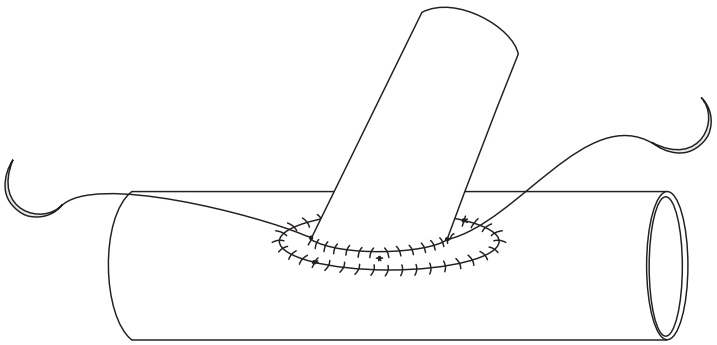
Tie both sutures.



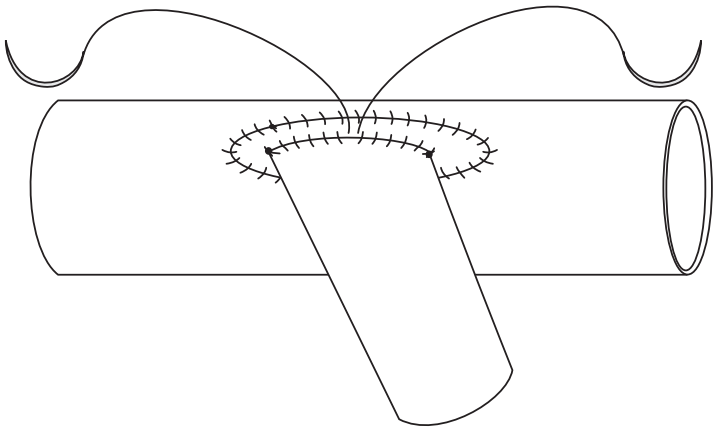
Start suturing with the heel suture. Introduce the needle outside-inside in the graft and inside-outside in the vein patch. Do the same with the apical suture.



Tie the sutures.

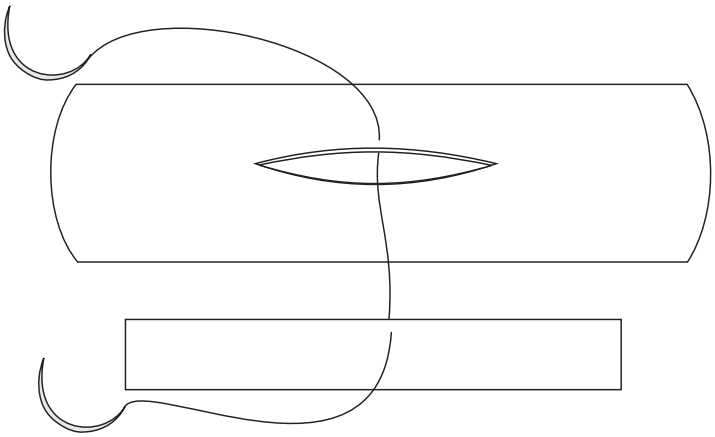


Flip the graft and replicate the suturing process on this side.



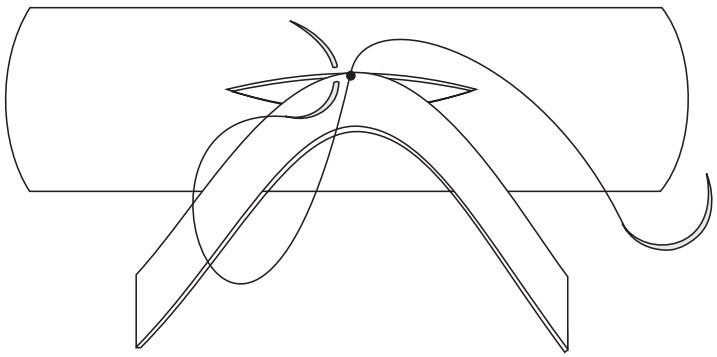
Vein Patches and Cuffs
Miller Cuff

Create an arteriotomy measuring 1.5–2.0 cm. Harvest a 4-cm segment of vein and slit the vein to create a patch.

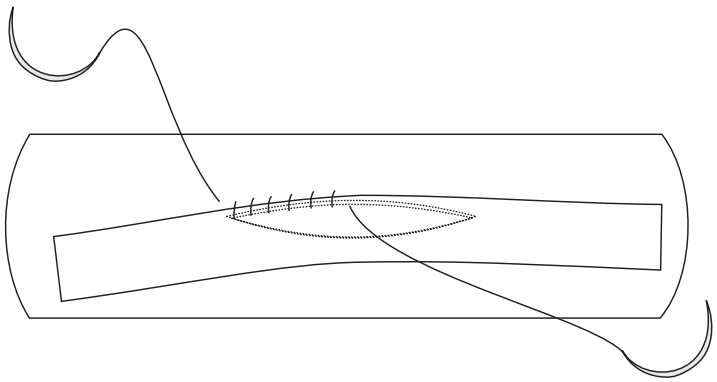


The suture is first started in the center of the vein patch. The needle is introduced from the adventitial side of the vein.

The needle is then introduced from the intimal side of the artery in the middle of the arteriotomy.

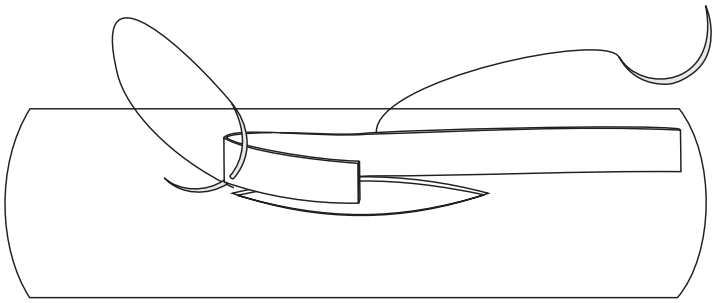


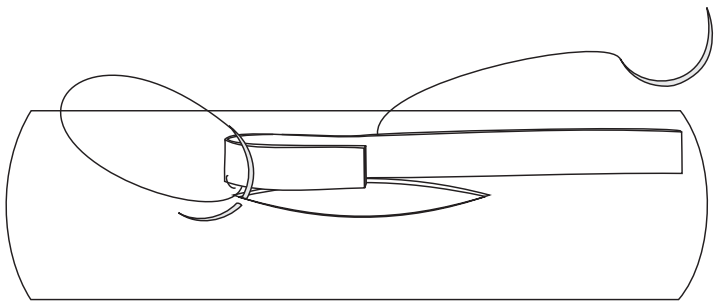
Tie the suture and start suturing by introducing the needle outside-inside in the vein patch and inside-outside in the artery.



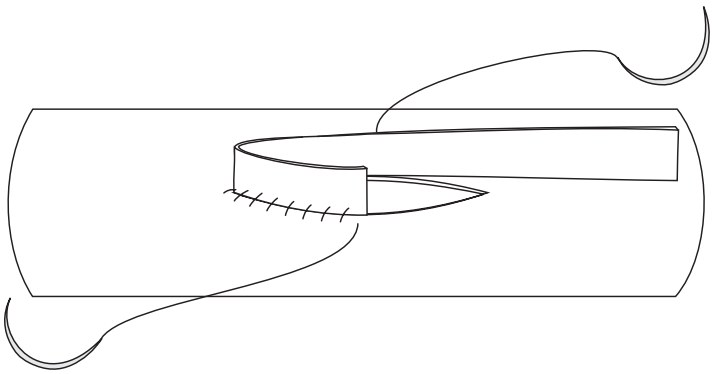
Vein Patches and Cuffs
Miller Cuff

Place several sutures until the apex is reached. Fold the vein cuff and place an apical bite in the vein.



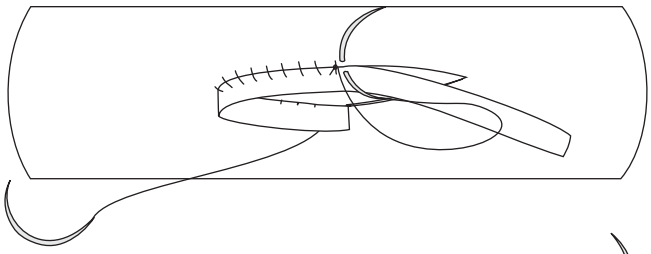


Introduce the needle through the apex of artery. Continue suturing until you reach one end of the patch.

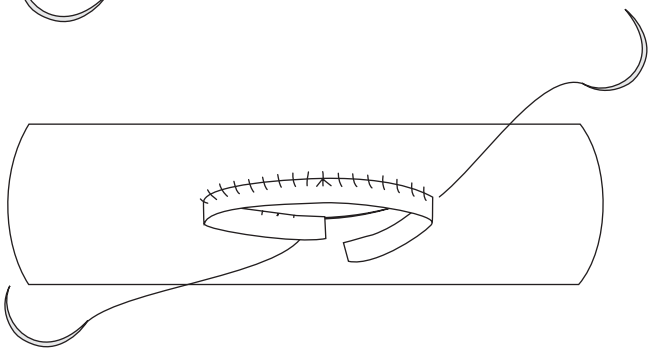


Vein Patches and Cuffs
Miller Cuff

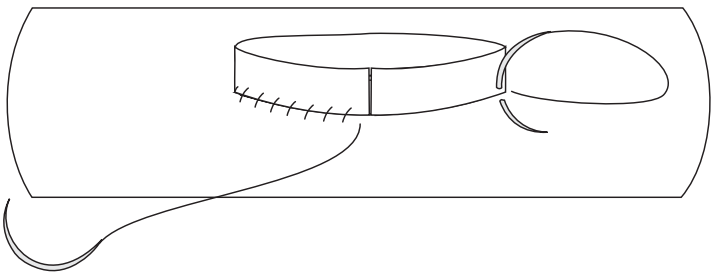
Flip the patch.



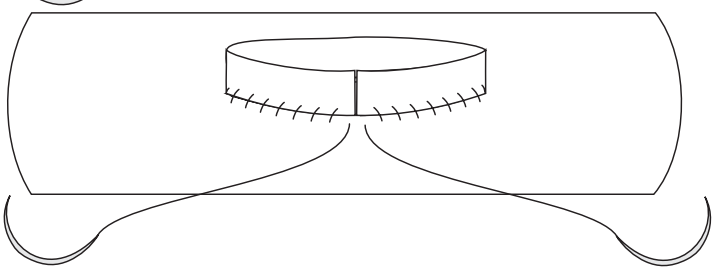
Again, introduce the needle from the adventitial side of the vein patch and then from the intimal side of the artery.



Continue suturing until the heel of the arteriotomy is reached.

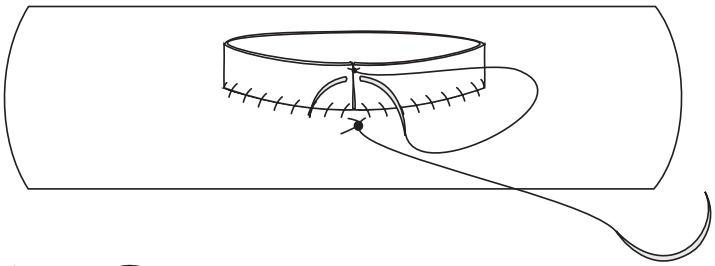


Fold the vein.

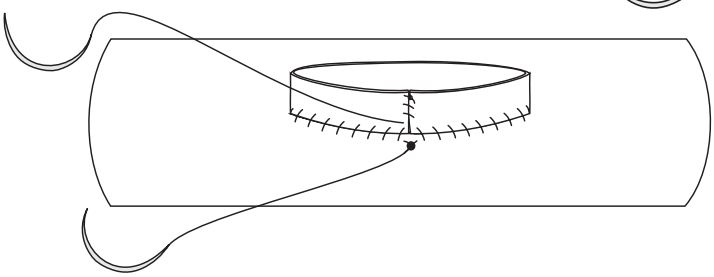


Vein Patches and Cuffs
Miller Cuff

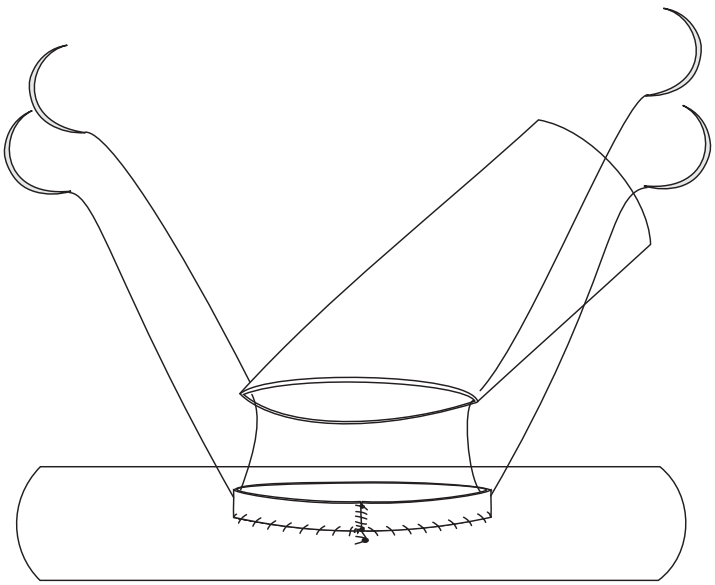
Place the heel sutures. (Again, outside-inside in the vein, inside-outside in the artery.) Continue suturing until both ends of the vein patch meet. Tie the sutures and cut one end.



Tie the sutures and cut one end. Start another suture at the apex to join the edges of the vein patch. Continue suturing toward the arterial suture line. Tie the sutures together.

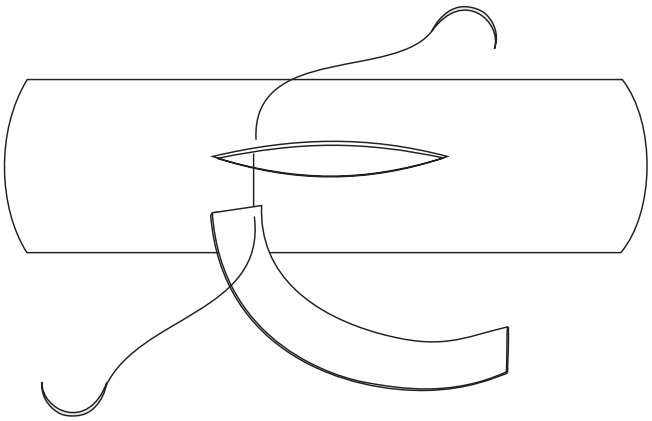


Transect the prosthetic graft in a beveled manner to match the vein cuff. Construct the anastomosis between the graft and the cuff as described in Chap. 9.

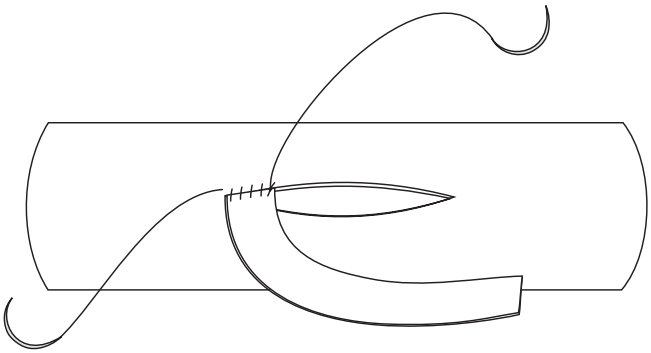


Vein Patches and Cuffs
Miller Cuff Modification
St. Mary's Boot

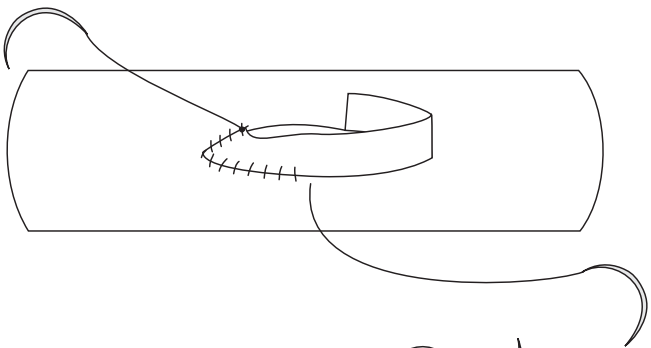
Start suturing from one corner of the vein patch.



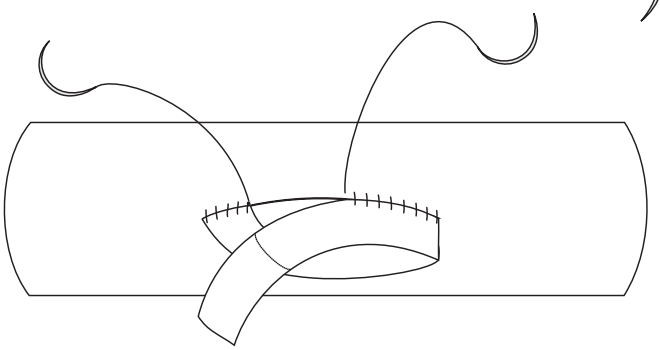
Tie the suture. Run one end toward the apex of the arteriotomy.



Fold the vein and continue running the suture toward the heel.



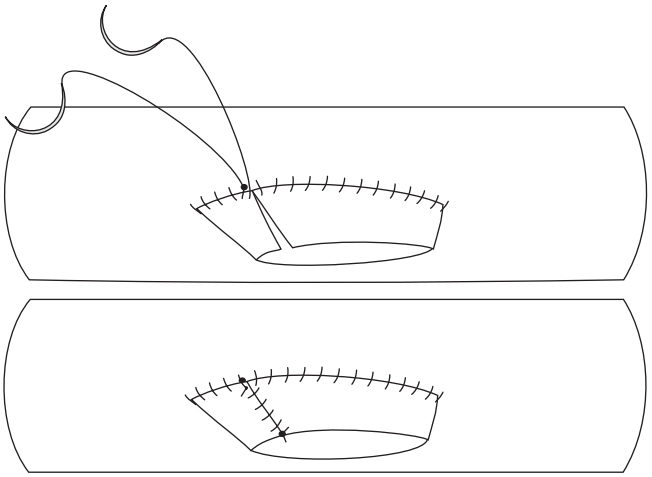
Fold the vein around the heel and continue running the suture toward the apex.



Vein Patches and Cuffs
Miller Cuff Modification
St. Mary's Boot

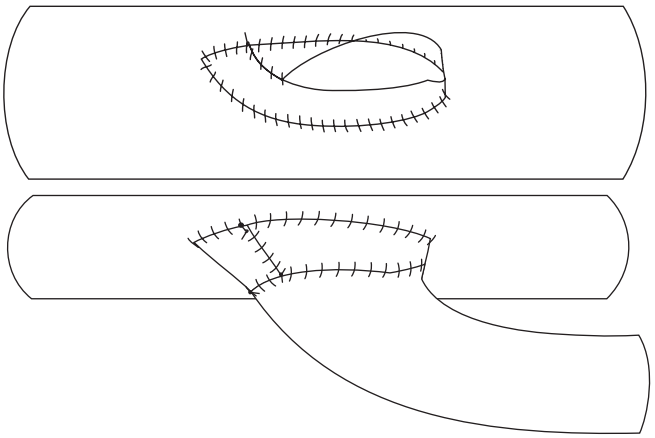
Trim the vein to the appropriate length.

Suture the edges of the vein patch.

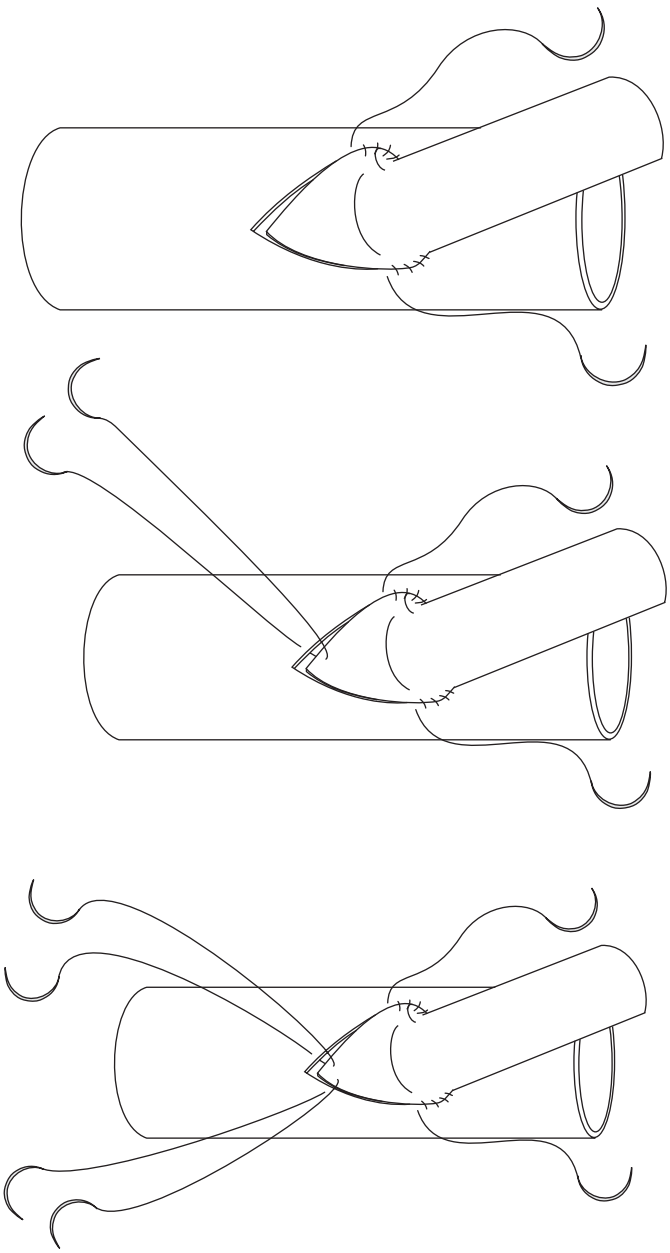


Excise a small wedge of the vein cuff at the heel.

Suture the graft to the vein cuff.

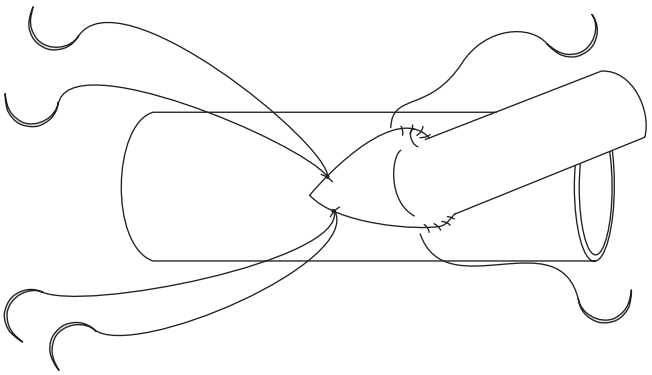


Vein Patches and Cuffs
Taylor Patch

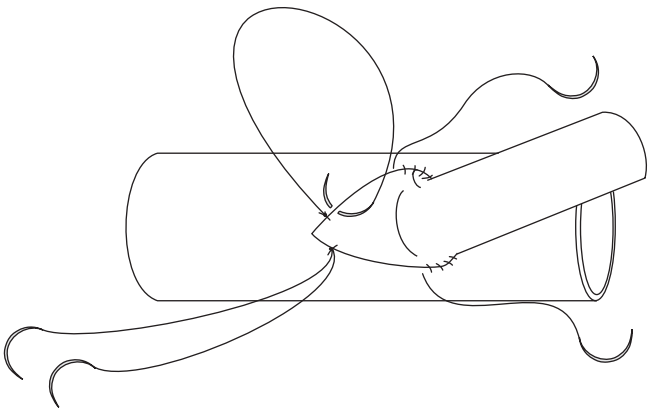


Construct the heel portion of the anastomosis using a parachute or tie-down technique. Place one suture on one side of the center of the apex. Introduce the needle outside-inside in the graft, inside-outside in the artery.

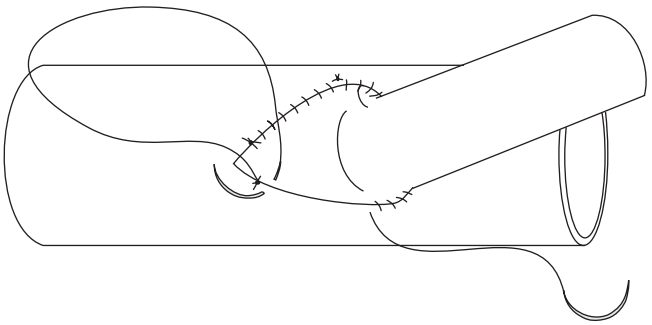
Vein Patches and Cuffs
Taylor Patch



Place an identical suture on the other side of the apex. Tie both sutures.

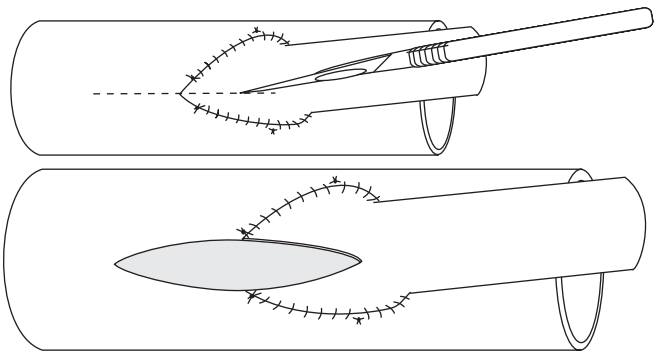


Run one end toward the heel suture. Run the other end toward the heel suture.

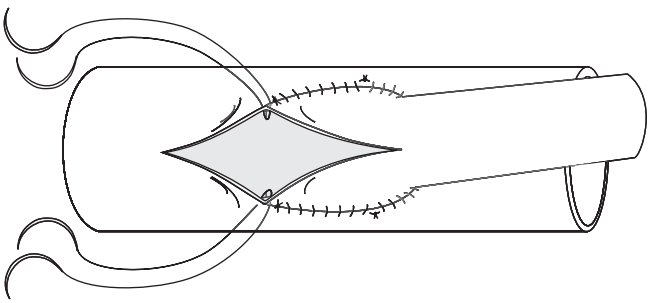


Vein Patches And Cuffs
Taylor Patch

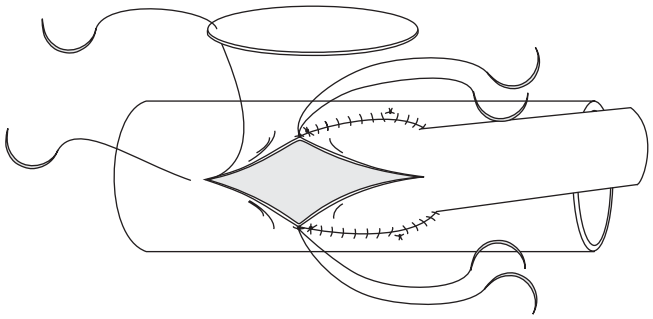
Incise the graft anteriorly and extend the incision across the center of the apex.

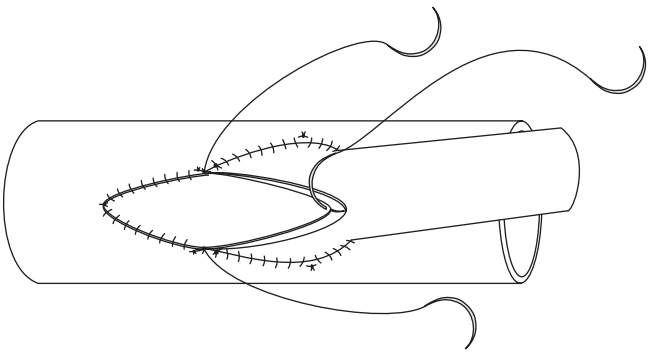


Place two stay sutures between the incised apices of the graft and artery. Suture the vein patch

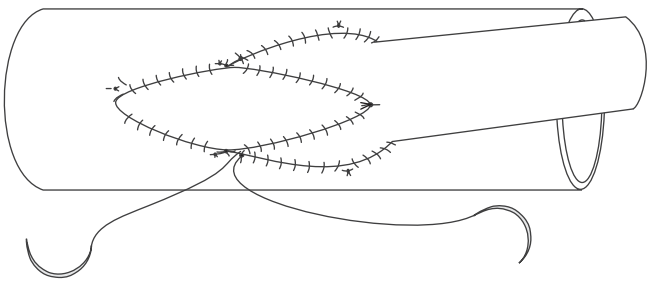


Vein Patches and Cuffs
Taylor Patch

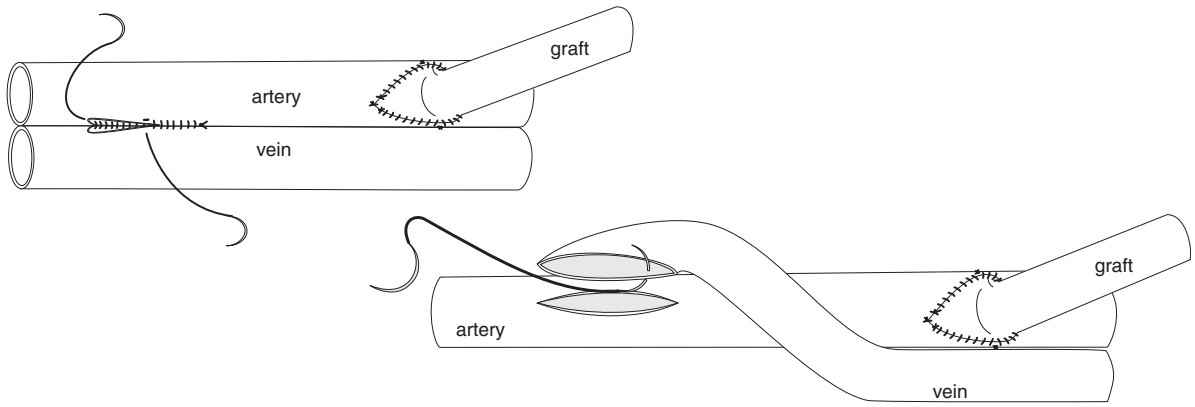




starting at the apex. You may use a parachute technique or an anchor technique as shown here. Run each end toward the stay sutures and tie them together.



Start another suture in the center of the heel. Run each end toward the remaining stay sutures and tie them together.



ARTERIOVENOUS FISTULAE

Poor distal runoff is often cited as a cause of infrainguinal prosthetic bypass failure. Several techniques have been developed in an attempt to improve the patency of prosthetic bypasses with disadvantaged outflow tracts. The main concept of these techniques is the creation of an arteriovenous (AV) fistula to improve the outflow and decrease the distal vascular resistance [12].

In one technique, after constructing the distal anastomosis between the prosthetic graft and the recipient artery, an arteriovenous fistula is constructed a few centimeters distal to the anastomosis [14]. This arteriovenous (AV) fistula can be constructed in a side-to-side fashion (Figure 13.1A) as described in Chap. 11.

The arteriovenous fistula can also be constructed by dividing the vein and joining its proximal end to the artery, a few centimeters distal to the anastomosis using an end-to-side configuration (Figure 13.1B).

In other techniques, the arteriovenous fistula is incorporated in the construction of the distal anastomosis (Figure 13.2) [12, 13]. In one variation, the arteriovenous fistula is constructed in a side-to-side fashion (section "Vein Patches and Cuffs"). An incision is created in the artery at the site selected for the distal anastomosis. A matching incision is created in the vein accompanying the artery. The adjacent walls of the artery and the vein are sutured together, resulting in a combined opening into the artery and the vein. The graft is then sutured to this newly created opening, allowing the blood to flow into the artery and the vein simultaneously. The size of the fistula can be theoretically controlled by changing the length of the venotomy. The longer the size of the venotomy, the larger is the fistula. One advantage of this technique is that it involves adding only one additional suture line between the adjacent walls of the artery and the vein. The disadvantage of this technique is that the prosthetic bypass is connected directly to the artery without the potential theoretical benefit of an interposed vein segment.

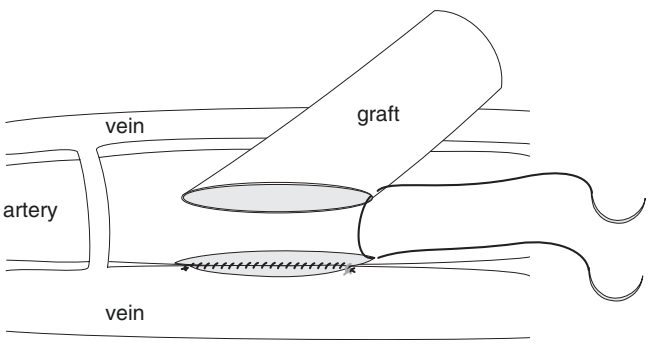


Figure 13.2 AV fistula incorporated in the anastomosis

Another variation described by Ascer involves incorporating the concept of vein cuff and the concept of arteriovenous fistula together (section "Arteriovenous Fistulae") [11]. In this method, one of the veins accompanying the artery is mobilized for several centimeters. An arteriotomy is created in the artery at the site selected for the distal anastomosis. The vein is transected and sutured to the artery in an end-to-side manner. It is important to mobilize the vein for a long segment to allow for a gentle curve of the vein over the artery. A venotomy is created in the hood of the vein and will serve as the new site for constructing the anastomosis with the prosthetic graft (Figure 13.3a). The graft is then sutured to the venotomy. Although this technique involves creating an additional anastomosis, it has several attractive features. The anastomosis between the vein and the artery and the anastomosis between the bypass and the vein are conducted by following the same principles of any end-to-side anastomosis. Surgeons are familiar with this type of reconstruction, which can be carried out even in heavily calcified vessels. The anastomosis between the graft and the vein can be accomplished with relative ease and expediency. At the completion of the anastomoses, the flow and the magnitude of the fistula can be controlled by banding of the fistula. The pressure in the graft is measured and compared to the radial artery pressure. Banding is considered unnecessary if the gradient is less than 30 mmHg, or if the pressure in the graft is greater than 100 mmHg. Banding can be accomplished by placing a 4-mm polytetrafluroethylene cuff (PTFE) ring around the vein (Figure 13.3b).

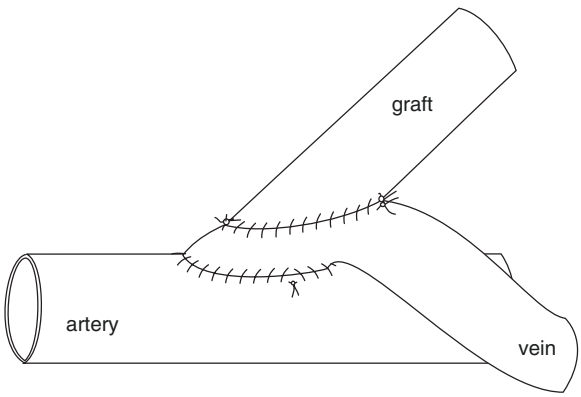


Figure 13.3 (a) End-to-side AV fistula incorporated in the distal anastomosis.

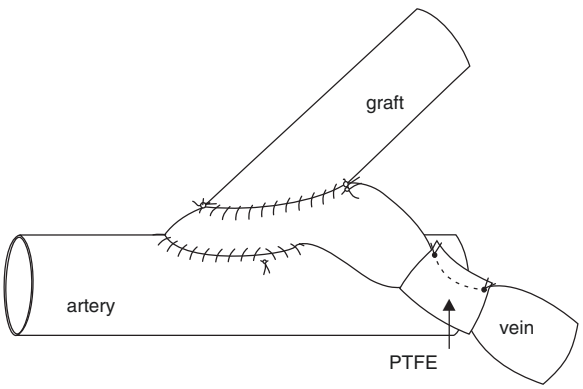
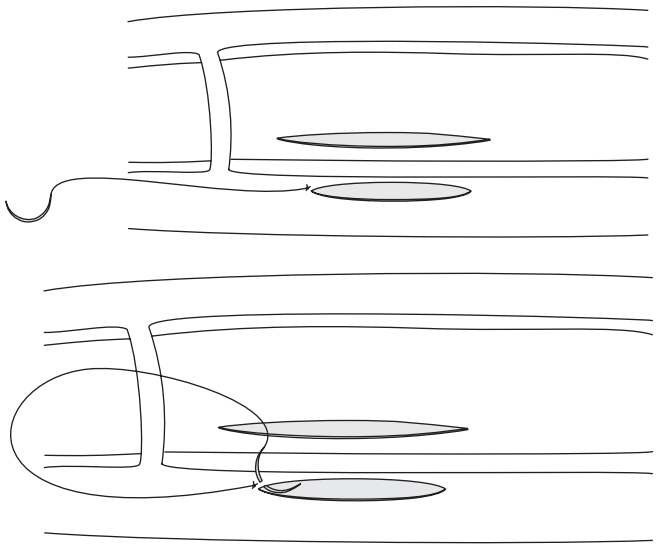


Figure 13.3 (b) Banding of the AV fistula using a PTFE ring.

REFERENCES

11. Ascer E, Gennaro M, Polina R, et al. Complementary distal arteriovenous fistula and deep vein interposition: a five-year experience with a new technique to improve infrapopliteal prosthetic bypass patency. J Vasc Surg. 1996;24:134–43.
12. Dean RE, Read RC. The influence of increased blood flow on thrombosis in prosthetic grafts. Surgery. 1964;55:581–4.
13. Harris PL, Campbell H. Adjuvant distal arteriovenous shunt with femorotibial bypass for critical ischaemia. Br J Surg. 1983;70(6):377.
14. Paty PSK, Shah DM, et al. Remote distal arteriovenous fistula to improve infrapopliteal bypass patency. J Vasc Surg. 1990;1:171–8.

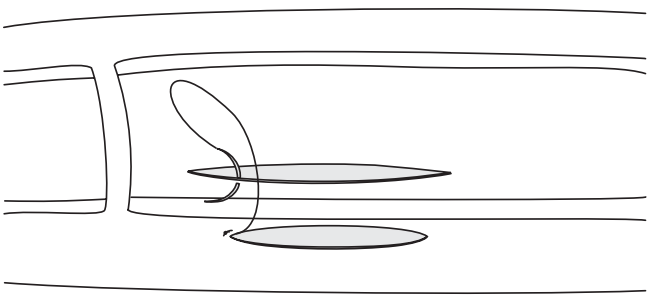
Arteriovenous Fistulae
Side-to-Side



Expose the infrapopliteal vessels. Select the larger accompanying vein for creating the AV fistula.

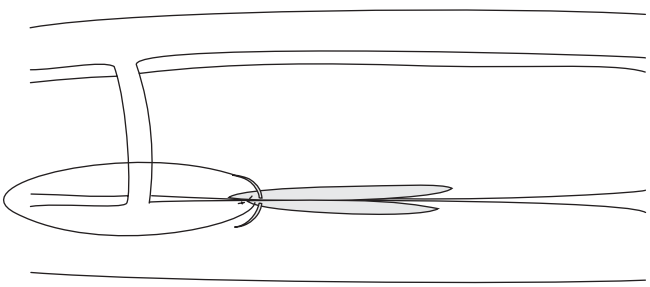
Create an arteriotomy in the anteroinferior aspect of the artery, close to the selected vein.

Create a venotomy in the selected vein, adjacent to the created arteriotomy. The size of the venotomy can vary according to the surgeon's preference.



Start a horizontal mattress suture at the apex of the venotomy. Tie the suture and cut one end.

Introduce the needle outside-inside in the vein, close to the start of the suture.

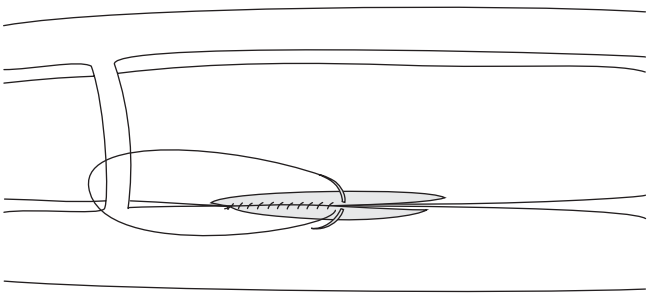


Introduce the needle in a corresponding site in the artery (inside-outside).

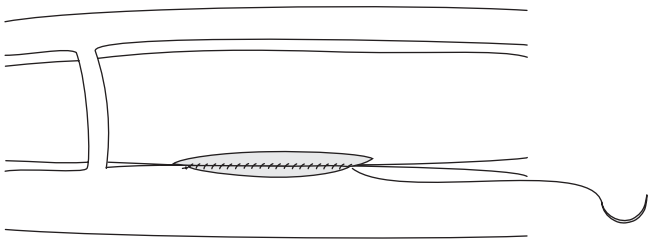
Pull the suture. Start suturing the adjacent arterial and venous walls together.

The needle is introduced from the intimal side of the artery and then from the adventitial side of the vein.

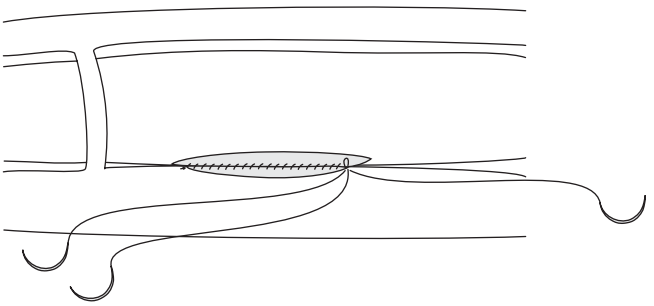
Arteriovenous Fistulae
Side-to-Side



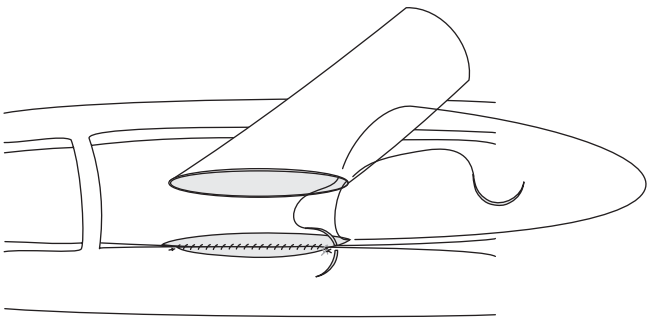
Continue suturing until the adjacent venous and arterial walls are fully approximated.



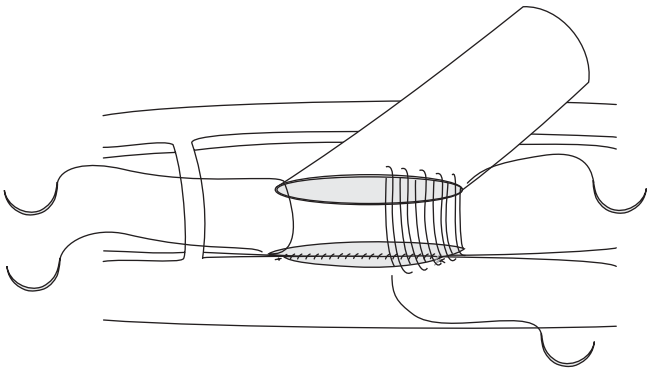
Start another stay suture at the apex of the venotomy and tie the sutures together Transect the graft to match the size of the arteriotomy.



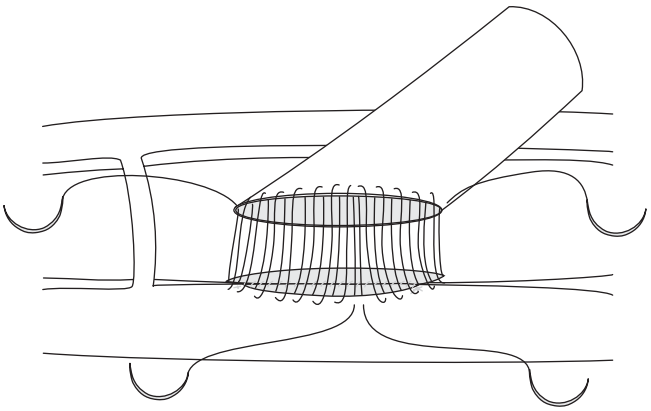
Start one suture at the center of the heel, outside-inside in the graft, inside-outside in the artery. You may tie the suture or use a parachute technique as shown here.



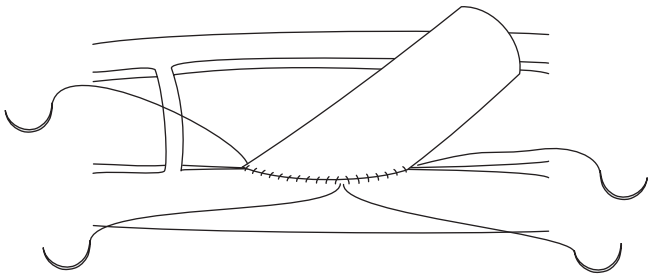
Arteriovenous Fistulae
Side-to-Side



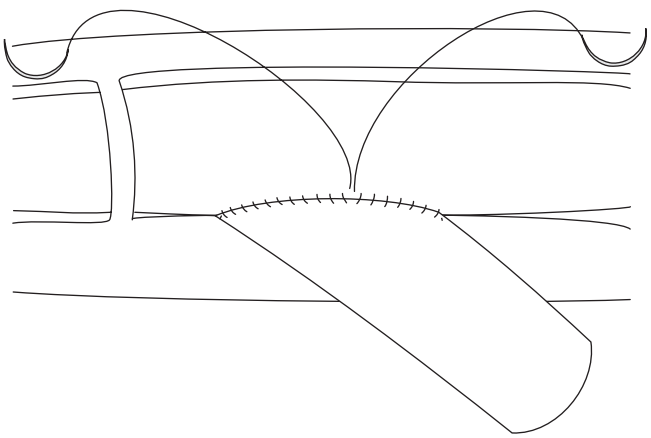
Start another suture at the apex. (Outside-inside in the graft and inside-outside in the artery.)



Continue until you reach the other suture.



Pull and tighten the sutures.



Flip the graft and replicate the suturing on this side.

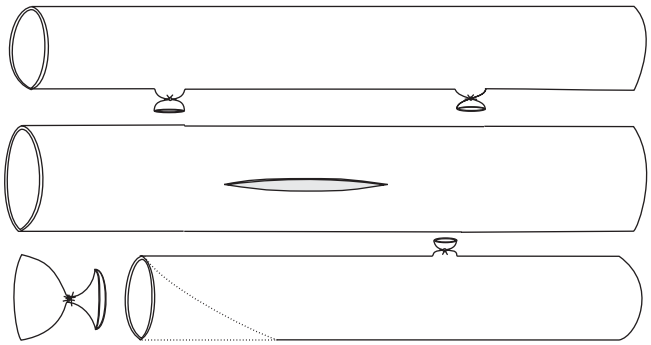
Arteriovenous Fistulae
Side-to-Side

Expose the tibial vessels and divide the venae comitantes.

Dissect a 5-cm segment of the larger accompanying tibial vein.

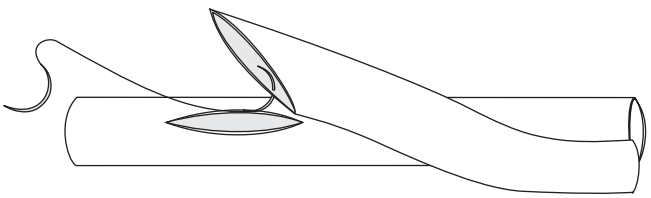
Ligate and transect the vein as distally as possible.

Perform an arteriotomy in the tibial artery.



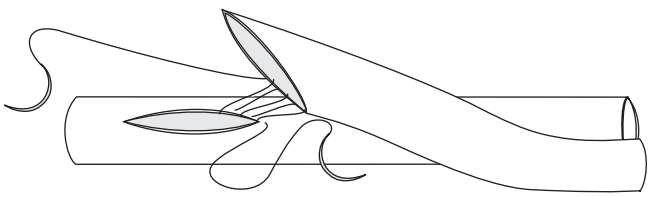
Incise the posterior wall of the transected vein to match the size of the arteriotomy.

Make sure to place the vein on the arteriotomy to accurately place the incision in the posterior wall of the vein.

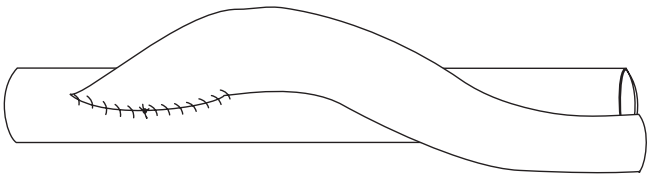


You may perform the anastomosis using an anchor technique or a parachute technique as shown here. Start suturing in the vein a few bites away from the center of the heel (outside-inside in the vein, inside-outside in the artery).

Continue suturing until you are a few bites beyond the center of the heel.



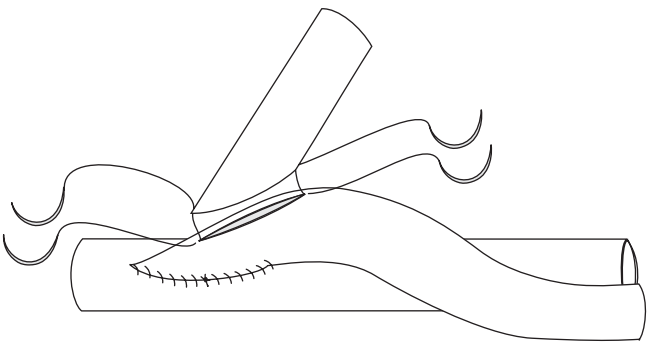
The anastomosis is completed and checked for hemostasis.



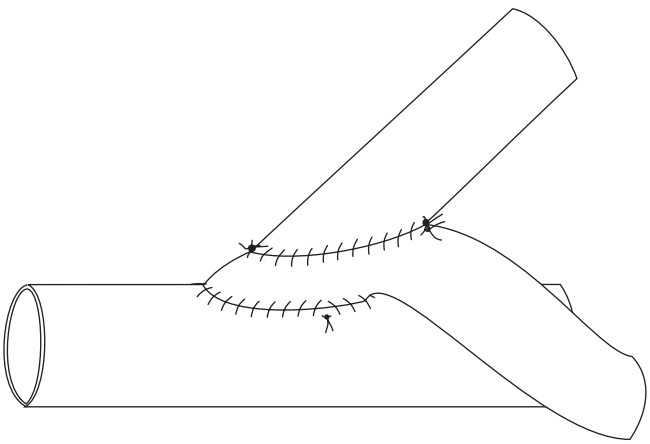
Create a 1–1.5-cm venotomy.

Transect the prosthetic graft in a beveled fashion to match the size of the venotomy.

Construct an end-to-side anastomosis between the graft and the vein as described in Chap. 9.



Check the suture lines for hemostasis.



Part IV

Aortic Surgery

14

Infrarenal Abdominal Aortic Aneurysm Replacement: Proximal Anastomosis

Jamal J. Hoballah

GENERAL PRINCIPLES

During the replacement of an infrarenal abdominal aortic aneurysm, the proximal anastomosis between the graft and the neck of the aneurysm is constructed in an end-to-end fashion. The basic techniques for preparing the neck of the aneurysm for the creation of the proximal anastomosis are illustrated in section "General Principles." The aneurysm wall is incised longitudinally on its anterior aspect keeping to the right of the origin of the inferior mesenteric artery. The incision in the aorta is carried to the level of the neck of the aneurysm.

INTACT POSTERIOR WALL

The incision is then teed off on each side of the neck, leaving the posterior wall intact. The needle will penetrate the aorta approximately 1 cm proximal to the aneurysm neck (Fig. 14.1b) and will exit the posterior aortic wall 1.5–2 cm distal to the aneurysm neck (Fig. 14.1b). When tension is applied to the suture line, the layers of the aorta just proximal and distal to the aneurysm neck will be pulled together, resulting in a "double-layer" bite (Fig. 14.1c). The theoretical advantage of the "double-layer" bite is that the two layers will buttress each other, resulting in a stronger and more hemostatic bite.

The placement of the bites can be technically demanding when the posterior aortic wall is left intact. Occasionally, when the needle is introduced through the posterior aortic wall, its tip, as it exits distally, may not be easily visualized. The temptation to be avoided in such situations is to place a shallower bite. Shallow bites placed in the posterior aortic wall without incorporating the adventitia could tear through the aortic wall. The placement of deep bites and the retrieval of the needle from the aortic wall can be facilitated using a large needle, such as an MH needle (Ethicon).

The posterior suture line can be carried out using either an anchor or a parachute technique. The parachute technique can be started in the center of the posterior wall or at the beginning of the posterior wall, as shown in section "Parachute Technique." When there is a mismatch between the diameter of the graft and the aortic neck, starting at the center could help in better judging the advancement between the bites.

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J. J. Hoballah, C. F. Bechara (eds.), *Vascular Reconstructions*, https://doi.org/10.1007/978-1-0716-1089-3_14

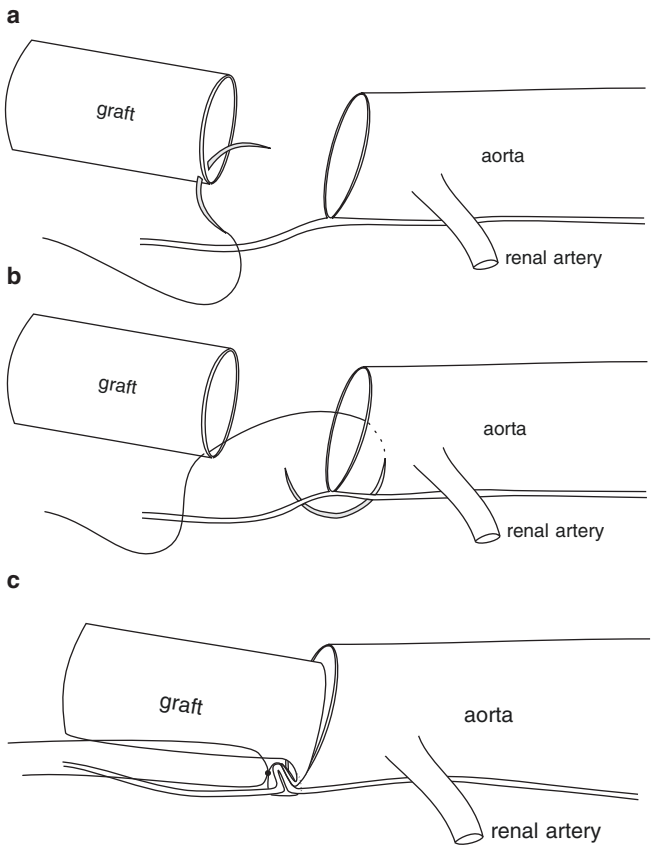


Figure 14.1. (a) needle going through the graft outside inside, (b) needle going through the intact posterior wall of the arota, (c) double layer posterior wall when the suture is tied

The anchor technique is usually started in the center of the posterior suture line (section "Anchor Technique"). In general, the placement of the sutures could be facilitated if the surgeon performs his side of the suture line and the first assistant performs the other side. In another modification, the entire or part of the posterior suture line is constructed using an interrupted horizontal mattress suture technique. This technique could be useful when the aortic neck is very diseased. Additional sutures may be needed after the release of the clamps to secure hemostasis, especially with a heavily calcified wall.

TRANSECTED POSTERIOR WALL

Another option is to transect the aortic wall completely (section "Transected Posterior Wall"). This facilitates the construction of the posterior part of the anastomosis. In this technique, after introducing the needle in the aortic wall, the needle tip can be easily visualized underneath the aortic stump. The transection of the aorta facilitates placing and retrieving the needle. The main disadvantage of this technique is the potential for venous injury during aortic transection. Injury to the vena cava or to a retroaortic renal vein or lumbar veins may result in undesirable bleeding. In addition, after transecting the aorta, the aortic wall may be found to be thinner than expected. In this situation, placement of pledget mattress sutures may be desirable to reinforce the aortic wall for a secure hemostatic anastomosis.

Transection of the aorta is routinely used in the technique of aneurysm exclusion with aortic bypass. It is also used when a transaortic endarterectomy of the renal arteries is contemplated in conjunction with an aortic reconstruction. In

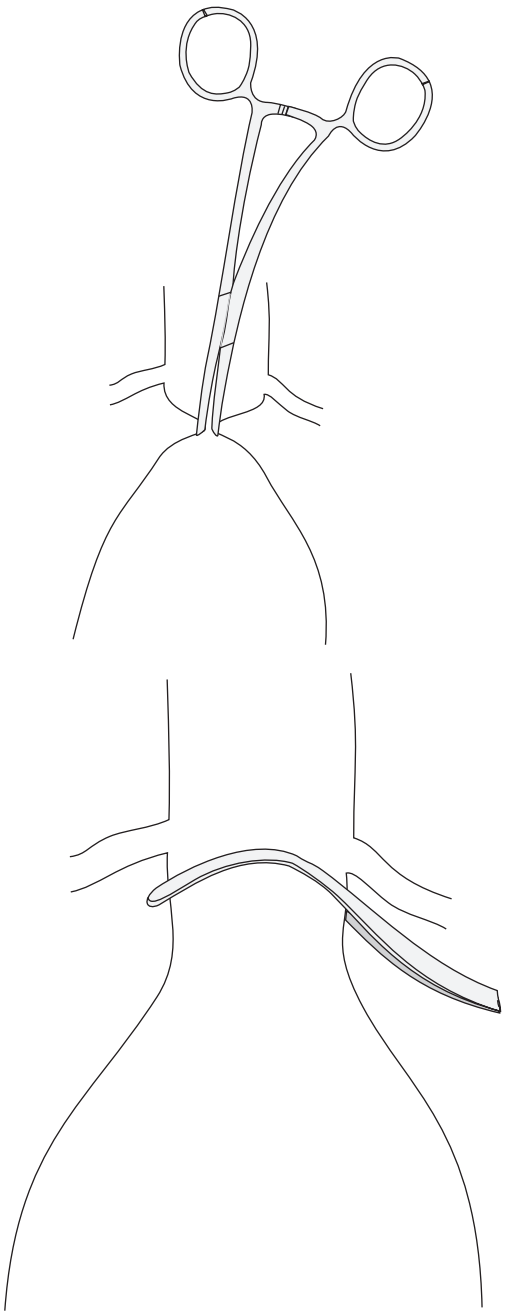
the management of aortoiliac occlusive disease, the proximal aorta may be transected when performing an aortobifemoral bypass routinely by some surgeons, especially when the aorta is heavily calcified or when dealing with a chronic aortic occlusion.

When the aortic wall is transected, the posterior suture line may be carried using an anchor or a parachute technique. The anchoring suture is usually started in the center of the posterior wall and may be a simple or a mattress suture. This technique could be ideal when the transected aorta is well exposed in a thin patient. If a parachute technique is used, the suture line may be started in the center of the posterior line or at one end of the posterior wall. Whenever the parachute technique is used, it is most important to check the tightness of the suture line with a nerve hook before tying the final knot.

In general, for right-handed surgeons, the construction of the posterior portion of the anastomosis is facilitated if performed from the opposite side of the table.

General Principles

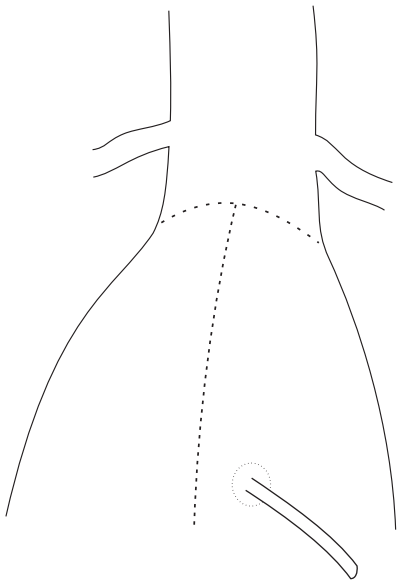
The aorta can be clamped in a horizontal or transverse manner depending on the presence of plaque in the aortic wall.



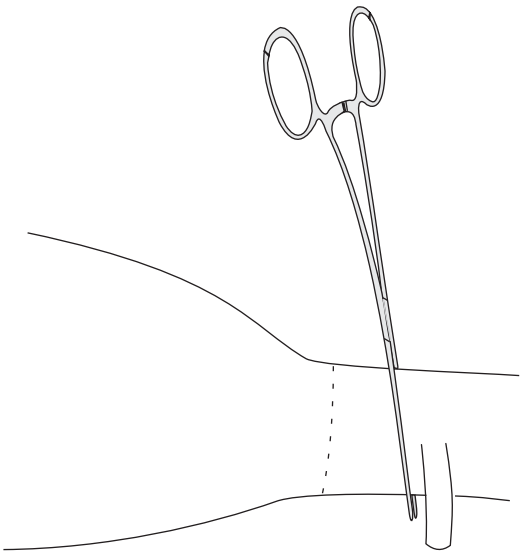
If the aortic wall is free of any palpable plaque or if the plaque is on the lateral wall of the aorta, the aortic clamp is applied in a vertical direction. The clamp is inserted under direct vision and advanced until the tips of the jaws are felt touching the vertebral column. This will ensure that the aorta is completely enclosed between the clamp's jaws.

In the presence of plaque in the posterior wall of the aorta, the aorta is dissected circumferentially and the clamp is applied in a transverse manner to appose the anterior aortic wall against the posterior aortic wall.

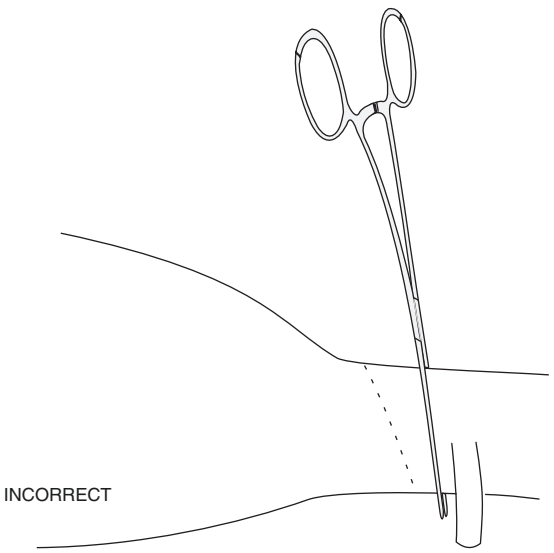
General Principles



The aorta is incised along its anterior wall. The incision is carried to the right of the inferior mesenteric artery (IMA). This allows for the protection of the IMA should reimplantation become necessary. The sympathetic nerves that run around the origin of the IMA are also preserved.



At the neck of the aneurysm, the incision is carried out in a T-fashion from anterior to posterior.

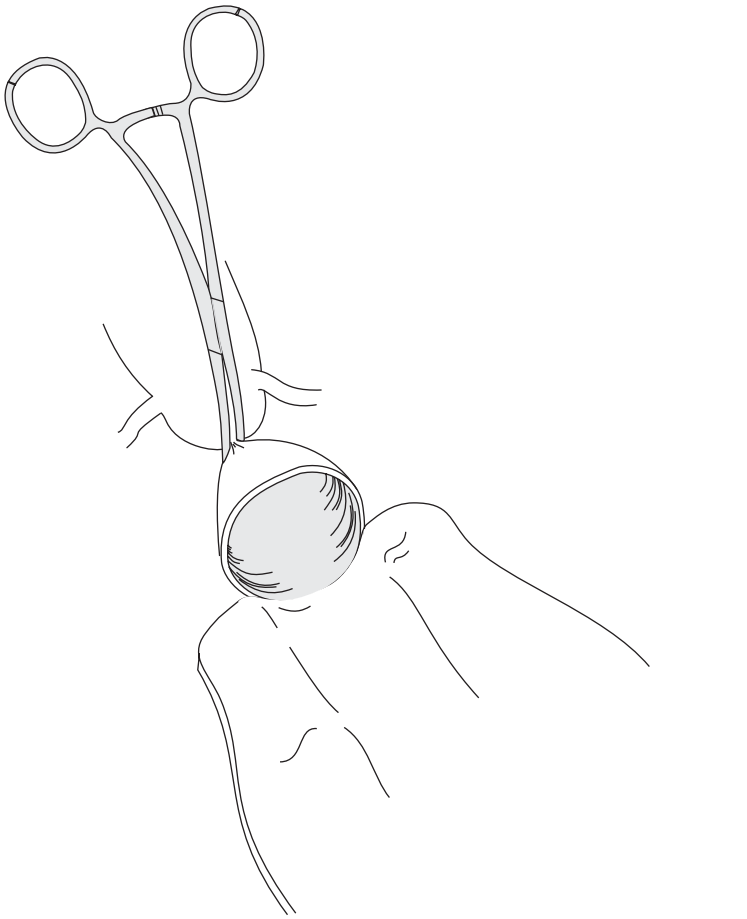


Avoid incising the lateral aspect of the wall in a cephalad direction, as this may compromise the placement of posterior sutures.

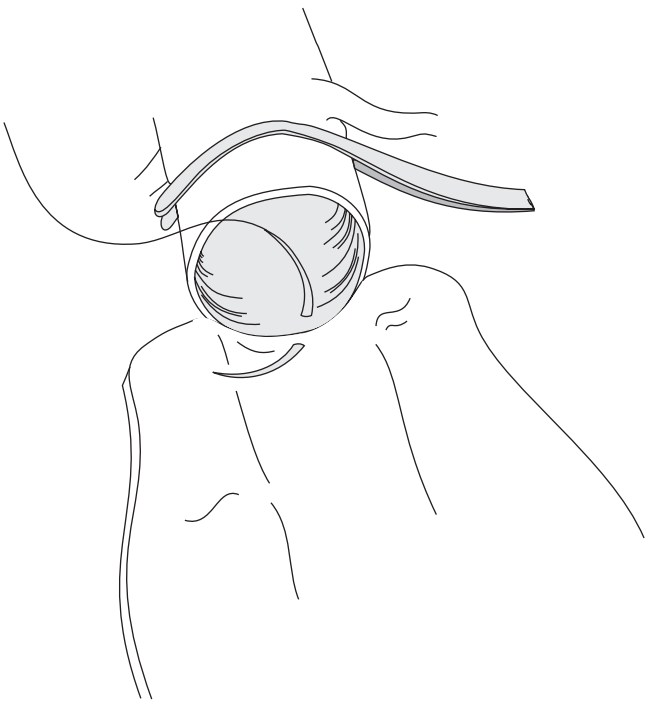
INCORRECT

General Principles

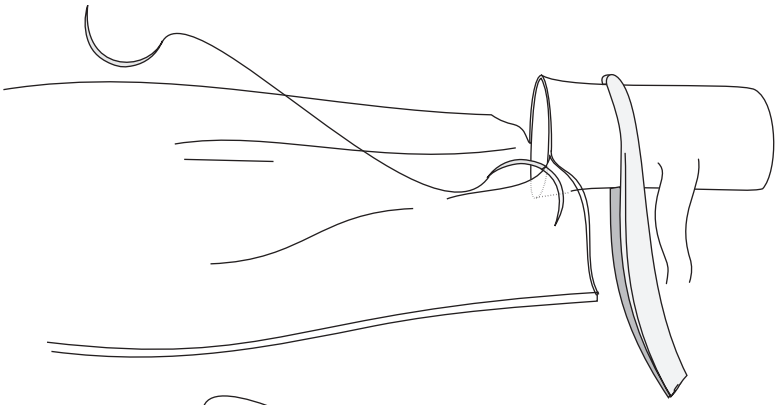
The posterior wall of the aorta can be left intact, which allows placement of a double-layer aortic wall suture. The double-layer sutures of the posterior wall of the aorta may be facilitated using a large needle.



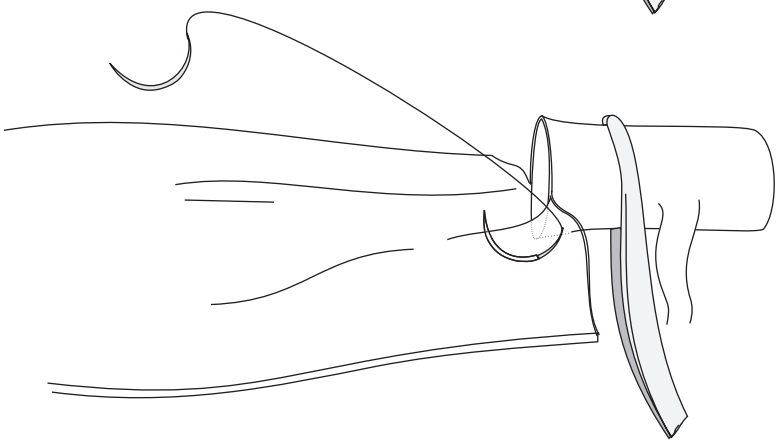
Avoid placing shallow bites in the posterior aortic wall.



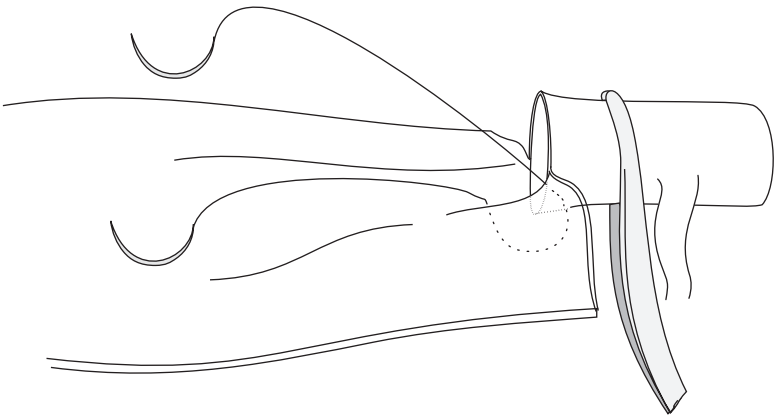
The needle should be introduced at a right angle to the posterior wall.



The needle is advanced through the posterior wall while following the curvature of the needle.



The resulting bite is a deep double-layer bite in the posterior aortic wall.



General Principles

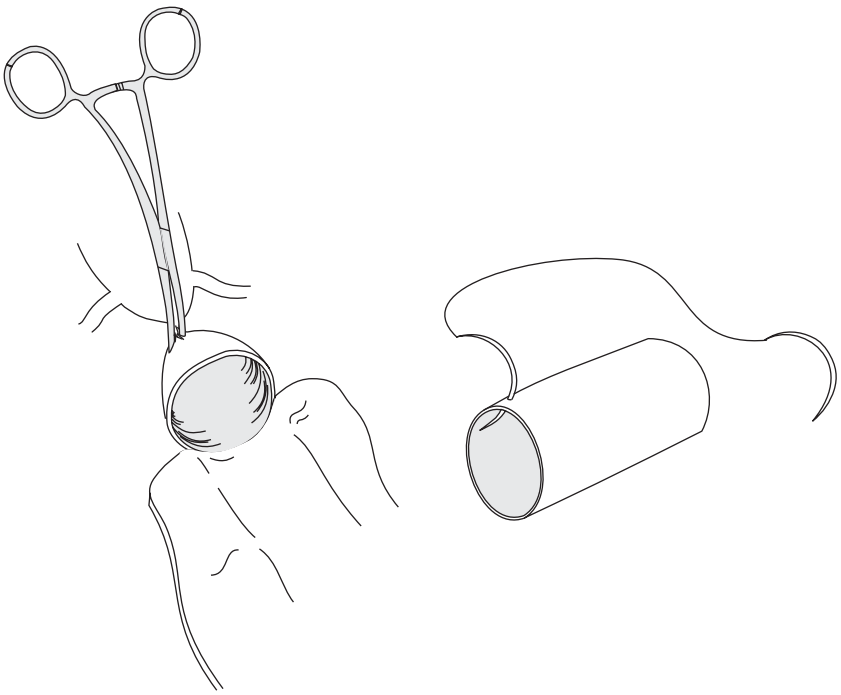
Alternatively, the posterior wall may be divided completely.

This technique will facilitate placement of the posterior wall sutures. If the wall is relatively thin, reinforcement of the wall with pledget sutures may be necessary.

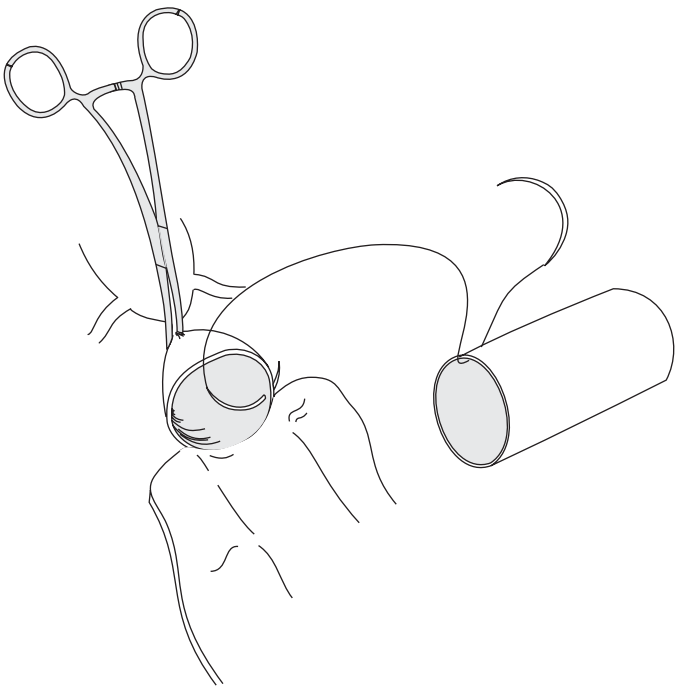
Intact Posterior Wall
Parachute Technique
Starting on the lateral aspect of the aorta

The following steps are conducted assuming the surgeon is standing on the patient's right hand side. If the surgeon is standing on the patient's left hand side, the suturing will start on the opposite side to allow for the sutures to progress toward the surgeon.

Start by introducing the needle (outside-inside) in the graft.



Place the next suture in the aortic wall very close to the line of division of the lateral wall. This bite is a single-layer bite in the aortic wall. Make sure that the suture line is not crossed by grabbing the needle from underneath the loop.

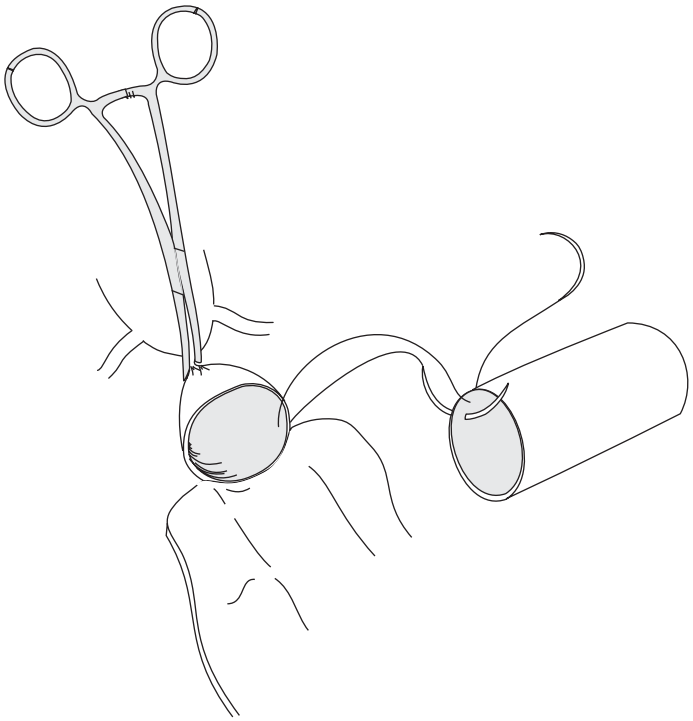


Intact Posterior Wall

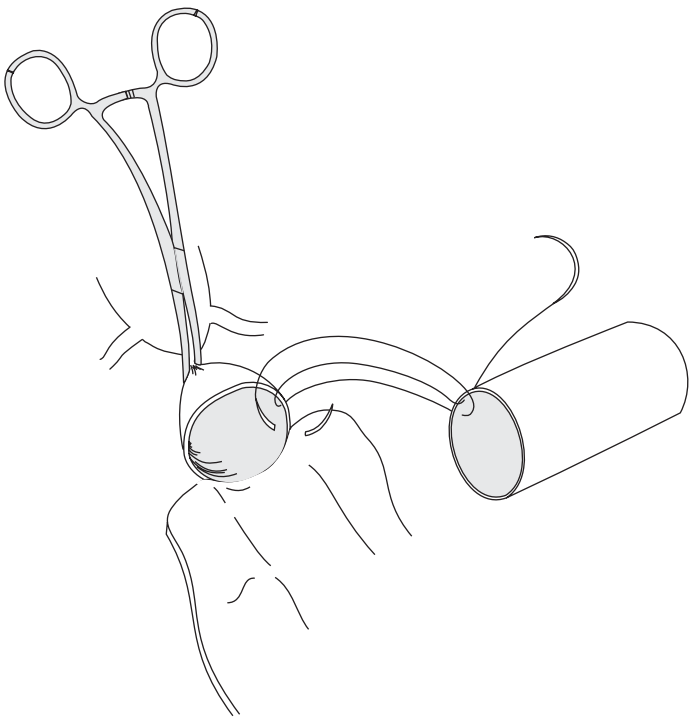
Parachute Technique

Starting on the lateral aspect of the aorta

Place the next bite in the graft. Make sure that the suture line, again, is not crossed and is passed underneath the loop.



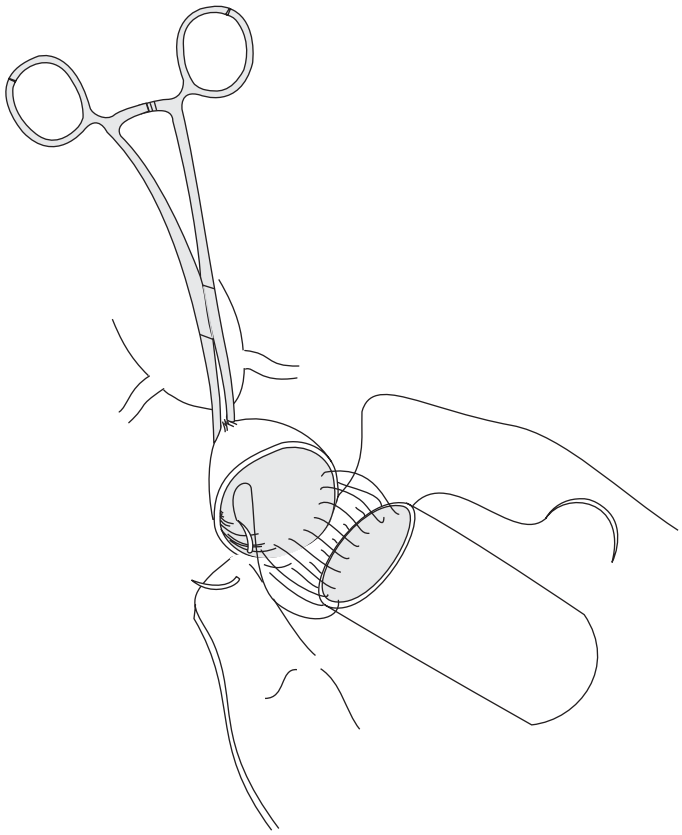
Place a double-layer suture in the aortic wall.



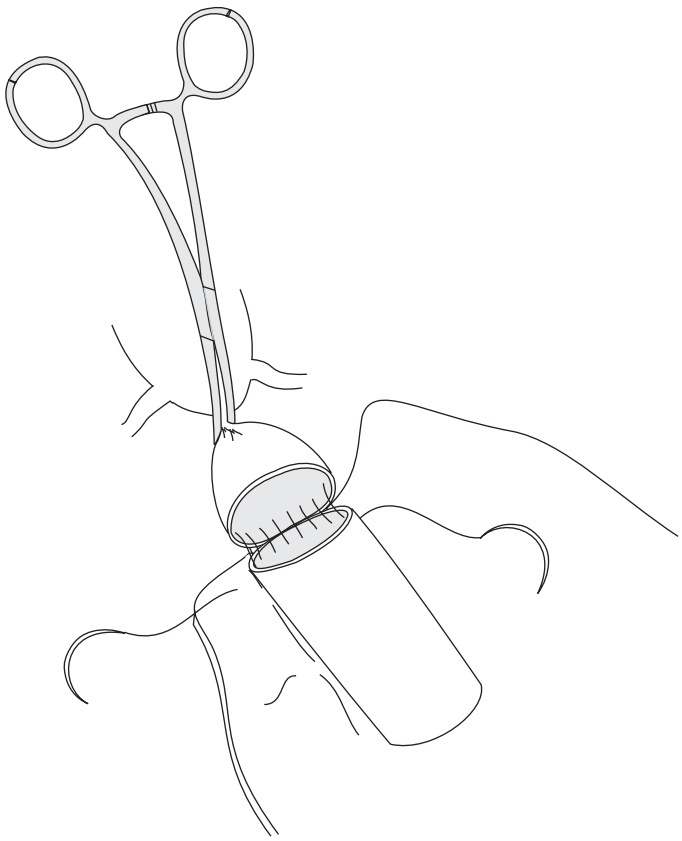
Intact Posterior Wall

Parachute Technique

Starting on the lateral aspect of the aorta

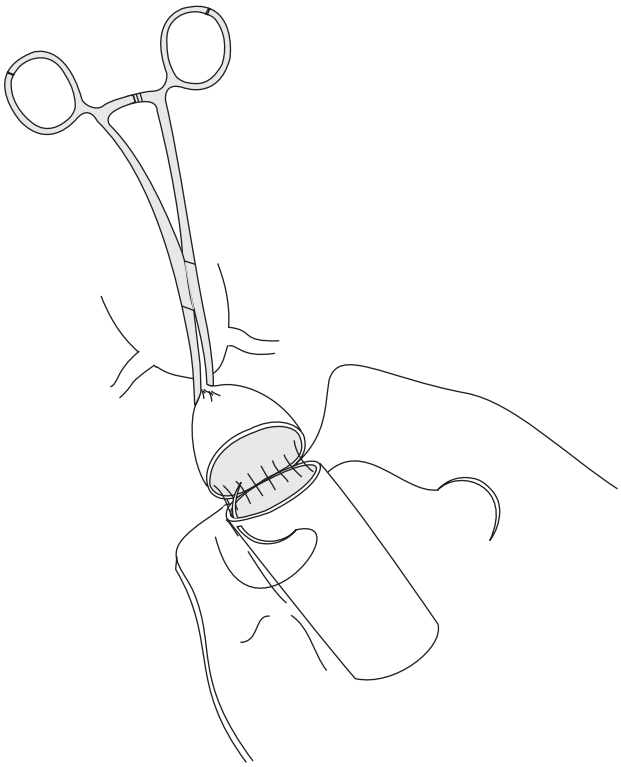


Continue suturing the back wall of the aorta with double-layer sutures until the posterior wall of the anastomosis is completed. Make sure the sutures are placed deeply through the posterior wall of the aorta.

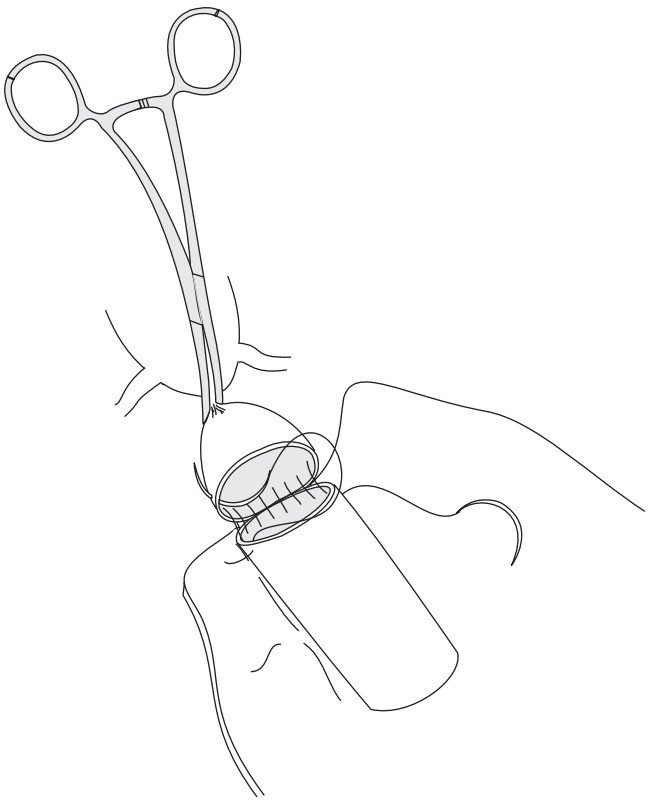


Bring down the graft to the aortic wall by pulling and tightening the suture. Use a nerve hook to ensure that the suture line is tight.

Intact Posterior Wall
Parachute Technique
Starting on the lateral aspect of the aorta



You may complete the entire anastomosis with one suture as shown above.

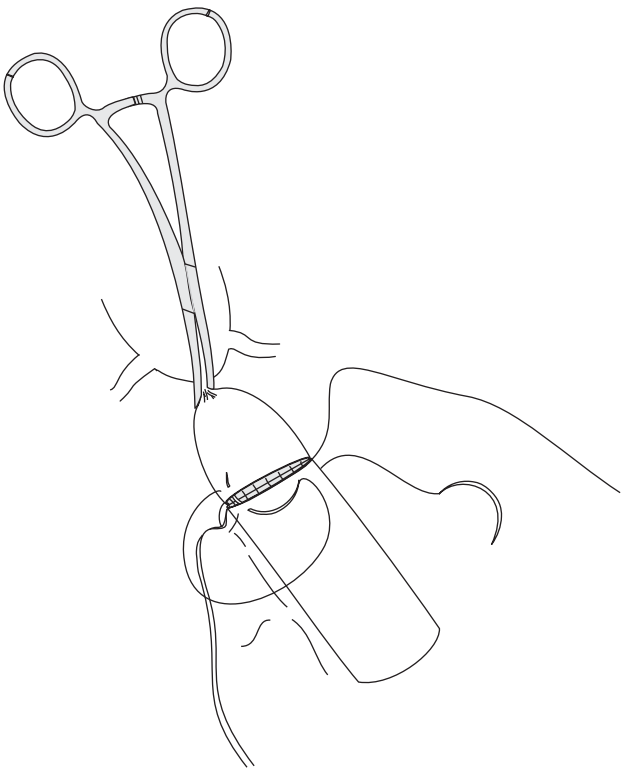


Introduce the needle in the graft. Introduce the needle in the single-layer aortic wall.

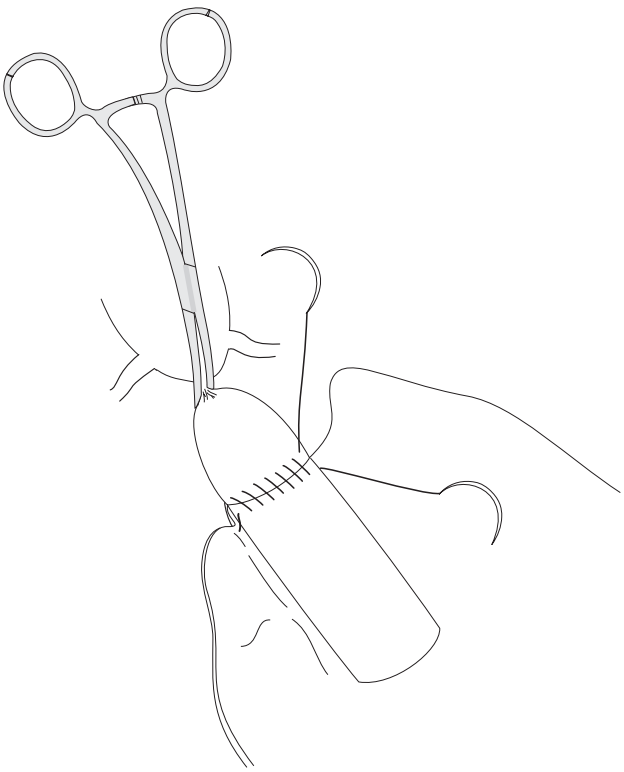
Intact Posterior Wall

Parachute Technique

Starting on the lateral aspect of the aorta



Pull and tighten the suture. Continue running the suture all the way along the anterior aortic wall. Pull and tighten the suture line on the

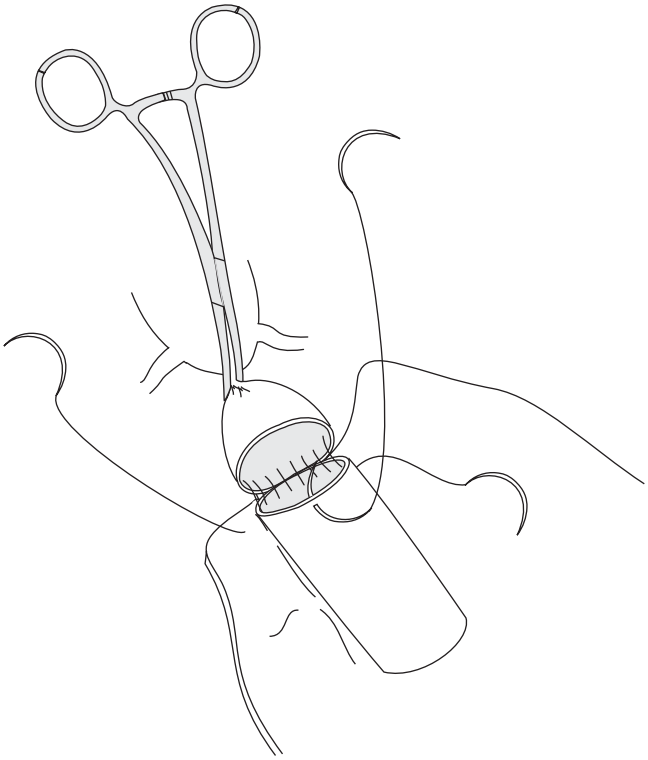


anterior wall and the posterior wall. Use a nerve hook again to ensure that the suture line is not loose.

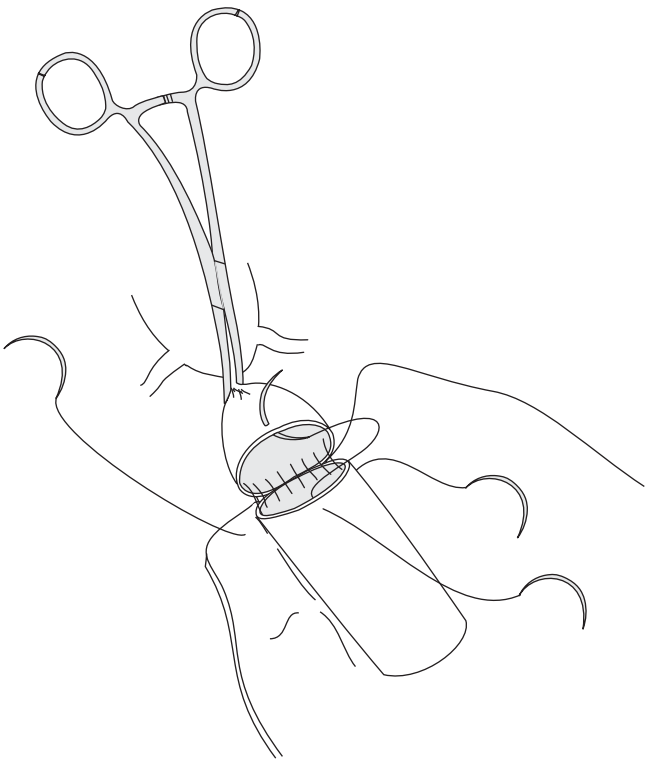
Intact Posterior Wall

Parachute Technique

Starting on the lateral aspect of the aorta



Alternatively, you may start another suture in the center of the anterior wall of the graft.



You may use a parachute technique for the anterior wall or an anchor technique as shown here.

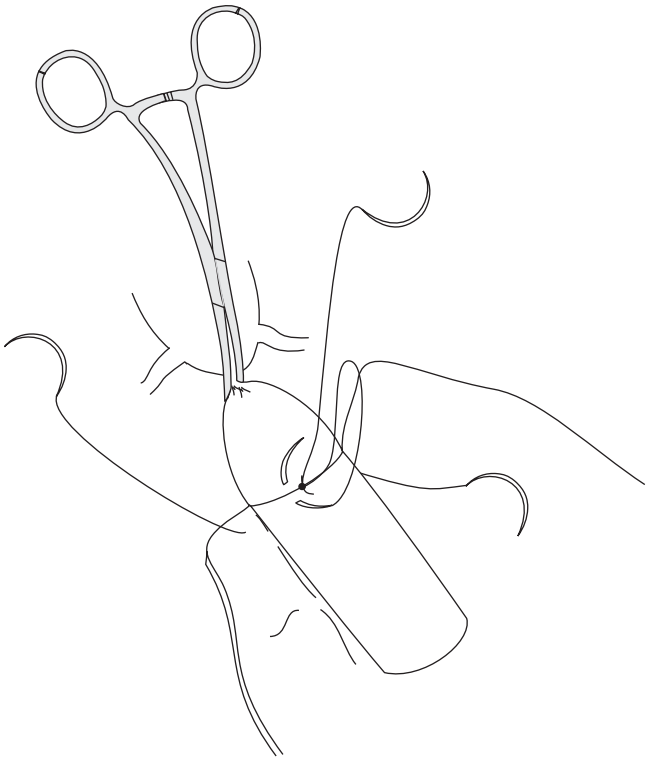
Introduce the needle in a corresponding site in the aorta. This suture may be a horizontal mattress or a simple suture as shown here.

Intact Posterior Wall

Parachute Technique

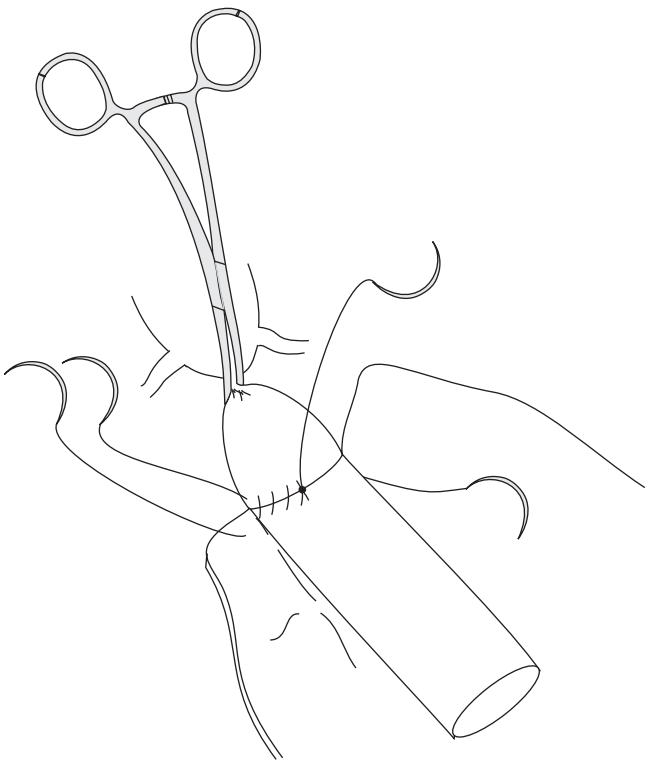
Starting on the lateral aspect of the aorta

Introduce the needle outside-inside in the graft and inside-outside in the aorta.



Continue suturing with one end of the suture toward the posterior wall of the aorta.

Tighten the suture.



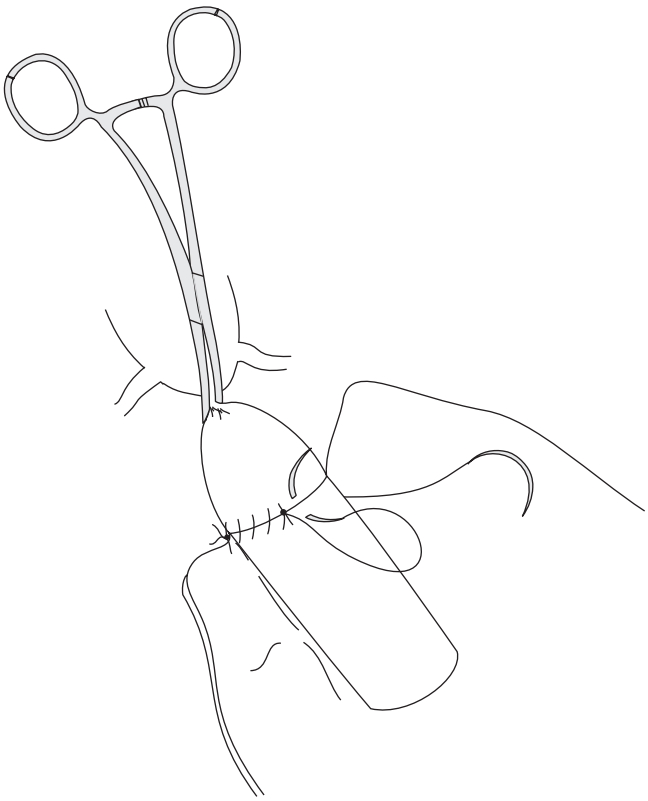
Intact Posterior Wall

Parachute Technique

Starting on the lateral aspect of the aorta.

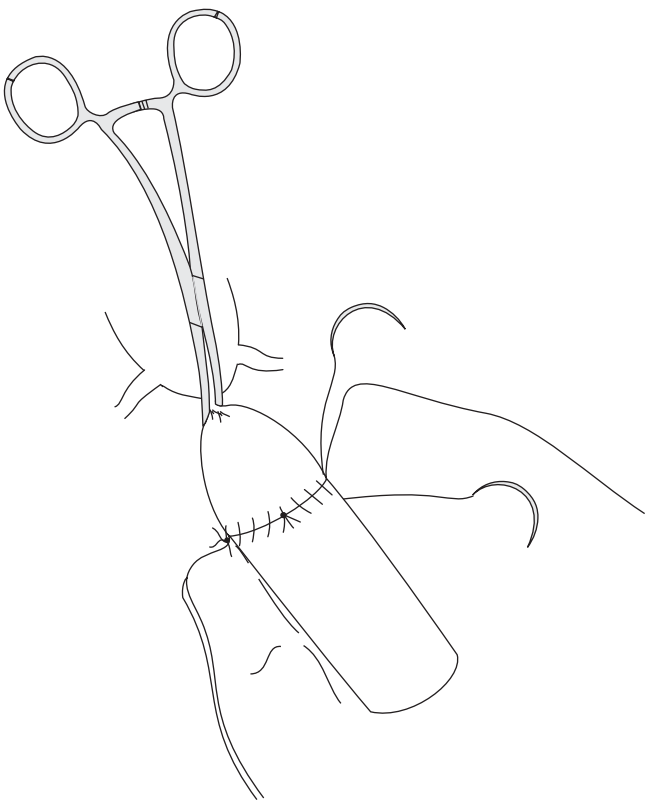
Start suturing with the other end toward the posterior wall of the aorta.

Introduce the needle outside-inside in the graft and inside-outside in the aorta.



Continue suturing until you reach the other suture.

Pull and tighten the suture line.

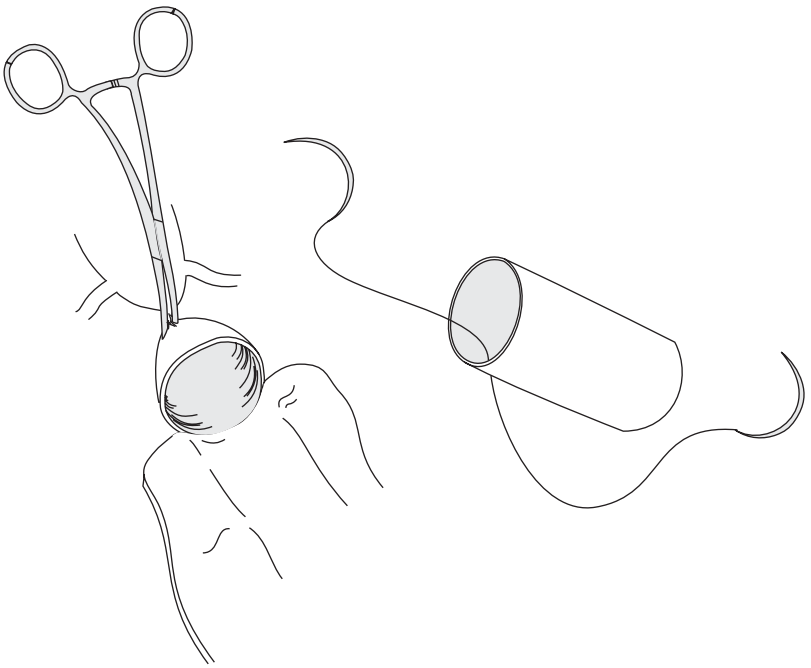


Intact Posterior Wall

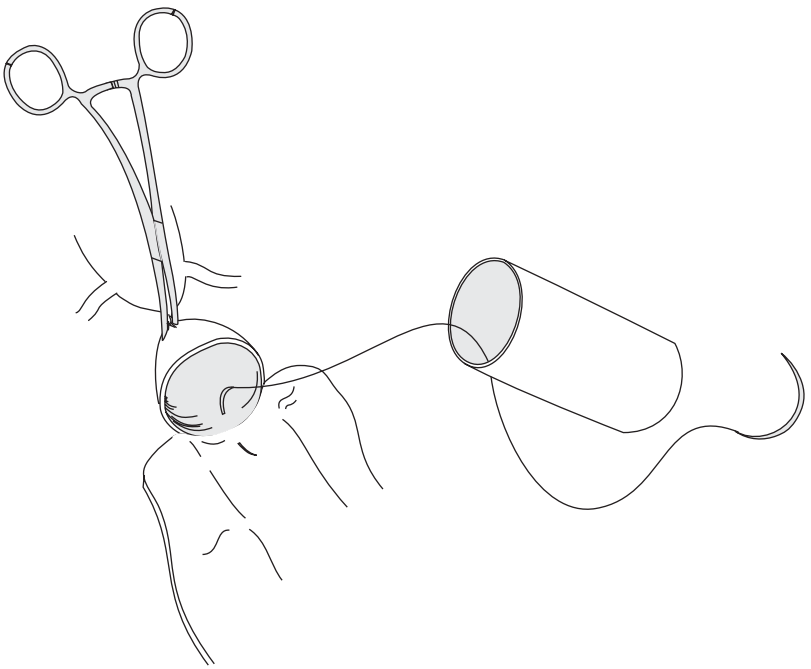
Anchor Technique

Continuous sutures

Another alternative is to use an anchor technique. Introduce the needle outside-inside on the graft.



Introduce the needle in the back wall of the aorta. Make sure that the bite in the aortic wall is deep and is incorporating the full thickness of the wall.

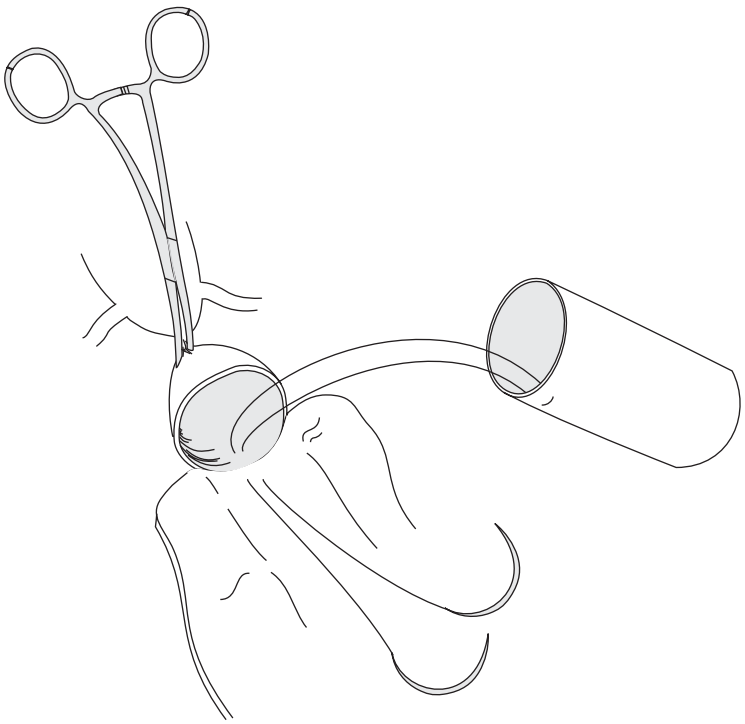


Intact Posterior Wall

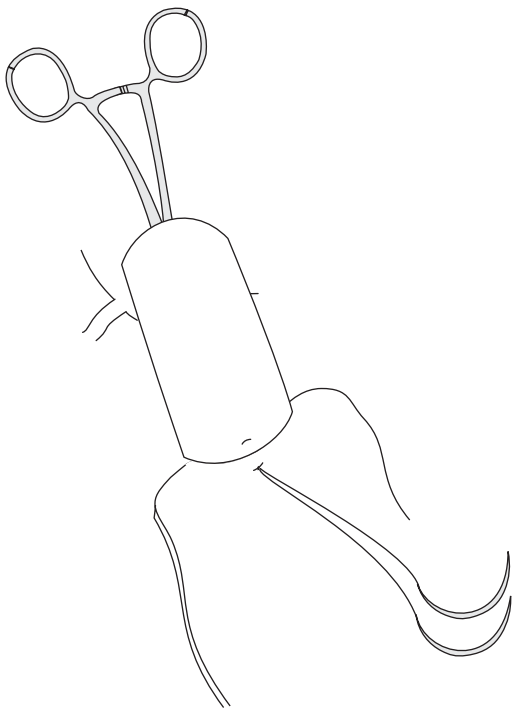
Anchor Technique

Continuous sutures

Introduce the needle 2–3 mm away from the previous suture. Repeat the same in the back wall of the aorta.**Intact Posterior Wall**

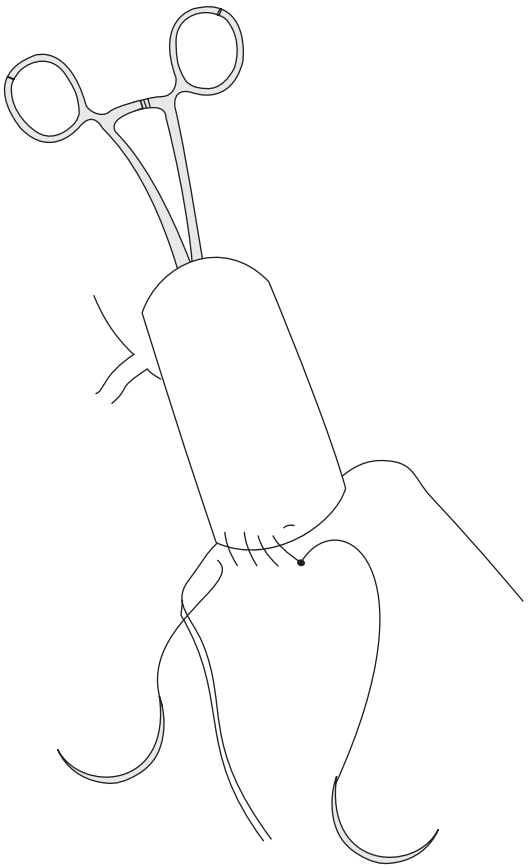


Tie the suture.



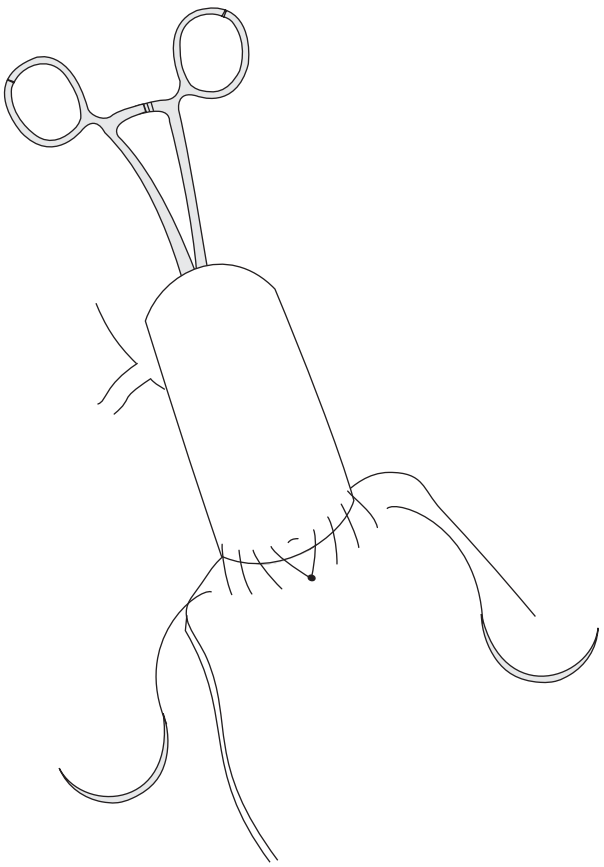
Anchor Technique
Continuous sutures

Start running the suture on one side. (Again outside-inside in the graft and inside-outside in the aorta.)



When performing a transabdominal aortic replacement, these bites are best placed with a forehand movement when the surgeon is standing on the right-hand side of the patient.

Start running the suture toward the other side.



The placement of the bites on this side will be facilitated if placed by the assistant using a forehand motion or using a backhand movement by the surgeon.

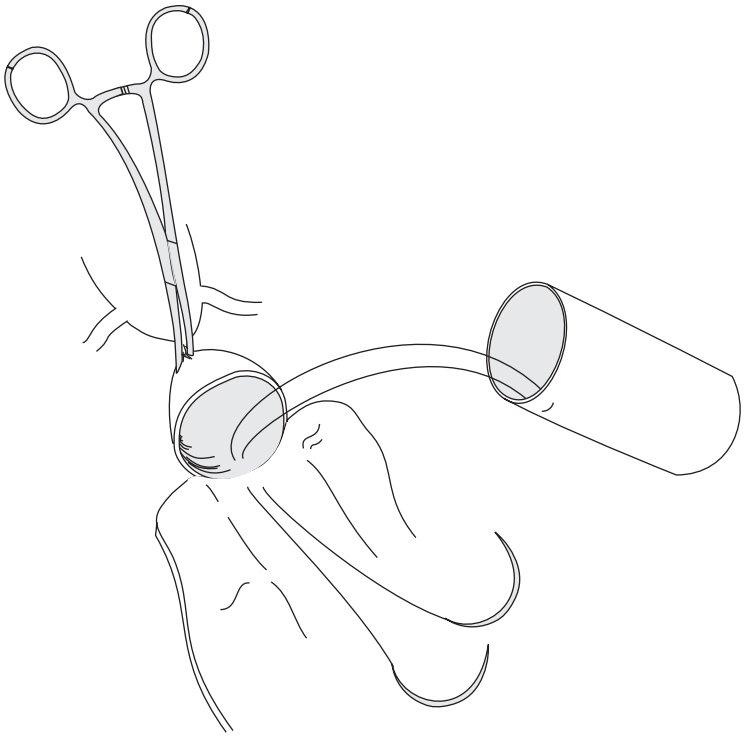
Intact Posterior Wall

Anchor Technique

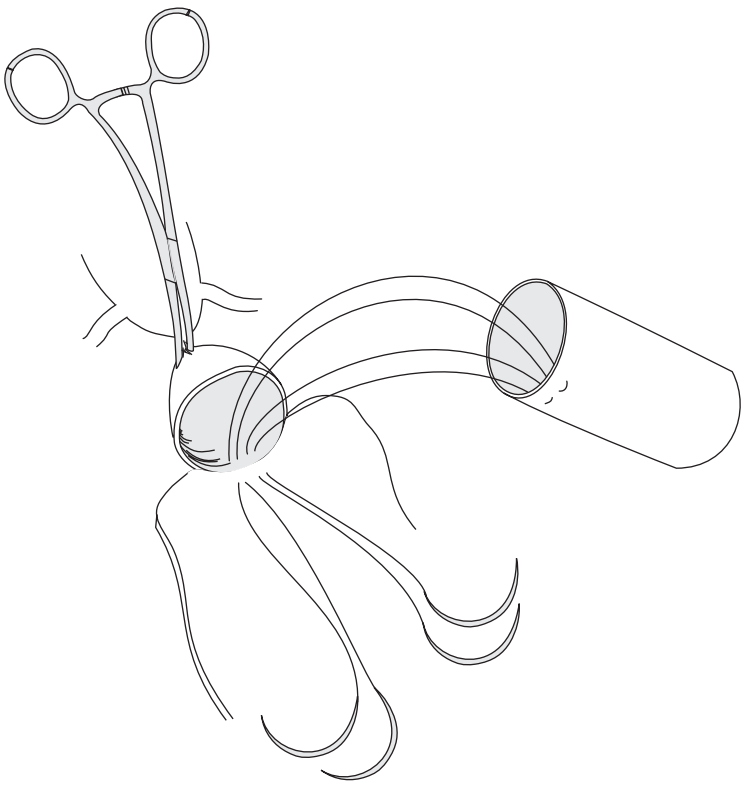
Continuous sutures

Alternatively, the posterior suture line is constructed using interrupted mattress sutures.

This technique may be used in a calcified aorta. Interrupted horizontal mattress sutures will be used for suturing the entire or part of the posterior wall suture line.



Start by placing horizontal mattress sutures in the graft and in the center of the back wall of the aorta.



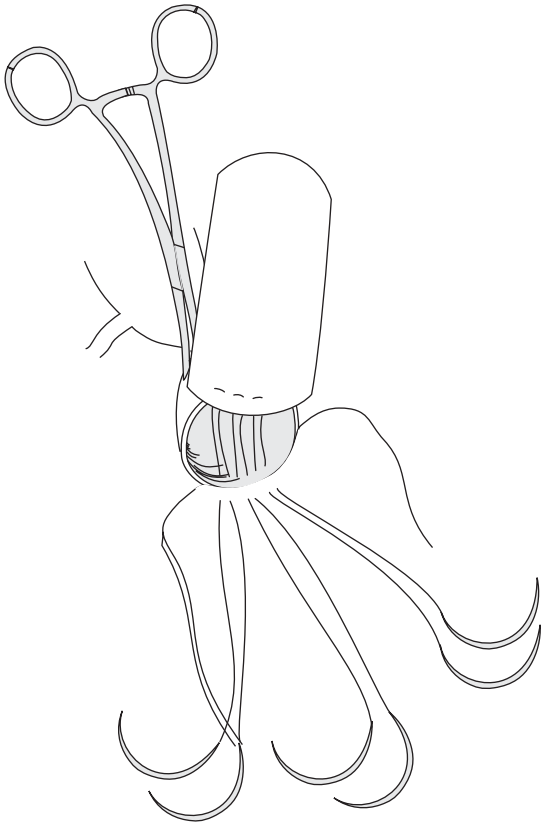
Place additional horizontal mattress sutures in the graft and the back wall of the aorta on either side of the center.

Intact Posterior Wall

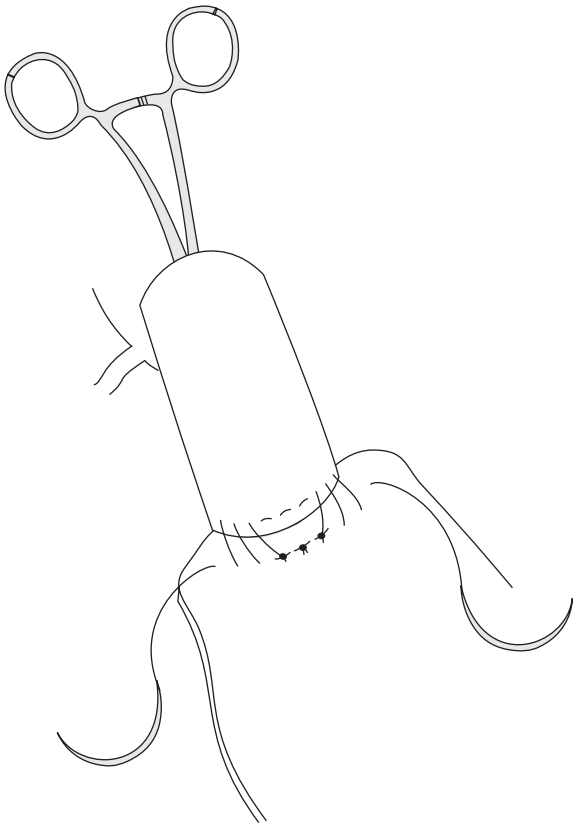
Anchor Technique

Interrupted mattress sutures

You may construct part of the posterior wall with interrupted mattress sutures.

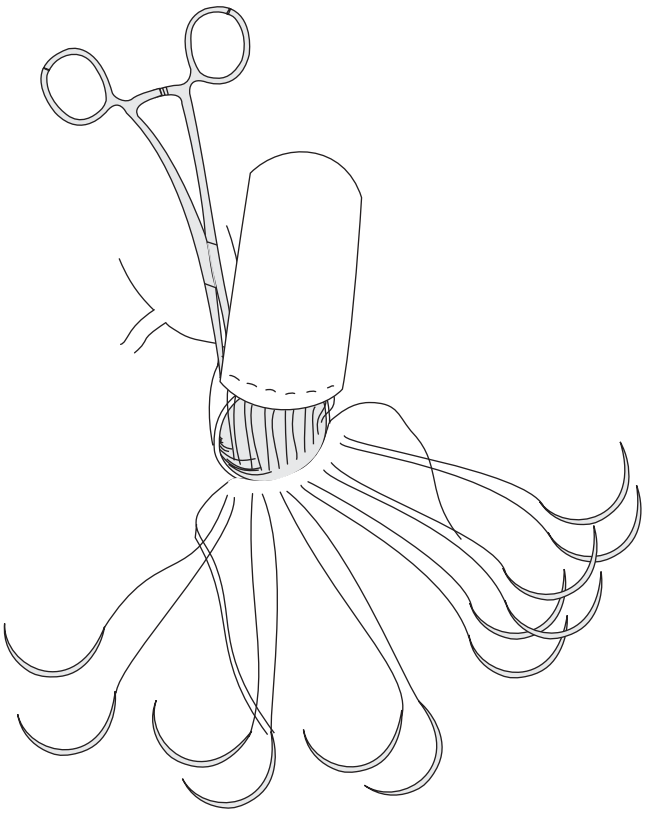


Tie the sutures. Construct the remaining part of the posterior anastomosis using a continuous running suture.

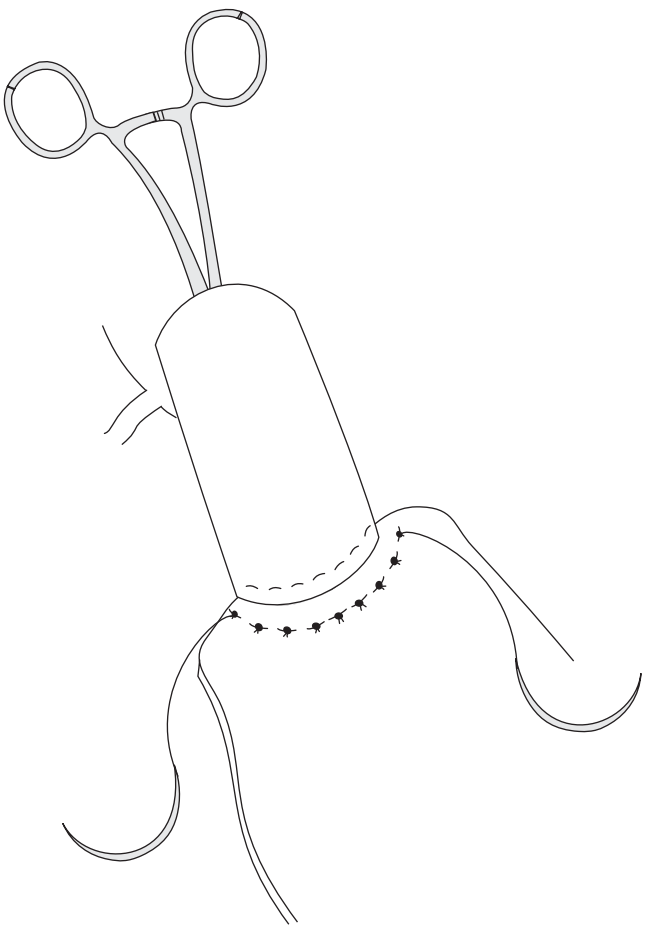


Intact Posterior Wall

Anchor Technique
Interrupted mattress sutures

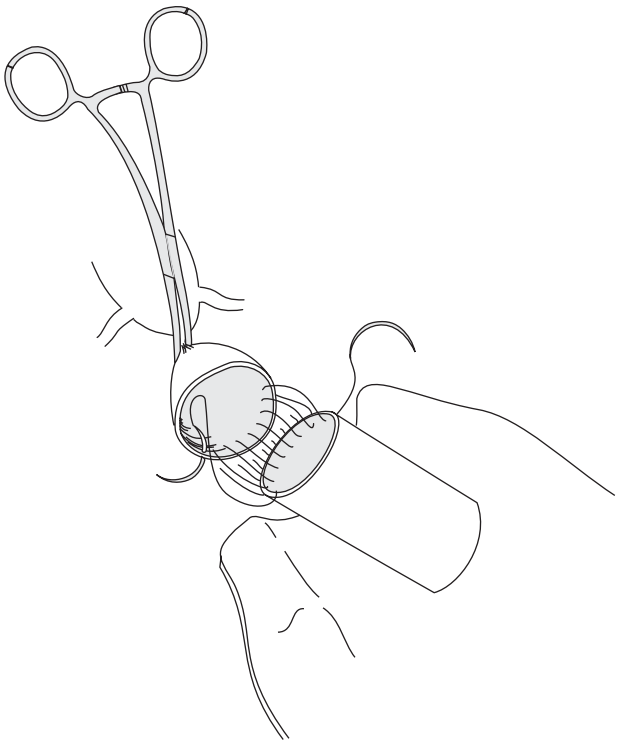


Alternatively, you may construct the entire posterior wall with interrupted horizontal mattress sutures.



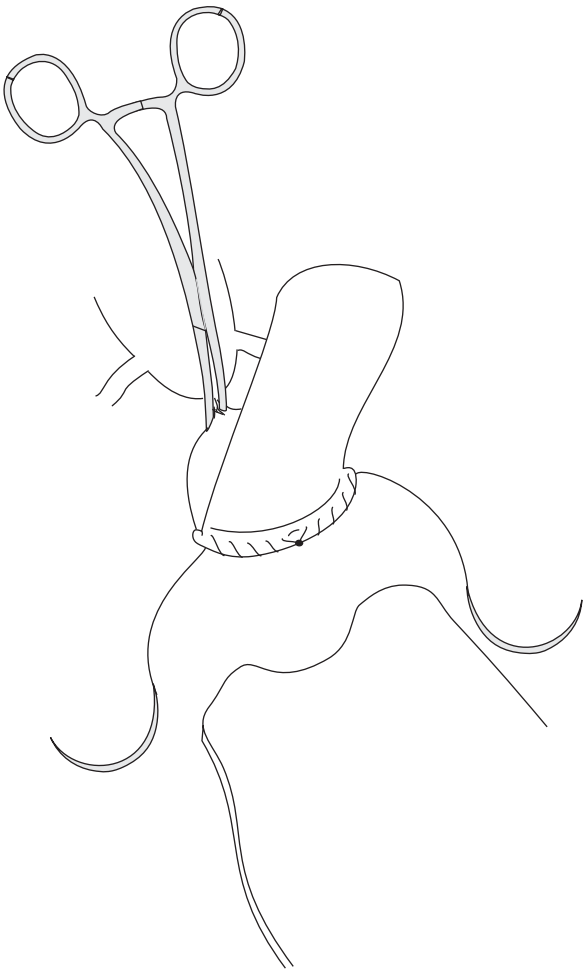
Transected Posterior Wall
Parachute Technique; Anchor Technique

Transecting the aortic wall can facilitate placement of the posterior wall sutures. Care should be taken to avoid injury to any retroaortic, lumbar, or renal vein branches.

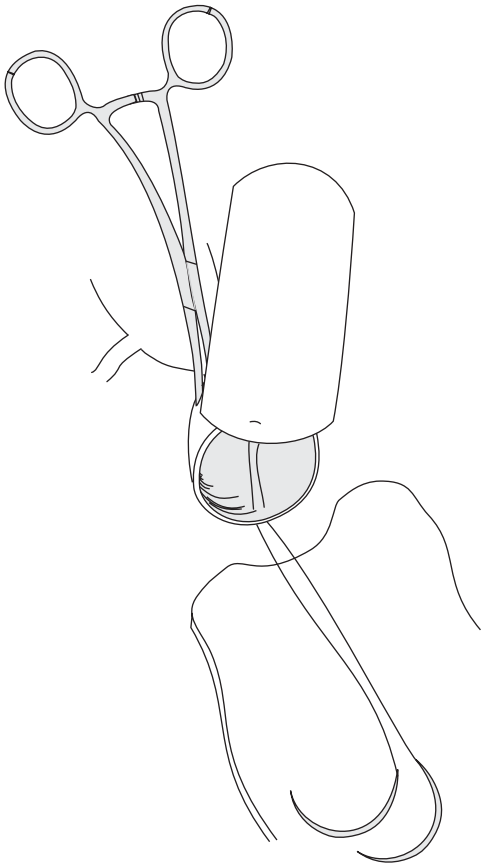


The entire posterior suture line can be performed in a running parachute fashion. Suturing is started from the end away from the surgeon and then progressed toward the surgeon's side, as illustrated in section "Intact Posterior Wall."

Alternatively, the entire posterior suture line can be constructed using an anchor technique, as illustrated in section "Transected Posterior Wall."

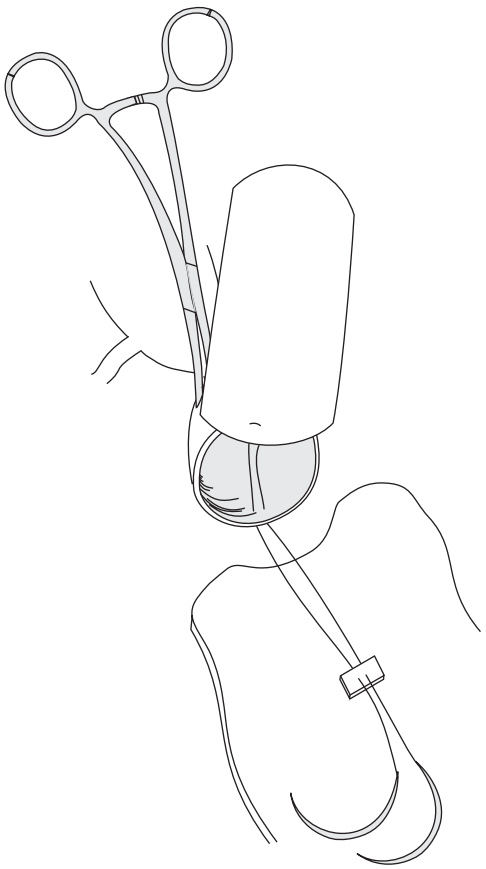


Transected Posterior Wall Interrupted Mattress Sutures



Alternatively, the entire posterior wall can be performed using interrupted sutures.

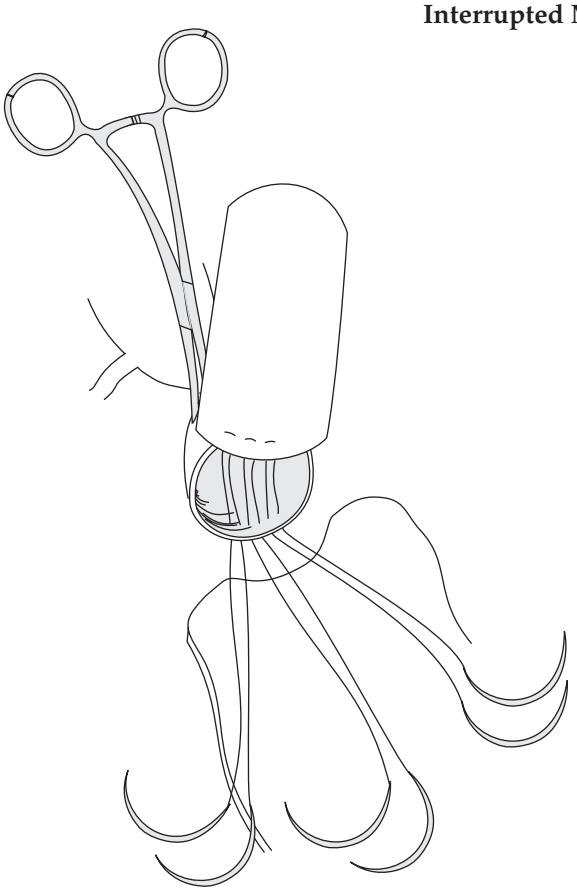
Place the horizontal mattress sutures as previously illustrated (outside-inside on the graft, inside-outside on the aorta).



If the aortic wall appears attenuated, pledget sutures can be placed to reinforce the suture line.

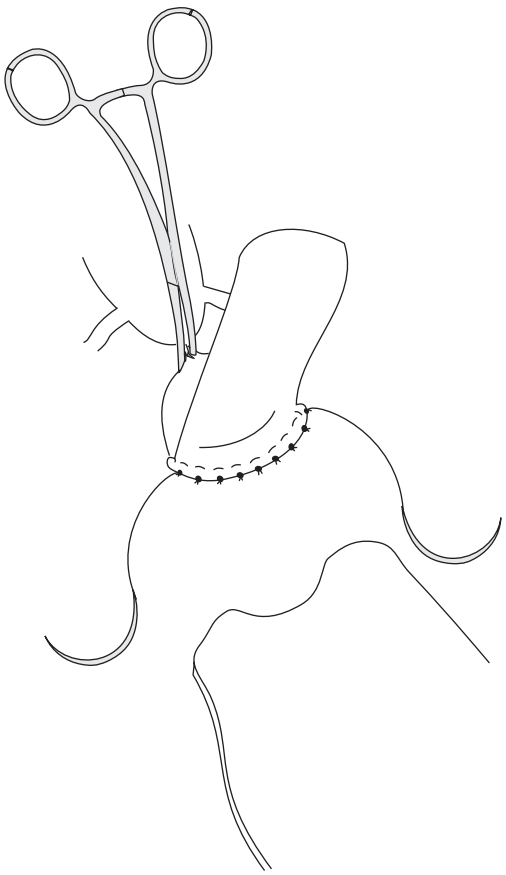
Transected Posterior Wall
Interrupted Mattress Sutures

Place as many horizontal mattress sutures as necessary.



Pull and tie the sutures.

The entire anastomosis can be constructed with interrupted mattress sutures. Alternatively, the anterior wall is constructed with a continuous suture, as previously illustrated.



You can inspect the posterior suture line by gently lifting the graft. This could allow accurate placement of any additional sutures to correct bleeding from the suture line.

15

Thoracoabdominal Aortic Aneurysm Replacement: Proximal Anastomosis

Jamal J. Hoballah

The technique used for the construction of the proximal aortic anastomosis in a patient with a thoracoabdominal aortic aneurysm depends on the extent of the aneurysmal pathology and the relationship of the aneurysm to the orifices of the celiac, superior mesenteric, and the right and left renal arteries.

PROXIMAL ANASTOMOSIS INCORPORATING THE CELIAC, SUPERIOR MESENTERIC, AND RIGHT RENAL ARTERIES

When the aneurysmal disease starts at the level of the celiac artery and the aorta becomes normal just proximal to the celiac artery (Crawford type IV), one option is to incorporate the orifices of the celiac, superior mesenteric, and both renal arteries in the proximal anastomosis. The anastomosis is appropriately tailored depending on the distance between the right and left renal arteries. In the presence of significant aneurysmal pathology between the right and left renal arteries, only the celiac, superior mesenteric, and right renal arteries are incorporated as a tongue of aortic tissue into the proximal anastomosis. The left renal artery will have to be reimplanted separately.

REIMPLANTATION OF THE CELIAC, SUPERIOR MESENTERIC, AND RIGHT RENAL ARTERIES ON AN AORTIC PATCH

When the aneurysmal pathology extends several centimeters proximal to the origin of the celiac artery, the visceral vessels cannot be incorporated in the proximal anastomosis. The proximal anastomosis is performed at the level where the aortic wall is normal. The celiac, superior mesenteric, and renal arteries will be reimplanted as an island. Generally, the left renal artery cannot be included in the island and is to be reimplanted separately. After completion of the distal anastomosis, a partial occluding clamp is applied on the aortic graft in preparation for the reimplantation of the left renal artery. It is important to avoid placing the clamp very close to the suture line, as it may cause an excessive stress on the suture line, resulting in bleeding. Another factor one must consider is to accommodate for the return of the left kidney to its normal anatomical position when selecting the site for the left renal artery reimplantation.

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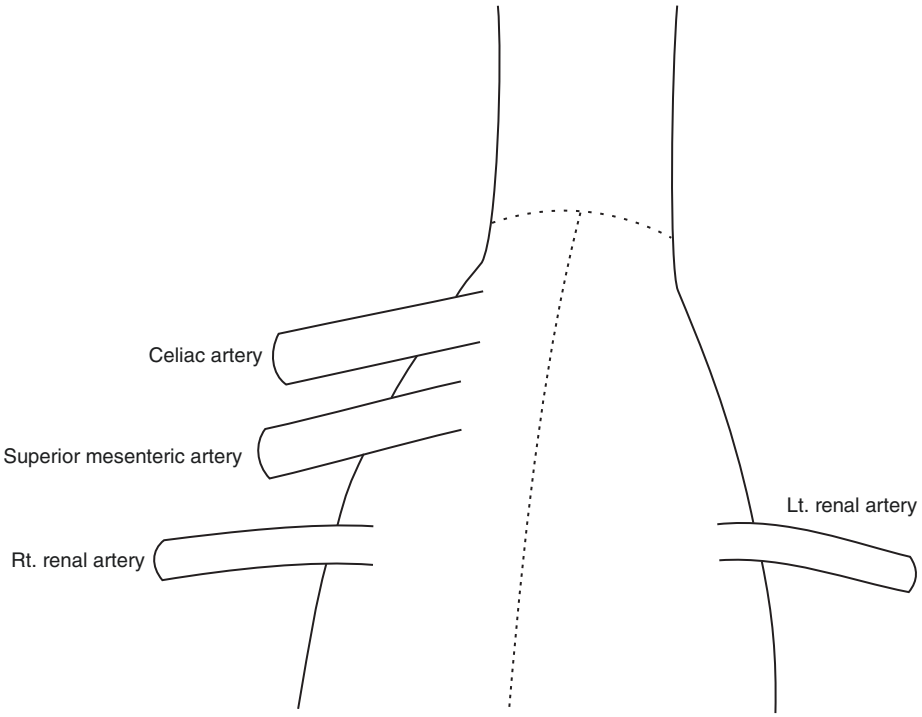
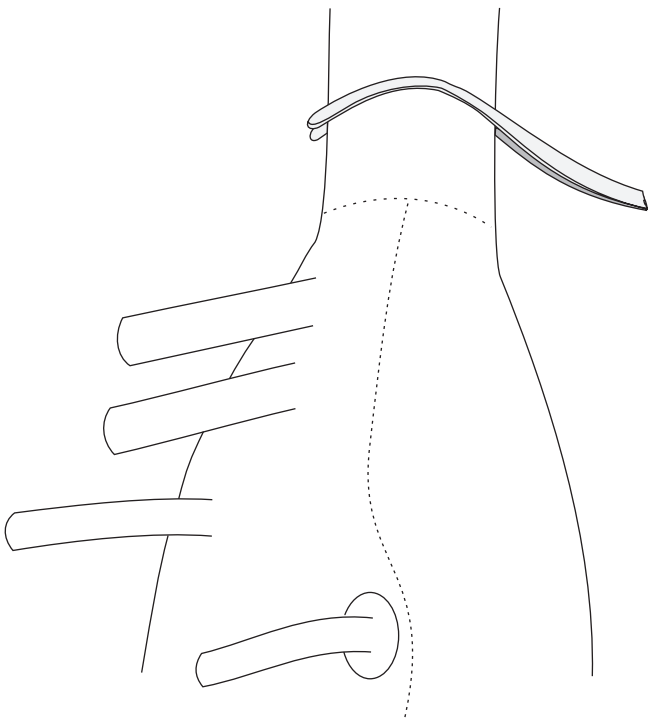
J. J. Hoballah, C. F. Bechara (eds.), *Vascular Reconstructions*, https://doi.org/10.1007/978-1-0716-1089-3_15

Proximal Anastomosis Incorporating the Celiac, Superior Mesenteric, and Right Renal Arteries

This picture shows the incision line of the procedure as performed through a thoracoabdominal approach or medial visceral rotation, with the left kidney remaining in its posterior location.

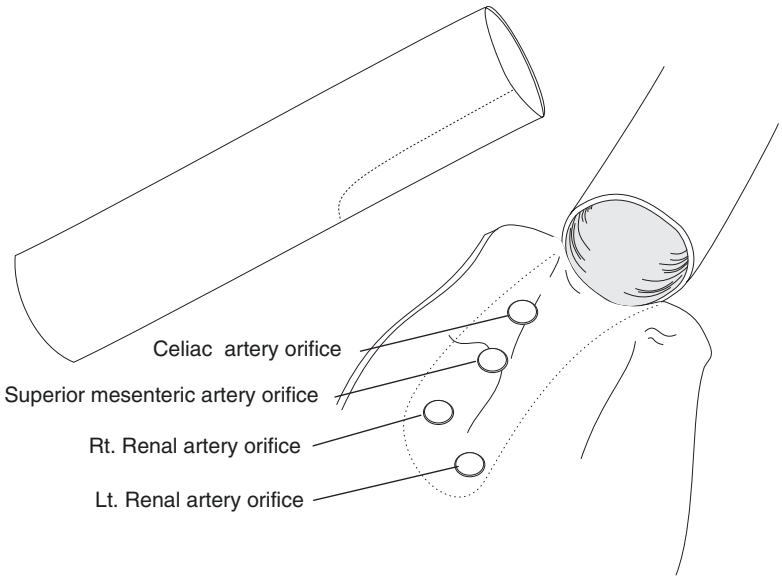


This picture shows the incision line if the procedure is performed through a medial visceral rotation, thoracoabdominal or retroperitoneal approach, with the left kidney being mobilized anteriorly.



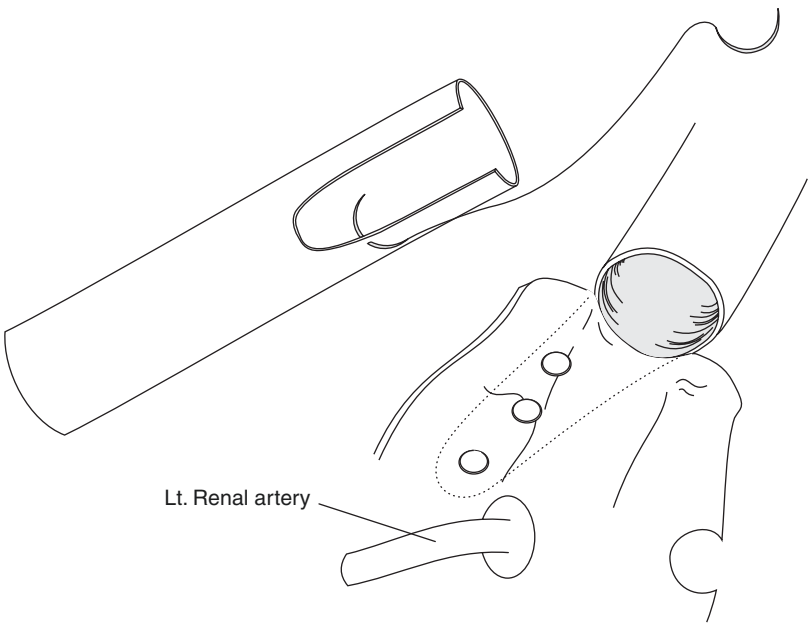
Proximal Anastomosis Incorporating the Celiac, Superior Mesenteric, and Right Renal Arteries

After opening the aortic aneurysm, the orifices of the celiac, superior mesenteric, and renal arteries are inspected to check if they can all be incorporated together in one tongue.



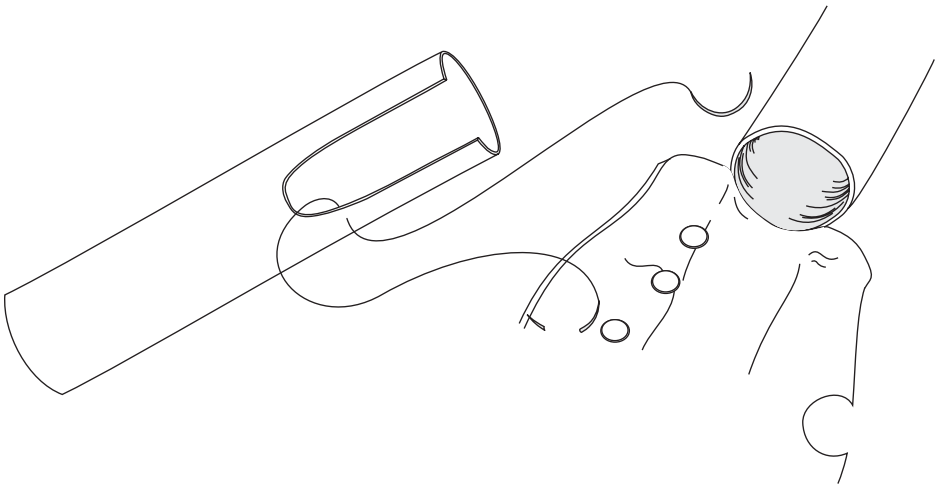
Most often, however, the celiac, superior mesenteric, and right renal arteries are close to each other and can be incorporated as one island, leaving the left renal artery to be reimplanted separately.

Excise a rectangular piece of the graft as shown here. Start placing the suture a few bites away from the center of the heel.

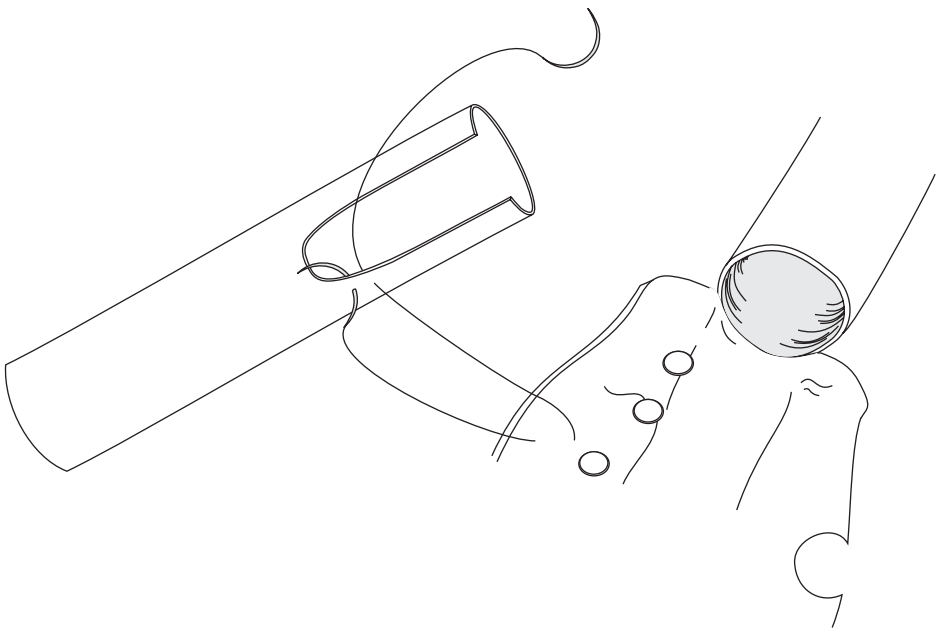


Proximal Anastomosis Incorporating the Celiac, Superior Mesenteric, and Right Renal Arteries

Introduce the needle in a matching location in the aorta using a double-layer bite.

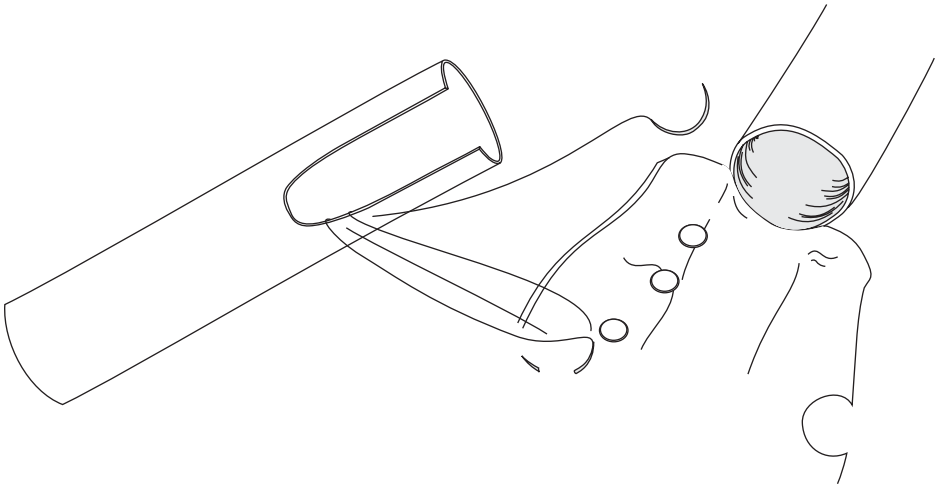


Introduce the needle in the graft (outside-inside)

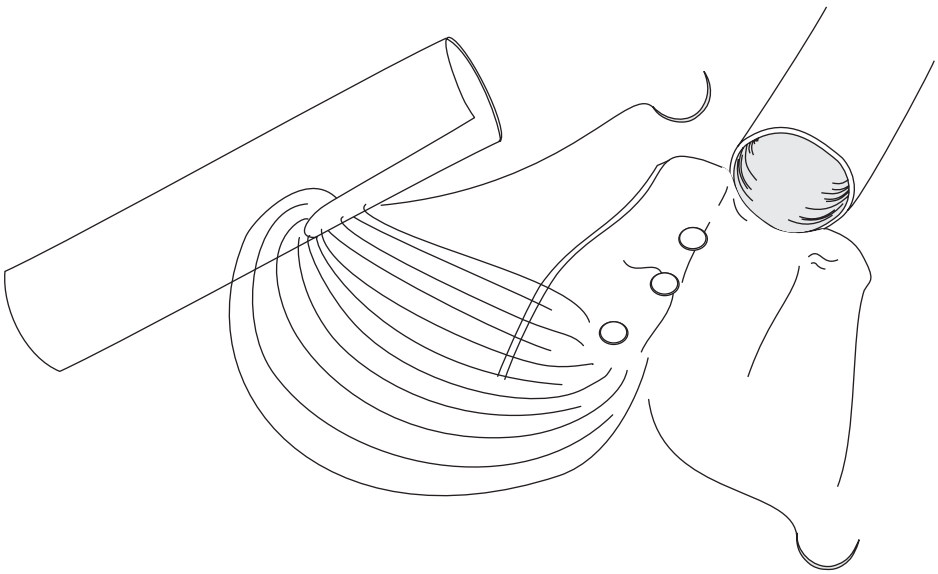


Proximal Anastomosis Incorporating the Celiac, Superior Mesenteric, and Right Renal Arteries

Introduce the needle in the aorta using a double-layer aortic bite.

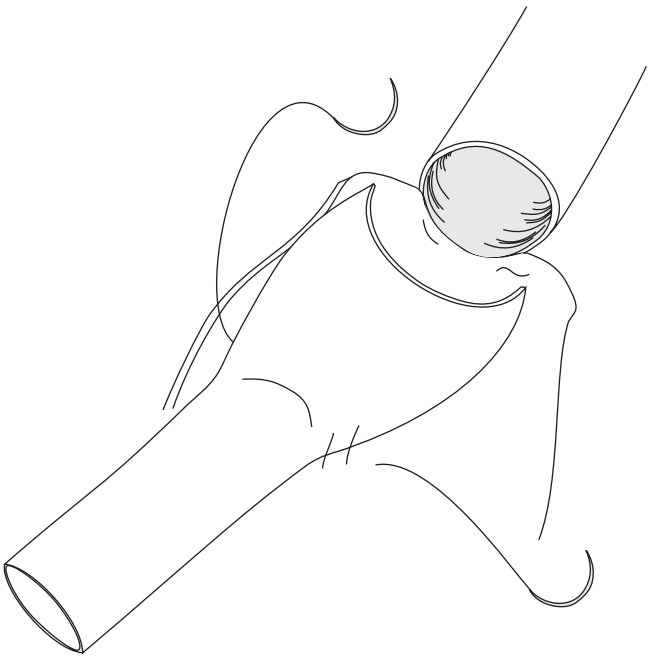


Continue running the suture until you are a few bites away from the center of the heel. Avoid wide advancement on the posterior suture line as bleeding in that area can be difficult to control.



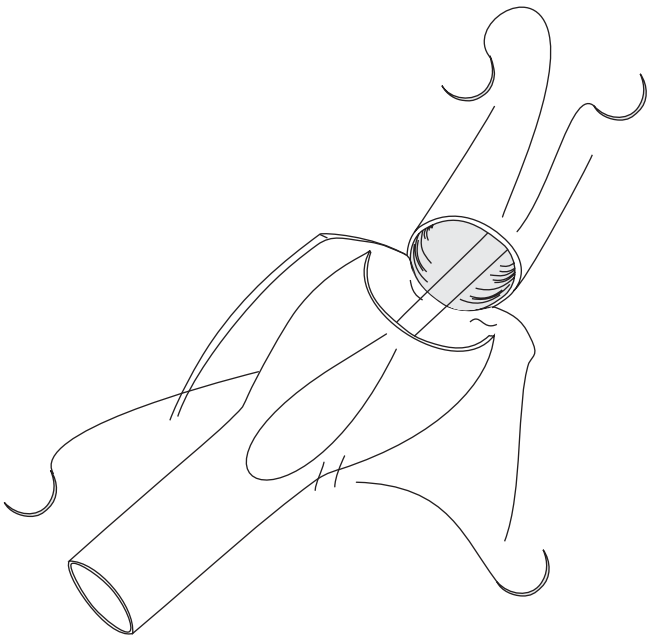
Proximal Anastomosis Incorporating the Celiac, Superior Mesenteric, and Right Renal Arteries

Tighten the suture line. Use a nerve hook to make sure that the suture line is not loose.



Start another suture in the graft in the center of the apex.

Introduce the needle in a matching point in the aorta.

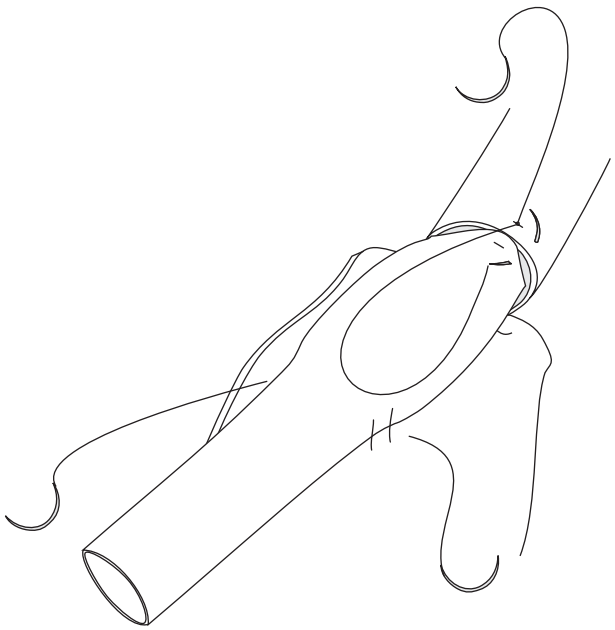


This suture may be a simple or a mattress suture as shown here.

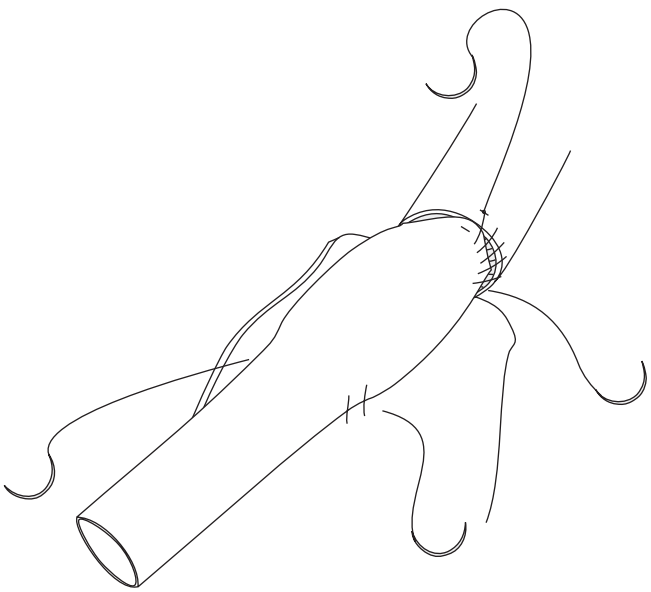
Proximal Anastomosis Incorporating the Celiac, Superior Mesenteric, and Right Renal Arteries

Tie the suture.

Start running one end of the suture toward the heel.

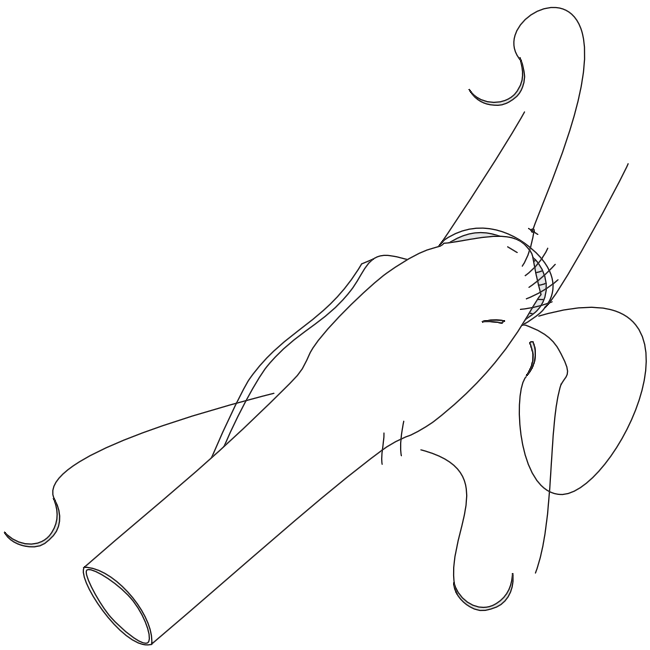


The needle is introduced outside-inside in the graft and inside-outside in the aorta.

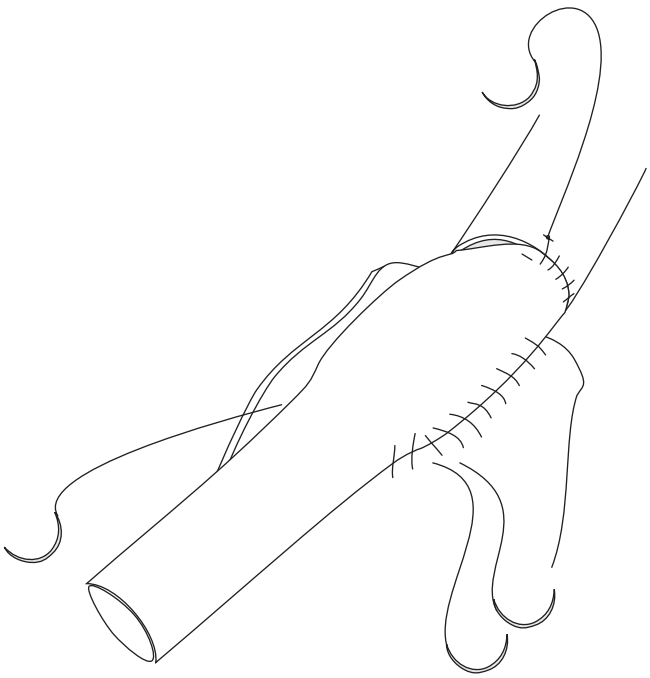


Proximal Anastomosis Incorporating the Celiac, Superior Mesenteric, and Right Renal Arteries

The aorta is usually free of any significant plaque at this level. Placing the sutures outside-inside in the aorta and inside-outside in the graft may be performed if the angle of suturing is more favorable.

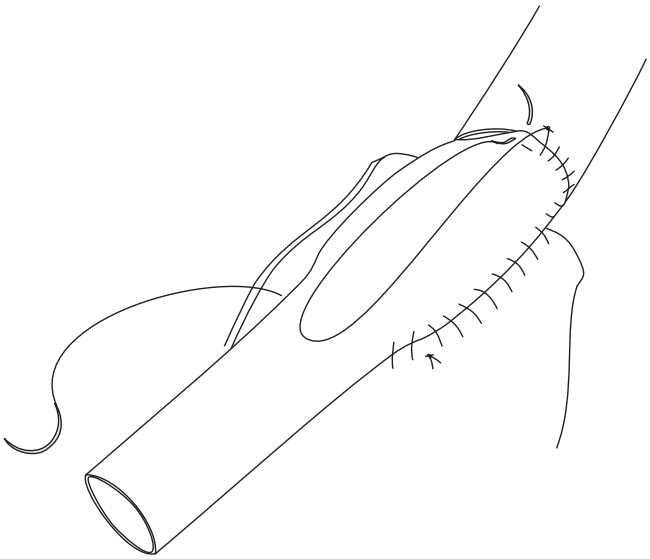


Tighten the suture line and tie the sutures together. Use a nerve hook to ensure that the suture line is not loose.

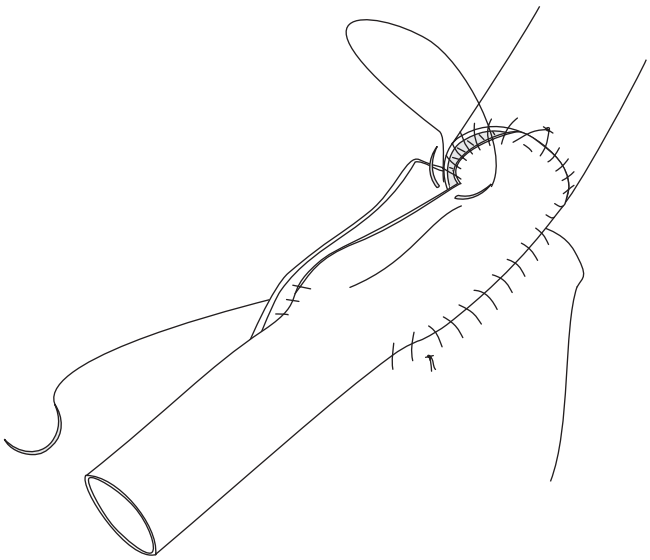


Proximal Anastomosis Incorporating the Celiac, Superior Mesenteric, and Right Renal Arteries

Start running the other end of the apical suture.

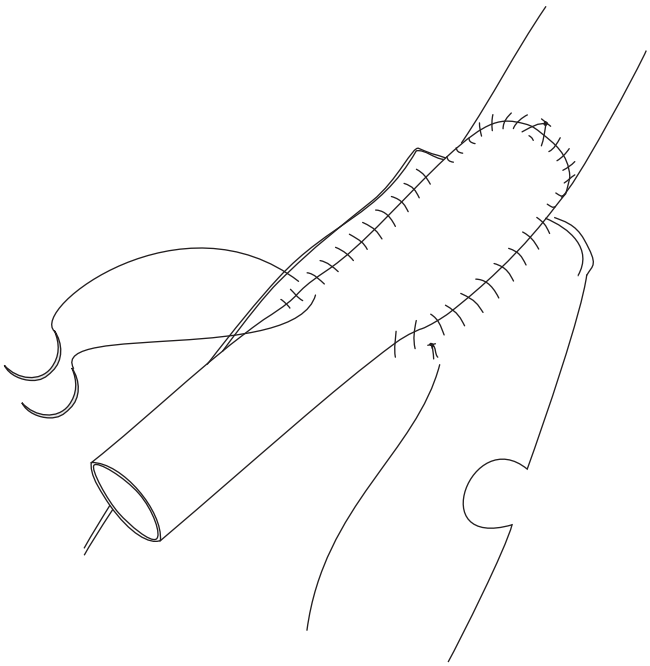


Keep running the suture toward the heel.

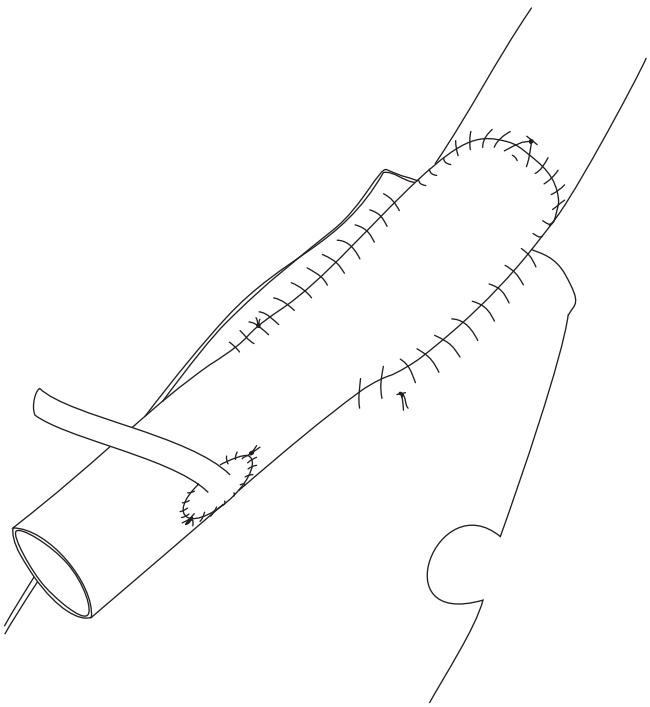


Proximal Anastomosis Incorporating the Celiac, Superior Mesenteric, and Right Renal Arteries

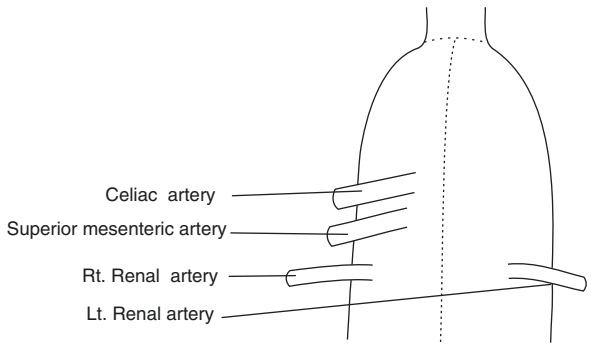
Tighten the suture line and tie the sutures.



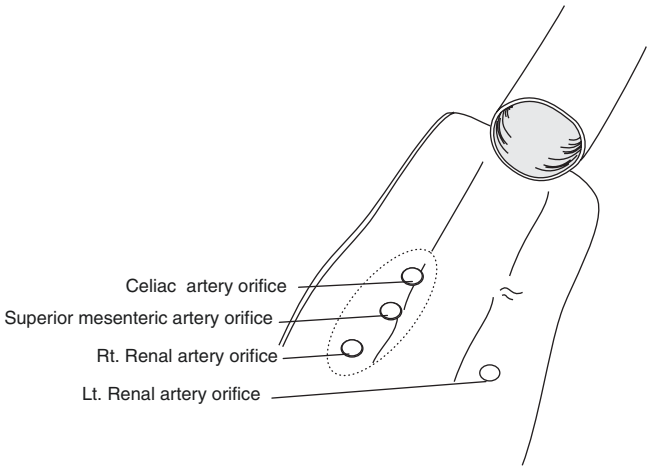
Reimplant the left renal artery as described in the inferior mesenteric artery reimplantation section (Chap. 17).



Reimplantation of the Celiac, Superior Mesenteric, and Right Renal Arteries on an Aortic Patch

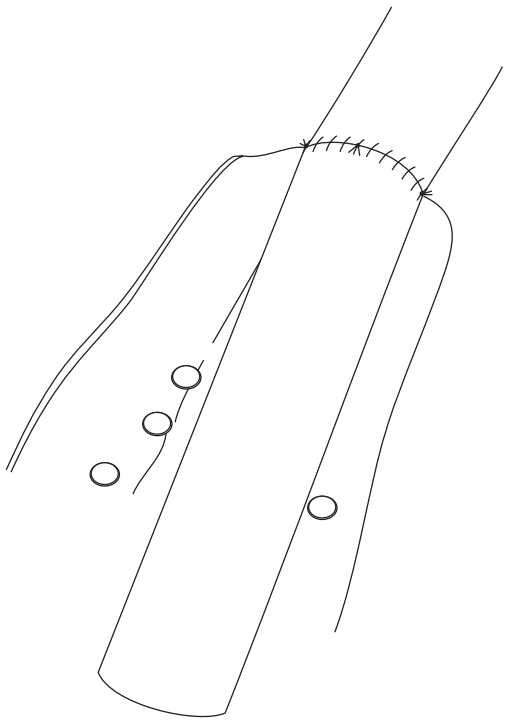


When the aneurysmal disease starts several centimeters proximal to the origin of the celiac artery, the proximal anastomosis will have to be performed first followed by reimplantation of the mesenteric and renal vessels. The celiac artery, superior mesenteric artery, and the right renal artery will be incorporated as one island. The left renal artery will be implanted separately.

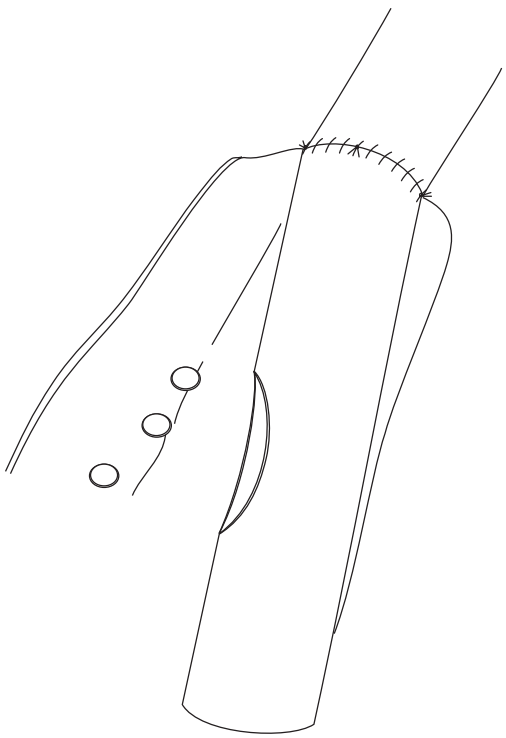


Reimplantation of the Celiac, Superior Mesenteric, and Right Renal Arteries on an Aortic Patch

Construct the proximal aortic anastomosis as previously described in the infrarenal abdominal aortic aneurysm replacement (Chap. 14).

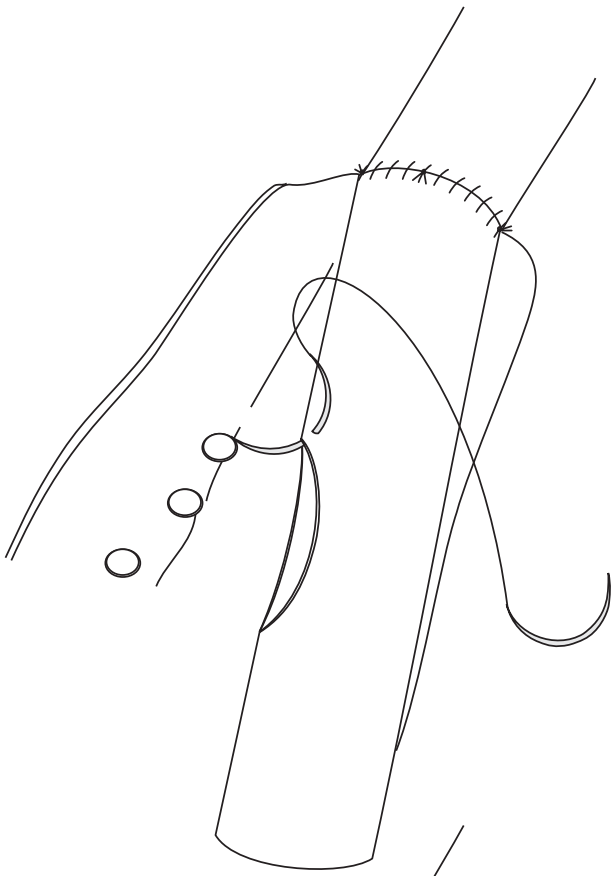


Excise an elliptical piece of the graft that matches the size of the island. The ellipse should not be too wide.

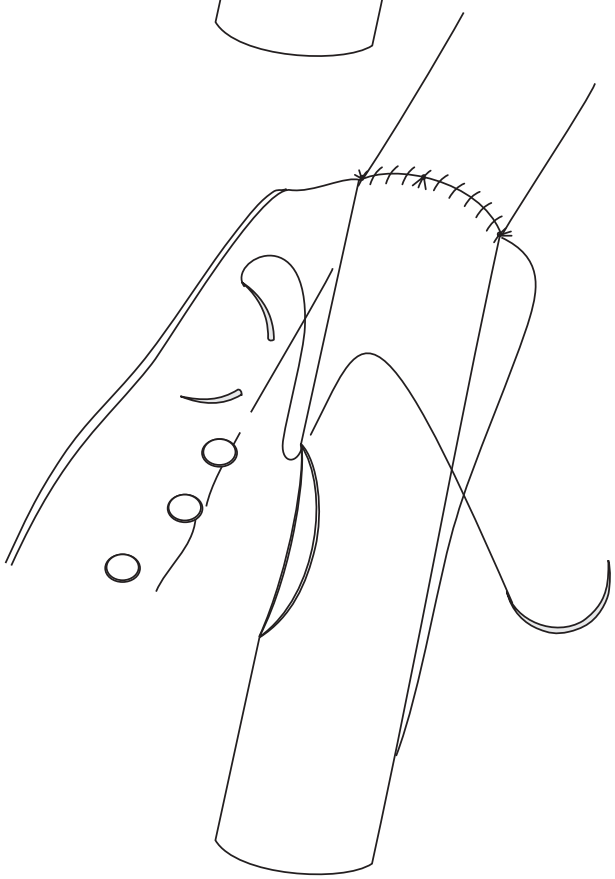


Reimplantation of the Celiac, Superior Mesenteric, and Right Renal Arteries on an Aortic Patch

Start the suture in the graft. Introduce the needle in the center of the apex (outside-inside).

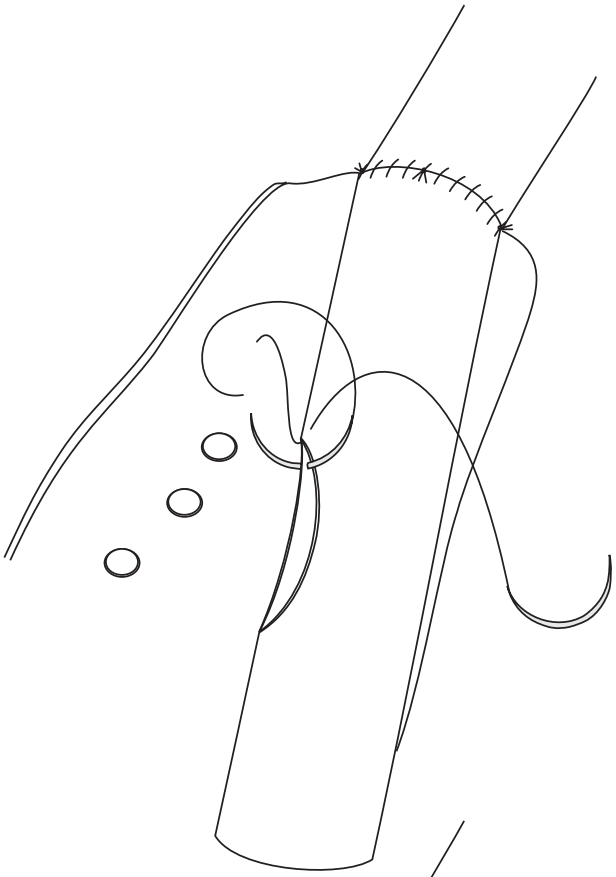


Introduce the needle in a matching location in the artery using a double-layer bite.

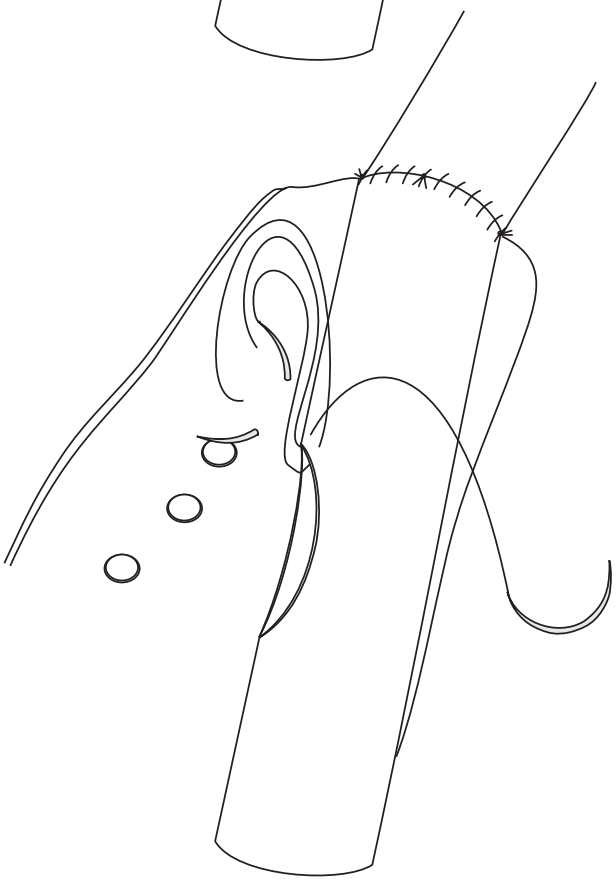


Reimplantation of the Celiac, Superior Mesenteric, and Right Renal Arteries on an Aortic Patch

The posterior part of the anastomosis is constructed first. Introduce the needle in the graft, inside-outside to facilitate the construction of the suture line.

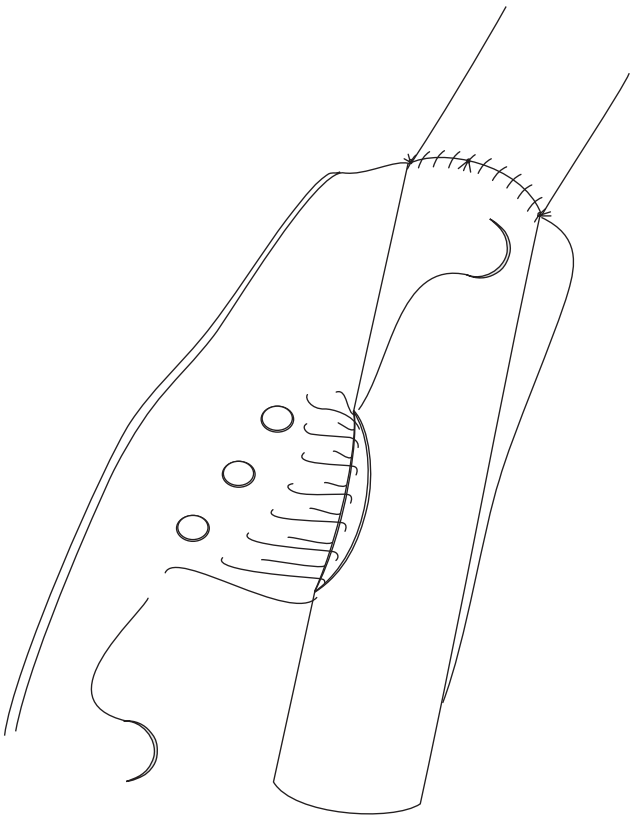


Place a double-layer bite in a matching location in the aorta.

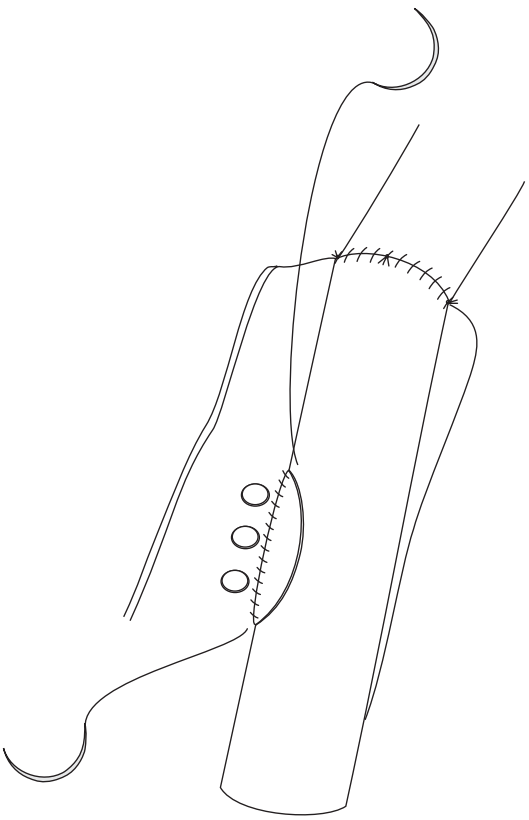


Reimplantation of the Celiac, Superior Mesenteric, and Right Renal Arteries on an Aortic Patch

Continue running the suture line until you have completed the posterior part of the anastomosis.

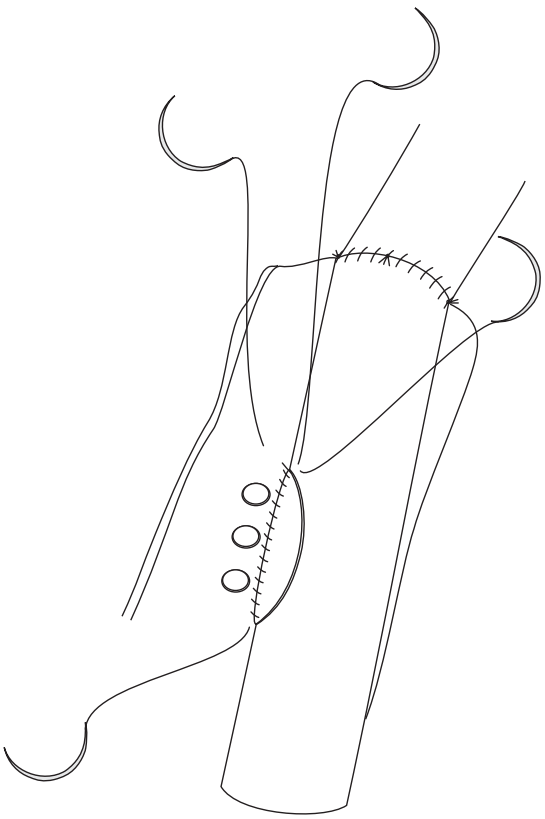


Pull and tighten the suture line.

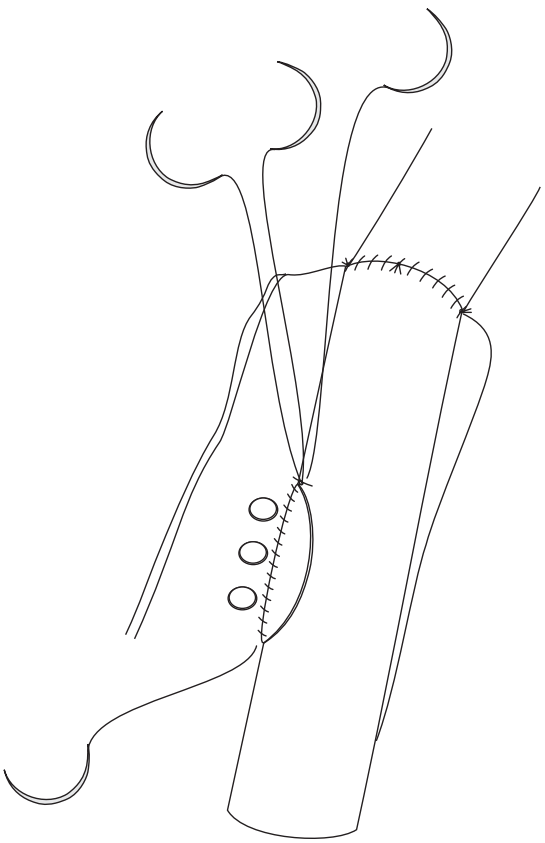


Reimplantation of the Celiac, Superior Mesenteric, and Right Renal Arteries on an Aortic Patch

Start a new suture at the apex very close to the starting point of the previous suture.



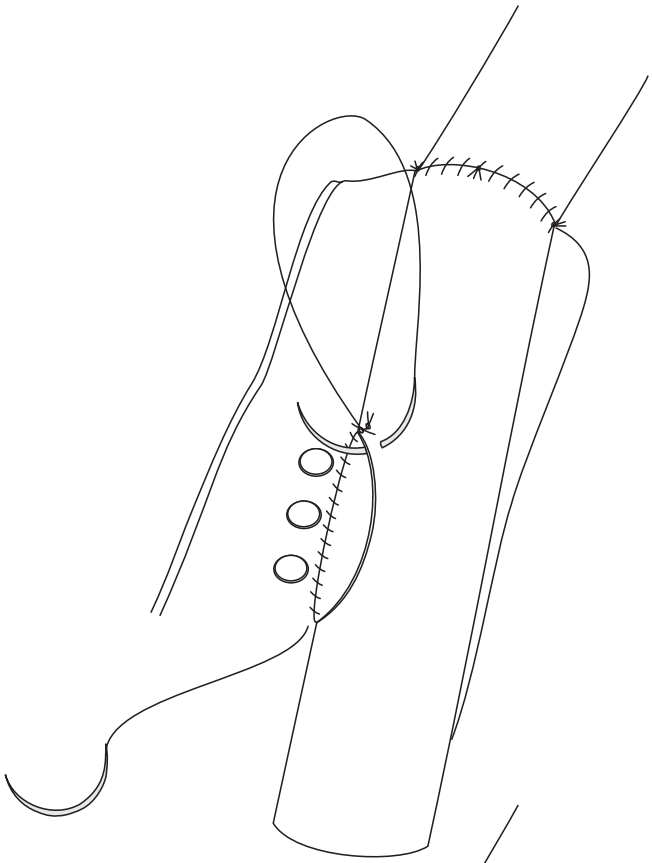
Tie one end of the suture to the posterior suture.



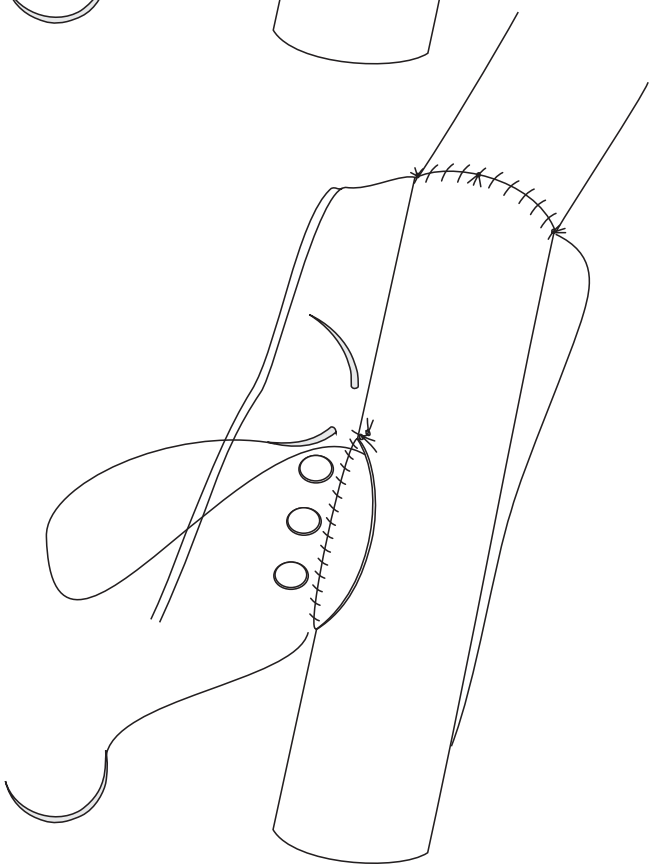
Reimplantation of the Celiac, Superior Mesenteric, and Right Renal Arteries on an Aortic Patch

Start running the suture along the anterior part of the anastomosis.

Introduce the needle in the graft.

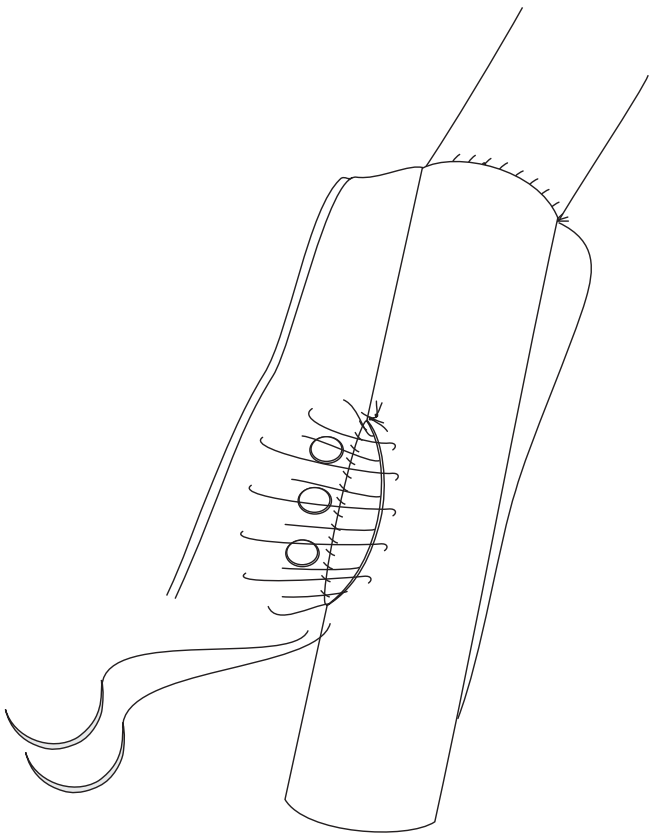


Introduce the needle in a matching location in the aorta.

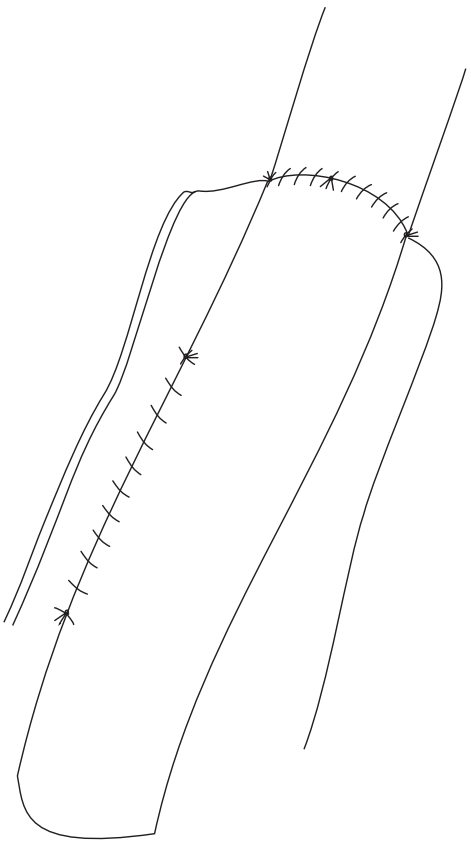


Reimplantation of the Celiac, Superior Mesenteric, and Right Renal Arteries on an Aortic Patch

Keep running the suture along the anterior wall until you reach the other suture.

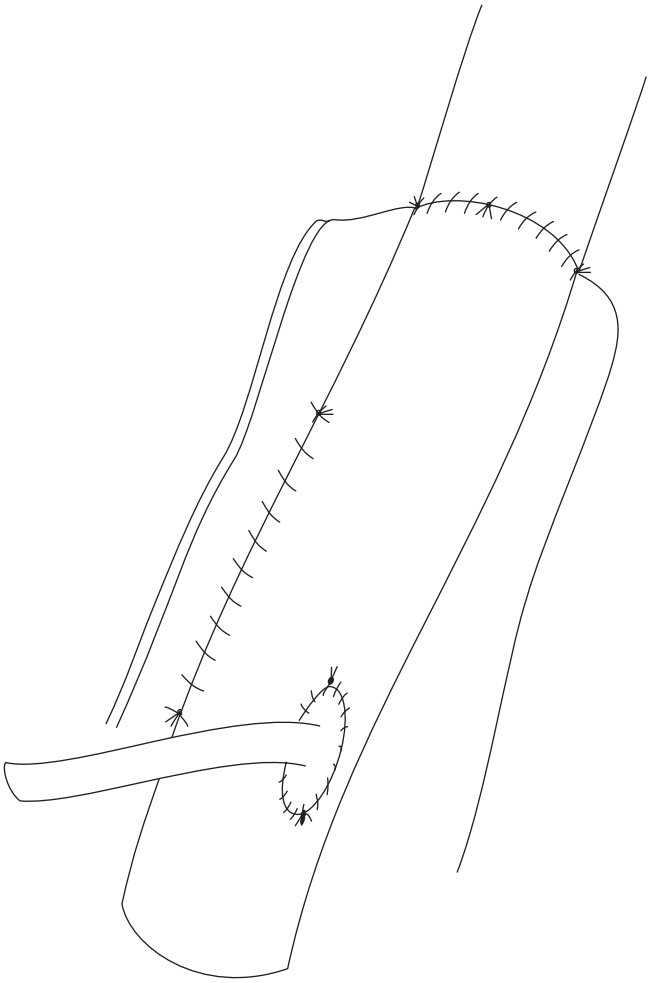


Pull and tie the suture.



Reimplantation of the Celiac, Superior Mesenteric, and Right Renal Arteries on an Aortic Patch

The left renal artery is reimplanted as previously described.

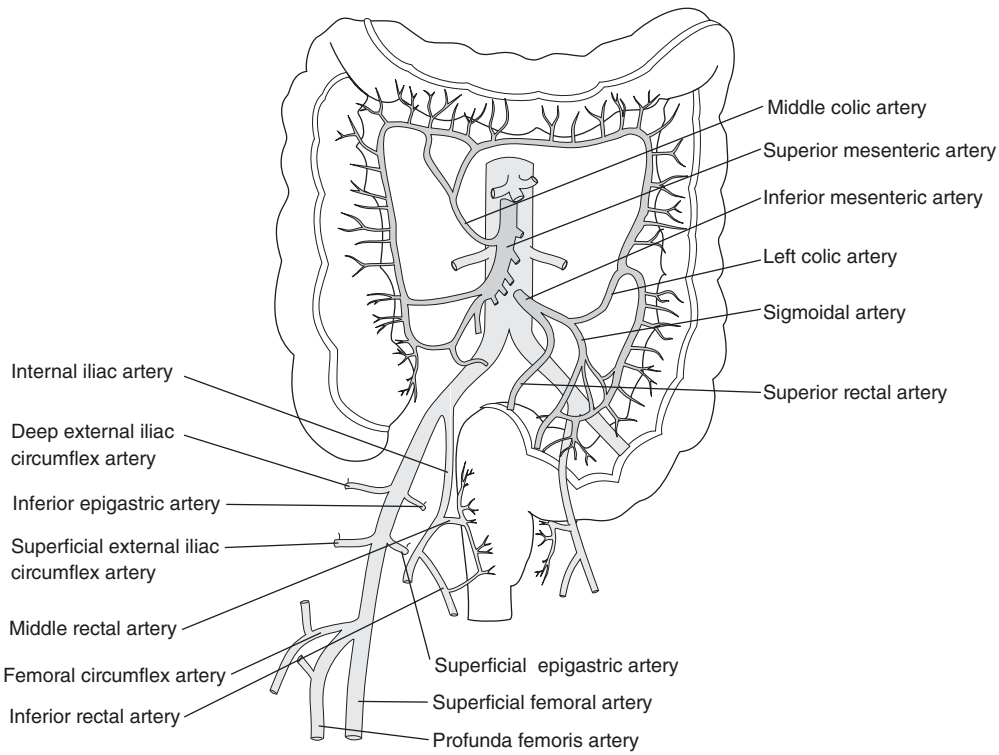


16

Pelvic Revascularization During Aortic Reconstruction

Jamal J. Hoballah

Preservation of pelvic perfusion should be an integral part of any aortic reconstructive procedure. Pelvic ischemia is an important complication that may, on occasion, be fatal. The clinical manifestations of pelvic ischemia include buttock claudication, buttock necrosis, rectosigmoidal ischemia, cord ischemia resulting in urinary and fecal incontinence, and sexual dysfunction. A knowledge of the pelvic blood supply is essential to understanding and planning the preservation of pelvic perfusion during aortic reconstruction.



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The pelvic blood supply is derived from several sources. The right and left internal iliac arteries provide the major blood supply to the pelvis. In addition, the pelvis receives some blood supply from branches of the external iliac artery. These branches include the inferior epigastric and the deep external iliac circumflex arteries. The inferior mesenteric artery (IMA) can also contribute to the pelvic blood supply. The inferior mesenteric artery divides into three main branches: the left colic artery, the sigmoidal artery, and the superior rectal artery. The contribution of the IMA to the pelvic blood supply is usually through the superior rectal artery, which communicates with the middle and inferior rectal arteries. The pelvis can also receive some blood supply from the superior mesenteric artery through its middle colic artery branch. The middle colic artery communicates with the left colic artery, which in turn connects with the superior rectal artery. The pelvis may also acquire further blood supply from the common femoral arteries through the superficial epigastric and superficial iliac circumflex arteries. In addition, the profunda femoris artery through its femoral circumflex branches can also contribute to the pelvic blood supply. Thus, the collateral blood flow to the internal iliac artery may originate from the contralateral internal iliac, the ipsilateral external iliac, the inferior mesenteric, the superior mesenteric, the common femoral, and the profunda femoris arteries.

An important principle of aortic reconstruction is to maintain the perfusion of at least one internal iliac artery to avoid the possible complication of pelvic ischemia [1, 4]. However, the perfusion of both internal iliac arteries is desirable if it can be safely accomplished without excessive prolongation of the duration of the procedure.

AORTOILIAC OCCLUSIVE DISEASE

In a patient with aortoiliac occlusive disease, the proposed reconstruction is usually an aortobifemoral bypass. The proximal anastomosis can be carried out in an end-to-end (section "Distal Anastomosis to the External Iliac Artery with a Bypass to the Internal Iliac Artery") or end-to-side configuration (section "End-to-End Aortobifemoral Bypass"). Pelvic perfusion may be maintained by constructing the proximal aortic anastomosis in an end-to-side fashion. This type of anastomosis is especially necessary when the external iliac arteries are heavily involved with occlusive disease. In this situation, an end-to-end aortofemoral bypass cannot provide retrograde perfusion to the internal iliac arteries due to the disease in the external iliac arteries. If an end-to-side aortobifemoral bypass cannot be performed, pelvic revascularization may still be achieved by constructing a side-to-side anastomosis between the graft limb and the common iliac artery bifurcation (section "End-to-End Aortobifemoral Bypass") [2]. It is important to perfuse the profunda and preserve its branches during the aortobifemoral bypass procedure. A profundaplasty should be performed if necessary.

AORTOILIAC ANEURYSMAL DISEASE

In aortic aneurysmal disease, the extent of replacement is usually governed by the extent of the aneurysmal disease and the anatomy of the pelvic circulation. If the aneurysmal disease is limited to the infrarenal aorta, a tube graft replacement is usually performed (section "Distal Anastomosis to the Aortic Bifurcation"). The perfusion of the internal iliac arteries is then restored to the preoperative status. Similarly, if the aneurysmal disease extends into the common iliac arteries but does not involve the iliac bifurcation, the preoperative internal iliac perfusion can be maintained by the placement of an aortobiiliac bypass graft.

When the aneurysmal disease extends to the level of the iliac bifurcation, several options may be available. One option is to transect the common iliac

artery approximately 1.5 cm proximal to the bifurcation. An arteriotomy is created into the origin of the external iliac artery for 1–1.5 cm. The limb of the graft is transected in a beveled fashion and sutured in an end-to-end manner to the transected common iliac artery (section "Distal Anastomosis to the Common Iliac Artery"). When constructing the posterior part of the anastomosis, the needles usually are introduced close to the orifices of the internal iliac and external iliac arteries, which are not involved in the aneurysmal pathology. The advantage of this technique is that it provides direct antegrade flow into the internal and external iliac arteries. In addition, it involves performing a single anastomosis. However, if the iliac arteries are heavily calcified, this anastomosis may be quite challenging. A localized endarterectomy may need to be performed with tacking of the endarterectomy endpoint.

Another option to preserve internal iliac artery flow is to transect the common iliac artery approximately 1.5 cm from the iliac bifurcation. The transected common iliac artery is oversewn without obliterating the orifices of the external and internal iliac arteries. The arteriotomy is then created in the external iliac artery. A limb of the aortobiiliac graft is sutured in an end-to-side manner to the external iliac artery. The perfusion into the internal iliac artery is provided by retrograde flow from the external iliac artery. This technique may be ideal when the iliac bifurcation is calcified and the plaque extends into the proximal part of the external iliac artery. In this situation, the distal external iliac artery is mobilized and the arteriotomy is created in the disease-free distal segment of the external iliac artery.

The aneurysmal disease may extend beyond the iliac bifurcation into the internal iliac artery with sparing of the external iliac artery. If the disease is limited to the proximal part of the internal iliac artery, one possible technique involves suturing the limb of the graft to the internal iliac artery in an end-to-end manner [3]. The external iliac artery is then reimplanted into the limb of the graft (section "Distal Anastomosis to the Internal Iliac Artery with Reimplantation of the External Iliac Artery"). If the aneurysmal disease extends into the proximal part of the external iliac artery, the limb of the graft can be connected to the external iliac artery in an end-to-end fashion. A separate graft is then sutured to the internal iliac artery (section "Distal Anastomosis to the External Iliac Artery with a Bypass to the Internal Iliac Artery"). This graft may originate from the body or limb of the aortic graft. If the aneurysmal disease extends into the distal part of the internal iliac artery, an anastomosis may not be technically possible. In this situation, ligation of the internal iliac artery becomes necessary.

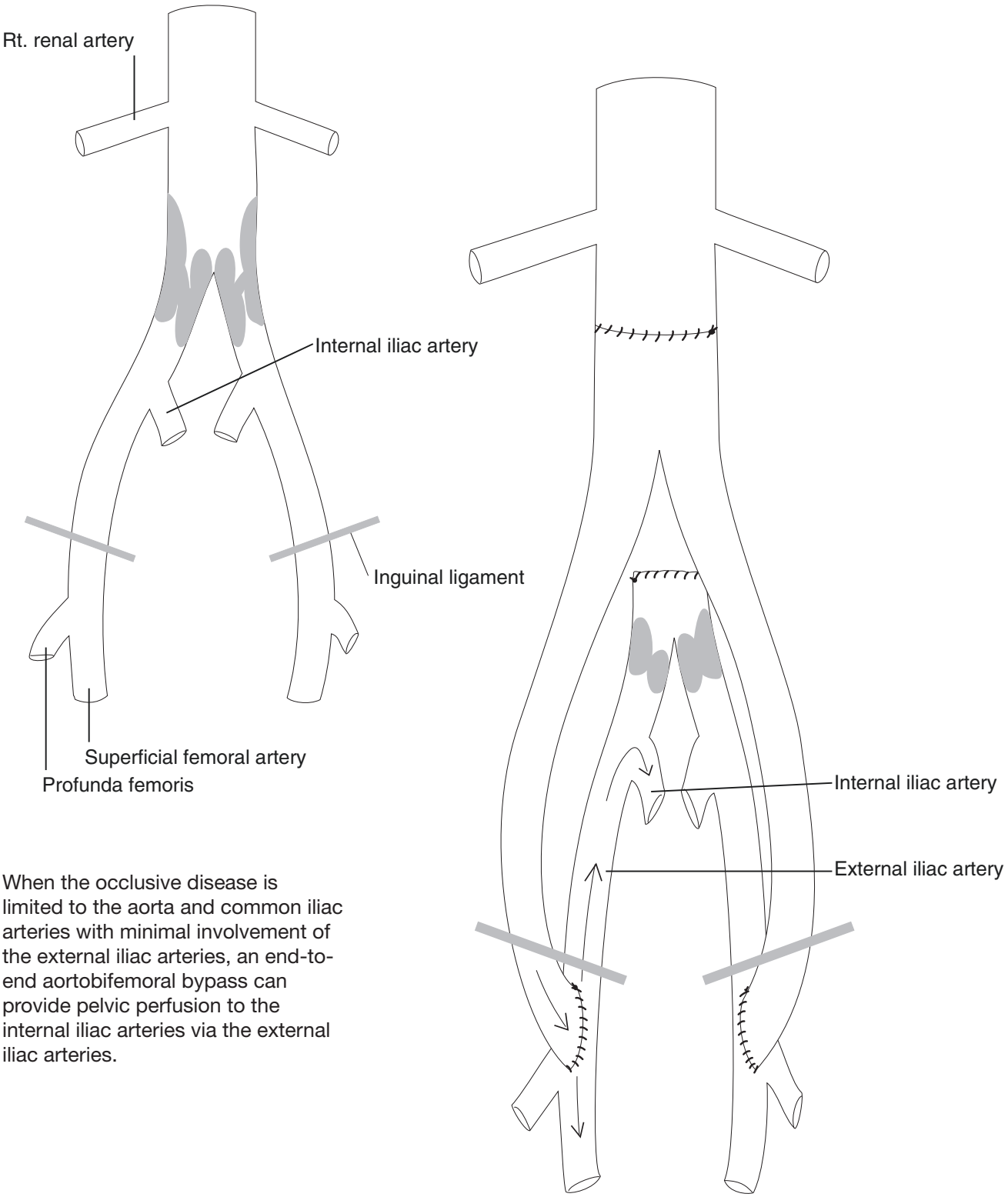
Infrequently, perfusion of at least one internal iliac artery is not possible because of extensive involvement by aneurysmal or occlusive disease. In this situation, the pelvic blood supply may be maintained by preserving the collateral blood supply of the internal iliac artery. This can be accomplished by reimplanting the inferior mesenteric artery. In addition, the blood flow into the external iliac artery and the profunda femoris artery and their branches should be maintained [4].

REFERENCES

1. Connolly JE, Ingegno M, Wilson SE. Preservation of the pelvic circulation during infrarenal aortic surgery. Cardiovasc Surg. 1996;4:65–70.
2. Cronenwett JL, Gooch JB, Garrett E. Internal iliac artery revascularization during aortofemoral bypass. Arch Surg. 1982;117:838–9.
3. Hoballah JJ, Chalmers RTA, Nazzal MM, Mohan CR, Corson JD. Internal iliac revascularization during aortic aneurysm replacement: a review and description of a useful technique. Am Surg. 1997;63:970–4.
4. Iliopoulos JI, Hermreck AS, Thomas JH, Pierce GE. Hemodynamics of the hypogastric arterial circulation. J Vasc Surg. 1989;9:637–42.

Aortoiliac Occlusive Disease

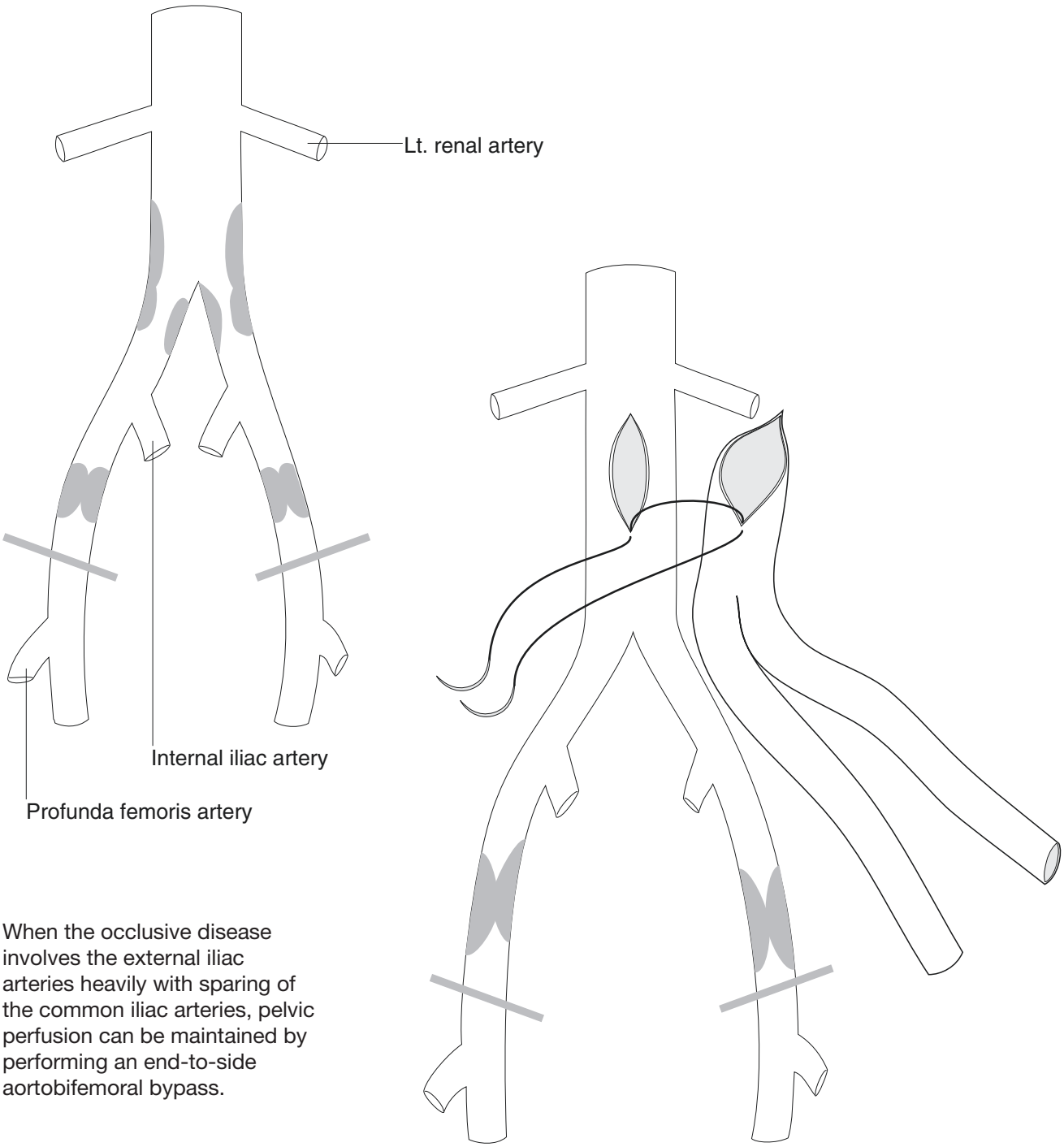
End-to-End Aortobifemoral Bypass



When the occlusive disease is limited to the aorta and common iliac arteries with minimal involvement of the external iliac arteries, an end-to-end aortobifemoral bypass can provide pelvic perfusion to the internal iliac arteries via the external iliac arteries.

Aortoiliac Occlusive Disease

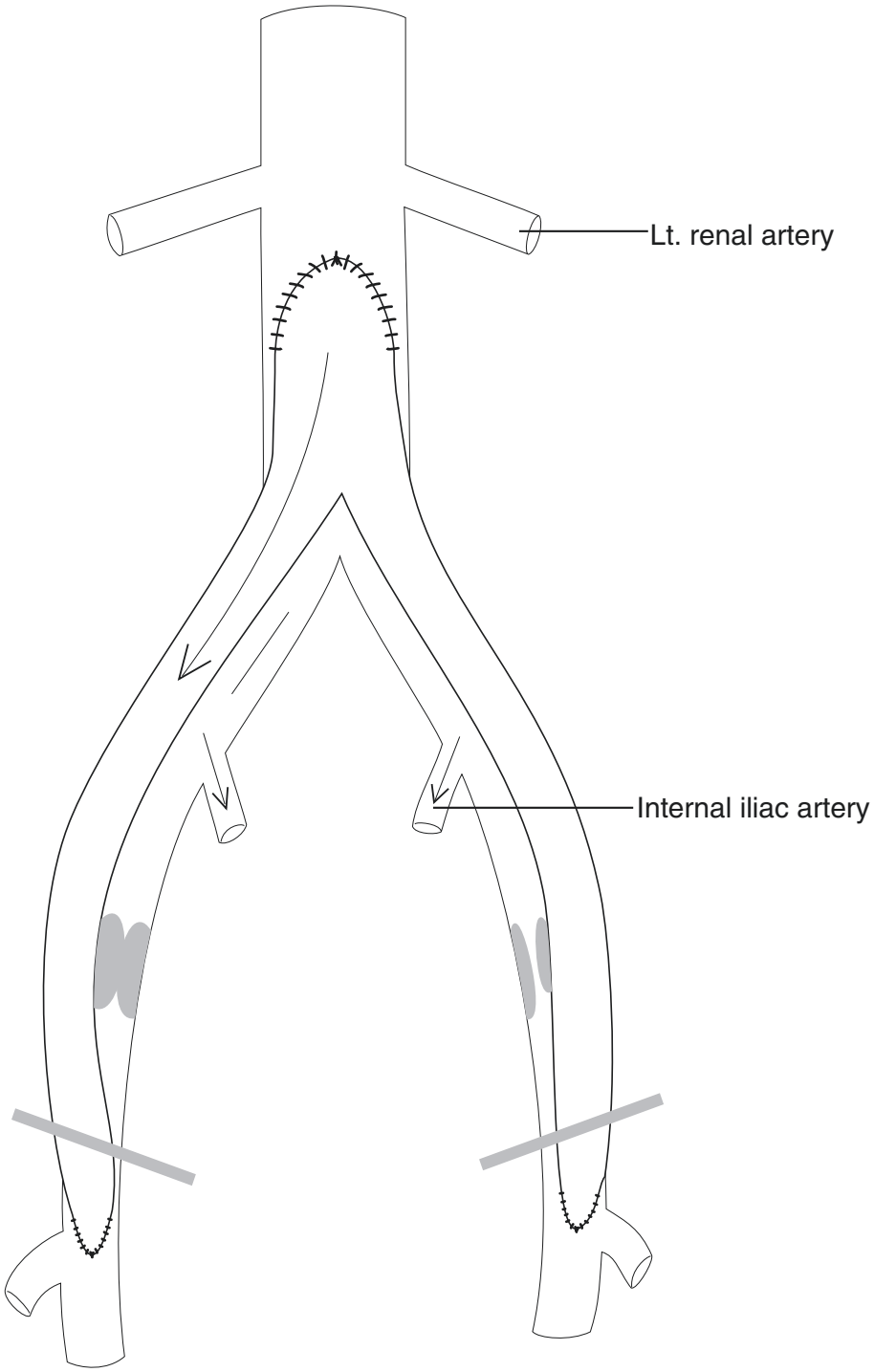
End-to-End Aortobifemoral Bypass



When the occlusive disease involves the external iliac arteries heavily with sparing of the common iliac arteries, pelvic perfusion can be maintained by performing an end-to-side aortobifemoral bypass.

Aortoiliac Occlusive Disease

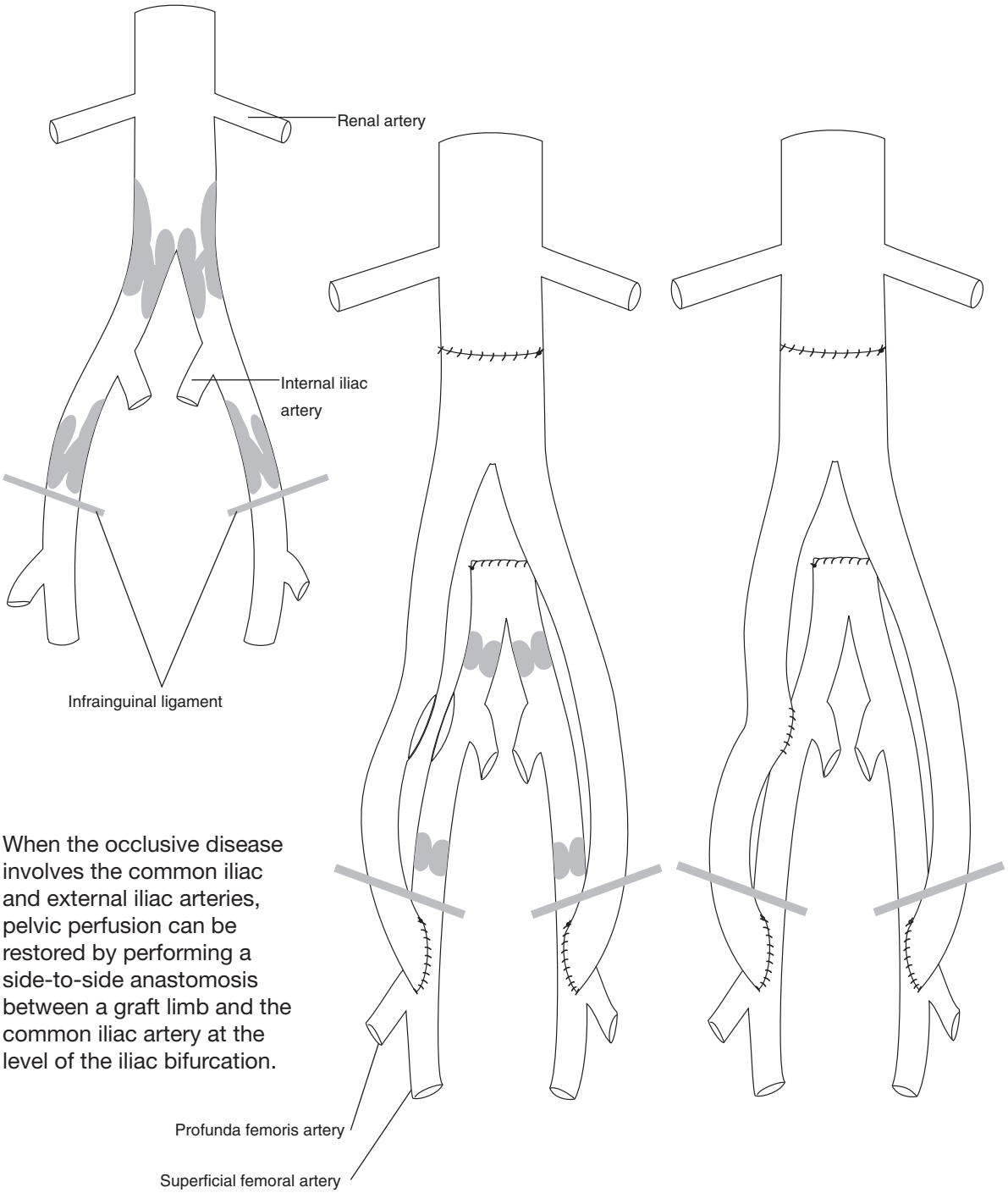
End-to-End Aortobifemoral Bypass



In the end-to-side reconstruction, the native circulation is usually left undisturbed.

Aortoiliac Occlusive Disease

End-to-End Aortobifemoral Bypass



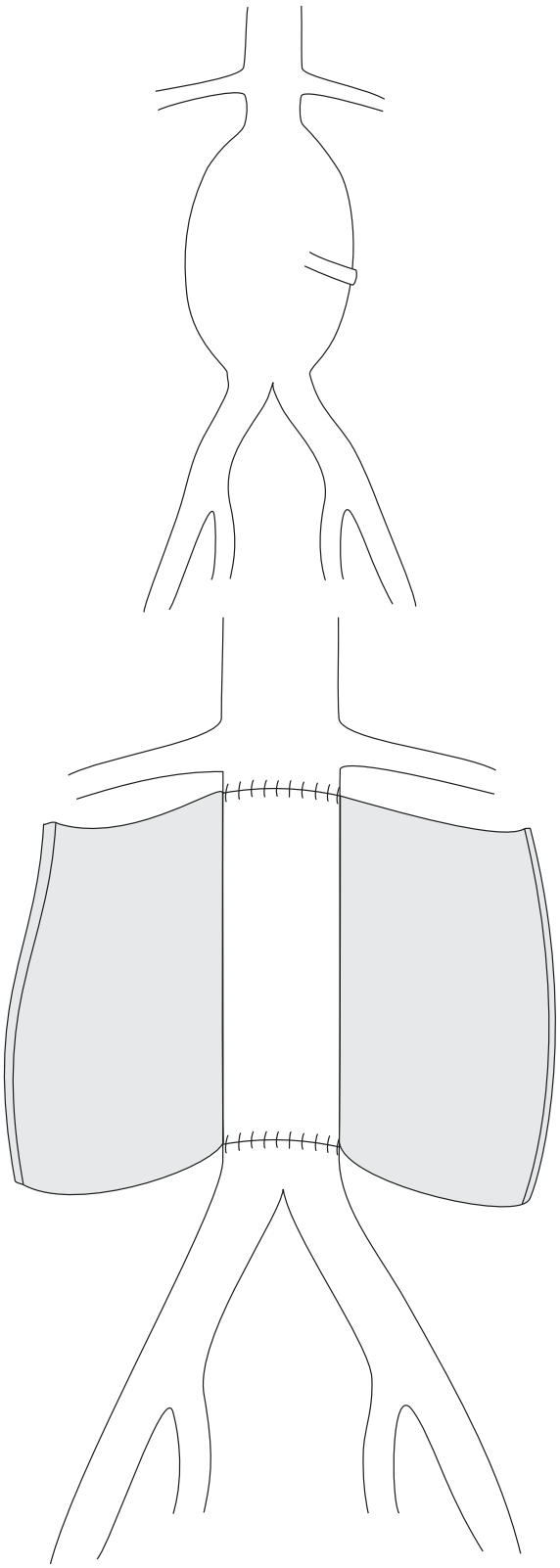
When the occlusive disease involves the common iliac and external iliac arteries, pelvic perfusion can be restored by performing a side-to-side anastomosis between a graft limb and the common iliac artery at the level of the iliac bifurcation.

Aortoiliac Aneurysmal Disease

Distal Anastomosis to the Aortic Bifurcation

When the aneurysmal pathology is limited to the aorta and does not involve the common iliac arteries, a tube graft replacement is performed.

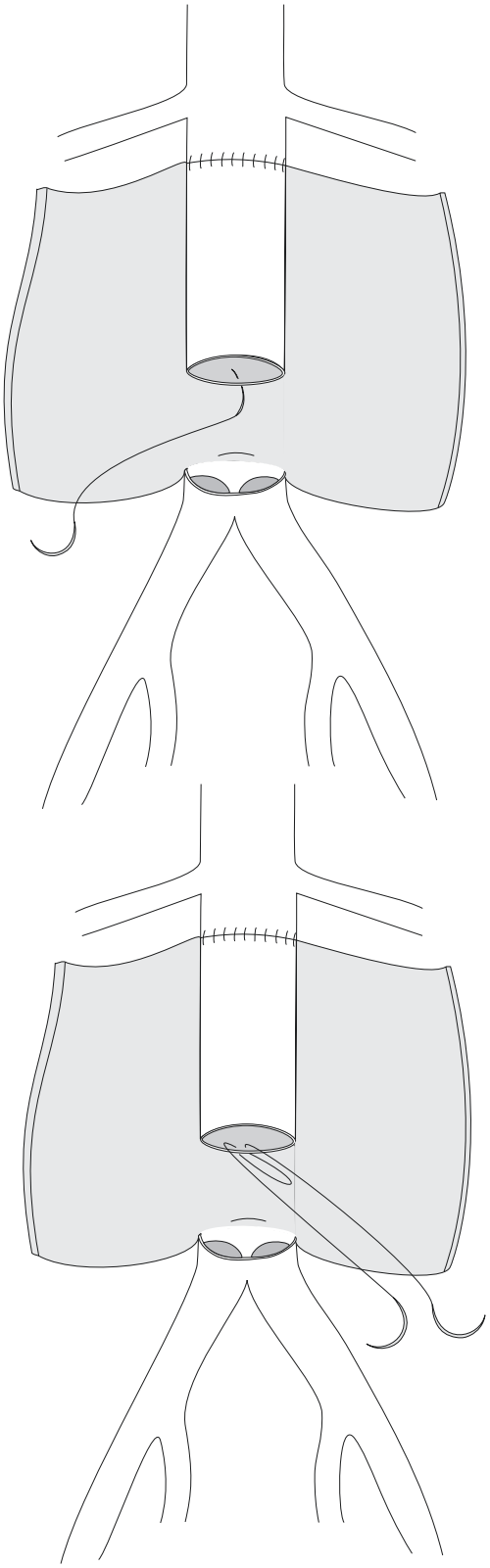
When performing a tube graft replacement, the distal anastomosis can be very challenging because of calcifications or the absence of a well-defined neck at the level of the aortic bifurcation.



Aortoiliac Aneurysmal Disease

Distal Anastomosis to the Aortic Bifurcation

The same principles discussed in the construction of the proximal aortic bifurcation apply here as well. The suture can be started at the center of the posterior suture line or on either side. However, when the neck is ill defined, starting at the center of the posterior wall can help to establish even progression on either side, as shown here.

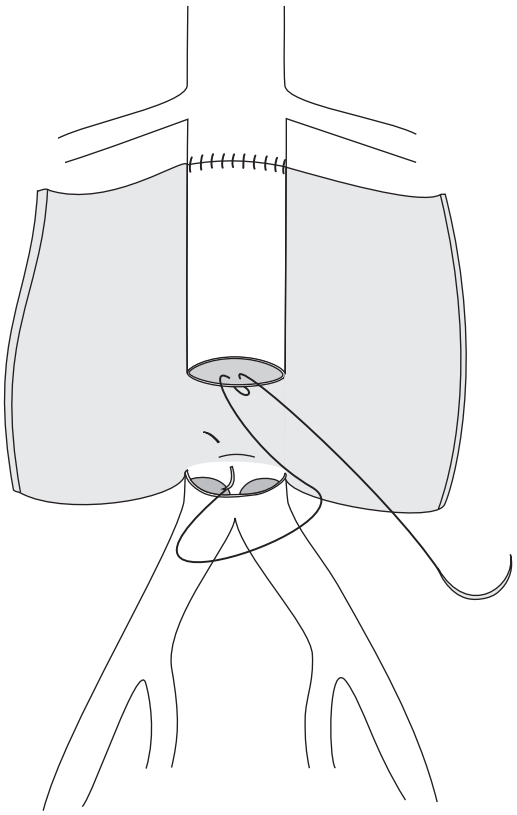


Start by placing a horizontal mattress suture in the center of the posterior wall of the graft.

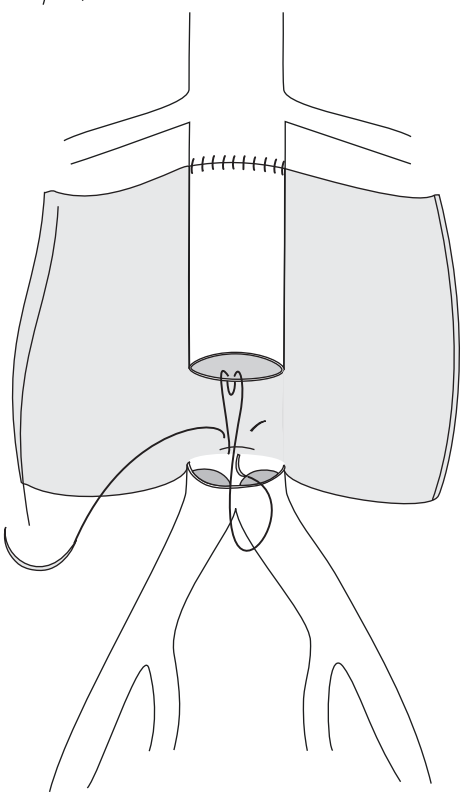
AORTOILIAC ANEURYSMAL DISEASE

Distal Anastomosis to the Aortic Bifurcation

Introduce the needle in the center of the posterior aortic wall. The site of introduction of the needle should be free of aneurysmal disease. The needle can be introduced very close to the orifices of the common iliac arteries. It is preferable to avoid excessive advancement when constructing the posterior wall because of the difficulty in controlling bleeding from the posterior suture line.



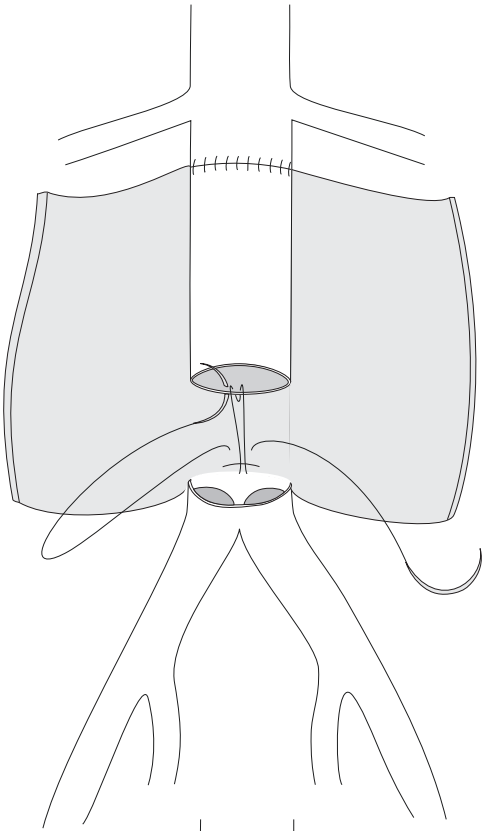
Place a matching horizontal mattress suture in the center of the posterior aortic wall.



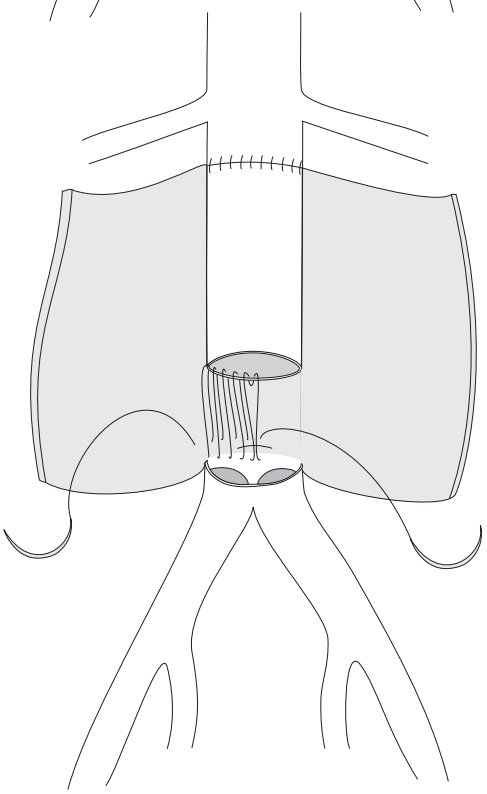
Aortoiliac Aneurysmal Disease

Distal Anastomosis to the Aortic Bifurcation

Introduce the needle in the graft.



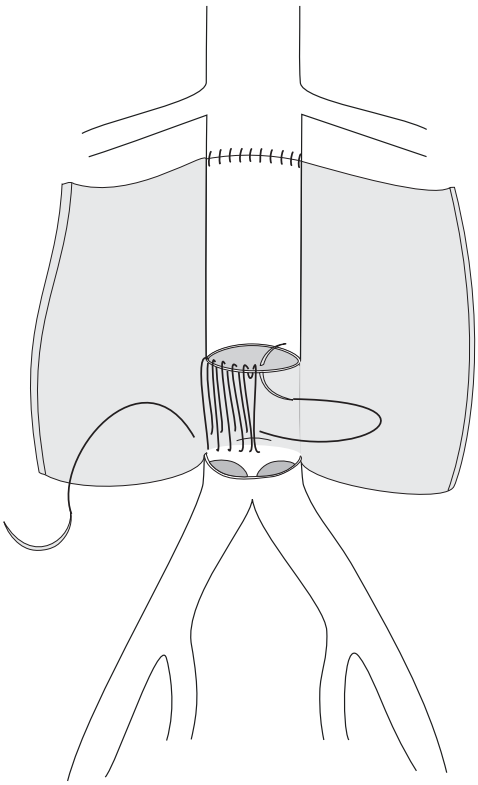
Complete suturing the posterior part of the suture line on one side.



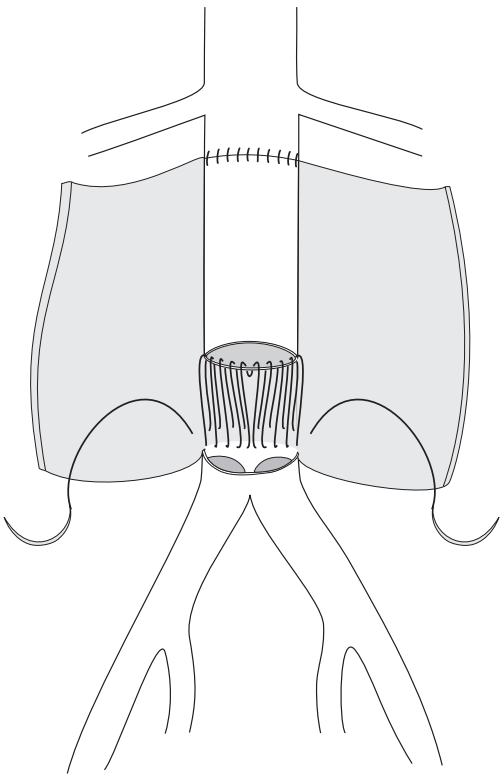
Aortoiliac Aneurysmal Disease

Distal Anastomosis to the Aortic Bifurcation

Do the same on the other side. Introduce the needle in the graft, outside-in.



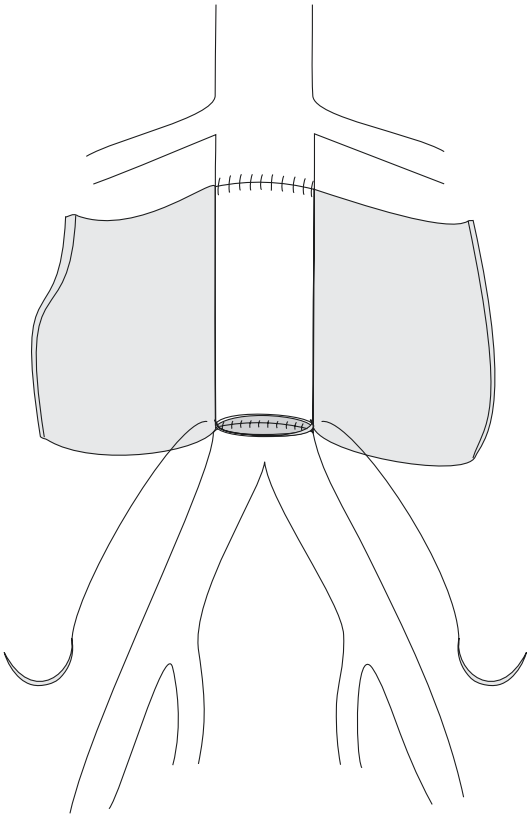
Complete the posterior suture line on the other side.



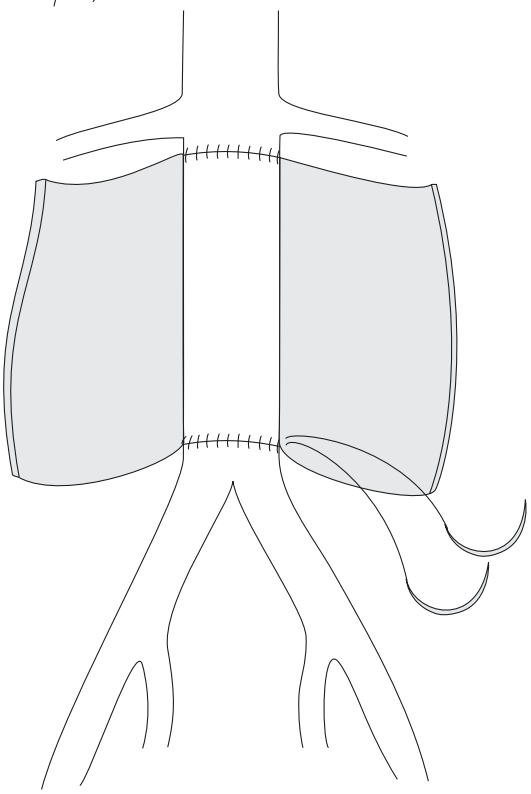
Aortoiliac Aneurysmal Disease

Distal Anastomosis to the Aortic Bifurcation

Pull and tighten the suture line. Use a nerve hook to ensure that the suture line is not loose.



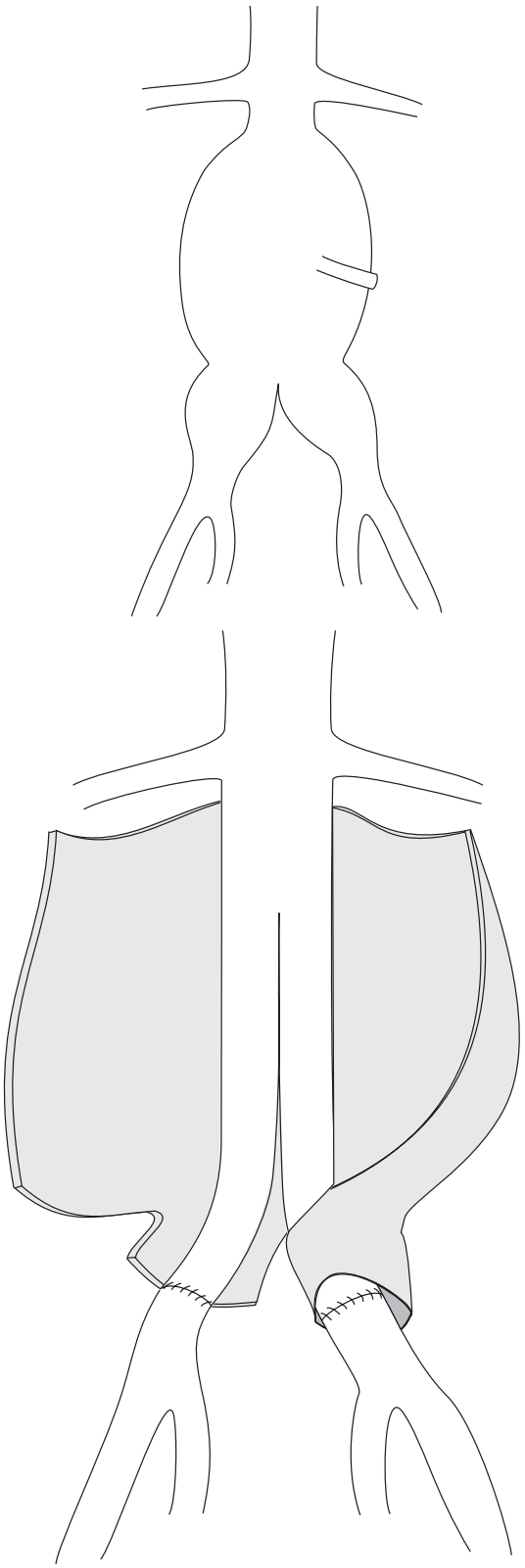
You may start another suture for the anterior part of the anastomosis. Alternatively, you may continue with the same suture to complete the anastomosis as shown here.



Aortoiliac Aneurysmal Disease

Distal Anastomosis to the Common Iliac Artery

When the aneurysmal pathology extends to the proximal portion of the common iliac arteries, a bifurcated graft replacement to the level of the distal common iliac arteries is performed.

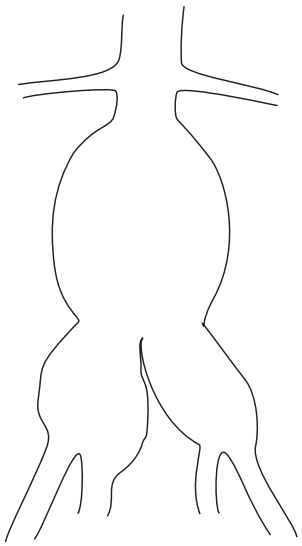


The posterior wall of the common iliac artery may be transected or left intact. Be careful to avoid injury to the iliac veins, which could occur during the transection of the common iliac arteries. In addition, make sure that the bites in the transected iliac artery include the adventitia. On the left side, the graft can be tunneled through the aneurysmal iliac artery.

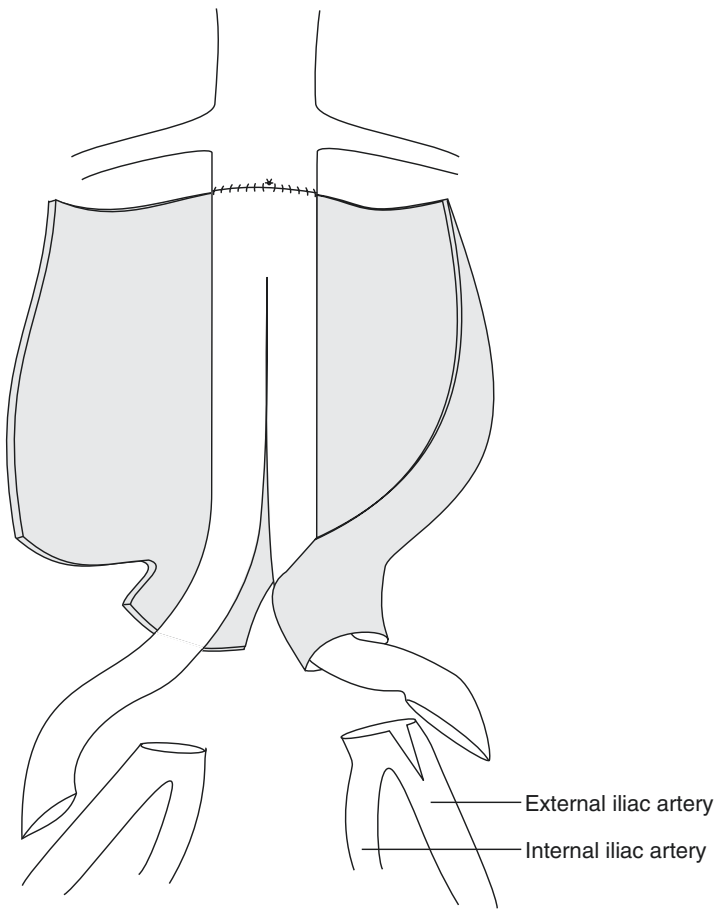
Aortoiliac Aneurysmal Disease

Distal Anastomosis to the Common Iliac Artery

When the aneurysmal disease extends to the iliac bifurcation, several options are available depending on the quality of the common iliac artery at the bifurcation.



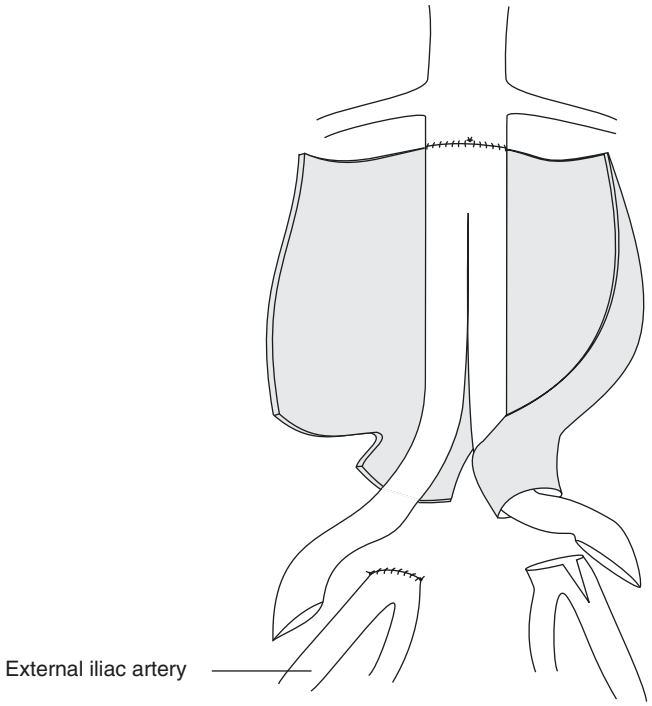
If the iliac bifurcation is not heavily calcified, the arteriotomy can be extended into the orifice of the external iliac artery as shown on the left side.



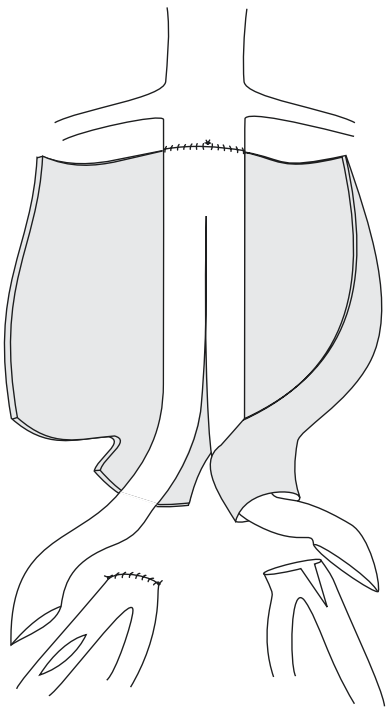
Aortoiliac Aneurysmal Disease

Distal Anastomosis to the Common Iliac Artery

If the iliac bifurcation is heavily calcified, or if the first part of the external iliac artery is involved with occlusive pathology, the transected common iliac artery is oversewn as shown on the right side.



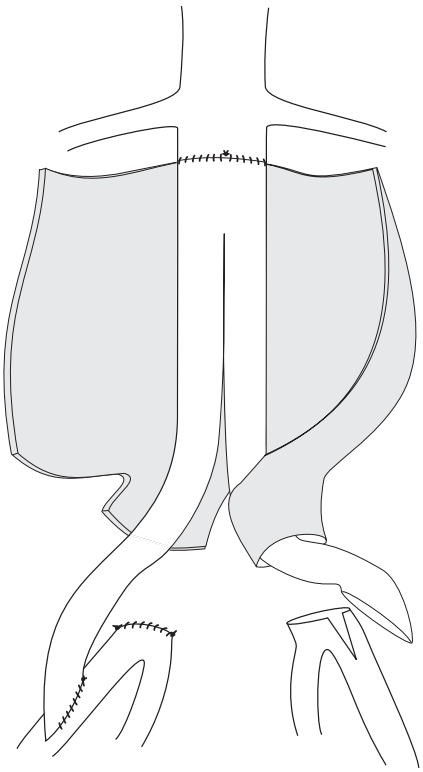
A soft area is then chosen in the external iliac artery for constructing the distal anastomosis.



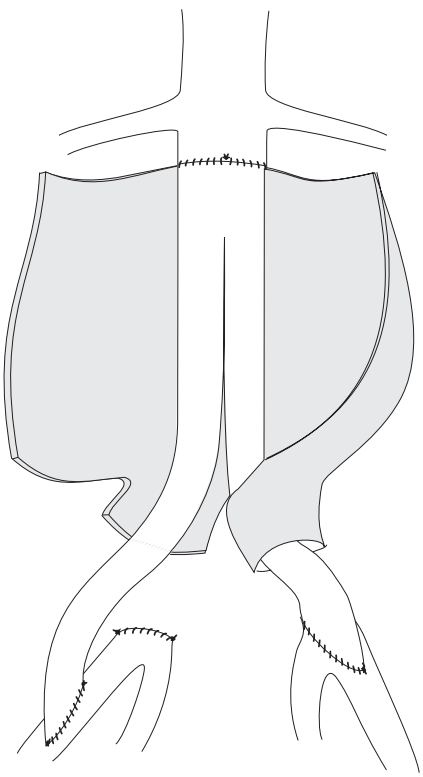
Aortoiliac Aneurysmal Disease

Distal Anastomosis to the Common Iliac Artery

An end-to-side anastomosis is then constructed to the external iliac artery, which will also provide retrograde flow into the internal iliac artery as shown on the right side.



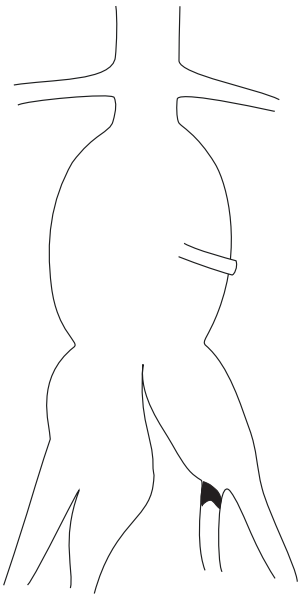
The reconstruction on the left side provides antegrade perfusion into the external and internal iliac arteries. If a localized endarterectomy is performed, tacking of the endarterectomy endpoint should be considered.



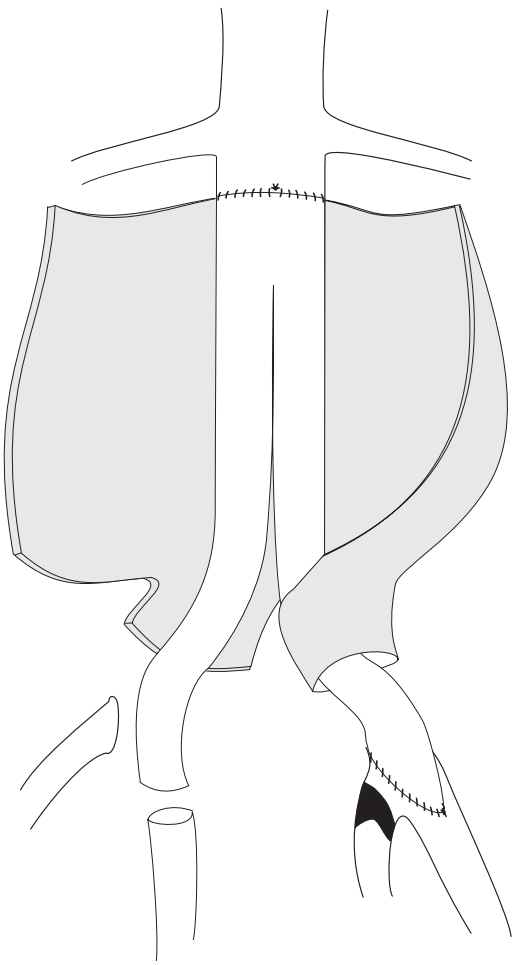
Aortoiliac Aneurysmal Disease

Distal Anastomosis to the Common Iliac Artery

When the aneurysmal disease extends beyond the iliac bifurcation into the proximal part of the internal iliac artery, revascularization of at least one internal iliac artery should be attempted.



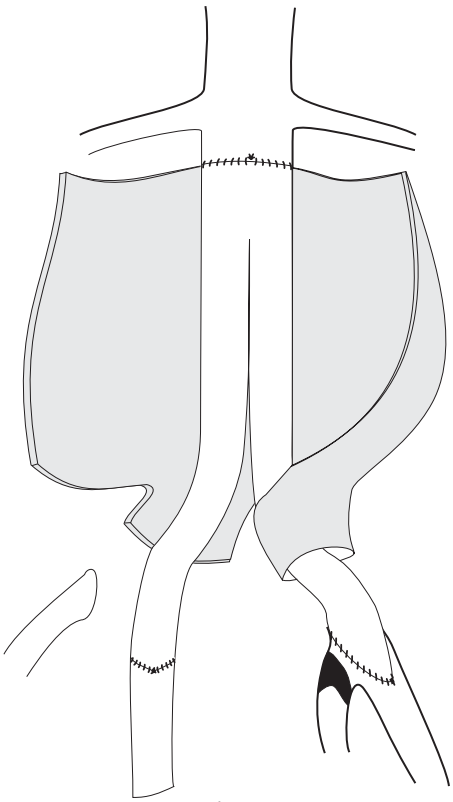
If the aneurysmal disease is limited to the very proximal part of the internal iliac artery, one option is to transect the external iliac artery at the level of the iliac bifurcation. The graft is anastomosed to the internal iliac artery using an end-to-end configuration as shown on the right side.The external iliac artery is then reimplanted into the limb of the graft.



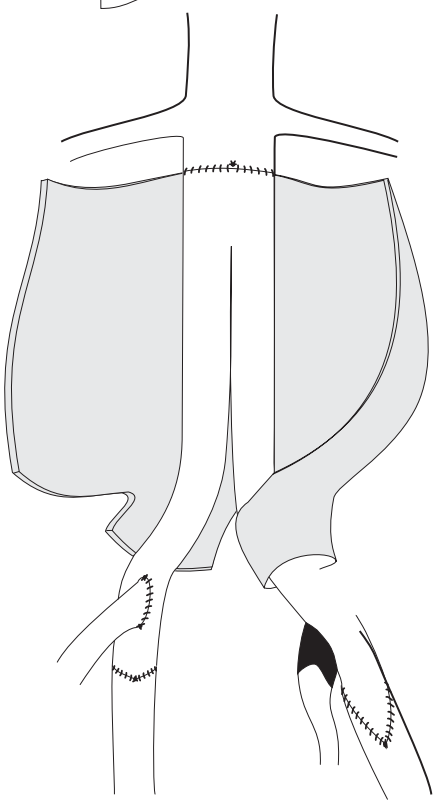
Aortoiliac Aneurysmal Disease

Distal Anastomosis to the Internal Iliac Artery with Reimplantation of the External Iliac Artery

The graft is anastomosed to the internal iliac artery using an end-to-end configuration as shown on the right side.



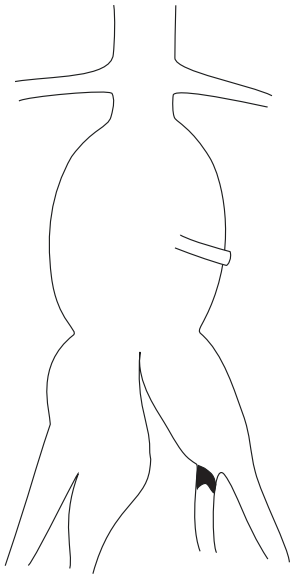
The external iliac artery is then reimplanted into the limb of the graft.



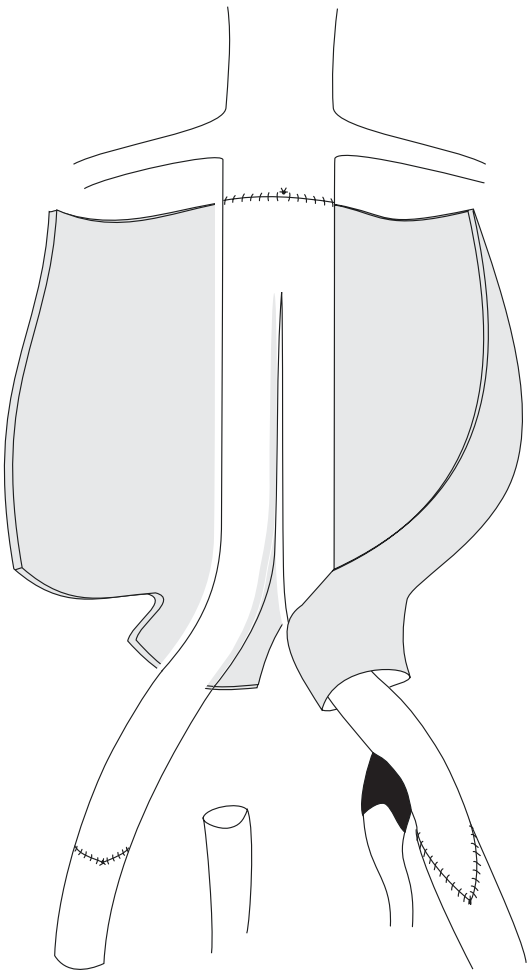
Aortoiliac Aneurysmal Disease

Distal Anastomosis to the Internal Iliac Artery with Reimplantation of the External Iliac Artery

Another option to revascularize the pelvis in the situation shown on the right side involves constructing a separate bypass to the internal iliac artery.



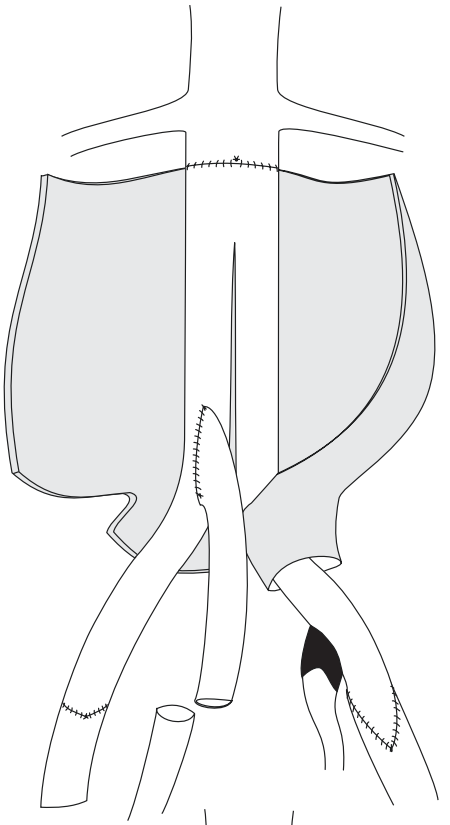
The graft limb is first anastomosed to the external iliac artery.



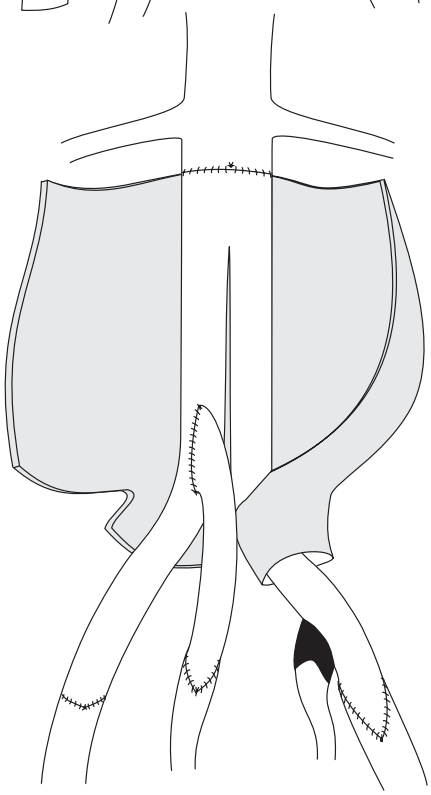
Aortoiliac Aneurysmal Disease

Distal Anastomosis to the External Iliac Artery with a Bypass to the Internal Iliac Artery

A separate graft is then sutured to the body of the graft or to one of its limbs as shown here.



The bypass is then anastomosed to the internal iliac artery.



17

Inferior Mesenteric Artery Reimplantation

Jamal J. Hoballah

MANAGEMENT OF THE INFERIOR MESENTERIC ARTERY DURING AORTIC ANEURYSM REPLACEMENT

When the aortic aneurysm sac is opened, the orifice of the inferior mesenteric artery should be inspected. If pulsatile backbleeding is noted, it is usually safe to oversew the origin of the inferior mesenteric artery. The orifice is suture ligated from within the aneurysmal lumen to avoid injury to its branches, especially at the junction of the left colic to the sigmoidal and superior rectal branches.

If the backbleeding from the inferior mesenteric artery is poor, the orifice is occluded by a Fogarty catheter. Alternatively, the inferior mesenteric artery may be carefully dissected and controlled close to its origin by a vessel loop. After completing the distal part of the aortic reconstruction and reestablishing distal flow, the backbleeding from the inferior mesenteric artery (IMA) is reassessed. If the backbleeding is brisk and pulsatile, the IMA is ligated from within. Occasionally, the backbleeding may not be impressive due to the presence of an orificial atherosclerotic plaque and will improve following endarterectomy of the origin of the IMA. If the backbleeding from a patent IMA is still weak even after completing the aortic reconstruction, reimplantation of the IMA may be necessary. If the backbleeding from the IMA is questionable, back pressure measurements can help determine the need for IMA reimplantation. IMA back pressure can be measured by inserting a blunt tip needle through the IMA orifice; a vessel loop is pulled around the needle to prevent bleeding around the needle. Reimplantation of the IMA is considered if the back pressure is less than 35 mmHg.

Other reasons for reimplanting the IMA include inability to perfuse at least one internal iliac artery, previous colonic resection that may have interrupted the collaterals between the left colic artery and the middle colic artery, and a widely patent IMA as seen by angiogram, with stenotic pathology in the superior mesenteric artery.

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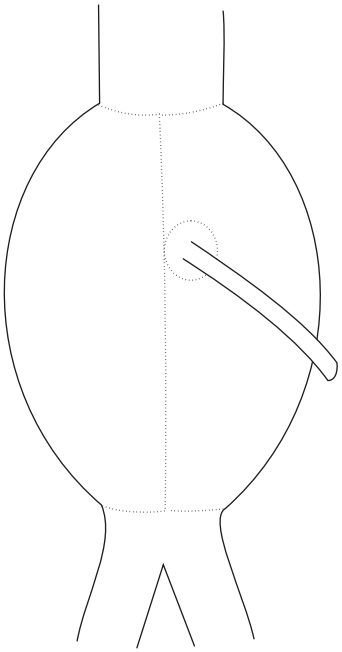
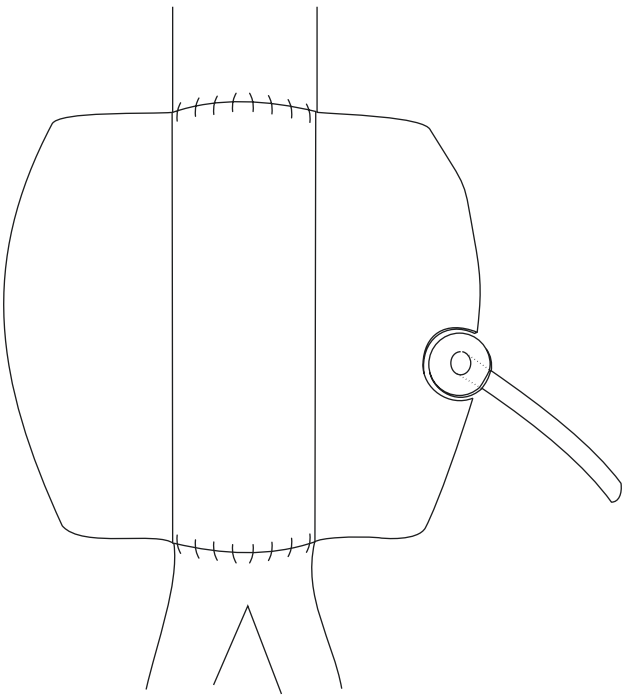
J. J. Hoballah, C. F. Bechara (eds.), *Vascular Reconstructions*, https://doi.org/10.1007/978-1-0716-1089-3_17

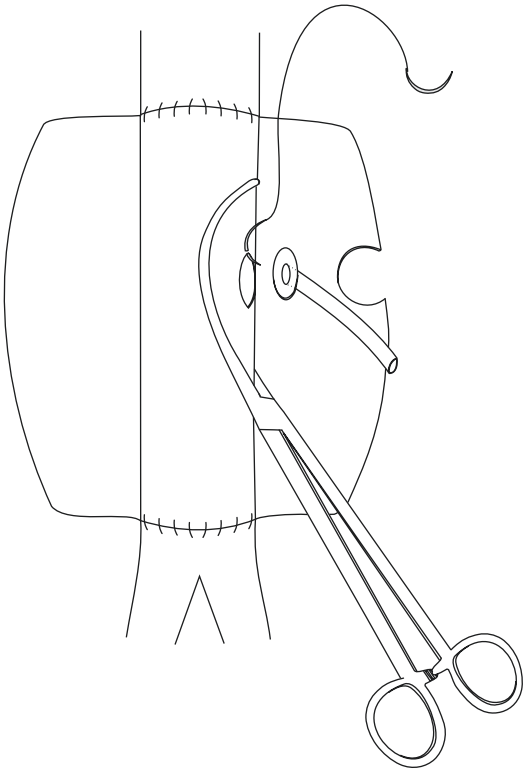
The incision in the aortic aneurysm is placed to the right side of the inferior mesenteric artery at least 1.0 cm from its origin in anticipation of the need of reimplanting the IMA.



When reimplantaion of the inferior mesenteric artery is deemed necessary, a circular button of aortic wall is then created around the orifice of the inferior mesenteric. Occasionally, an eversion endarterectomy of the orifice of the inferior mesenteric artery will be necessary.



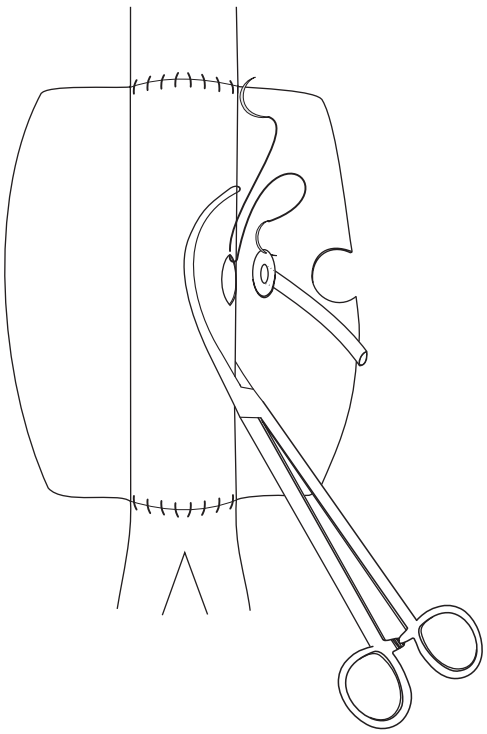
After completion of the aortic replacement, a side-biting clamp will be applied to the aortic graft, thus maintaining the blood flow into the lower extremities.



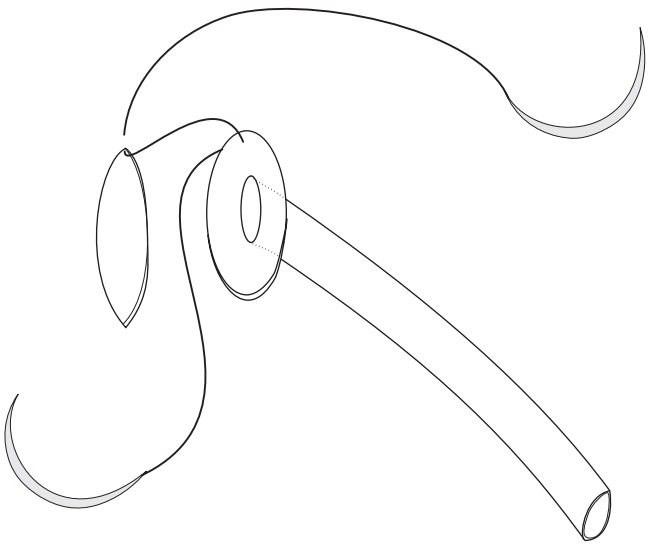
Proper positioning of the clamp is essential to avoid excessive tension on the suture lines. An incision in the graft is then performed and the suture line is started at the apex of the aortic graft incision. A small wedge of the graft may be excised to facilitate the construction of the anastomosis.

The needle is introduced into the Carrel patch of the mesenteric artery in a corresponding location. The suture can be tied at this level or continued in a parachute fashion, as shown here.

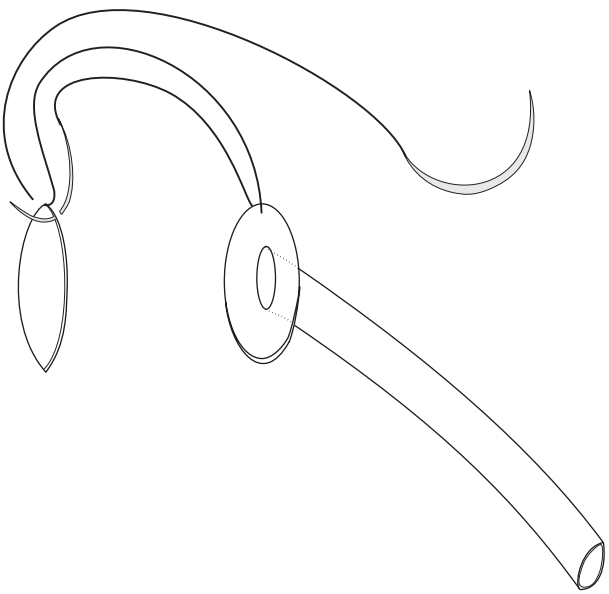
The posterior portion of the anastomosis is sutured first.

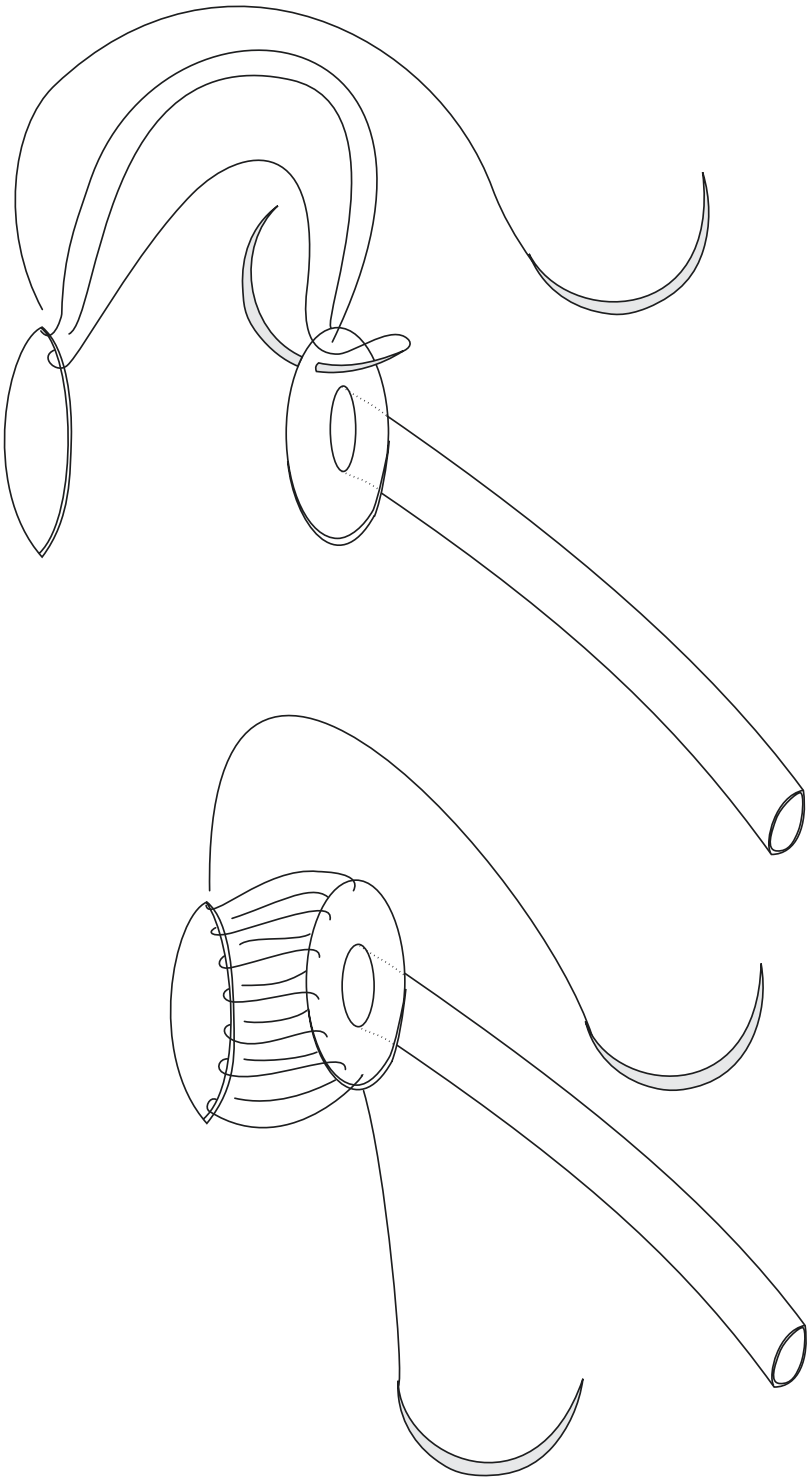


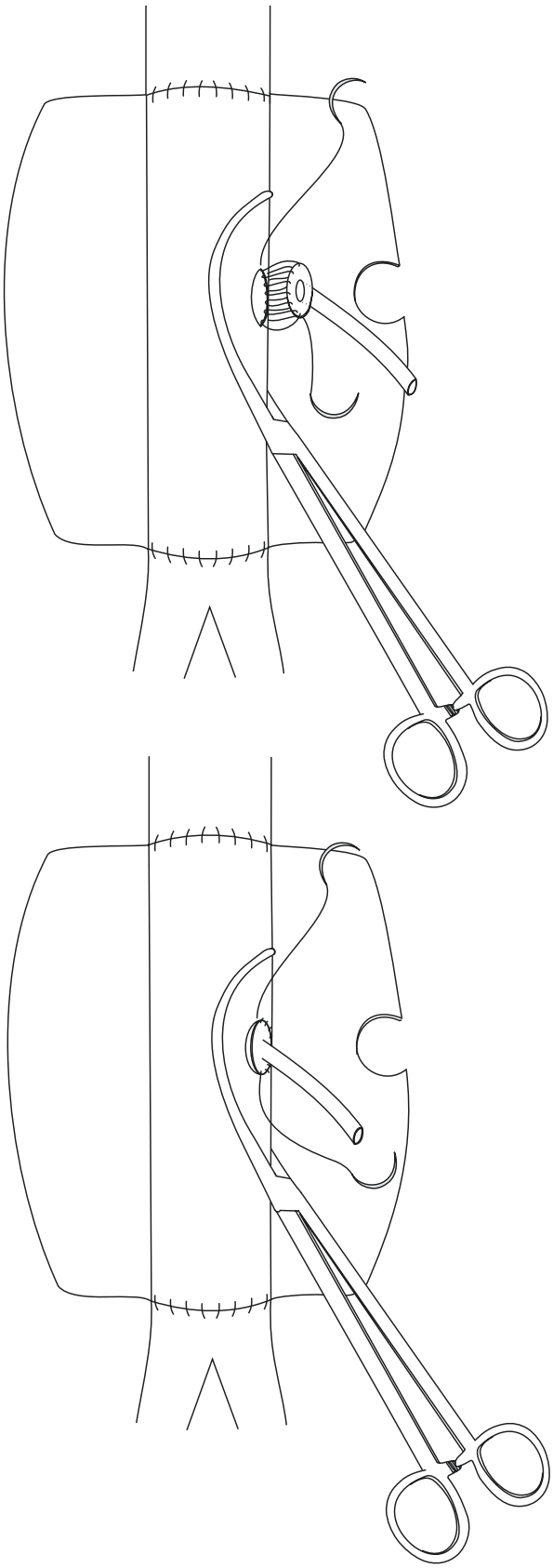
The needle is then introduced into the aortic graft. Multiple bites are placed until one side of the anastomosis has been completely sutured.



Again the needle is introduced inside-outside in the IMA patch and outside-inside in the graft.

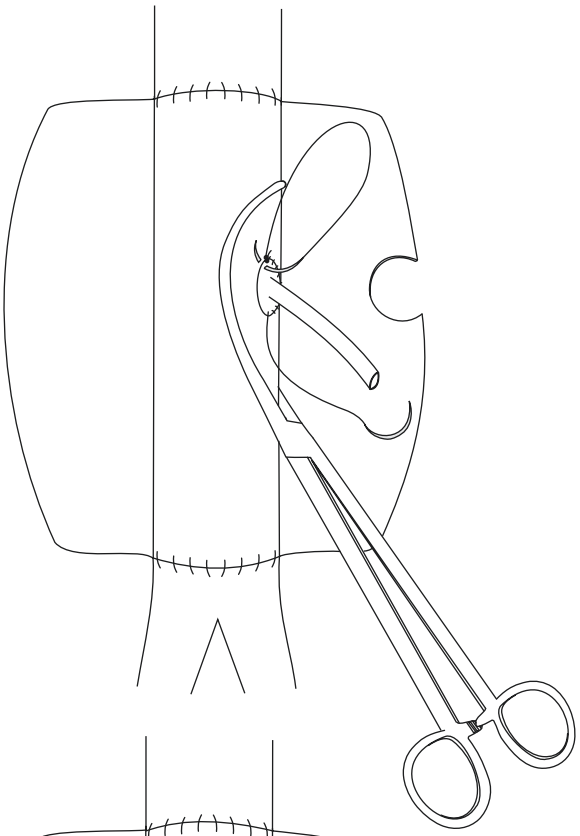






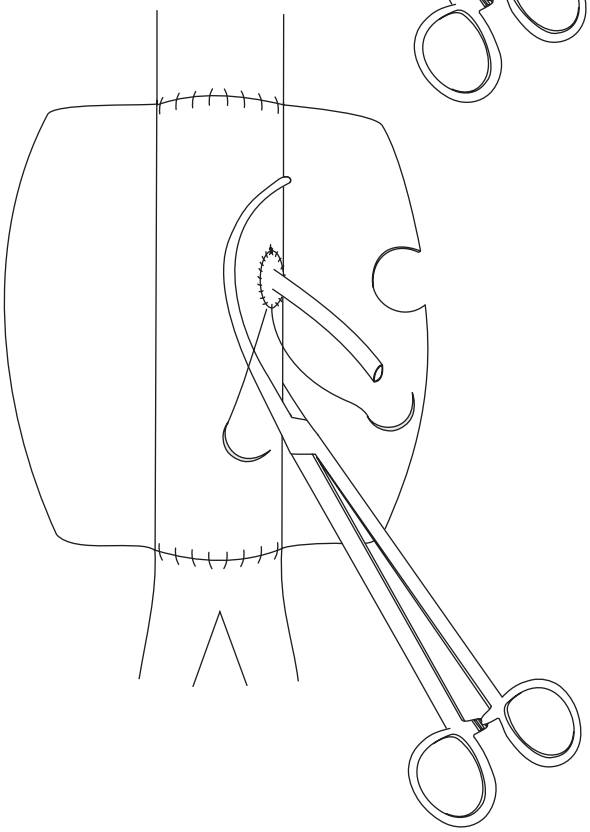
The suture line is then tightened. The upper suture may then be used to complete the suture line all the way down on the anterior portion of the anastomosis.

Alternatively, another suture may be started at the apex as shown here.



The suture is tied to itself. One end of the suture is tied to the original apical suture.

The new suture is then used to complete the anastomosis.



In this part of the anastomosis, the needle may be introduced outside-inside in the IMA patch and then inside-outside in the graft.

Run the upper suture toward the lower suture and tie the sutures.

18

Coverage of Abdominal Aortic Grafts

Jamal J. Hoballah

The interposition of viable tissue between an aortic graft prosthesis and the posterior wall of the duodenum has long been recognized as an important technique to limit the incidence of graft-enteric erosions and fistulae. In patients with aortoiliac occlusive disease, the periaortic tissue is approximated over the aortic prosthesis to insulate the graft from the adjacent bowel.

ANEURYSM WALL WRAP

In patients with aneurysmal disease, the redundant aneurysm wall is wrapped around the implanted aortic graft before approximating the periaortic tissue. The redundant aneurysmal wall is usually closed over the graft with an attempt to minimize the dead space between the aortic prosthesis and the aortic wrap. In the presence of a very large aneurysmal sac, a vest-over-pants closure of the excessively redundant aortic wall may be necessary.

OMENTAL FLAPS

Occasionally, the aneurysmal aortic wall or the periaortic tissue cannot adequately cover the aortic prosthesis, especially at the level of the proximal anastomosis. This can be encountered in patients with small aneurysms or in thin patients with aortoiliac disease where an end-to-side aortobifemoral graft has been placed. Similarly, in patients in whom an aortorenal bypass or an aortomesenteric bypass has been performed in addition to an aortic reconstruction, coverage of the bypass grafts with periaortic tissue may be hard to perform without compressing the aortorenal or aortomesenteric bypass. In these situations, omental flaps can be developed and used to cover the aortic prosthesis [1, 2, 3]. Omental flaps have also been used in the management of infected aortic grafts to wrap the transected aortic stump.

The omental flap can be based on any patent omental artery. In thin patients, the entire omentum may have to be used as a flap. To cover the aortic prosthesis, the omental flaps are placed in either an anticolic or a retrocolic position. When using the anticolic position, there is a potential for the development of an internal hernia between the omentum and the colon mesentery [2]. Securing the

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omentum with a running suture along its edges can be effective in closing any potential hernia defects. The retrocolic position of the omental flap can avoid the creation of a potential hernia defect. However, this method usually requires the mobilization of the omentum from the colon and then creating a defect in the mesocolon to pass the omental flap to the desired location.

A simple technique is to create a flap based on the left omental artery, which is usually a constant anatomical finding [3]. The flap is created by dividing the omentum in an avascular plane in a direction perpendicular to the transverse colon. The splenic flexure will serve as the base of the flap, which usually measures 10–15 cm in width. The graft to be covered is exposed. The flap is allowed to fold gently over the transverse colon mesentery and is placed over the aortic prosthesis. The flap is first secured in place with few interrupted 3-0 silk sutures. A running 3-0 silk suture is also used to secure the edges of the flap to the mesocolon to prevent any herniation between the transverse colon and the omentum. In this technique, the omentum is divided in only one plane. The major part of the omentum supplied by the right and middle omental arteries is left intact and can still be placed under the midline abdominal incision.

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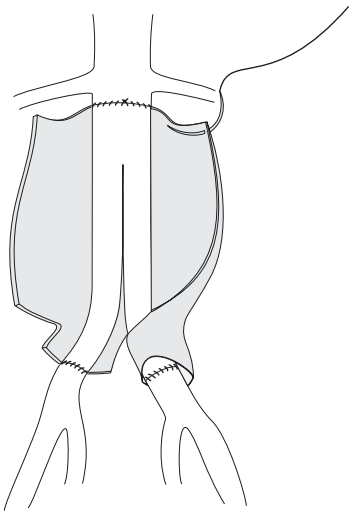
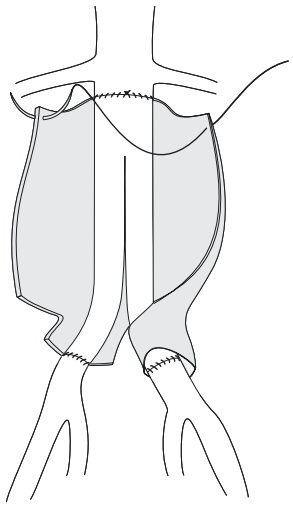
2. Foy H, Fay S, Johansen K. Bowel obstruction following omental patching of aortic grafts. Am Surg. 1985;51:661–3.
3. Hoballah JJ, Mohan CR, Nazzal MM, Corson JD. The use of omental flaps in abdominal aortic surgery: a review and description of a simple technique. Ann Vasc Surg. 1998;12:292–5.

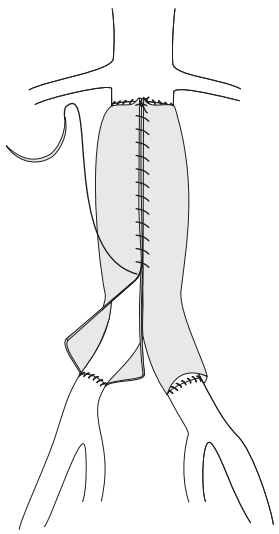
Aneurysm Wall Wrap

Start one suture in the edge of the proximal aneurysmal wall.





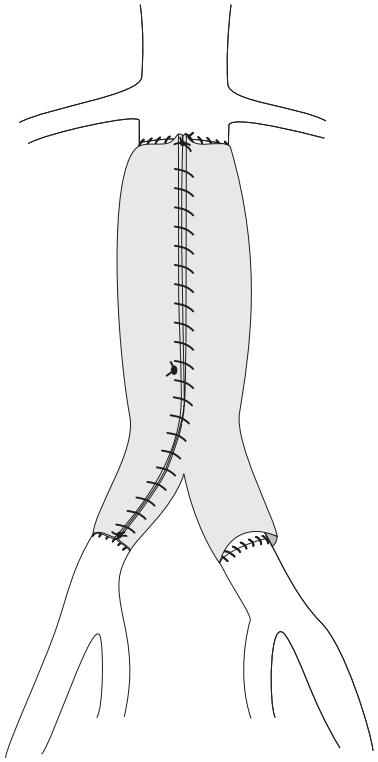
Tie the suture and run it toward the aortic bifurcation. This suture will help control bleeding from the edges of the aneurysmal wall.



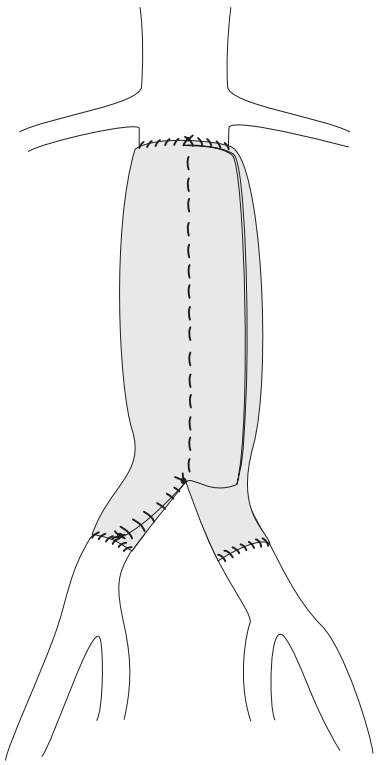
Aneurysm Wall Wrap

Start another suture in the wall of the right common iliac artery.

Run the suture cephalad.
Tie the sutures together.

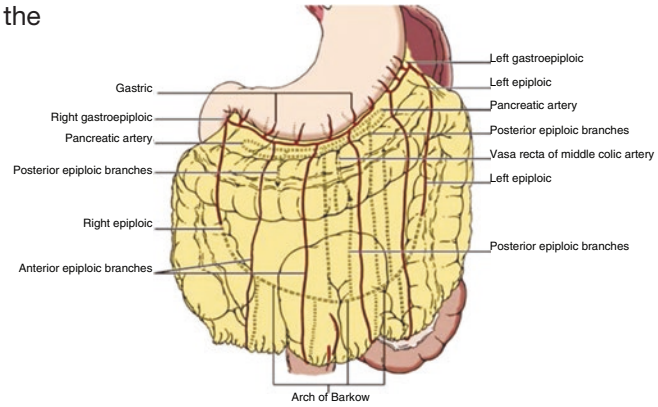


In the presence of excessive redundant aneurysmal wall, a vest-over-pants closure may help eliminate excessive dead space between the aortic prosthesis and the aortic wrap.

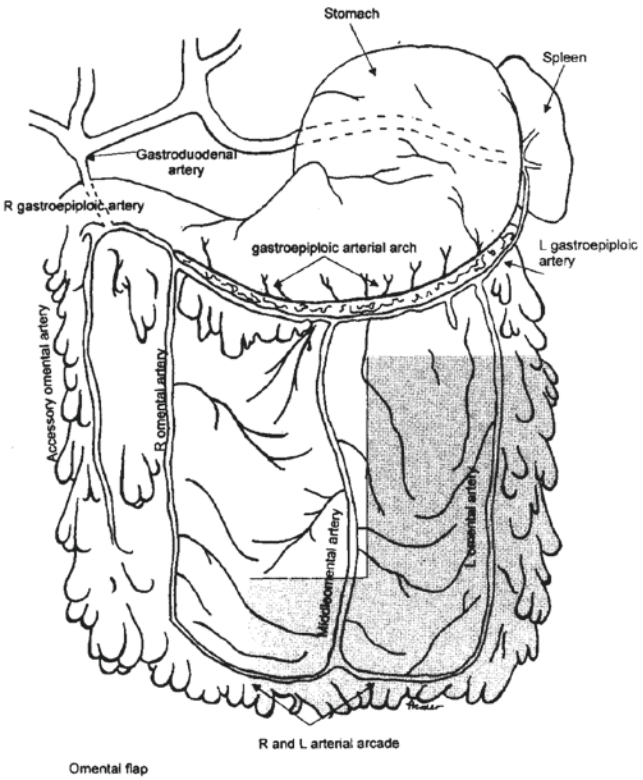


Omental Flaps

When developing an omental flap, the blood supply to the greater omentum is first evaluated.



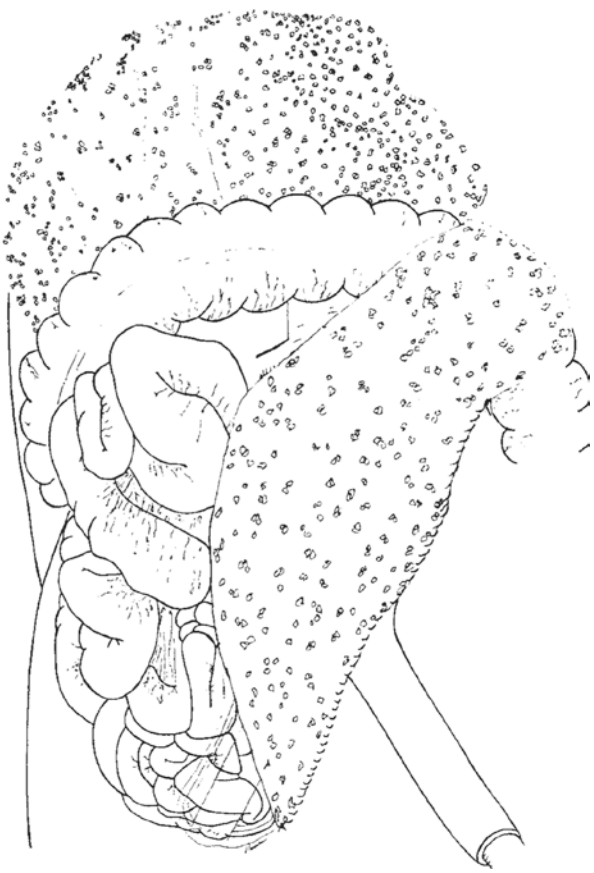
The omental flap is created by dividing the omentum perpendicular to the transverse colon. The longer flap can be developed by dividing the inferior part of the omentum parallel to the transverse colon.



Omental Flaps

The graft to be covered is exposed.

The omental flap is folded gently over the transverse colon mesentery and is placed over the aortic prosthesis. The flap is secured in place with a few interrupted sutures. The edge of the flap is secured with a running silk suture to the mesocolon.



Part V

Endovascular Surgery

19 Basic Angiography: Radiation Safety, Power Injector Use, and Image Intensifier Positioning

Zachary Williams and Leila Mureebe

Radiation Safety

Radiation exposure can lead to injury via deterministic or stochastic effects. Deterministic effects are dose-related damage to tissue, such as skin burns, hair loss, radiation sickness, cataract formation, and congenital abnormalities of fetuses that were exposed to radiation. Stochastic effects are observed in the statistically increased risk of cancer due to radiation exposure. This risk is not directly dose-related, but a higher cumulative lifetime dose increases the risks of radiogenic cancer.

During angiography, x-ray beams are emitted from the x-ray generator and directed through the patient and angiography table towards the image intensifier (Fig. 19.1). The majority of the radiation passes between the generator and the image intensifier, but when the x-ray beams hit the patient and table, radiation scatter occurs and impacts the surrounding healthcare workers.

The amount of radiation employed during a given procedure varies significantly between operators. Diligent radiation management by the operator can produce the greatest modification of the radiation exposure to the patient and healthcare staff. Before starting the procedure, the interventionalist operating the fluoroscopy pedal should ensure that all members of the healthcare team are wearing adequate protective equipment. Healthcare workers operating within 4 feet of the image intensifier should wear a two-piece 0.5 mm lead equivalent apron, thyroid shield, and leaded glasses. A radiation dosimeter should be worn to ensure that personnel exposure remains below allowable limits. There should be routine monitoring and feedback of dosimetry results. A movable below-table lead skirt and ceiling-mounted leaded glass shield should be used to block and reduce scatter exposure (Fig. 19.2).

Fig. 19.1 X-ray generator and image intensifier

The operator should use fluoroscopy only when looking at the image and should make liberal use of last-frame hold to review imaging. Use of magnification should be minimized when possible, because magnification generates higher radiation doses. Pulse fluoroscopy should be used in place of cine fluoroscopy whenever possible. Cine runs are automatically stored, but pulse fluoroscopy runs are not, so the operator should be sure to store the run if he or she wishes to save it for later review. For cine fluoroscopy, the lowest frames per second that achieves adequate image quality

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Fig. 19.2 Angiography suite with below-table lead skirt and ceiling-mounted shield

should be used. Careful timing of contrast injection also can decrease the duration of cine fluoroscopy runs. The power injector has an option for radiation delay. For example, if the tip of the catheter is in the common femoral artery and the tibial arteries are being imaged, a 2-second radiation delay allows time for the contrast to reach the target vessel, minimizing radiation exposure. Longer radiation delays are needed if significant arterial occlusive disease is present. Maintaining the image intensifier as close to the patient as possible also decreases scatter and maximizes the image area. Positioning the patient closer to the x-ray generator decreases scatter radiation but increases the dose to the patient. Collimation—shutters to limit the x-ray field—should be utilized whenever possible (Fig. 19.3). Collimation should exclude areas at the far ends of the exposure spectrum (air, metal) and allow enough context for image identification afterwards.

Fluoroscopy times over 60 minutes should be avoided; consider performing procedures in stages. If prolonged radiation exposure does occur, the patient should be notified to look for skin changes over the area that received the highest dose. Rigorous clinical follow-up must be documented.

The operator should stand as far away from the x-ray generator and patient as feasible. The x-ray scatter attenuates proportionally to the inverse of the distance from the x-ray source squared ($1/d^2$). Use of a power injector for digital subtraction runs can allow the operator to step further away than is necessary with hand injections. Scatter increases with the thickness of the patient at the treatment area, so procedures in obese patents and excessive image angulation produce more scatter radiation and often require higher radiation doses to achieve adequate image quality. The left anterior oblique and cranial angulations provide the highest exposure to the operator when standing to the patient's right side.

Use of the Power Injector

The power injector (Fig. 19.4) is a high-pressure contrast injector used to administer precise contrast boluses during cine digital subtraction runs. A typical setting for aortic imaging would be a rate for 20 mL/second for a total of 30 mL of contrast at a pressure of 800 PSI, colloquially described as "20 for 30 at 800." Hand injections are often used for imaging within more distal arteries, but power injection can be used safely by reducing the pressure and flow. In addition, the bolus can be administered over a longer time by adding a "rise" to the settings, which serves to minimize catheter whip during power injection via selective catheter. Table 19.1 lists commonly used rates and volumes at various arterial locations. In general, vessel diameter relates to the flow rate, and the resistance of the vascular bed determines the volume injected.

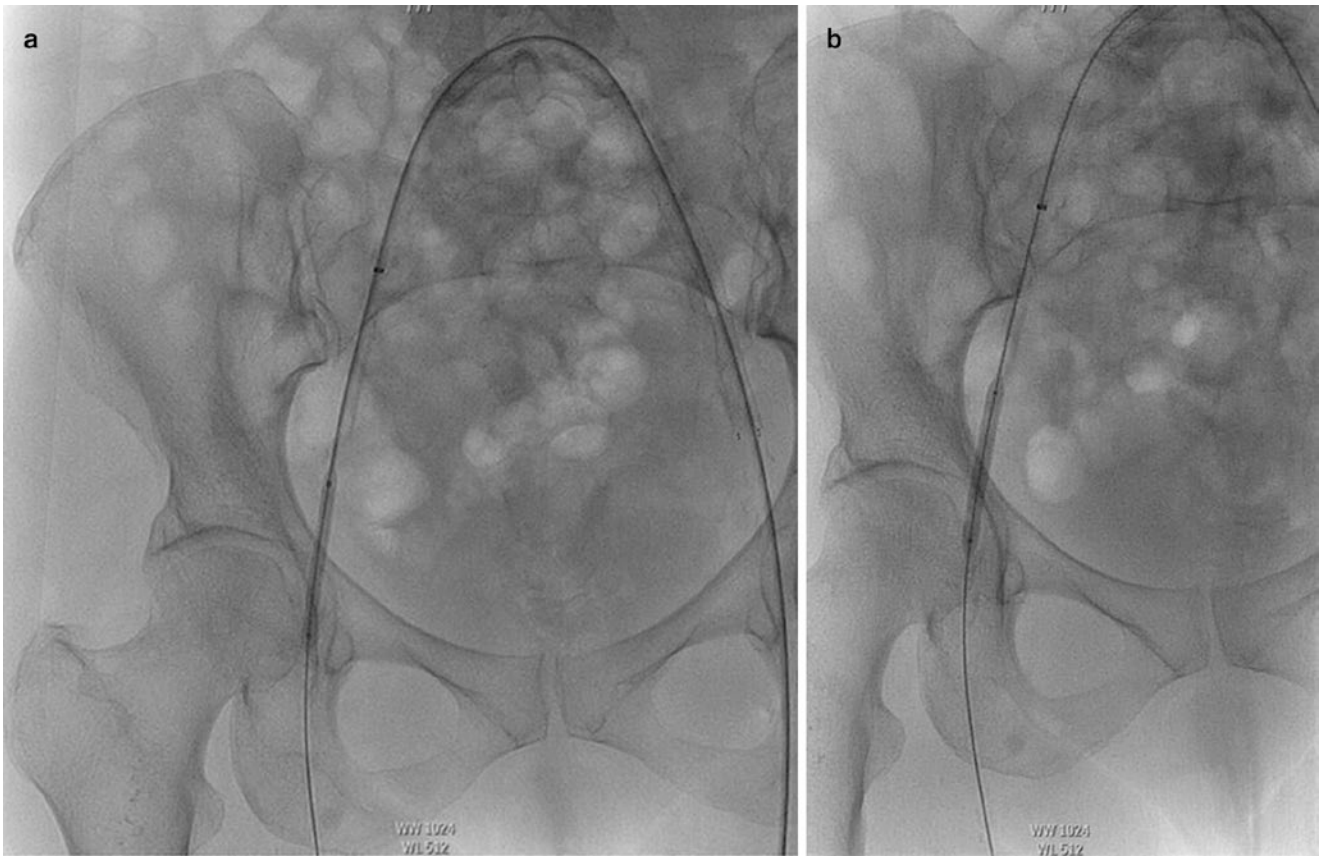

Fig. 19.3 Image without collimation (left) and collimated image (right)

Fig. 19.4 Power injector

Table 19.1 Example Contrast Injection Settings by Location

Location	Rate (mL/sec)	Total Volume (mL)	Pressure (PSI)
Aorta	20	30	800
Iliac	15	10	800
Infrainguinal	6	10	200

Image Intensifier Positioning

As discussed previously, the image intensifier should be kept close to the patient and angulation avoided to minimized radiation scatter. Sometimes, however, angulation is necessary to visualize the target vessel. Imaging of the aortic arch typically requires 35–45° of left anterior oblique angulation. The mesenteric orifices are best visualized with a complete lateral view. Visualization of the iliac bifurcation requires 15–25° of contralateral anterior oblique view, and 15–45° of ipsilateral anterior oblique view is typically needed to image the femoral bifurcation.

Suggested Reading

American College of Cardiology Foundation/American Heart Association/American College of Physicians Task Force on Clinical Competence and Training; Society of Atherosclerosis Imaging and Prevention; Society for Cardiovascular Angiography and Interventions; Society of Cardiovascular Computed Tomography; Society for Cardiovascular Magnetic Resonance; Society for Vascular Medicine and Biology, et al. ACCF/AHA 2007 clinical competence statement on vascular imaging with computed tomography and magnetic resonance: a report of the American College of Cardiology Foundation/American Heart Association/American College of Physicians Task Force on Clinical Competence and Training: developed in collaboration with the Society of Atherosclerosis Imaging and Prevention, the Society for Cardiovascular Angiography and Interventions, the Society of Cardiovascular Computed Tomography, the Society for Cardiovascular Magnetic Resonance, and the Society for Vascular Medicine and Biology. Circulation. 2007;116:1318–35.

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General Considerations for Endovascular Access

20

John T. Baber Jr and Sharif Ellozy

The initial step when performing an endovascular procedure is obtaining access to the vasculature. Whether access is obtained percutaneously or via surgical cut-down and exposure of the vessel, the first principle that must be employed is identifying the appropriate anatomic landmarks for the intended access site. Once the intended access site has been localized by these landmarks, surgical exposure can be undertaken. Alternatively, if percutaneous access is planned, further identification of the vessel and the intended site of puncture is undertaken using a combination of ultrasound and fluoroscopic guidance. These specifics of vessel localization and identification for access for specific sites are discussed in this chapter.

After the intended site of access has been identified, percutaneous access to the vessel is gained using standard Seldinger technique (Fig. 20.1). Under ultrasonographic guidance, a small-caliber (typically 21-gauge) needle is advanced into the vessel until blood-return is visualized, and an appropriately-sized guide-wire is advanced through the needle and into the vessel. Once placement of the wire into the appropriate vessel is confirmed using fluoroscopy or ultrasound, the needle may be removed, and a larger-diameter access device can be inserted over the wire. Once this larger-gauge access has been inserted, the access wire can exchanged for a larger-diameter wire suited for performing vascular intervention.

Femoral Artery Access

The common femoral artery (CFA) is the most common access site for the performance of vascular interventions. It is located on the anteromedial aspect of the proximal thigh, and is defined from the more proximal external iliac artery (EIA) by the inguinal ligament and the branching of the inferior epigastric artery. It bifurcates in the proximal thigh into the superficial femoral artery (SFA) and profunda femoris artery (PFA). Of note, 90% of CFAs cross the femoral head, but the remaining 10% have a high take-off of the PFA and will be at risk of inadvertent puncture (Fig. 20.2).

Percutaneous Access

Percutaneous access of the CFA begins with visualization of the artery using ultrasound. The CFA can be differentiated from the more medial common femoral vein (CFV) based on the compressibility of the vein (Fig. 20.3). Ultrasound should be used to trace the path of the CFA and identify the site of bifurcation into the SFA/PFA (Fig. 20.4). A suitable site for puncture of the artery should be identified proximal to this bifurcation, and the overlying site on the skin should be marked with a radiopaque instrument, such as a Kelly clamp. Fluoroscopy should then be employed to confirm that the planned access site overlies the distal third of the femoral head (Fig. 20.5), which serves as a solid surface against which pressure may be held to control bleeding from the access site.

Once a suitable site has been identified (no thrombus and minimal calcifications), access to the vessel is performed using Seldinger technique. It is the author's preference to use a micropuncture access set with 21-gauge needle and 0.018-inch wire and Seldinger technique, followed by insertion of a 4F micropuncture sheath. After successful placement of the 4F micropuncture sheath, a 0.035-inch guidewire is inserted, and a sheath of appropriate diameter and length for the planned intervention can be positioned. Alternatively, a 19-gauge needle may be employed for arterial puncture, followed by insertion of a 0.035-inch guidewire.

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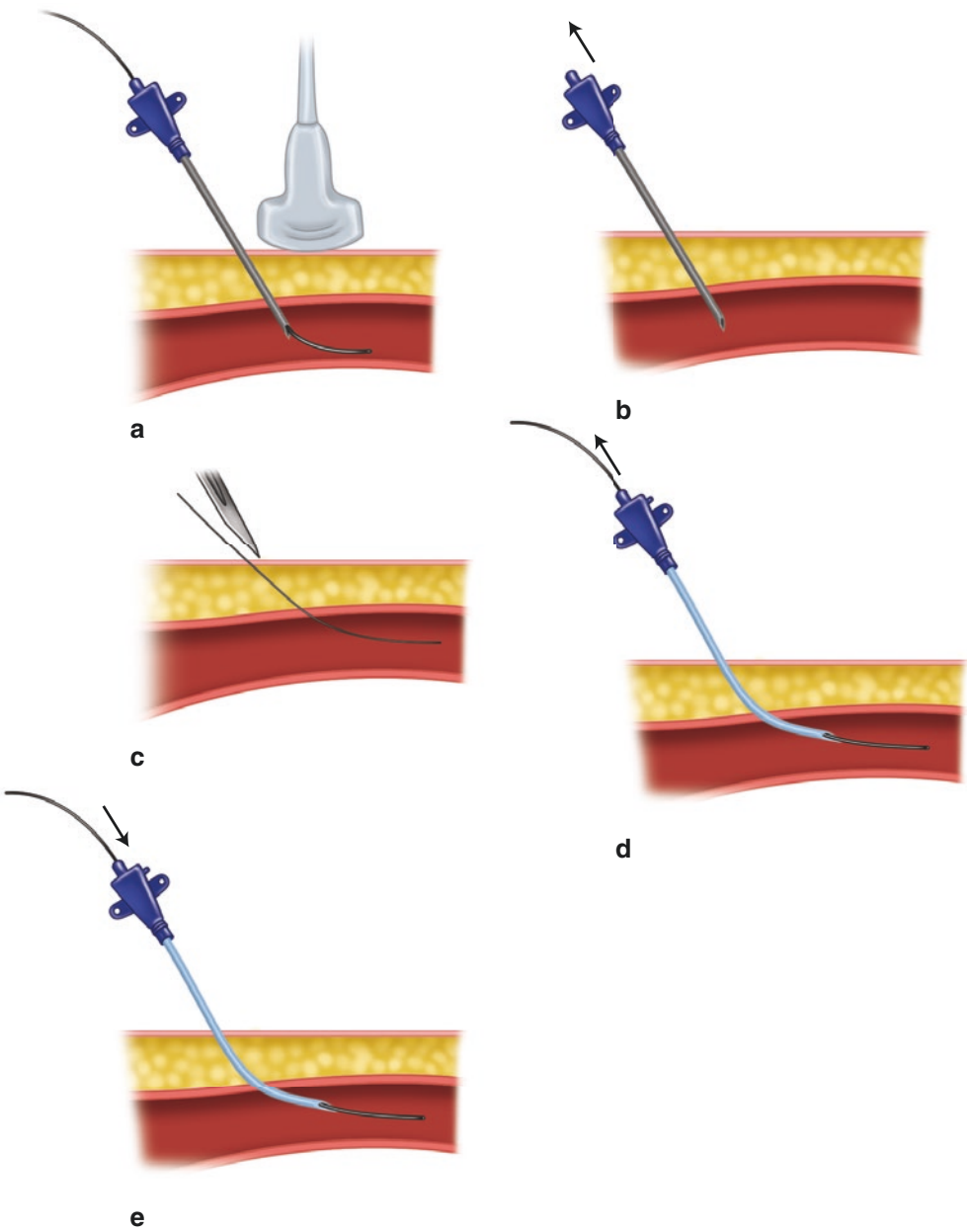

Fig. 20.1 (**a–e**), Seldinger technique

Suture-Mediated Closure (Pre-Close Technique)

If the planned intervention requires a sheath of 8F diameter or greater, post-procedure hemostasis cannot be achieved through the use of arteriotomy closure devices placed at the end of the procedure. Use of the Perclose ProGlide™ device (Abbott, Abbott Park, IL, USA) in a pre-close technique allows a suture to be placed around the access site at the beginning of the procedure; this technique allows percutaneous closure of arteriotomies of up to 24F. The following description of the pre-close technique is adapted from the Instructions for Use for the Perclose ProGlide device [1].

After successful access to the CFA is achieved with a 10 cm, 5F sheath and 0.035-inch guidewire, the 5F sheath is removed, leaving the wire in place. Pressure is held at the arteriotomy site while the first ProGlide device is inserted over the wire and into the arteriotomy (Fig. 20.6a). Once the guidewire exit port is at skin level, the guide-wire is removed (Fig. 20.6b), and the device is inserted until pulsatile blood flow is noted from the marker lumen (Fig. 20.6c). The device is then rotated 30° away from midline, and the footplate is deployed (Fig. 20.6d, e). The device is then retracted until pulsatile flow from the marker lumen ceases and resistance is felt (Fig. 20.6f). The device plunger is then depressed, deploying the suture through the arterial wall (Fig. 20.6g).

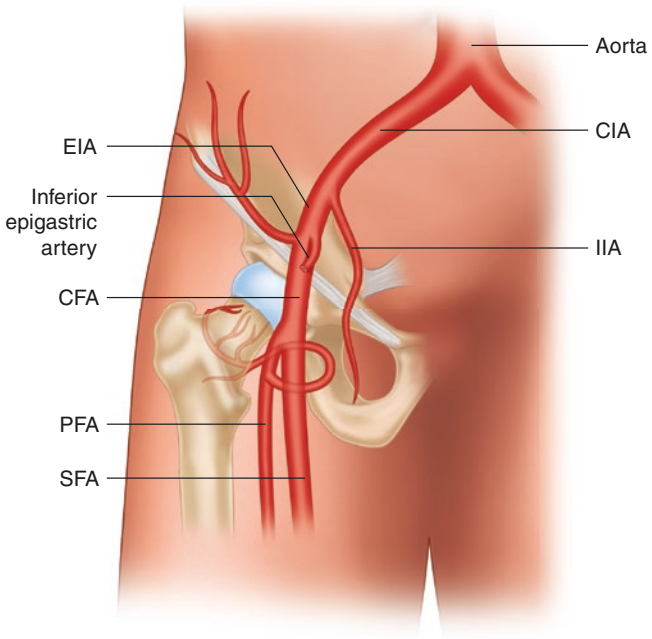

Fig. 20.2 The common femoral artery (CFA) is the most common access site for the performance of vascular interventions. It is located on the anteromedial aspect of the proximal thigh, and is defined from the more proximal external iliac artery (EIA) by the inguinal ligament and the branching of the inferior epigastric artery. It bifurcates in the proximal thigh into the superficial femoral artery (SFA) and profunda femoris artery (PFA)

The plunger is then removed from the device (Fig. 20.6h), and the attached suture is cut using either scissors or the included QuickCut® device (Fig. 20.6i). The footplate lever is then returned to its starting position (Fig. 20.6j), and the ProGlide device is carefully removed from the arteriotomy until the guidewire exit port and deployed sutures are identified (Fig. 20.6k). The sutures are secured with a rubber-shodded clamp, with care taken to avoid placing tension on the non-rail (white-tip) suture (Fig. 20.6l), and the guidewire is then re-inserted via the exit port into the artery until the tip is visualized in the distal abdominal aorta (Fig. 20.6m). The device is subsequently removed over the guidewire, while applying manual pressure to the arteriotomy site.

The above sequence of steps is then repeated with a second ProGlide device, taking care to rotate the device 30° away from the midline in the opposite direction before deployment. When the use of devices of very large diameter (20F or greater) is expected, a third ProGlide device can be deployed, with the device remaining in the midline at the time of deployment. After placement of the appropriate number of ProGlide sutures, an 8F or larger sheath can then be inserted over the guidewire.

At the end of the procedure, advance a 0.035-inch guidewire into the vessel. Remove the clamp from the sutures from the first ProGlide device, and wrap the rail (blue) suture around the left forefinger. Apply back tension on the rail suture in a direction coaxial to the tissue tract while the sheath is removed over the guidewire, and hold manual pres-

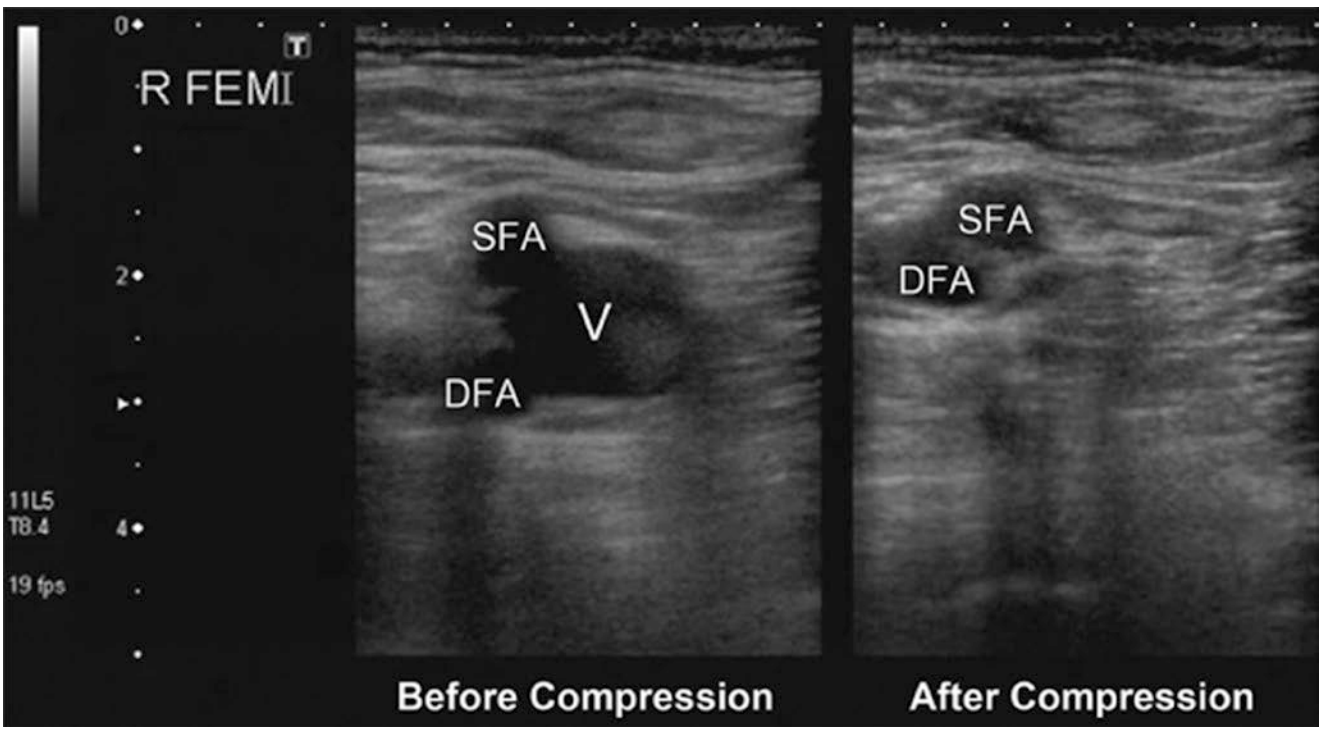

Fig. 20.3 Visualization of the CFA using ultrasound, before and after compression, differentiating it from the common femoral vein (CFV)

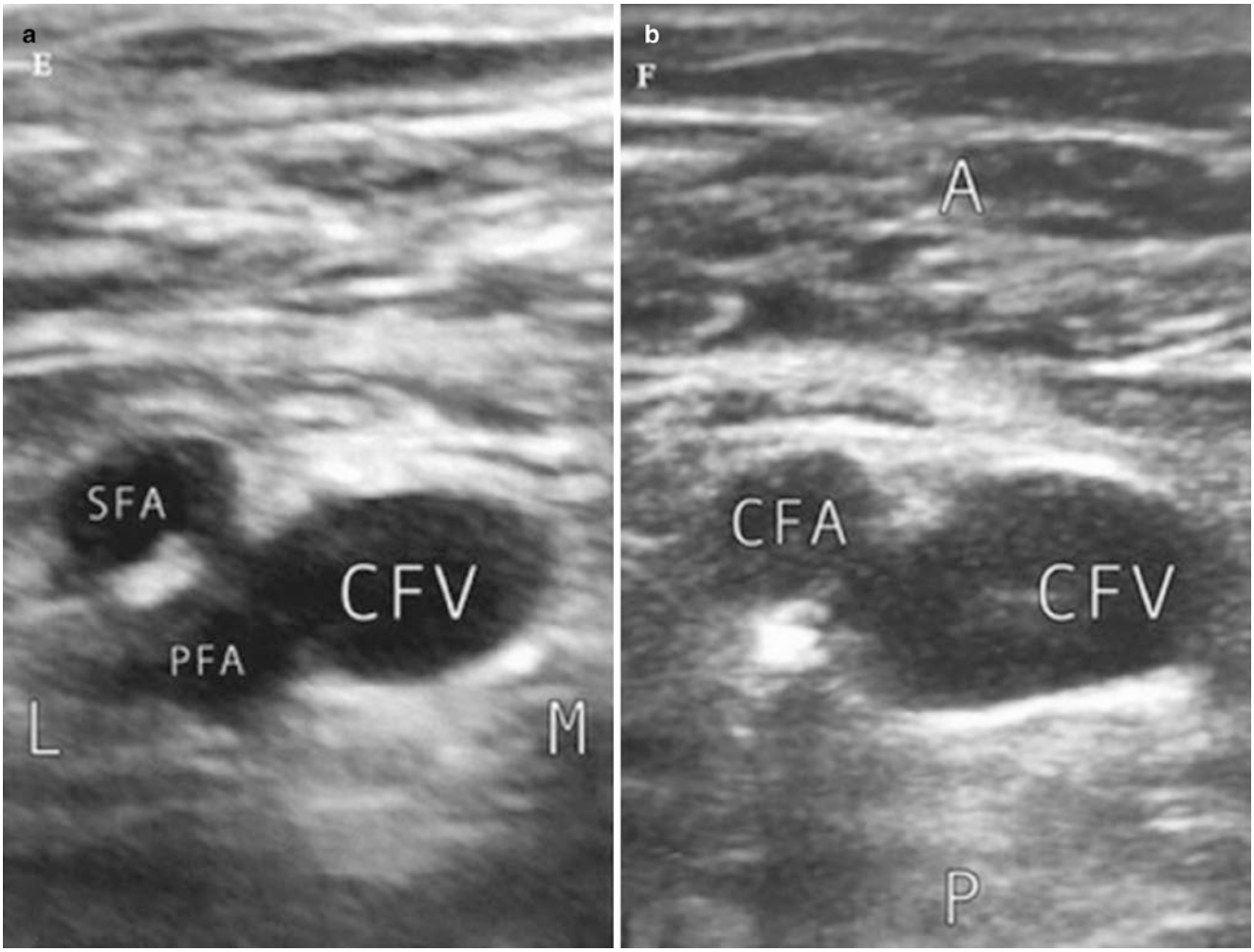

Fig. 20.4 Identifying the level of the bifurcation of the CFA into the SFA and PFA, using ultrasound. CFV common femoral vein

sure over the arteriotomy. The provided knot-pushing device can be placed onto the rail suture to aid in the advancement of the suture knot (Fig. 20.7a). The rail and non-rail sutures are then re-secured to one another using a clamp, and this process is repeated with the remaining ProGlide sutures. Hemostasis is then assessed by removal of manual pressure from the arteriotomy site. If hemostasis appears inadequate, an additional ProGlide device can be inserted over the guidewire and deployed.

Once hemostasis is deemed adequate, the guidewire is removed from the arteriotomy (Fig. 20.7b) and the first rail suture is once again placed on tension while the knot pusher is advanced along it until the knot is against the arteriotomy (Fig. 20.7c). The knot is then secured by pulling firmly on the non-rail (white) suture (Fig. 20.7d). This sequence is then repeated until all knots are secured. The sutures can then be cut using the associated cutting device.

Alternatively, if mild bleeding from the puncture site is identified after the knots are secured, a Rummel-style tourniquet can be fashioned by cutting a segment of plastic tubing from the injection port of a sheath, as originally described by Furlough et al. [2]. The tails of the suture are then threaded through the tubing, and pressure is applied against the suture knot by simultaneously pulling up on the sutures and pressing down with the tubing. The tubing can then be secured in place for 5–10 minutes by applying a clamp to the sutures above the tubing (Fig. 20.8). After hemostasis is confirmed, the sutures can be cut in normal fashion.

Brachial Artery Access

Several contraindications to brachial artery access should be considered prior to deciding on an access site. Appropriate preoperative imaging should be obtained to confirm that the more proximal upper extremity vessels are patent and of an appropriate diameter to accommodate the necessary devices. Typically, 7F is the maximum diameter that can be placed in the brachial artery without risking arm ischemia or damage to the vessel, but the size of the brachial artery may vary

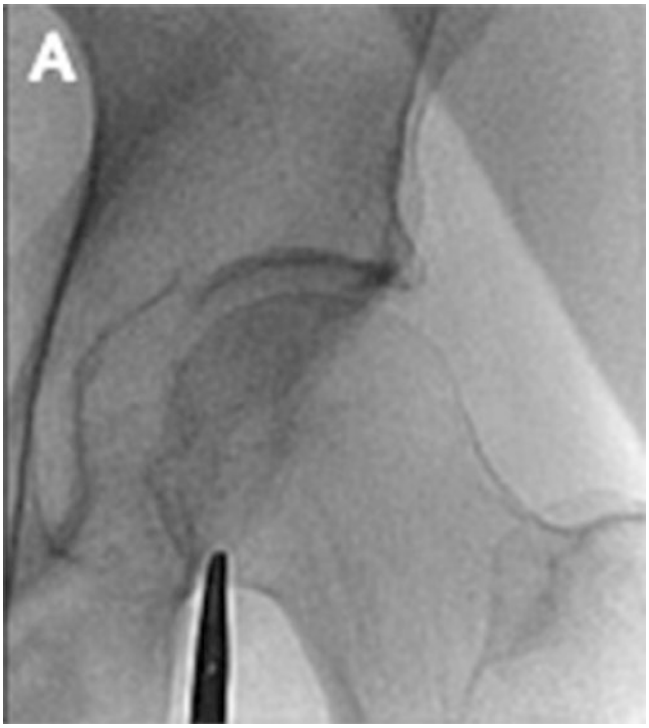

Fig. 20.5 Identification of the femoral head underlying the planned access site, using fluoroscopy

considerably based on the size and gender of the patient. The distance from the access site to the planned site of intervention should also be considered, and devices of appropriate length should be available. The presence of an arteriovenous fistula for hemodialysis on the upper extremity excludes it from use as an access site, owing to risk of fistula thrombosis. Prior exposure of the brachial artery may obscure dissection planes, making exposure more difficult.

Percutaneous Access

For percutaneous access of the low brachial artery, the arm is circumferentially prepped and positioned in an extended and supinated position on an arm board. Using ultrasound guidance, the brachial artery is identified a few centimeters proximal to the antecubital crease, where the artery can be compressed against the distal humerus for postprocedural hemostasis (Fig. 20.9). Care should be taken to identify and avoid the median nerve, which lies in close proximity to the artery in this location. After identification of an appropriate window, access should be gained with a 21-gauge micropuncture needle, with placement of an 0.018-inch wire into the vessel, and exchange for a micropuncture sheath. An 0.035-inch wire of can then be introduced into the vessel and advanced under fluoroscopic guidance into the subclavian artery, with subsequent exchange of the micropuncture sheath for a 10-cm 5F sheath. After initial sheath placement, the patient should be systemically anticoagulated to reduce the risk of arterial thrombosis.

After conclusion of the procedure, systemic anticoagulation should be reversed, or appropriate time should be allowed to elapse for the activated clotting time to reach an appropriate level before the sheath is removed and manual pressure is applied to the puncture site, compressing the artery against the distal humerus.

Once hemostasis is achieved, neurovascular checks should be performed regularly for at least 2 hours to rule out postoperative bleeding, nerve compression, or ischemia. Development of such symptoms may necessitate urgent surgical exploration for hematoma evacuation, nerve decompression, arterial repair, or thrombectomy. The brachial sheath is a small space, so even a small hematoma can potentially cause nerve compression.

Open Surgical Exposure

After preparation and positioning of the patient's arm as described above, a site for arterial access is chosen. Use of the more proximal brachial artery allows access to a larger vessel, which may accommodate up to two 7F sheaths for intervention, whereas the diameter of the distal brachial artery typically restricts the surgeon to a single 7F sheath. In either location, the artery may be identified on the medial aspect of the arm, posterior to the belly of the biceps brachii, by palpation of the pulse or through the use of ultrasound (Fig. 20.10a). After the overlying skin is incised and the overlying subcutaneous tissues are dissected, the artery should be separated from the neighboring median nerve, ulnar nerve, and brachial vein (Fig. 20.10b). It is then circumferentially dissected for an adequate length for access, and controlled proximally and distally with vessel loops. The brachial artery is then accessed using a micropuncture set as described previously, with at least 2 cm separating puncture sites if multiple sheaths are employed (Fig. 20.10c). After completion of the procedure, the sheaths are withdrawn, and the arteriotomies are closed primarily with 6–0 polypropylene suture in an interrupted fashion (Fig. 20.10d).

Axillary Artery Access

Techniques for use of the axillary artery during complex endovascular procedures have generally been developed in response to the shortcomings presented by more distal upper extremity arterial access. Such limitations include long working distance, limitations in sheath diameter, potential for limb ischemia, and risk of nerve injury. Additionally, when the axillary artery is utilized, the patient's arm can be

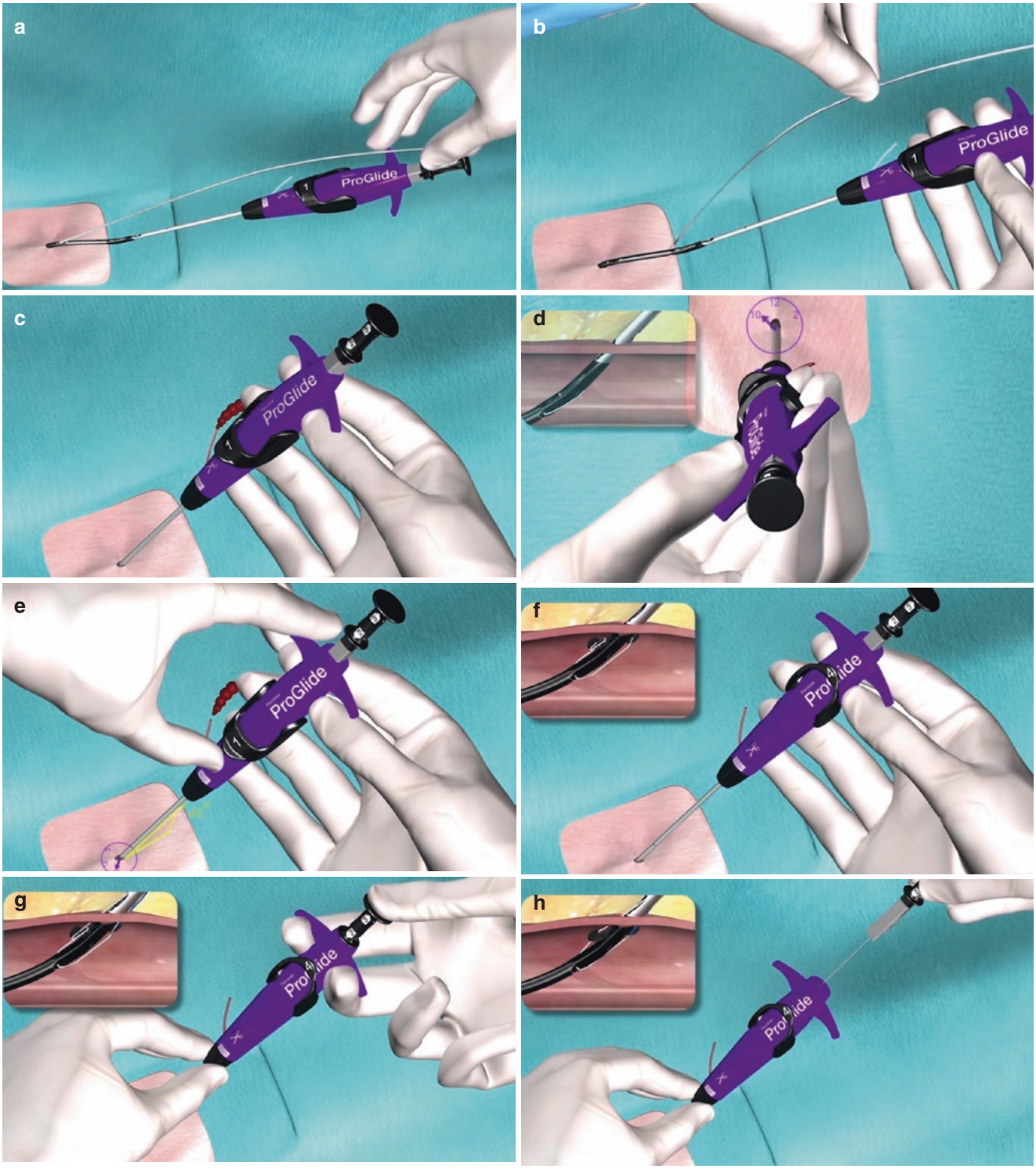

Fig. 20.6 Pre-close technique for use of the Perclose ProGlide™ device. (**a**) The first ProGlide device is inserted over the wire and into the arteriotomy. (**b**) Once the guidewire exit port is at skin level, the guidewire is removed. (**c**) The device is inserted until pulsatile blood flow is noted from the marker lumen. (**d**, **e**) The device is then rotated 30° away from midline, and the footplate is deployed. (**f**) The device is then retracted until pulsatile flow from the marker lumen ceases and resistance is felt. (**g**) The device plunger is then depressed, deploying the suture through the arterial wall. (**h**, **i**) The plunger is then removed from the device and the attached suture is cut, using either scissors or the included QuickCut® device. (**j**) The footplate lever is then returned to its starting position. (**k**) The ProGlide device is carefully removed from the arteriotomy until the guidewire exit port and deployed sutures are identified. (**l**) The sutures are secured with a rubber-shodded clamp, with care taken to avoid placing tension on the non-rail (white-tip) suture. (**m**) The guidewire is then re-inserted via the exit port into the artery until the tip is visualized in the distal abdominal aorta. The device is subsequently removed over the guidewire, while applying manual pressure to the arteriotomy site [16]

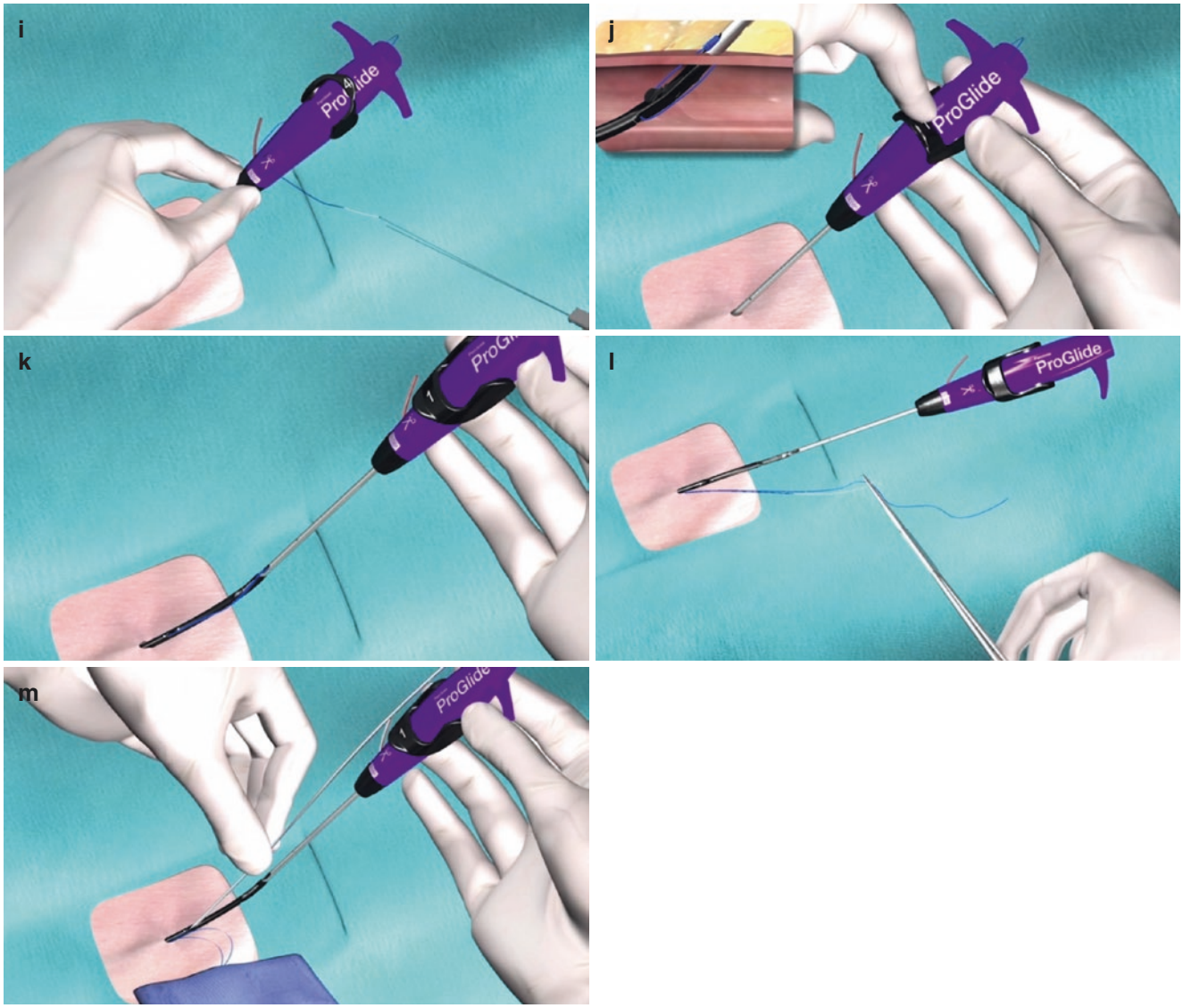

Fig. 20.6 (continued)

positioned at his or her side, facilitating rotation of the C-arm during the procedure.

Several relative contraindications to use of the axillary artery for access may necessitate the use of the contralateral side or a different access site altogether. The presence of an overlying permanent pacemaker, tunneled catheter, or subcutaneous port can obstruct exposure of the artery. Patients with bypasses from the left internal mammary artery to the left anterior descending coronary artery should not undergo left axillary artery access because of a risk of occluding the inflow to the bypass, resulting in myocardial ischemia. The difficulty of exposing the artery may be greater in obese or barrel-chested patients. Axillary artery access on the same side as an arteriovenous fistula may promote fistula thrombosis. Finally, prior axillary artery exposure or chest-wall irradiation will obscure the dissection planes, potentially posing additional technical difficulties with exposure. In each of these cases, the risks of access should be considered, and use of the contralateral axillary artery or an alternative access site should be pursued if necessary.

Open Surgical Exposure

Open surgical exposure has become the standard method of axillary artery access for endovascular procedures. Proper exposure of the artery is facilitated by placement of a roll under the shoulder blades to extend the shoulder prior to sterile preparation of the entire arm, supraclavicular area, and thorax. Once appropriately draped, the arm is positioned at the patient's side, and the exposure is begun by making a transverse skin incision

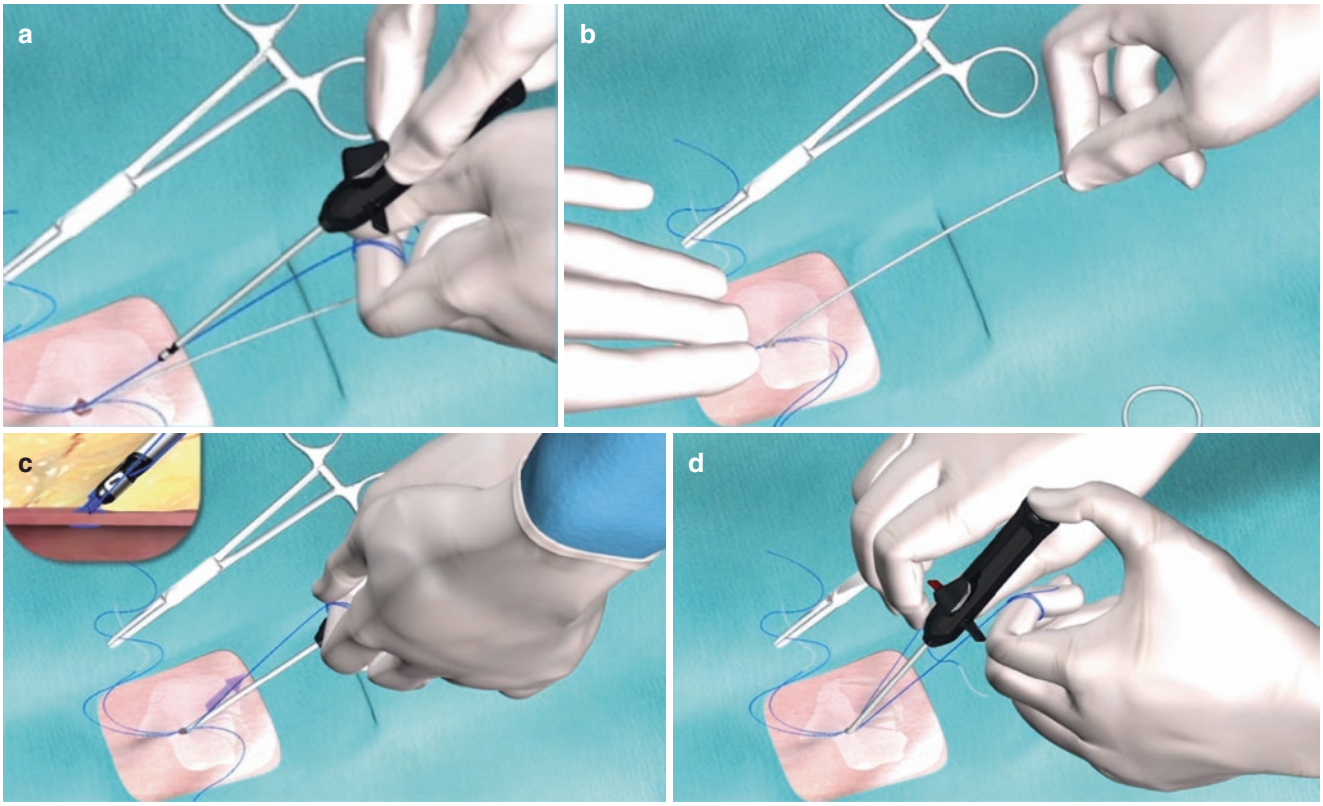

Fig. 20.7 Advancement of the suture knot using the ProGlide device. (**a**) The knot-pushing device can be placed onto the rail suture to aid in the advancement of the suture knot. (**b**) Once hemostasis is deemed adequate, the guidewire is removed from the arteriotomy. (**c**) The first rail suture is once again placed on tension while the knot pusher is advanced along it until the knot is against the arteriotomy. (**d**) The knot is then secured by pulling firmly on the non-rail (white) suture [17]

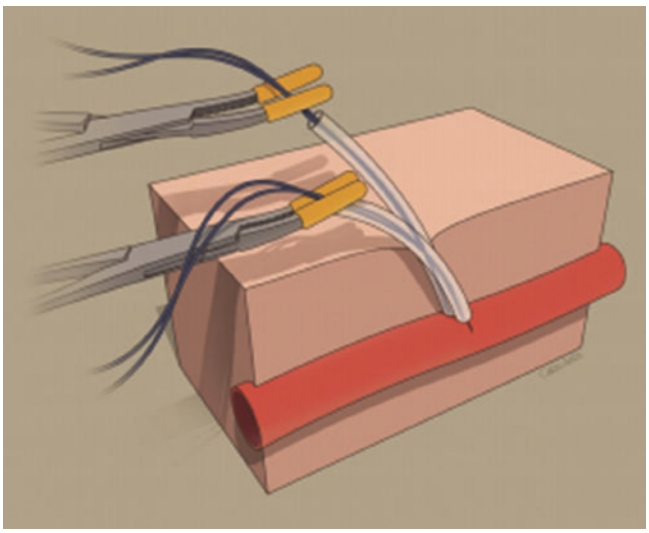

Fig. 20.8 "Sheath-tourniquet" assembly (*Reproduced from* Furlough et al. [2], *with permission from Elsevier*)

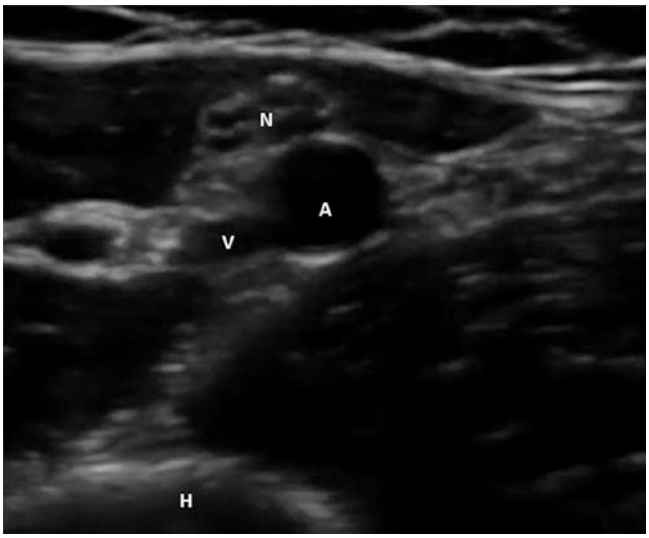

Fig. 20.9 B-mode ultrasound of the brachial artery. A brachial artery, H humerus, N median nerve, V brachial vein

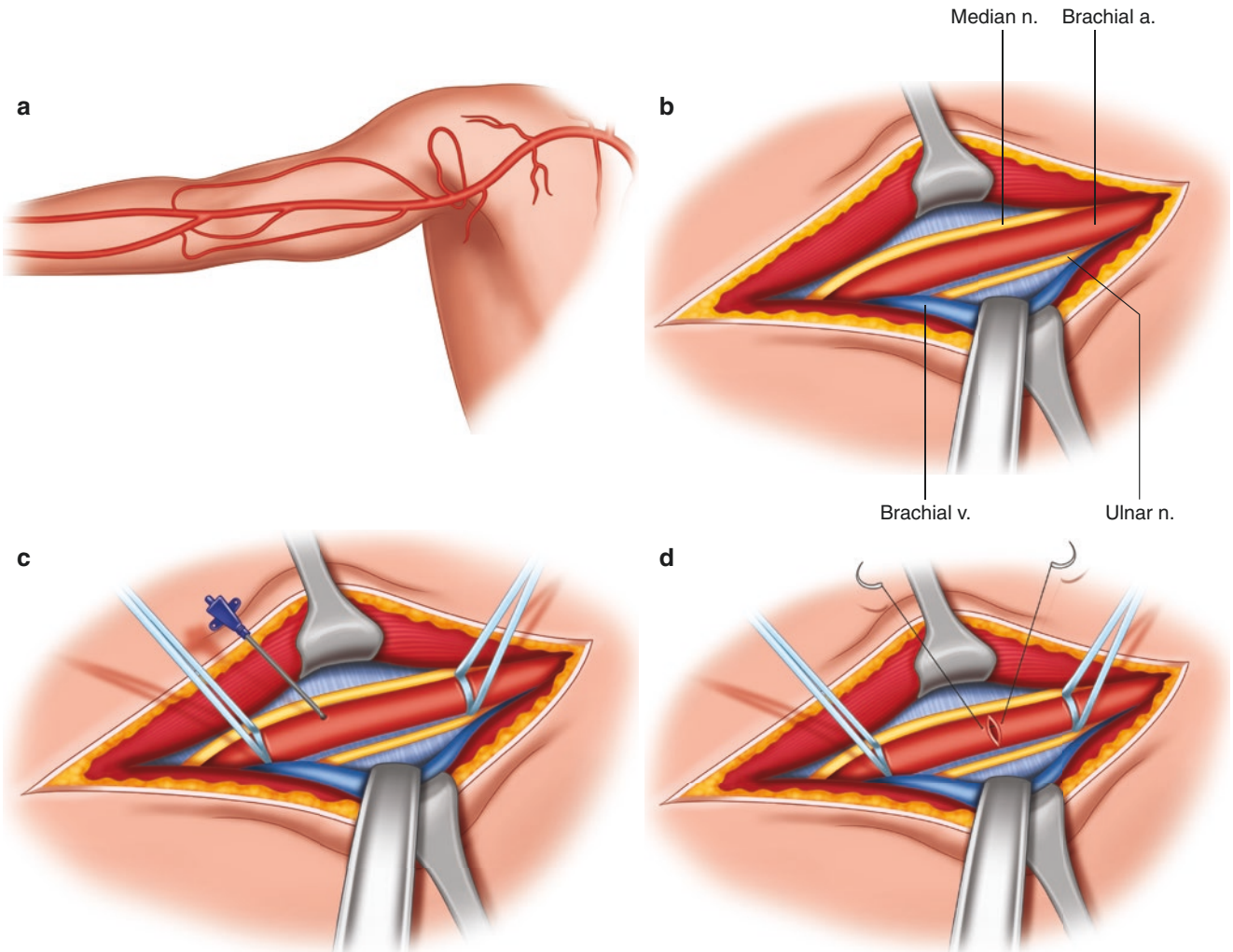

Fig. 20.10 Brachial artery access by surgical exposure. (**a**) The course of the brachial artery along the medial aspect of the arm is indicated by the *dashed line*. (**b**) Exposure of the brachial artery and surrounding structures. The proximal arm is to the right of the photo. (**c**) Access of the brachial artery. After the vessel is controlled and occluded with vessel loops proximally and distally, access is performed via standard Seldinger technique. (**d**) Closure of arteriotomy. After the sheath used for access is removed, the remaining arteriotomy is repaired with multiple interrupted polypropylene sutures

one fingerbreadth below the clavicle beginning at the medial aspect of the middle third of the clavicle and extending towards the deltopectoral groove (Fig. 20.11a). After dissection of the subcutaneous tissues, the pectoralis major fascia is incised and the muscle fibers are separated bluntly, exposing the clavipectoral fascia (Fig. 20.11b). This layer is then incised, exposing the pectoralis minor and the axillary sheath, which is opened sharply (Fig. 20.11c). The axillary vein must be carefully dissected off the anterior aspect of the artery, with care taken to identify and protect branches of the brachial plexus that may come into view laterally (Fig. 20.11d). The axillary artery is then circumferentially dissected and controlled (Fig. 20.11e). Careful division of the pectoralis minor muscle can allow for exposure of additional axillary artery length.

Once the axillary artery has been successfully isolated, access can be achieved either via Seldinger technique after placement of a purse-string suture in the vessel (if only small-diameter access is required), or by the construction of a conduit by performing an end-to-side anastomosis between the artery and a Dacron graft 6 mm in diameter (or larger, perhaps 10 mm if multiple sheaths are needed), using 5–0 polypropylene suture (Fig. 20.11f, g). To use a conduit, tun-

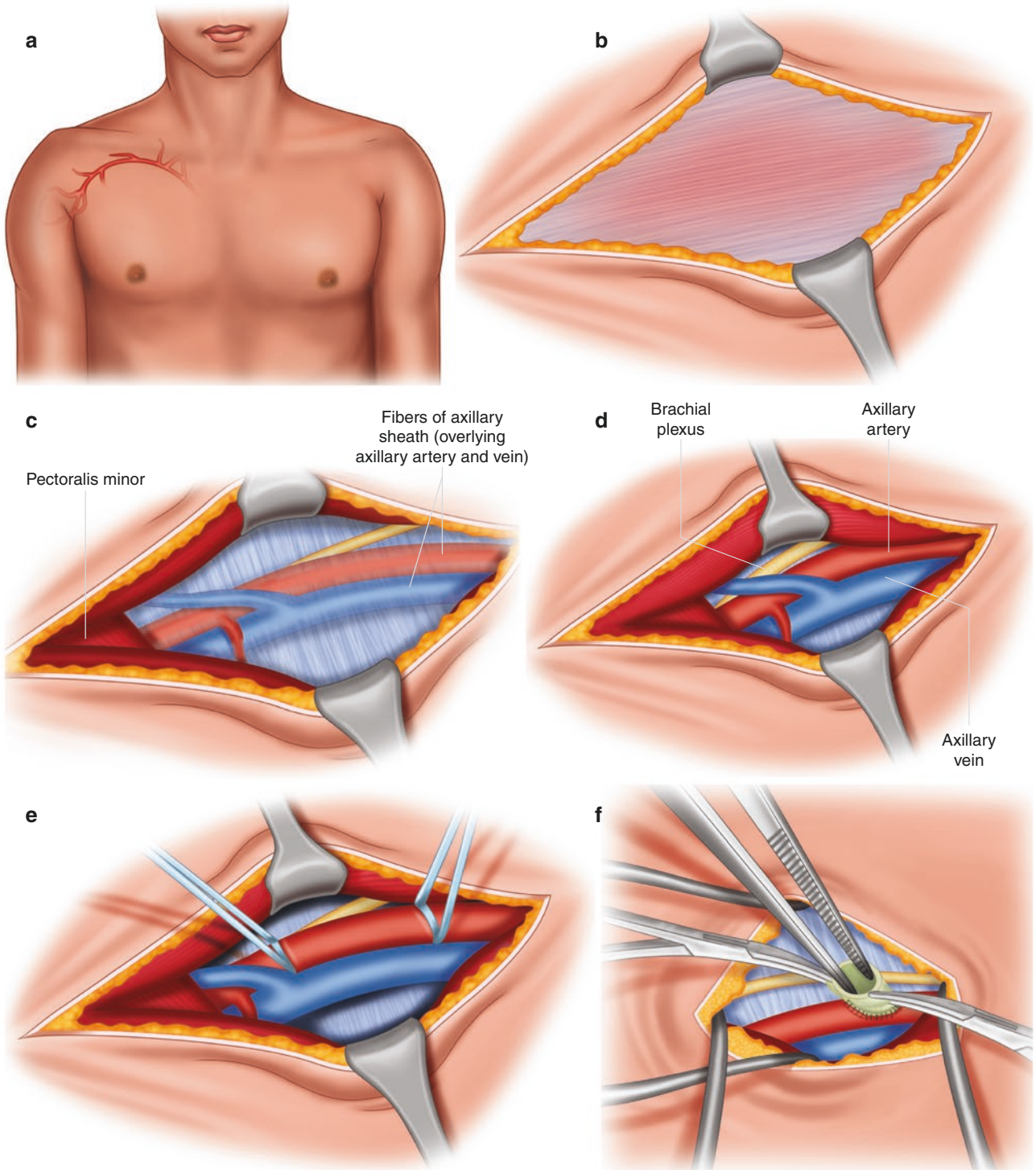

Fig. 20.11 Axillary artery access by open surgical exposure. (**a**) Typical incision for exposure of the proximal axillary artery (*dashed line*). (**b**) Dissection of the subcutaneous tissues reveals the pectoralis major and overlying fascia. (**c**) Division of the pectoralis major fascia and separation of its fibers reveals the pectoralis minor (laterally) and axillary sheath. (**d**) Incising the axillary sheath reveals the axillary vein, which must be carefully separated from the antero-inferior surface of the axillary artery. (**e**) After circumferential dissection, proximal and distal control of the axillary artery is obtained with vessel loops. (**f**) Creation of an axillary conduit. After vascular clamps are applied to the vessel proximally and distally, a longitudinal arteriotomy is created in the most superficial aspect of the vessel wall. (**g**) Creation of an axillary conduit. An end-to-side anastomosis is created between the axillary artery and a Dacron vascular graft at least 6 mm in diameter. (**h**) Creation of an axillary conduit. After completion of the anastomosis, the distal end of the conduit is brought through the skin via a separate stab-incision to prevent kinking of the graft during the procedure. (**i**) At the conclusion of the procedure, the conduit should be transected close to the anastomosis, and the remaining cuff oversewn in two layers

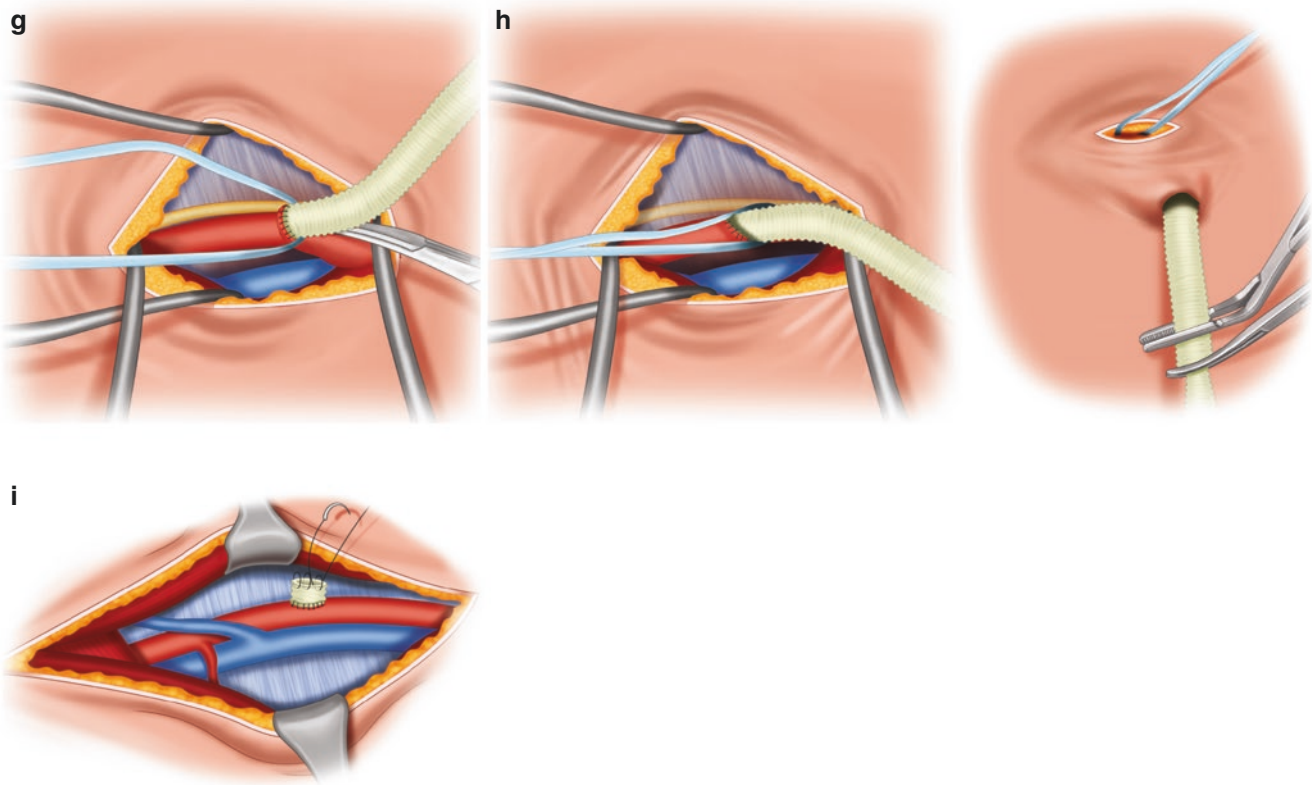

Fig. 20.11 (continued)

nel the distal end of the conduit to exit through a separate, inferolateral counter-incision, to improve ergonomics during the remainder of the case (Fig. 20.11h) [3].

At the conclusion of the case, closure of the arteriotomy is performed either through the use of the previously placed purse-string suture, or by transection of the conduit and oversewing of the remaining 3 to 4 mm of Dacron cuff in two layers (Fig. 20.11i). After hemostasis is confirmed, the subcutaneous tissues and skin are closed with multiple layers of absorbable suture.

Percutaneous Access

Given the additional surgical time required to expose the axillary artery for access, and to subsequently repair the arteriotomy and close the incision, alternative methods of accessing this vessel have been investigated. Percutaneous access of the axillary artery was initially described for the implantation of transcatheter aortic valves [4]. These techniques have been adopted for use in vascular procedures, with initial reports demonstrating positive results [5]. At this time, no device has gained FDA approval for percutaneous closure of axillary artery access.

Preoperative imaging should be used to evaluate the axillary artery, to ensure that it is of adequate diameter to accommodate the required sheath and that it and the subclavian artery are free of disease. Subsequently, the patient is sterilely prepped and draped in the same manner as for surgical exposure of the axillary artery. Ultrasound is used to visualize the axillary artery either proximal or distal to the pectoralis minor, and percutaneous access is obtained in a standard fashion, with eventual placement of a short 5F sheath into the artery over a 0.035-inch guidewire (Fig. 20.12a). Care should be taken during access of the vessel to identify and avoid the brachial nerve, which runs in close proximity to the axillary artery. Our preference is to access the artery distal to the pectoralis minor, to facilitate surgical control of the artery if it becomes necessary.

With the tip of the wire in the ascending aorta, the 5F sheath is withdrawn, and two ProGlide closure devices are deployed using the standard pre-close technique previously described for CFA access (Fig. 20.12b). After successful pre-close suture deployment, a long sheath of up to 12F can be inserted over the guidewire for intervention. Establishment of axillo-femoral arterial through-wire access facilitates navigation of larger-caliber sheaths into the descending thoracic aorta (Fig. 20.12c).

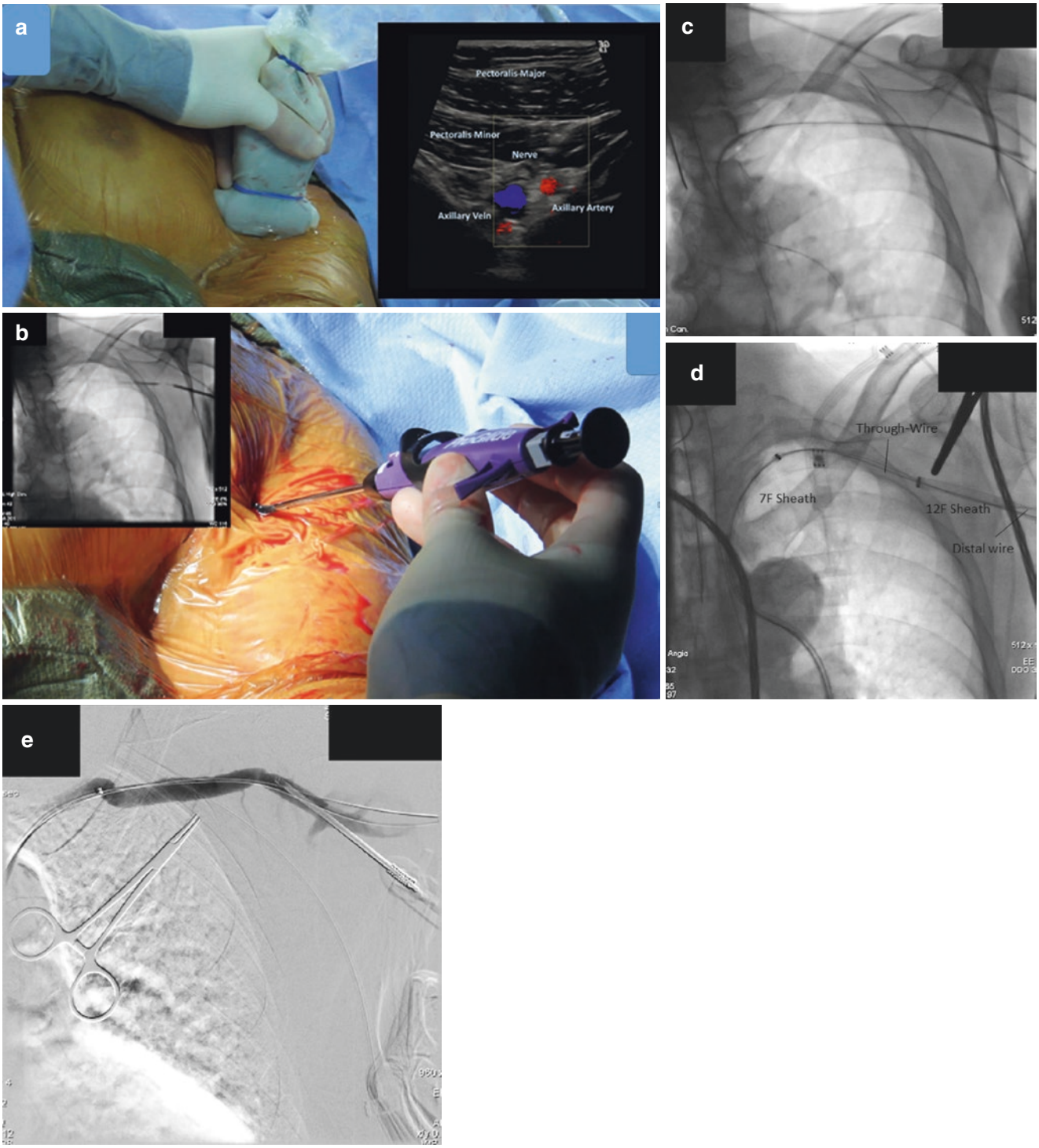

Fig. 20.12 Percutaneous access to the axillary artery. (**a**) Ultrasound identification of the axillary artery. With the patient's arm abducted to 90°, the ultrasound probe is positioned in the deltopectoral groove. *Inset:* Ultrasound imaging identifying the axillary artery, neighboring axillary vein and brachial nerve, and overlying pectoralis major and minor. (**b**) Insertion of Perclose ProGlide device. After successful guidewire insertion into the vessel, the Perclose ProGlide device is inserted into the arteriotomy for pre-close suture deployment. Device insertion should be performed under fluoroscopic guidance to ensure safe positioning of the tip of the device in the proximal subclavian artery/aortic arch. (**c**) Axillo-femoral arterial through-wire. Establishment of a through-wire facilitates delivery of a large-caliber sheath from the axillary artery into the descending thoracic aorta. (**d**) Closure of axillary arteriotomy. Prior to removal of the axillary sheath, a 7F sheath is advanced over the through wire from the femoral access site and into the subclavian artery. A wire is then passed from the femoral sheath into the brachial artery to maintain axillary arterial access during arteriotomy closure. (**e**) Completion angiogram. After the axillary sheath is withdrawn and pre-close sutures are secured, angiography via the femoral sheath demonstrates no extravasation or pseudoaneurysm

At the conclusion of the endovascular procedure, prior to attempted closure of the axillary arteriotomy, we recommend advancing a 7F sheath from the femoral artery and into the subclavian artery while the axillary sheath is withdrawn (Fig. 20.12d). After the 7F sheath is positioned within the subclavian artery, a wire is passed into the brachial artery, and a 0.035- inch wire is passed through the axillary sheath proximally to maintain wire access while the pre-close sutures are secured. Placement of a wire distal to the arteriotomy allows the surgeon to maintain access to the vessel in case of inability to close the arteriotomy with the pre-close technique. After the pre-close sutures are secured, an angiogram can be performed via the 7F sheath to confirm the absence of extravasation or pseudoaneurysm, and a covered stent-graft or occlusive angioplasty balloon can be quickly deployed if either is detected (Fig. 20.12e) [3].

Radial Artery Access

Background

Percutaneous transradial arterial access is a well-described technique in the setting of coronary angiography and intervention [6, 7]. This technique has also been employed for the treatment of noncoronary vascular disease, but the associated literature is mostly limited to case reports and small series [8–10]. Radial artery access offers some potential advantages over brachial or axillary artery access, including increased patient comfort, elimination of the potential for brachial sheath hematoma or median nerve palsy, and reduced risk of hand ischemia due to the maintained patency of the ulnar artery and palmar arch [11]. The small diameter of the access vessel and the long working lengths of the required devices limit the variety of interventions that can be performed via this method, but it is a technique with which surgeons performing advanced endovascular interventions should be familiar.

Technique

Before attempting trans-radial access (TRA), ultrasound should be used to evaluate the vessel for patency, degree of tortuosity, and size. Size greater than 2 mm is necessary for TRA to be performed. Adequacy of collateral circulation via the ulnar artery also should be evaluated with a modified Allen's test using a pulse oximeter, known as the Barbeau test (Fig. 20.13a) [12]. A pulse oximeter is placed on the patient's thumb, the radial pulse is identified, and the waveform is analyzed. The radial artery is then compressed, and the pulse oximeter waveform is again analyzed for up to 2 minutes and graded according to the following categories: (A) No dampening of the pulse tracing immediately after compression; (B) Initial dampening of the pulse with restoration of a normal waveform within 2 minutes; (C) Persistent dampening of the pulse tracing beyond 2 minutes; and (D) Loss of pulse tracing without recovery within 2 minutes. Grade D is a contraindication for TRA. The use of TRA in Grade C is at the discretion of the surgeon.

Once suitability for TRA has been confirmed, the patient's arm should be placed on an arm board at his or her side, with the wrist positioned in a supinated and extended position. The arm is sterilely prepped and draped. The radial artery is accessed using a 21-gauge micropuncture needle and 0.018-inch guidewire under ultrasound guidance (Fig. 20.13b). Once wire placement has been achieved, a slender, hydrophilic sheath designed for radial access, such as the Glidesheath Slender ® (Terumo Interventional Systems), can be inserted directly over the 0.018-inch wire. These sheaths have a thin, hydrophilic wall, which allows for luminal access of up to 7F, while maintaining an outer diameter of a typical sheath that is one French size smaller.

After successful sheath insertion, a medication "cocktail" should be administered into the artery to reduce local vascular tone and prevent vasospasm. We administer a mixture of 3000 IU of heparin, 2.5 mg of verapamil, and 200 mcg of nitroglycerin as a one-time dose, but there is no consensus on the ideal mixture [13]. Verapamil is known to produce a burning sensation, so a gradual injection is recommended.

After the completion of the procedure, hemostasis is achieved by using the patent hemostasis technique (Fig. 20.13c, d), which has been proven to have less risk of radial artery thrombosis than the standard application of manual pressure [14]. This technique is performed using a wristband such as the TR Band ® (Terumo Interventional Systems) [15]. Prior to complete removal of the radial sheath, the band is positioned over the access site and inflated to a pressure at which the distal radial artery pulse is lost. The sheath is then fully withdrawn, and the arteriotomy is observed to ensure hemostasis. If bleeding is observed, additional air is added to the band. The band is then deflated slowly until a palpable pulse returns, and if no bleeding from the arteriotomy site is observed, the band is maintained at this pressure for 30 to 120 minutes, depending on the specifics of the procedure. The band is then slowly deflated at 15-minute intervals until it is loose. If bleeding is observed from the puncture site, the band is re-inflated for 20 minutes and the process is repeated.

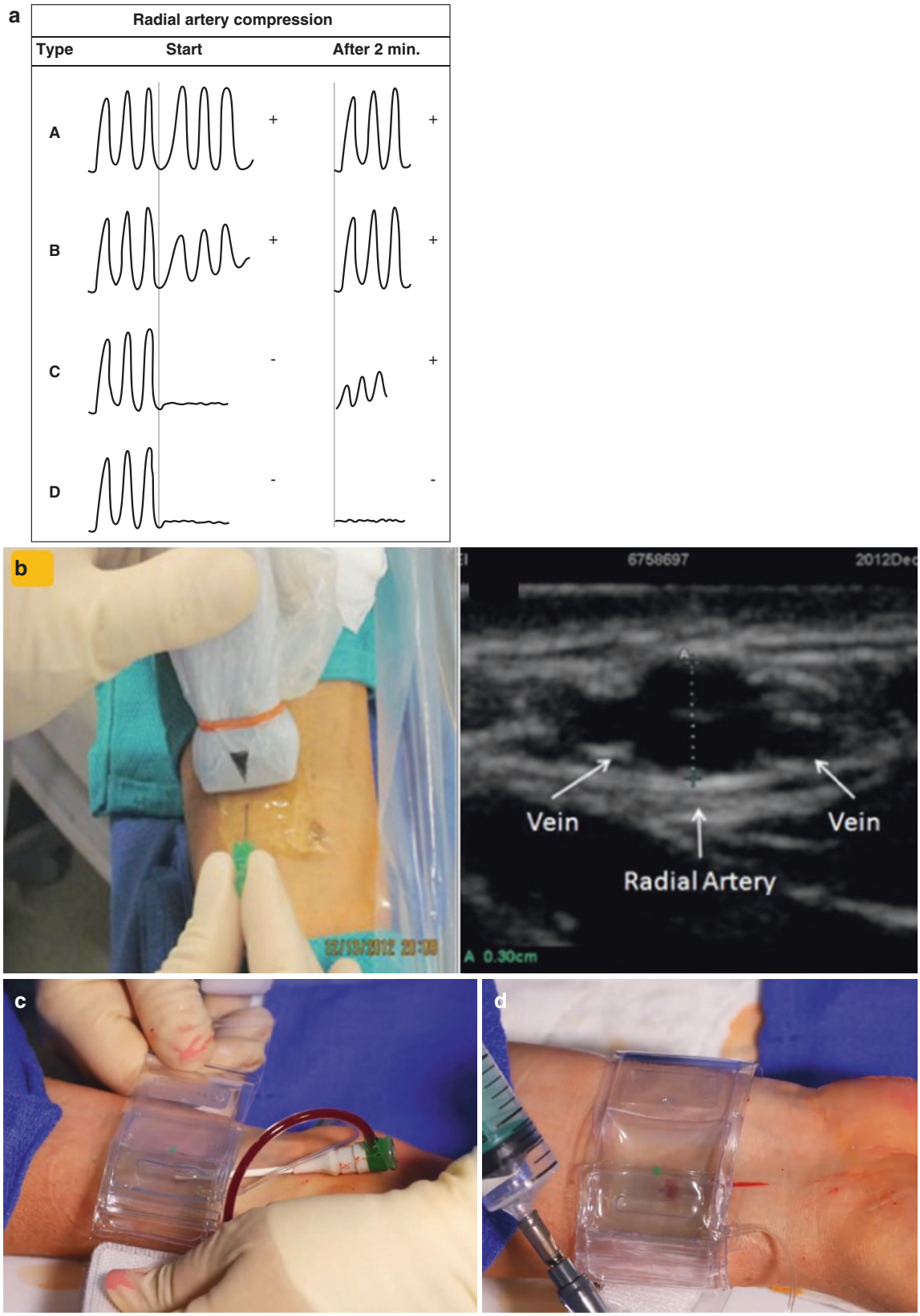

Fig. 20.13 Trans-radial access. (**a**) Barbeau test. After placement of a pulse oximetry probe on the index finger or thumb and manual compression of the radial artery, the pulse oximetry waveform is interpreted. The waveform is classified into one of four grades. (**b**) Ultrasound-guided access of the radial artery. *Left:* The radial artery is accessed using a 21-gauge needle under ultrasound guidance. *Right:* The appearance of the radial artery at the wrist, with parallel radial veins coursing medially and laterally. (**c**) Patent hemostasis technique. Prior to complete removal of the radial sheath, the hemostasis band is applied to the arteriotomy site. (**d**) The sheath is fully withdrawn with the band inflated, and the arteriotomy is monitored for bleeding

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Wires, Sheaths, and Catheters

21

Houssam K. Younes

Endovascular procedures include vessel access, obtaining diagnostic images, navigating and crossing the lesion, treating the lesion, and vessel closure. To accomplish these tasks, the operator needs to have a continuous platform between the vascular access site and the true lumen of the vessel distal to the lesion. Devices used to establish that platform are guidewires, catheters, guiding catheters, and sheaths.

Trainees often witness the performance of procedures using different combinations of tools based on the operator's familiarity and experience. There are many different brands of similar products, making the selection process confusing and communication during the procedure cumbersome. This chapter covers the nomenclature, basic properties, uses, and interrelation of various types of wires, catheters, and sheaths (Fig. 21.1).

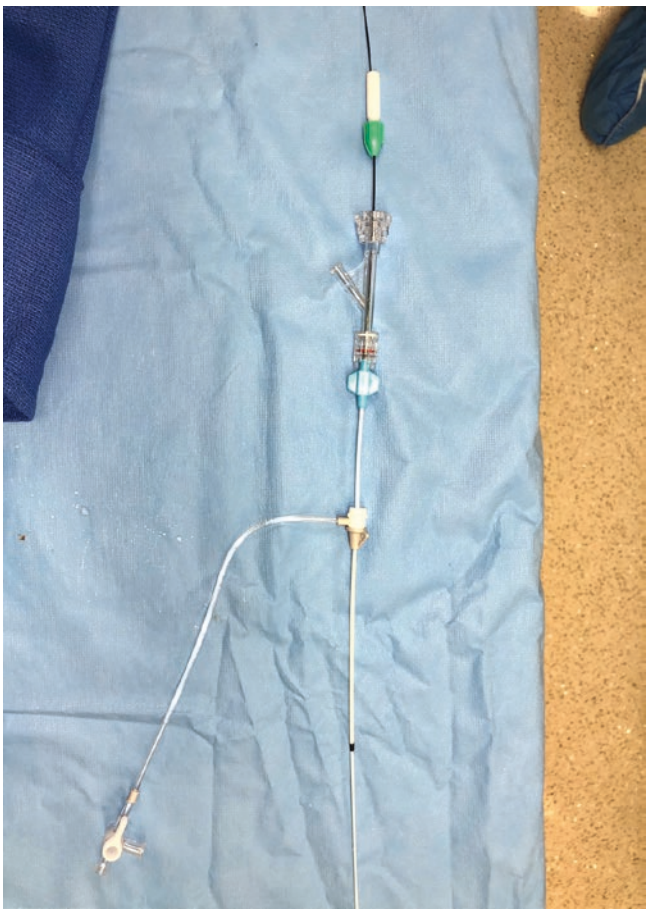

Fig. 21.1 Interrelation of endovascular procedures platforms. From top to bottom: 0.35 glide wire, torque device, Tuohy-Borst, 5 Fr Bernstein catheter, and 5 Fr sheath

Guidewires

Guidewires are the innermost and leading devices of endovascular interventions. They are used to maintain access, insert sheaths, and deliver catheters and therapeutic devices.

Tip Design

The wire tip can be straight, angled, or J-shaped. All wires have various length of floppy tip to reduce the incidence of vessel injury. Floppy tip wires buckle as they meet resistance, whereas a J tip reshapes into a reverse J shape as it enters the vessel. Therefore, both types are used for initial vascular access with low vessel injury. Angled tips are used to maneuver tortuous vessels and tight lesions by manipulating the external wire and choosing the lumen of lower resistance. Shaped tips (e.g., Rosen Wire, Boston Scientific) are used for end organ or visceral vessels to provide stability and avoid perforation (Fig. 21.2). Small 0.014-inch wires have different tip loads (the minimum force needed to bend the tip), which range from 0.5 to 30 g; these wires are preferred for crossing chronic total occlusion (CTO) lesions. The selection of the weight of the wire tip is determined by the lesion type. Lower weights are used to cross thrombotic lesions; heavier ones are used to cross fibrotic or highly calcific lesions.

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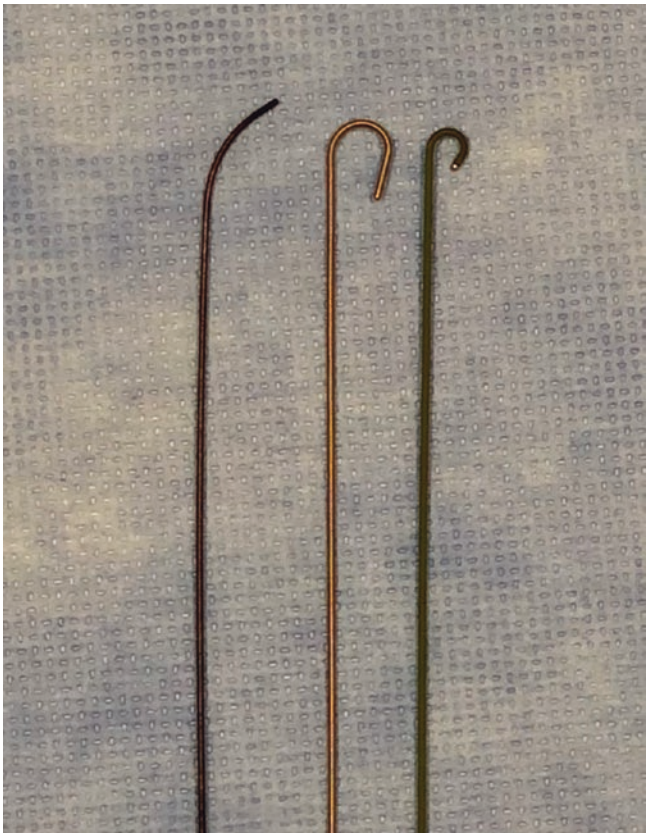

Fig. 21.2 Angled-tip glide wire (*left*), J-wire (*center*), and Rosen wire (*right*)

Length

Wires come in different lengths to cover the cumulative distance from the access to beyond the targeted lesion. The length of wires varies between 15 cm and 480 cm. Short wires of 15 to 45 cm are usually used for initial vessel access. Longer wires of 260 to 300 cm are mainly used in coaxial systems to allow the insertion and exchange of catheters, sheaths, and therapeutic devices. Intermediate wires, 145 to 180 cm, are used with monorail system or for target lesions close to the access, such as diagnostic studies or iliac artery or anterograde tibial interventions.

Thickness

Wire thickness is measured in inches. Available thicknesses are 0.014, 0.018, 0.025, 0.035, and 0.038 inches. Selection of the size is based on the diameter of the smallest target vessel. Thicker wires are used for larger vessels like the aorta or iliac, femoral, and popliteal vessels. Similarly, thinner wires are used for tibial, carotid, or visceral artery work. Wire size selection determines the platform for the size of catheters, sheaths, and therapeutic devices that can be inserted after crossing the lesion.

Stiffness

Soft wires are usually used for maneuvering through lesions and crossing tortuous vessels. These are often exchanged for stiffer wires before starting the intervention.

Stiffer wires are used to straighten tortuous vessels or to provide a stable platform for the delivery of sheaths and devices, especially large sheaths and devices like those used for aortic interventions.

Hydrophilic Coating

Some wires have a hydrophilic coating (Teflon, polytetrafluoroethylene, or silicone), which make it slippery when wet. The coating decreases the friction between the vessel walls, catheter, and sheaths, thereby improving the crossing ability of the wire. Hydrophilic wires can get sticky when dry, however, so they can be accidentally withdrawn during exchanges. For that reason, the wire should be wet-wiped during exchanges.

Hydrophilic wires are used for maneuvering through smaller vessels and tight lesions, but because of their high crossing ability, hydrophilic wires may cause undesired subintimal dissection. On the other hand, that can become useful in crossing total occlusive lesions by creating a subintimal plane with the goal of re-entry into the vessel past the lesion.

Non-coated wires are easier to grip but may encounter increased resistance during passage through narrow areas. They are better exchanged over a catheter.

Selection

Wire selection should be based on vessel anatomy and lesion characteristics. A combination of wires is usually needed to accomplish the task. Access should be performed using a wire with non-hydrophilic coating, to avoid needle shearing, and a long floppy tip or J-shaped tip to avoid vessel trauma. For maneuvering through vessels or crossing lesions, hydrophilic, soft wires with an angled or straight tip can be used.

When advancing a sheath or larger-diameter catheter or devices, a stiff wire should be used as a rail for support. In some cases, crossing the lesion while providing enough support to deliver longer sheaths can be accomplished by using hybrid wires that have a soft, angled, hydrophilic tip and non-coated, stiff wire body, such as the Glidewire Advantage® (Terumo Interventional Systems) (Fig. 21.3).

Torque Devices

Torque devices (Fig. 21.4) are attached to the external part of the wire to allow maneuvering of the wire tip to select ori-

Fig. 21.3 *Top*, Glidewire Advantage® guidewire (Terumo Interventional Systems) with soft, angled, hydrophilic tip and non-coated stiff wire body. *Bottom*, The metal marker indicates the transition, which can be identified during fluoroscopy

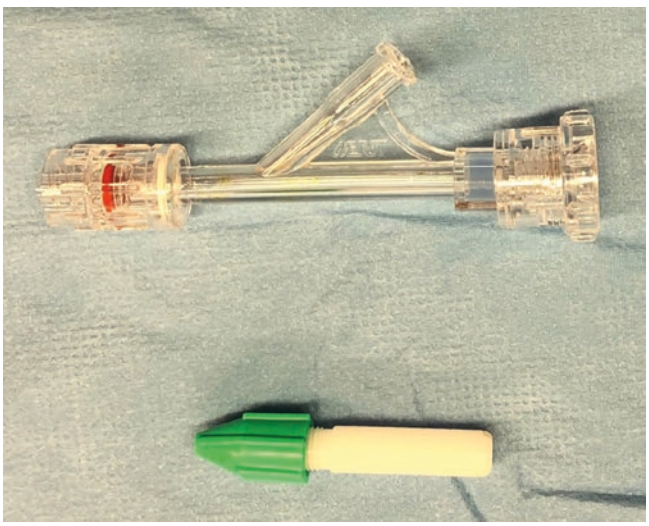

Fig. 21.4 *Top*, Tuohy-Borst side arm adapter. *Bottom*, Torque device

fices or probe lesions. They are especially helpful for use with hydrophilic wires, because the slipperiness of the wire may make it difficult to control. Torque devices also assist with precise advancement of the wire in a tortuous vessel or proximal stenotic lesions, where it is important to avoid buckling or coiling of the wire or subintimal dissection. Furthermore, adequate maneuvering of the wire protects the platinum tip of the wire from deforming and kinking, which impedes the use of selective features of the tip.

Sheaths and Guiding Catheters

Sheaths

A sheath is the outermost component of the endovascular platform. It is used to secure the arterial access site and provide a passage for the wires, catheters, and all other devices. Sheaths provide a path for contrast media injection while wires and sometimes other devices remain in place. They

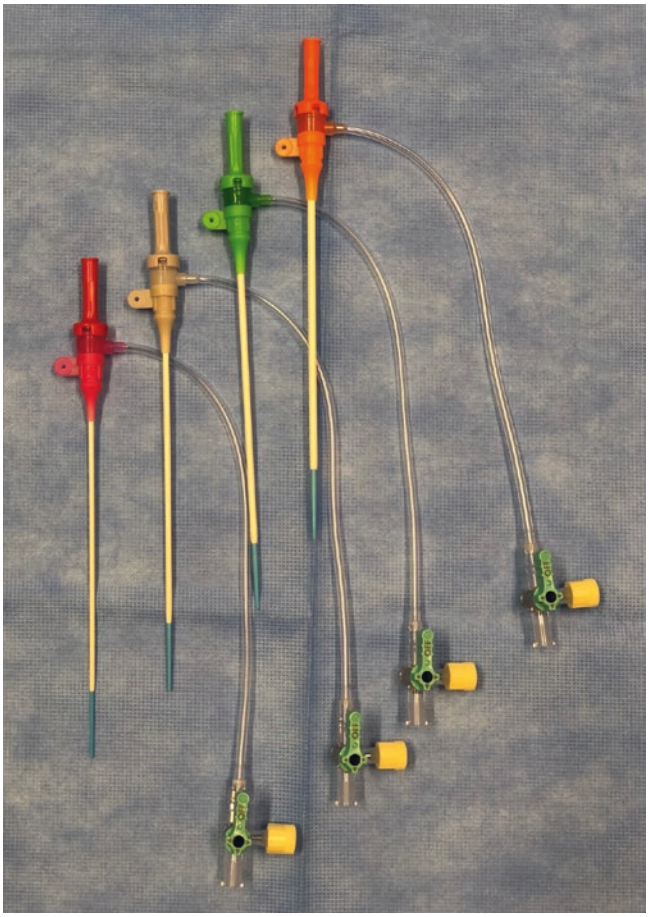

Fig. 21.5 Sheath sizes are color-coded (*left to right*): red, 4 Fr; grey, 5 Fr; green, 6 Fr; orange, 7 Fr

also provide a stable platform for the passage of devices through tortuous vessels or tight lesions.

Sheath size is the diameter of its inner lumen in French, which determines the size of the catheters or other devices that can be used. The sizes are color-coded. For example, a 4 Fr sheath is red; 9 Fr or larger is black (Fig. 21.5). Sheaths have integrated dilators with tapered tips that allow the dilation of the soft tissue track and the arterial puncture site and sometimes pre-dilate distal stenotic vessels to allow for safe insertion stenotic vessels to allow for safe insertion of the sheath. They have a one-way hemostatic valve to allow the insertion of wire and devices while preventing back bleeding. They also have a side port that allows for blood draws and injection of contrast. Some sheaths (such as BRITE TIP® interventional sheath, Cordis) have a radiopaque marking at the tip to facilitate accurate positioning of the sheath's end (Fig. 21.6).

Sheaths range in length from 5 cm to 100 cm, with the length used depending on the distance between the access site and the location of the vessel tree to be treated. The standard femoral access sheath length is 11 cm, which secures access into the ipsilateral external iliac artery (Fig. 21.6b). Short sheaths are used for a fistula or retrograde tibial artery work; long sheaths are used for work involving the aortic

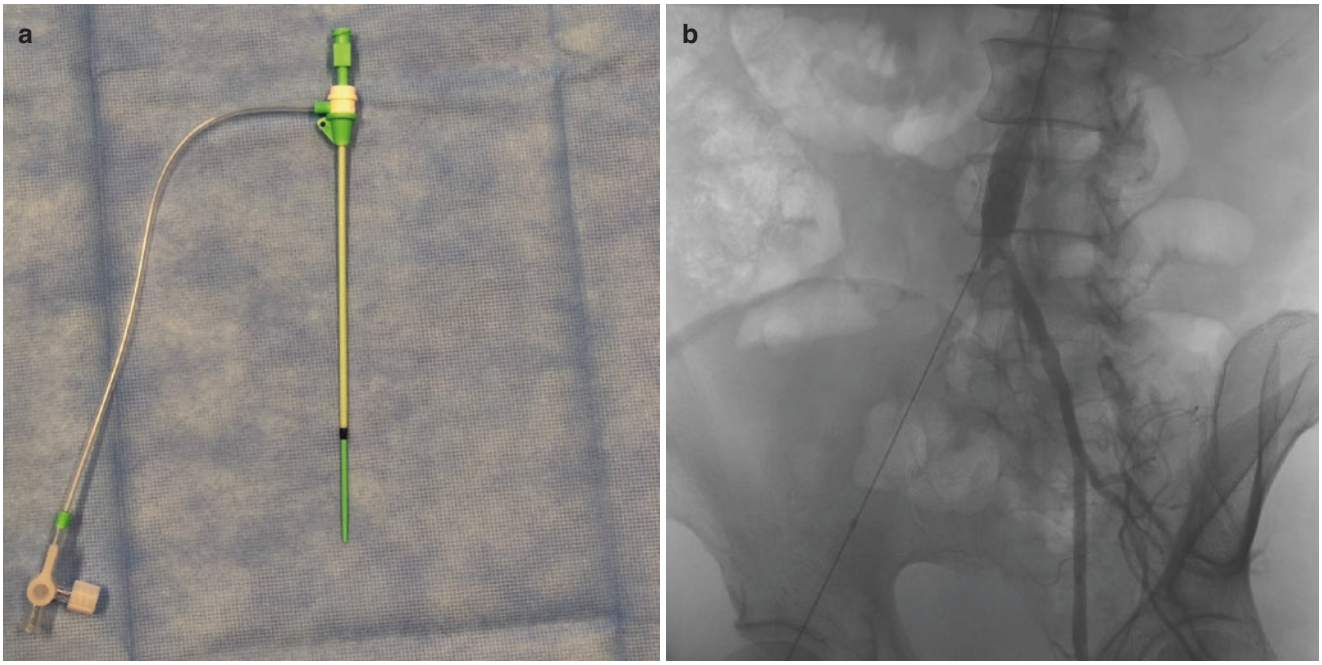

Fig. 21.6 (**a**) BRITE TIP® sheath with radiopaque marking at the tip, indicated by the black line. (**b**) The radiopaque tip shows the position of the sheath in the right external iliac artery, indicated by black dot

arch and contralateral peripheral arteries. Straight sheaths are the most common, but some sheaths are pre-curved. A curved sheath can more easily pass over the aortic bifurcation, for example.

Guiding Catheters

Guiding catheters are tubes that are intermediate between sheaths and catheters. The sizes of guiding catheters are the outer circumference. The dilator is not always integrated, and they do not have a hemostatic valve at the hub. Guiding catheters can be used to secure access to vessel orifices and to introduce crossing catheters or devices.

Selection of Sheaths

It is recommended to start access with a micropuncture sheath and then exchange it for a small sheath (size 4 to 5 Fr) to ensure safe and adequate access to the vessel. The final sheath size should be based on the largest device that is intended to be used during the procedure. The sheath should not be advanced without a dilator, to avoid injury or shelving of the vessel. Pre-dilatation should be considered before insertion of large sheaths. In some cases, a longer sheath is placed, reaching beyond the lesion to be treated, in order to deliver the device (such as a balloon-expanding stent) safely without disrupting the lesion or dislodging the device (Fig. 21.7).

Catheters

Catheters are tubes that are designed to facilitate the delivery of wires, radiopaque contrast, medication, or coils to specific areas of the vascular tree, or to selectively obtain blood samples from remote vessels. They are made of polyethylene, nylon, or polyurethane. Some catheters have a hydrophilic coating to decrease friction with the blood vessels, to increase their crossing ability and decrease the chance of vessel injury.

Length

Catheters are designed in multiple lengths ranging from 60 cm to 150 cm, depending on the estimated distance of the work area from the access site. Short catheters (60–65 cm) are usually used for dialysis access or for iliac cases or peripheral lower extremity cases approached in anterograde fashion. Intermediate catheters (90–110 cm) are used for work involving contralateral distal femoral or popliteal arteries or visceral branches or aortic arch branches. Long catheters (130–150 cm) used for cases involving the contralateral tibial arteries or upper extremities arteries.

Diameter

The diameter equals the outer circumference of the catheter in French size. The catheter size determines the wire size that

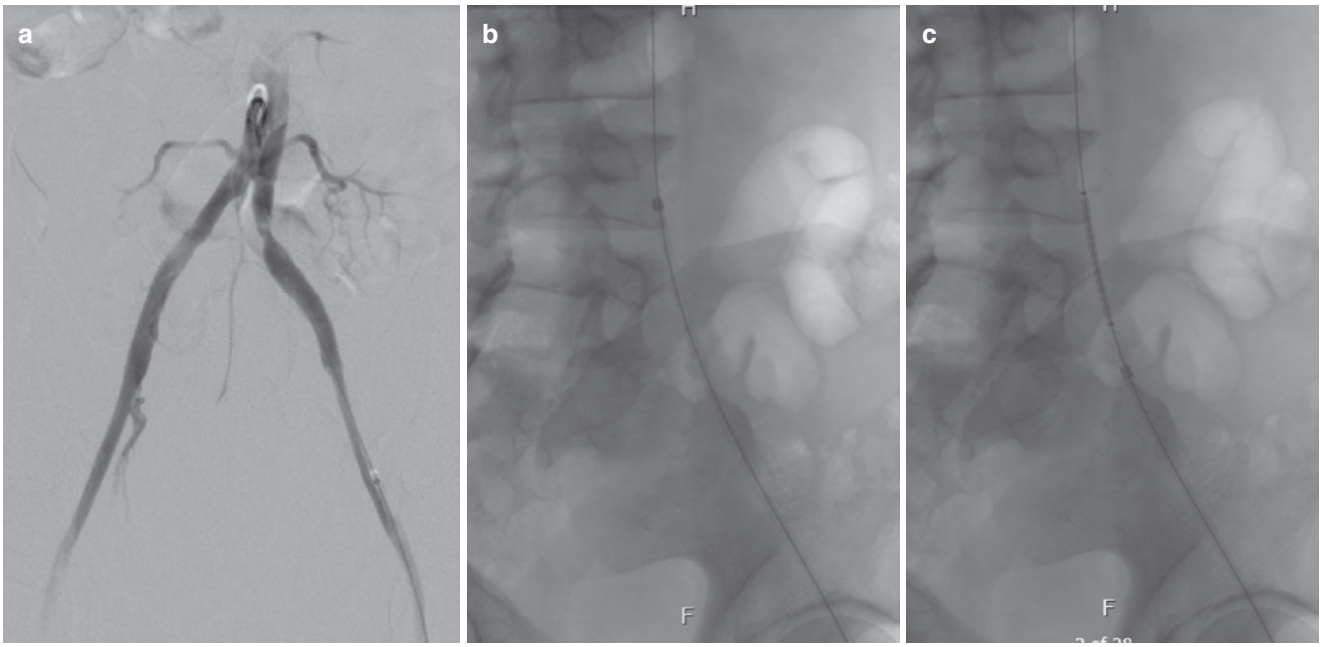

Fig. 21.7 Use of a long sheath to deliver a balloon-expandable stent. (**a**) The sheath is initially placed in the left external iliac artery. (**b**) The sheath is advanced over the dilator beyond the lesion to be treated. (**c**) The balloon-expandable stent is delivered and the sheath is pulled back to allow deployment

can be used with it, so a 2–3 Fr catheter accommodates 0.014-inch or 0.018-inch wires, whereas 0.035-inch or 0.038-inch wires require a 4–5 Fr catheter. Larger catheters are usually used as guiding catheters.

Types

Nonselective Flush Catheters

Nonselective catheters are used mainly for diagnostic purposes. They usually have 6 to 8 side holes distributed circumferentially about 20 mm from the tip. The tip is curved or coiled to increase resistance and allow high-pressure propulsion of contrast through the side holes, which results in the displacement of blood and filling of the vessel with contrast to allow imaging of the vessel tree. Some catheters (e.g., Accu-Vu® Sizing Catheter, AngioDynamics) have radiopaque markers to allow for measurement of lesion length or distance of the vessel area that needs to be treated, which helps in choosing the correct device length (Fig. 21.8). Some diagnostic catheters (Omni™ Flush, Angiodynamics or Contra catheters, Boston Scientific) come with a curved tip that allows both diagnostic and selective functions. These are commonly used to perform diagnostic abdominal aortogram then cross the aortic bifurcation in an up-and-over fashion.

Selective Catheters

As the name implies, selective catheters are used for selecting branches and crossing lesions. They have single end-holes where they are threaded over the wire. The wire can be removed and contrast can be injected for selective images in small-diameter vessels. Low-pressure injections should be used to avoid vessel wall injury or dislodgment of the catheter from vessel orifices.

There are multiple catheter tip designs for different uses, including simple curves and multiple curves. The simple-curve catheters have one curve with an angle of less than 45°. They are used to select orifices in larger vessels, as the wider angle improves reachability. They also can be used to guide straight-tip wires through a tortuous vessel or to select vessels.

Catheters with multiple curves come in wider angles of 45–90°. The multiple curves may be either self-forming or require manual formation. An example of a self-forming catheter is Shepard hook (Merit OEM), which is used to select renal arteries. An example of a manually formed catheter is the SIM catheter (Cook Medical), commonly used in the aortic arch. The catheter can be reformed by selecting a branch (like the subclavian artery or superior mesenteric artery) or by bouncing it off the aortic valve.

Catheter Selection

Usually the smallest diameter of catheter that accomplishes the job is chosen. The selection of the length should be based on the distance of the target vessel or lesion from the access site, keeping enough distance outside the sheath to

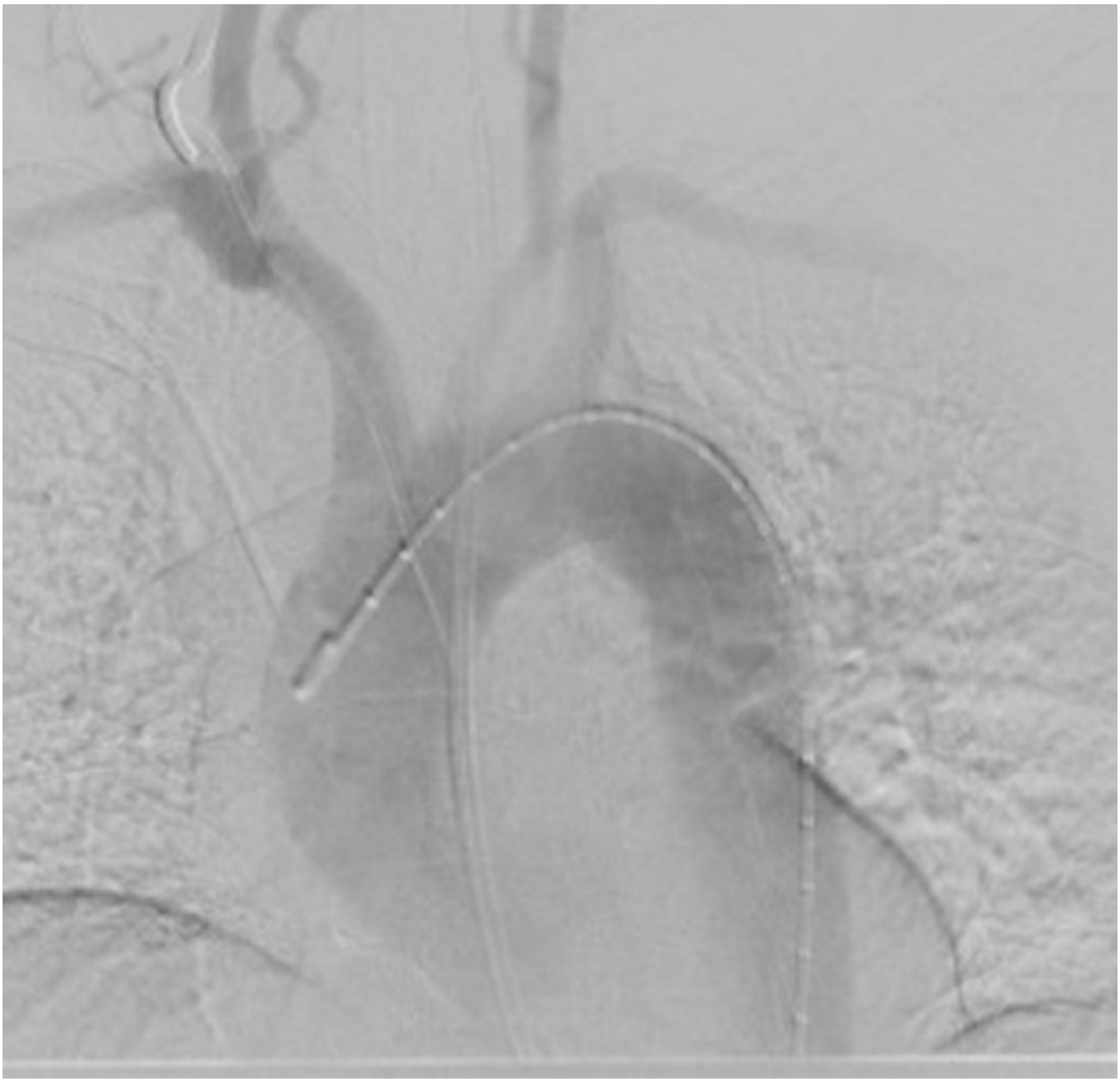

Fig. 21.8 Arch aortogram performed with a marked pigtail catheter

allow for manipulation of the catheter. Also, the difference in the length between the catheter and wire should allow exchange of the catheter without losing the wire. If injection around the wire is intended, a larger catheter can be passed over a smaller wire to allow enough space in the lumen for injection of contrast or vasodilators with the help of a hemostatic valve like the Tuohy-Borst side arm adapter (Cook Medical) (*see* Fig. 21.4). The sheath should be chosen according to the size of the largest anticipated catheter.

Suggested Reading

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Balloons: Plain, Drug-Coated, and Cutting

22

Chiranjiv Virk, Claudie Sheahan, Kevin Au, and Malachi Sheahan

Balloon Angioplasty

Arterial angioplasty was first reported by Dotter and Judkins in 1964 for the treatment of peripheral vascular lesions using rigid intravascular dilators [1]. Inflation of an angioplasty balloon in the artery causes dissection of the atherosclerotic plaque and adjacent intima. The medial and adventitial layers are also dilated. This controlled stretch injury increases the cross-sectional area of the vascular lumen. Over several weeks, the artery remodels via re-endothelialization of the intima [2, 3].

Types of Balloon Catheter

The two main types of balloon delivery catheters are over the wire (OTW) catheters and single operator exchange (SOE) catheters.

In OTW catheters (Fig. 22.1), the guidewire enters at the distal end of the balloon and exits at the proximal end of the catheter. Generally, OTW catheters offer more support than SOE catheters. Care must be taken to use a wire with adequate length when exchanging an OTW balloon angioplasty catheter. The minimum length of wire needed is the sum of the distance between the access site and the treatment lesion plus the length of the catheter plus 10 cm (Fig. 22.2).

SOE catheters (Fig. 22.3) are also commonly referred to as rapid exchange or monorail systems. The wire enters at the distal end of the balloon and exits the catheter along the shaft approximately 10 inches proximal to the balloon. These delivery catheters offer the advantage of simpler catheter exchange, and they often eliminate the need for cumbersome exchange-length wires.

Both types of angioplasty balloon delivery catheters come in a variety of shaft lengths and outer diameter profiles. The shaft length is critical to determine whether the catheter is of adequate length to reach the target lesion. The shaft length also must be longer than the sheath or guiding catheter through which the balloon delivery catheter is being advanced. As an example, if a 90-cm destination sheath is placed, then a 75-cm working length balloon will not reach the lesion. The outer diameter profile will determine the minimum inner diameter of the sheath or guiding catheter through which the balloon can be advanced. In general, smaller-profile balloons are more likely to succeed in crossing extremely stenotic or occluded lesions. It is also important to note the recommended wire diameter. Balloon catheters often can be advanced over wires smaller than the recommended size, but not over wires that are larger. This can be helpful when using low-profile balloons over 0.014 wire for tibial lesions in which the same wire can be used for treating femoropopliteal lesions that usually go over an 0.035 wire. Note that there will be bleeding from the manifold because the wire is smaller in diameter.

Balloon delivery catheter specifications are listed on the packaging and should be noted prior to passing the device to the sterile field, to avoid waste. It is always a good idea to ensure sheath and wire compatibility before opening a balloon.

Angioplasty Technique: General Principles

Crossing the lesion: After obtaining vascular access, arteriography is performed to identify the lesion. The target vessel stenosis is crossed with a wire and support catheter. Once the lesion is crossed, the wire is withdrawn and contrast is injected into the crossing catheter to confirm its location in the true lumen. The wire is then re-advanced and the support catheter is exchanged for the balloon delivery catheter.

Balloon selection: The length of the balloon should be slightly longer than the length of the lesion being treated. Standard balloon lengths can vary from under 1 cm to 25 cm.

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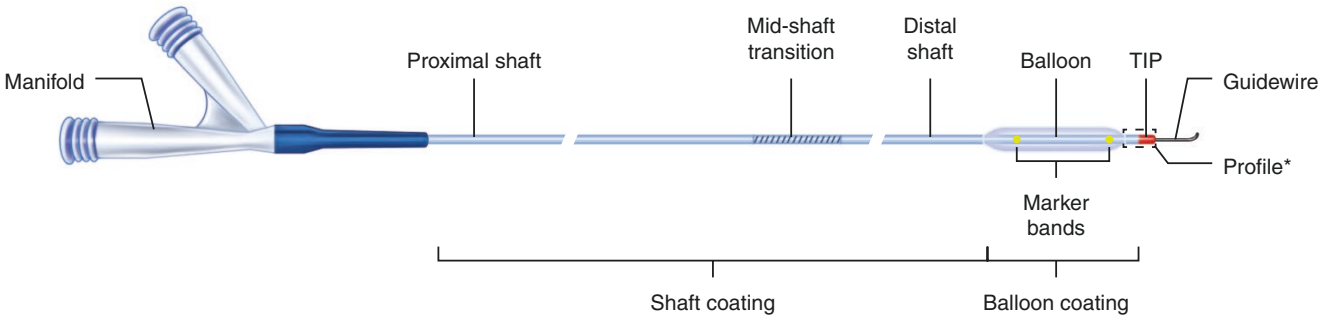

Fig. 22.1 Over-the-wire (OTW) balloon catheter

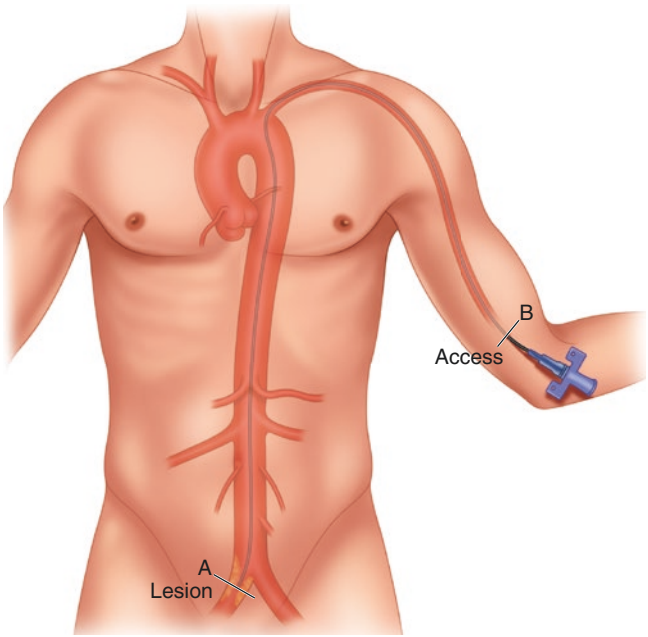

Fig. 22.2 Calculating the minimum length of wire needed for use with an OTW balloon catheter

The diameter of the balloon should generally match the width of a healthy section of the vessel being treated. Some general sizing guidelines are shown in Table 22.1.

Balloon inflation: Expansion of the balloon is performed using dilute contrast in an inflating device. The balloon is initially inflated to the rated nominal pressure. Further inflation can be performed as needed, up to the rated burst pressure. In general, higher inflation pressures increase the risk of vessel dissection and rupture.

Table 22.1 Balloon sizing

Artery	Balloon diameter (in mm)
ICA	4–6
CCA	6–8
Vertebral	2–5
Aorta	10–20
Subclavian	6–8
Axillary	5–7
Brachial	4–6
Radial	2–3
Renal	5–7
Common Iliac	6–10
External Iliac	6–8
SFA	5–7
Popliteal	4–6
Tibial	2–3

Balloon length: Ideally, a balloon length just slightly longer than the lesion length is chosen

Deflation: The balloon should be completely deflated prior to withdrawal from the sheath. It is vital to maintain wire access across the lesion until the completion angiogram is performed.

Balloon Compliance

The compliance of angioplasty balloons affects their performance. They can be generally categorized as semi-compliant or non-compliant. Semi-compliant balloons expand in diameter as the atmospheres are increased. This may result in a "dog bone" shape of the balloon as it expands in a lesion (Fig. 22.4). Non-compliant balloons maintain a consistent diameter throughout their length as they inflate, even at high pressures. Selection of the appropriate balloon compliance

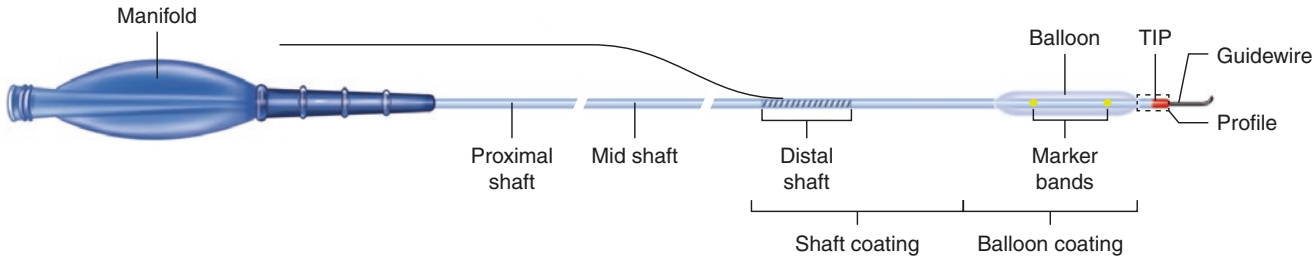

Fig. 22.3 Single operator exchange (SOE) catheter. The wire exits the catheter along the shaft, proximal to the balloon

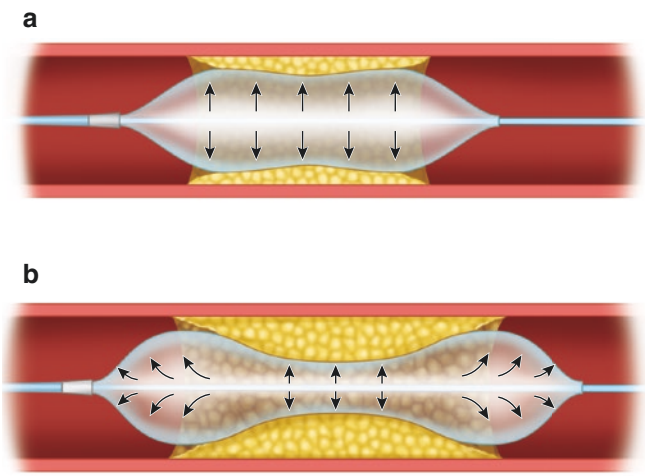

Fig. 22.4 Balloon compliance. (**a**) Non-compliant balloons maintain a consistent diameter throughout their length as they inflate. (**b**) Semi-compliant balloons may inflate in a "dog bone" shape within a lesion, but they may be more easily delivered

depends on the nature and location of the target lesion. Balloons that are more compliant will conform to the vessel wall and are more easily delivered. Less-compliant balloons are useful when a specific diameter of expansion is desired or when higher-pressure inflation is needed.

Special Balloon Types

Drug-Coated Balloons

Balloons covered with cytotoxic drugs such as paclitaxel are often used to reduce the risk of restenosis. Care should be taken to review the current FDA guidelines regarding the use of these balloons. Drug-coated balloons (DCBs) are available only in limited size options, and their use requires some special considerations:

Sizing: The nominal balloon diameter must match the diameter of the vessel distal to the lesion. The length of the balloon should exceed the length of the lesion by about 1 cm on both the proximal and distal ends.

Vessel preparation: To avoid the loss of drug from the balloon during the crossing of the lesion, predilation should be performed. This also ensures equal distribution of the drug across the vessel surface.

Inflation time: For optimal mechanical dilation of the vessel, an inflation time of 180 seconds is recommended. Adequate drug transfer occurs in the first 60 seconds of inflation.

Cutting Balloon

The cutting balloon technology was first developed in the mid-1980s for the coronary arteries by Dr. Peter Barath and was initially called the Barath Balloon. The device is composed of a conventional balloon catheter with three or four atherotomes (microsurgical blades) that are mounted longitudinally along the balloon surface, designed to create controlled incisions along the length of the lesion and thus reducing the complex arterial dissection created during conventional angioplasty. Clinically, these devices are particularly useful in focal, fibrotic lesions such as vein graft stenosis [4].

The diameter of the cutting balloon catheter is selected to approximate a 1.0:1.1 ratio (balloon to the reference vessel diameter). Oversizing increases the risk of perforation and rupture. Cutting balloons are available in a variety of diameters. Balloon lengths are often shorter than conventional balloons, usually 15–20 mm. If unable to get the vessel size from a CT scan or intravascular ultrasound, some use a plain balloon to best estimate the cutting balloon diameter size to avoid oversizing and rupture.

Because of the special configuration of the atherotomes, cutting balloons should be inflated and deflated slowly (generally 1 atm every 2–3 seconds) to avoid damaging their structural integrity. Some advocate rotating the balloon and inflating it multiple times to score the lesion.

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Endovascular Stenting

23

Mark Conant, Chetan Dargan, and Murray L. Shames

Endovascular stenting has become increasingly popular for treatment of lower extremity arterial disease, venous disease, visceral arterial disease, and aneurysmal disease. The basic principle of stenting involves accessing the vessel and then placing a wire, sheath, catheter, and a self-expanding stent or a balloon-expandable stent (either covered or bare metal) at the location of disease.

Percutaneous Access

Percutaneous vessel access is performed using the modified Seldinger technique under ultrasound guidance. Typically, the retrograde common femoral artery is chosen as the access point for most arterial vascular procedures. (This chapter will not discuss upper extremity access.) The side selected for cannulation depends upon the disease location and the patency of the vessel targeted for cannulation. Contralateral access is preferred for most lower extremity interventions, excluding cases necessitating antegrade access or those involving common iliac disease or proximal external iliac disease [1]. The location of the common femoral artery is demarcated by the medial half of the femoral head, identifiable on fluoroscopy. It is very important to mark it with a radiopaque marker or on the skin, because the femoral head will serve as a point of posterior compression should it be necessary to hold manual pressure on the arterial access. Ultrasound should be deployed to identify the external iliac, common femoral, profunda femoris, and superficial femoral arteries (Fig. 23.1). Local anesthetic should be injected at the site of intended puncture.

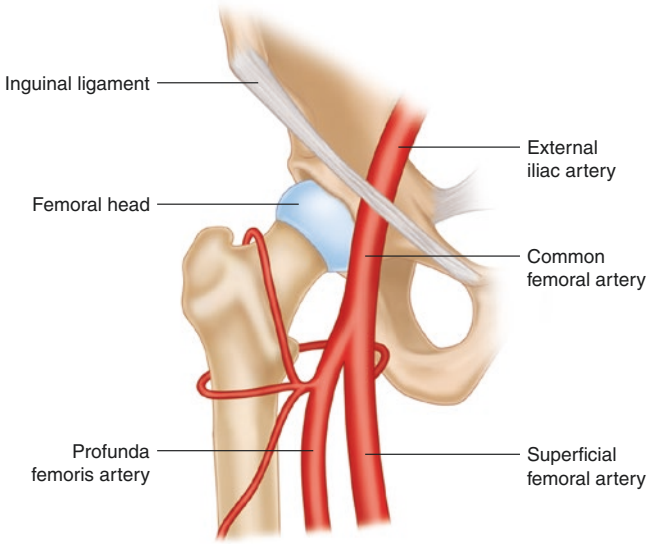

Fig. 23.1 Anatomy of the femoral arterial system. The common femoral artery should be accessed below the inguinal ligament, above its bifurcation, and over the medial third of the femoral head

Access to the common femoral artery should be accomplished using a micro-puncture needle or angiographic needle. (Micro-puncture technique, which has less risk of arterial trauma, is described.) The needle should be positioned at approximately a 45-degree angle to the skin, though the body habitus of the patient may necessitate an alternative angle of access; patients with more redundant tissue may require a steeper angle of incidence. After back bleeding has been established, an 0.018 access wire should be advanced into the needle, with the pliable end of the wire advanced first to decrease risk of arterial trauma. Fluoroscopy should confirm placement of the wire in the artery. The needle should be removed from the back end of the wire, followed

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by placement of a micro-puncture sheath, taking care not to lose the wire at any point during the exchange.

After the sheath is in place, the 0.018 wire should be removed and a 0.035 steerable, stiff wire is advanced into the aorta below the level of the renal arteries. Wire length for initial access is typically 145 cm, but selection of the wire is provider-dependent. If an intervention or diagnostic imaging of the superficial femoral artery is the goal, some providers elect to select a longer wire, to improve upon resource utilization. The micro-puncture sheath should be removed from the back end of the wire and the procedural sheath advanced (Fig. 23.2). Sheath size selection depends upon the purpose of the procedure: Interventional procedures typically require at least a 6 Fr sheath, but a 4 Fr or 5 Fr sheath is adequate for diagnostic procedures [1, 2].

Initial Imaging

A diagnostic catheter is placed into the aorta, with the level of placement dependent upon the disease location. For lower extremity disease, an aortogram below the renal arteries is performed, with iliac runoff to the level of the common femoral artery to identify arterial landmarks and potential

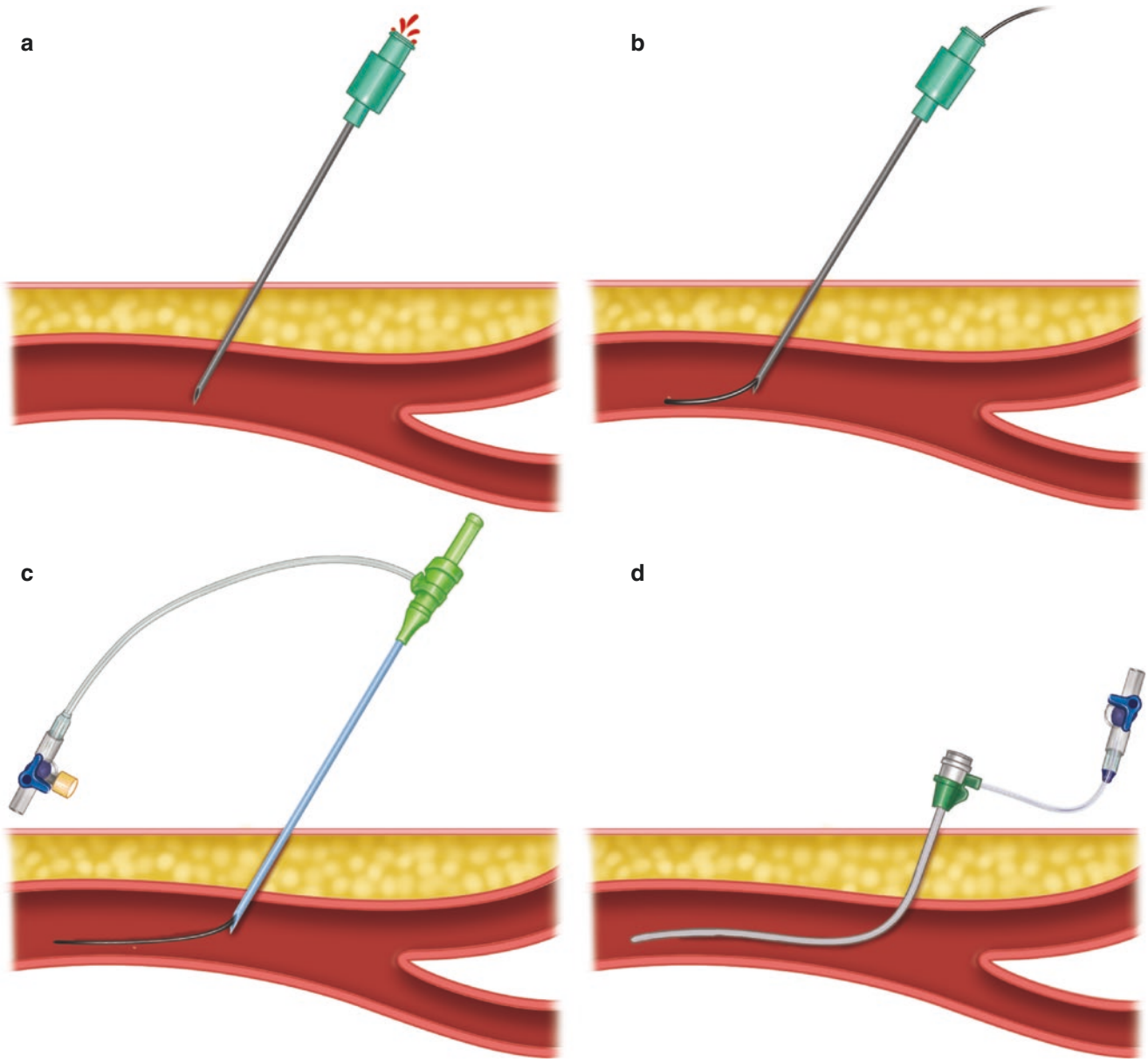

Fig. 23.2 Percutaneous access of the common femoral artery. (**a**) A micropuncture needle is introduced into the common femoral artery, and back-bleeding is established. (**b**) A 0.018 mm wire is introduced through the needle into the artery. (**c**) After exchange of the needle for a micropuncture sheath, a 0.035 mm wire replaces the 0.018 mm wire and the micropuncture sheath is exchanged for an introducer sheath. (**d**) The wire has been removed and the introducer sheath retains access into the common femoral artery

disease. After removal of the wire, contrast is injected through the catheter, using either hand injection or a power injector. "Up and over" access is then obtained with a wire through the catheter. This step may be difficult, depending upon the angulation of the aortic bifurcation. A reverse-curve catheter generally provides the angulation needed to enter the contralateral iliac [2]. Wire is moved to the level of the contralateral external iliac artery, followed by advancement of the catheter to stabilize the system. Wire is then advanced to the level of the common femoral artery, again followed by advancement of the catheter. The wire is then removed, and diagnostic imaging of the superficial and profunda arteries under a 30-degree ipsilateral oblique is obtained to separate the origins of the two arteries. The wire and catheter should be moved in procession for multiple stations until the remainder of the arterial system is imaged to the level of the foot.

Catheter placement for imaging depends upon the degree of disease. A more distal catheter position is required for diseased arteries. That is, a catheter may need to be placed at the infragenicular, popliteal artery to provide adequate imaging of the tibial vasculature. This placement is important, to provide a baseline prior to intervention and offer the operator a general idea of disease location.

Imaging runs taken when the catheter is more proximal will require a delay of digital subtraction, allowing time for the contrast to reach the intended imaging target while reducing radiation exposure. If an artery is occluded, the contrast run to the intended target may be prohibited or significantly delayed, as the contrast may require collateral pathways to reach the intended imaging target.

Crossing a Lesion

After the general area of the lesion is identified during the diagnostic runs, repeat imaging of the lesion is performed. Lesions should be addressed typically in a distal-to-proximal fashion, to ensure that access to the distal lesion is not compromised during proximal lesion intervention. The location of the lesion is marked with imaging or manually, and the station is not moved. A flexible hydrophilic sheath is deployed across the aortic bifurcation, over wire to add support to the system. The sheath is generally 6 Fr or greater, as most stent systems and angioplasty systems require this size [3]. The sheath should be placed as distally as possible with the introducer in place. Next, the introducer is removed, and a hydrophilic catheter is placed through the sheath over the wire. Repeat imaging is performed with the catheter placed just proximal to the area of interest, with or without magnified imaging. (Note that magnification of the imaging increases radiation exposure.)

Therapeutic anticoagulation should be administered prior to crossing of the lesion, as embolic phenomena may occur during wire manipulation within the diseased arterial segment. The lesion is then crossed with a soft-tipped hydrophilic wire. After the lesion is crossed, a catheter is advanced over the wire across the lesion [3]. If a lesion is difficult to cross, movement of the catheter to the most distal aspect may improve wire support and improve chances of crossing. After the lesion is crossed and the wire is removed, a diagnostic run is performed to verify placement of the catheter, assuring the operator that the lesion is in fact crossed within the true lumen of the vessel and not in the subintimal plane. A stiff wire is then placed to support the stent or percutaneous transluminal angioplasty (PTA) system and stationed distal to the lesion. The catheter is then removed. A final contrast run is performed through the sheath to verify the location of the lesion, and end points are selected for the stent placement [1].

Stent Selection

Stent selection varies depending on the disease location and indication for treatment. As discussed in Chap. 4, various types of stents are currently available, generally divided into self-expanding and balloon-expandable stents; these are further classified as bare metal or covered stents, and some are drug-eluting. Self-expanding bare metal stents provide the advantage of flexibility, as they are composed of a nitinol framework. The flexibility of these stents allows them to be utilized in tortuous anatomy, as they are resistant to crushing. Self-expanding stents will not expand past the intended manufactured size, however, so they are generally slightly oversized in comparison to the measured vessel lumen [3]. Self-expanding stents deploy in a distal-to-proximal fashion, with deployment mediated by various methods such as rotary wheel deployment and push-pull techniques. Self-expanding stents are often post-dilated with an angioplasty balloon sized to the vessel to conform the stent to the entirety of the vessel lumen. These stents are often deployed in the iliofemoral and femoropopliteal vasculature, arteriovenous fistulas, and upper extremity vasculature. Although the stents are self-expanding, they typically are not deployed in vessel segments that undergo frequent or extreme movement, such as the thoracic outlet (prior to rib removal) or the popliteal fossa, as they are at a higher risk for crushing [1, 3].

Self-expanding covered stents can be utilized in a manner similar to self-expanding bare metal stents. They are covered with a fabric that provides a barrier between the vessel wall and lumen. These stents have been studied in their application for venous anastomotic stenosis in arteriovenous access, as well as disease in the femoral popliteal segments in both TransAtlantic Inter-Society Consensus Class C and D lesions. Their application is common in cases of arterial rupture during endovascular treatment and arterial injury during trauma (Fig. 23.3) [3, 4].

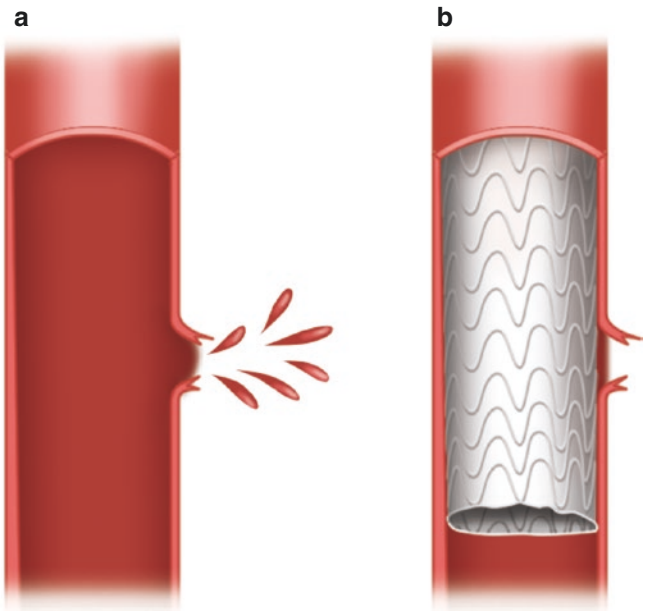

Fig. 23.3 (**a**) Rupture of the arterial wall with active extravasation. (**b**) A covered stent has been deployed across the arteriotomy, providing a barrier between the vessel lumen and wall

Balloon-expandable bare metal stents are often deployed in vessel segments that may require precise placement and significant radial force. These stents are more rigid than self-expanding stents and are often deployed in the mesenteric, iliac, and renal vasculature. These stents are pre-loaded onto a balloon and are deployed in a "dog-bone" fashion, as both the proximal and distal segments are expanded simultaneously. Balloon-expandable stents may be oversized, using a larger angioplasty balloon, but they will foreshorten if they are stretched past their intended diameter [3, 5].

Balloon-expandable covered stents have been studied on a limited basis. They are deployed in the same anatomical locations as uncovered balloon-expandable stents, but limited studies have shown improved patency of the covered balloon-expandable stent when utilized in the iliac vasculature [5]. They provide the obvious benefit of coverage in the event of vessel trauma.

Drug-eluting stents are bare-metal self-expanding stents that are bound with an antineoplastic medication. These stents are thought to reduce the occurrence of neointimal hyperplasia after stent placement. Currently, paclitaxel and sirolimus are the compounds of choice. Limited studies have shown questionable benefit of drug-eluting stents in the femoral popliteal segments, but these stents are often used because similar technology has been successfully applied in the coronary vasculature [3].

Technique

The technical considerations for stent deployment vary depending on stent type and anatomic location.

Self-Expanding Stents

Self-expanding stents are encased within a deployment sheath. Although placing an access sheath as distal as possible will provide support for the system, it is not necessary to keep the stent within the access sheath prior to deployment. The self-expanding stent is marked by two radiopaque markers delineating the distal and proximal portions of the stent. After a lesion is crossed with wire, the stent system is positioned so that the diseased segment is located at the most central aspect of the stent. If the stent cannot be passed through the lesion, it may be necessary to pre-dilate the lesion with an angioplasty balloon to allow the stent to traverse the lesion. Self-expanding stents are all deployed in a similar fashion, distal to proximal, but each stent has a different deployment system. Attention should be directed to each stent's individual preparation instruction prior to insertion into the body and to the deployment system (push, pull, cogwheel, or other). Self-expanding stents have a propensity to "jump" forward slightly during deployment. Anecdotally, it is important to partially deploy the stent (allow the distal aspect to "flower" but not expand fully) and then reposition the stent appropriately. The remainder of the stent should be deployed with some back tension maintained on the stent, which allows the stent to maintain the most linear deployment pattern possible, without foreshortening (Fig. 23.4). Wire access should always be maintained across the stent; this is of high importance, as emergent access across the lesion may be needed in the event of a rupture. Post-dilation of the stent should be performed using an angioplasty balloon profiled to the vessel size. A "waist" of the balloon may be visible as this marks the area of the disease. The balloon should then be removed after full insufflation and left on the wire in case of rupture. A post-angioplasty contrast run should be completed at this time, with runoff to ensure patency of distal vasculature. If post-intervention angiography shows significant extravasation, an angioplasty balloon should be placed at the level of the rupture to temporize hemorrhage. Use of a covered stent or alternative repair technique should then be undertaken immediately. Immediate hypotension following stent deployment or post-deployment angioplasty may be the first indicator of arterial rupture [1, 3].

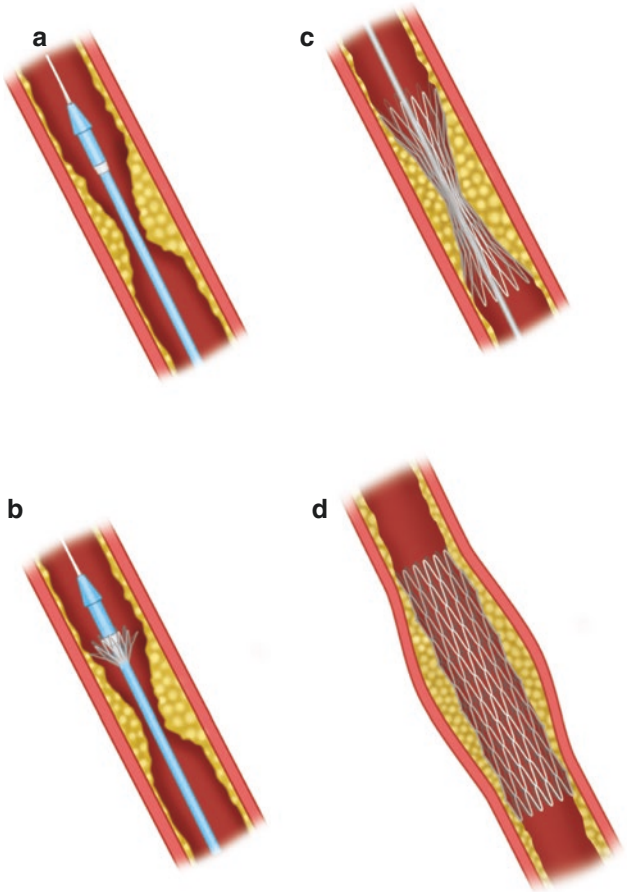

Fig. 23.4 Deployment of a self-expanding, bare metal stent into an arterial lesion. (**a**) The stent is placed over a stiff wire across the lesion. (**b**) Partial deployment allows flowering of the distal portion of the stent. Repositioning can be undertaken at this point if needed. (**c**) The stent is fully deployed, and the deployment system has been removed. (**d**) Full restoration of the patency of the vessel lumen after ballooning of the stent

Balloon-Expandable Stents

Balloon-expandable stents are not encased in a deployment sheath, so stent deployment occurs in a "dog-bone" fashion with both the proximal and distal aspects deployed simultaneously, followed by the central aspect of the stent (Fig. 23.5). Some texts recommend oversizing the stent by 10 to 20% relative to the vessel lumen. Balloon-expandable stents should be maintained within the access sheath until deployment. If the stent is not contained within the access sheath, it may erroneously separate from its sheath prior to deployment. The access sheath tip should be advanced across the lesion, and the stent should then be positioned within the

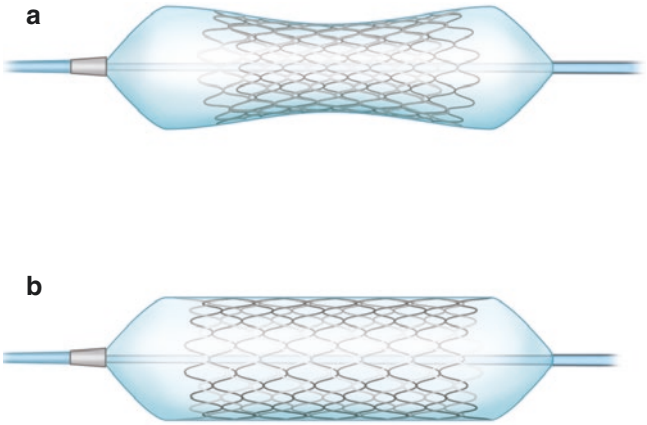

Fig. 23.5 Deployment of a balloon expandable stent in a "dog-bone" fashion. Note the proximal and distal aspects of the stent deploying first in (**a**), followed by the central aspect in (**b**)

sheath to the desired location of deployment. The sheath is then retracted partially to expose the stent, and the stent should then be deployed by inflating the deployment balloon according to the manufacturer's instructions for use. The stent may be oversized by insufflating beyond the instructions or by using a larger post-dilation balloon, but the stent will partially foreshorten as the diameter of the stent is increased. As with self-expanding stents, precautions regarding rupture should be undertaken, and post-deployment angiography with runoff should be completed. A closure device or manual pressure should then be used to achieve hemostasis upon completion [1–3].

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Adjunctive Endovascular Tools

24

Faisal Aziz, Sandra Toth, and Besma Nejim

Endovascular techniques have now become the first-line treatment for most diagnoses in vascular surgery. The success rate for endovascular therapies initially was mediocre, but endovascular technology has evolved, with the development of adjuncts that can be used to facilitate endovascular procedures. With the addition of such tools to the vascular surgeon's armamentarium, the success rate of endovascular therapies has increased dramatically. This chapter focuses on a brief review of two adjunctive endovascular therapies: intravascular ultrasound (IVUS) and embolic protection devices (EPDs).

Intravascular Ultrasound

The concept of using ultrasound technology to evaluate vasculature is not new for vascular surgeons. The majority of diagnostic vascular studies in the modern era are based on ultrasound technology. The introduction of ultrasound to image vasculature from the inside out takes this technology to the next level. This system was first utilized by interventional cardiologists during coronary interventions [1–4]. The IVUS catheter is inserted into a blood vessel over a guidewire. The tip of the catheter produces sound waves, which are transmitted through the blood to the blood vessel wall. The sound waves then come back to the catheter tip and create an image of the vessel wall, providing a plethora of useful information about the vasculature, including vessel diameter, characteristics of the intima, echogenicity or echolucency, length of lesions, and characteristics of lesions [5].

A typical image from an IVUS is shown in Fig. 24.1. The innermost circle represents the IVUS catheter. Moving outward in a radial fashion, much more information can be gleaned from this image. The black halo around the catheter represents blood. The radiopaque circle surrounding the blood is the intima of the blood vessel. The layers outside the intimal layer are the media and the adventitia. Penetration into deeper structures can be obtained by decreasing the frequency of sound waves, but this is accompanied by a decline in the resolution of the image. Generally, lower-frequency IVUS catheters are used for large-diameter blood vessels, and vice versa. The use of IVUS may help determine accurate sizing of stents and may help avoid or reduce the use of contrast, reduce radiation dose, and decrease operative times. In addition, IVUS can provide invaluable information regarding plaque characteristics.

Currently, two manufacturers have devices that are approved for non-coronary use in the United States: Volcano (Volcano Corp., San Diego, CA) and Boston Scientific (Boston Scientific Corp., Marlborough, MA). The Boston Scientific device is compatible with an 0.018″ system, and Volcano devices are compatible with 0.014″, 0.018″, and 0.035″ systems.

Clinically, IVUS can be used in the various clinical scenarios discussed below.

Peripheral Endovascular Interventions

Most patients with peripheral arterial disease are now treated with endovascular interventions, which are usually performed with angiographic guidance. Conventional angiography provides a two-dimensional view of the vessel of interest. IVUS has the advantage of providing a three-dimensional view of the vessel and any lesions present. It is also of signficant help in determining stent patency (Fig. 24.2). A recent Japanese study revealed superior 5-year patency rates for interventions performed under IVUS guidance when compared with those performed without IVUS (65% vs. 35%) [6]. Another study showed that use of IVUS helps determine the presence of under-expanded stents in 40% of patients [7]. It is worth noting that conventional angiography in these cases had failed to determine this crucial finding. Similarly, another study showed improved patency rates for interventions when IVUS

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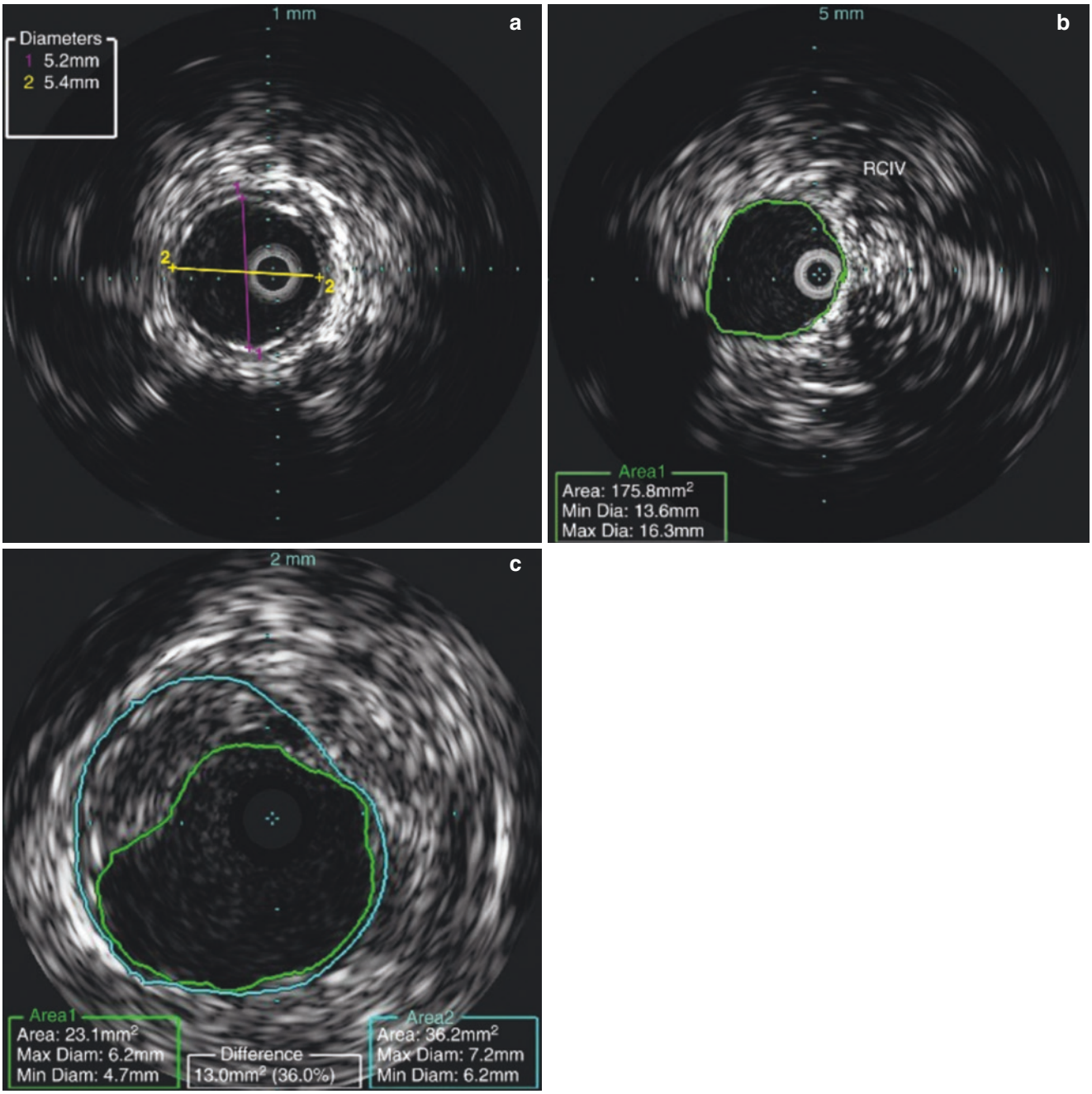

Fig. 24.1 Typical images from intravascular ultrasound (IVUS) (*From* Yammine et al. [33]; *with permission*)

was used to guide therapy [6]. The use of IVUS with re-entry devices has been shown to be associated with accurate re-entry into the true lumen and successful recanalization of occluded arterial segments [8, 9].

Aortic Dissection

Traditionally, type B thoracic aortic dissections have been managed conservatively with medical therapy. With advancements in the endovascular treatment of these dissections, a growing number of experts are now advocating endovascular repair of the aorta in these patients to prevent long-term sequelae such as aneurysmal degeneration. Nonetheless, the accurate placement of the guidewire in the true lumen can be quite challenging under direct fluoroscopy alone, which produces two-dimensional images. IVUS can be very useful in delineating the true lumen, false lumen, origins of visceral branches of the aorta, and the proximal and distal extent of dissections (Fig. 24.3) [10]**.** Further, the use of IVUS may

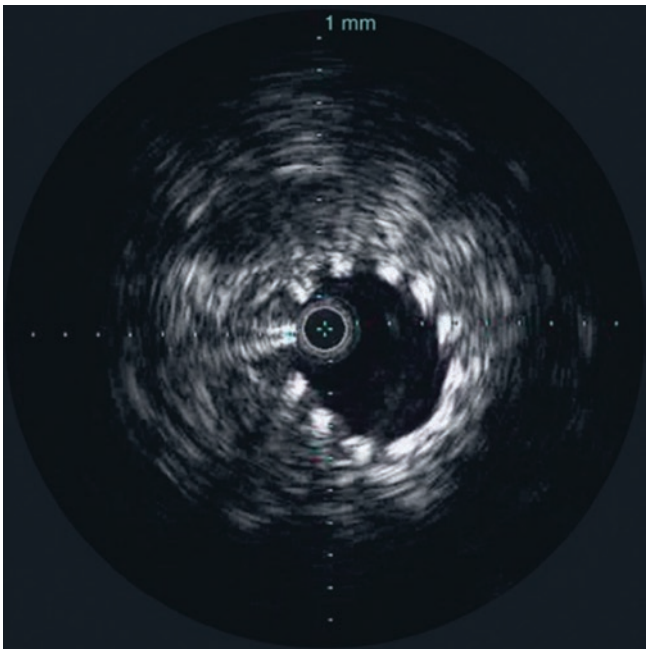

Fig. 24.2 IVUS evaluation of a stent graft (*From* Yammine et al. [33]; *with permission*)

assist in the accurate sizing of aortic endografts and their placement in the true lumen without compromising perfusion to the visceral vasculature [11].

Venous Stenting

In May-Thurner syndrome, the left common iliac vein is compressed between the right common iliac artery and the vertebrae. This pathology is treated in appropriately selected patients by placing self-expanding stents in the compressed area. It may be difficult to determine the exact area of extrinsic compression under conventional fluoroscopy alone. The use of IVUS in such cases can accurately determine the exact area of stenosis by extrinsic compression and can help in accurate stent placement (Fig. 24.4). In addition, the use of IVUS offers a complete assessment of thrombus after thrombolysis [12, 13]. It also can help with proper sizing to avoid stent migration in these compressed vessels.

To summarize, IVUS can be used in many clinical scenarios and can help with accurate visualization of intravascular pathology and in guiding successful endovascular treatment.

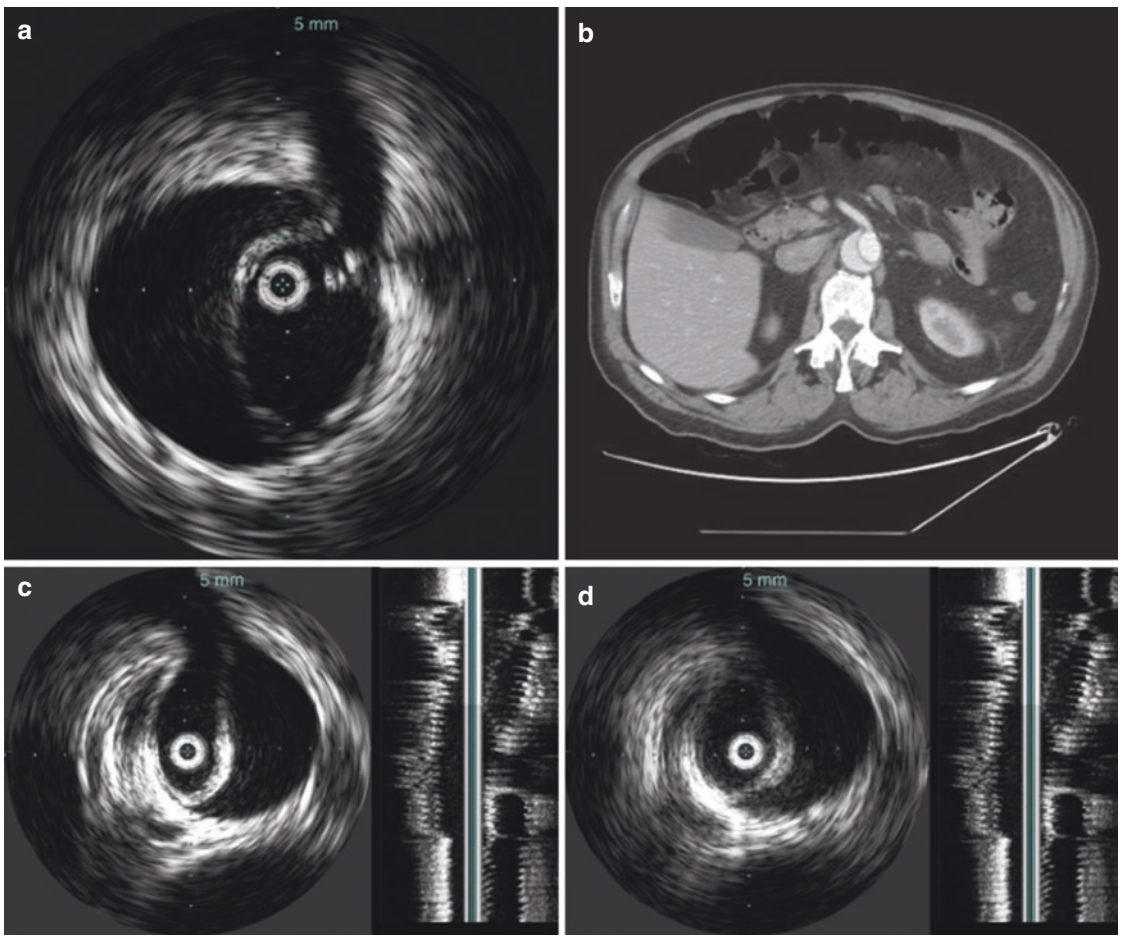

Fig. 24.3 Using IVUS to accurately identify true and false lumens in an aortic dissection (*From* Yammine et al. [33]; *with permission*)

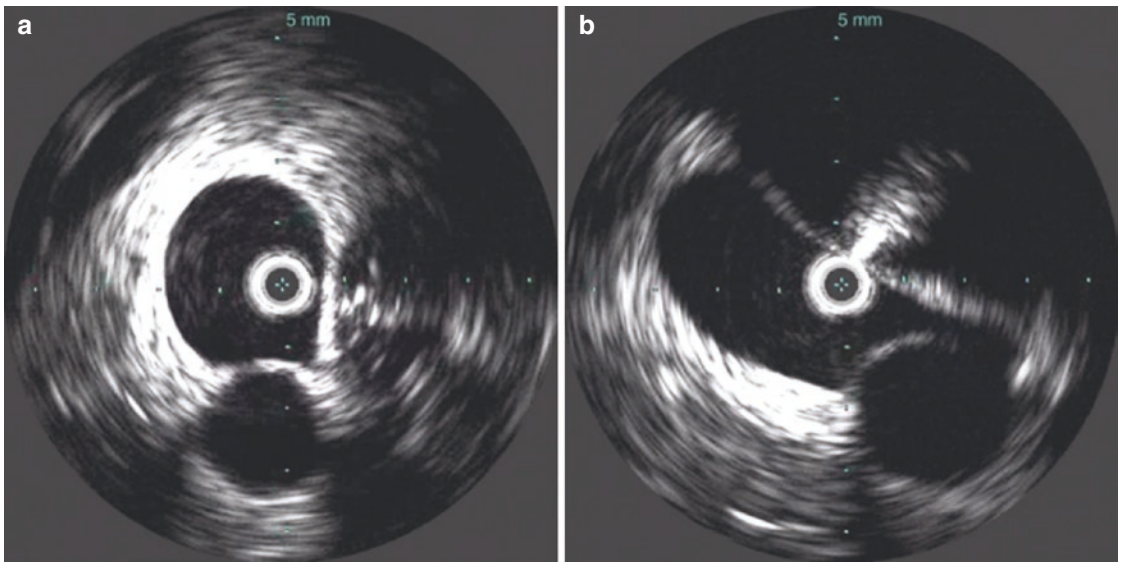

Fig. 24.4 Visualizing iliac vein compression by using IVUS (*From* Yammine et al. [33]; *with permission*)

Embolic Protection Devices

Conceptually, embolic protection devices (EPDs) are designed to prevent distal embolization. To understand the history of the development of EPDs, it is important to review the history of carotid artery stenting (CAS). Carotid endarterectomy (CEA) is considered the gold standard for treatment of severe carotid disease. CAS as an alternative to CEA was introduced by Mathias in 1977 [14]. Since the introduction of CAS, surgeons have raised concerns regarding the fracture of atherosclerotic plaque and distal embolization, which may have disastrous consequences, primarily embolic stroke. Theron et al. [15] coined the term "cerebral protection" to describe any methods used to prevent cerebral embolism. Cerebral protection is now categorized into proximal and distal types, with respect to the location of the carotid lesion. Early distal protection techniques included the placement of a balloon in the distal internal carotid artery (ICA). While the balloon prevents emboli from traveling upstream during the carotid stenting procedure, it also prevents blood flow in the occluded vessel. To counter this problem, filter devices were developed to allow for distal perfusion while preventing embolic events. The EVA-3S trial [16] showed that CAS procedures performed in the absence of distal protection had a four-fold increase in stroke when compared with CAS procedures performed with distal embolic protection. Proximal protection by a balloon inflated in the common carotid artery (CCA) was first described by Parodi et al. [17]. Subsequently, Criado et al. [18] described the technique of flow reversal from the CCA. Because the sheath for flow reversal is placed in the CCA, it is considered a form of proximal protection. The ROADSTER trial [19] investigated the safety of this technique and showed a rate of 30-day stroke lower than the rate reported in any previous trial.

Distal Protection

Balloon Occlusion

Balloon occlusion is the earliest described method of cerebral protection. Theron et al. [15] described the use of balloon occlusion distal to the carotid lesion prior to passing a stent. This technique entails first placing a wire in the distal ICA, followed by over-the-wire placement of a guiding catheter in the CCA. A small polyethylene catheter with a non-detachable balloon is then inserted into the ICA, and the balloon is then inflated to occlude the ICA. After endovascular intervention like angioplasty, the ICA should be thoroughly aspirated with an angioplasty catheter, and then the balloon is withdrawn. Aspiration and flushing of the guiding catheter and sheath removes any particles of debris from the atherosclerotic plaque.

Filters

The next generation of EPDs comprises filters. In contrast to occlusive balloons, filters can capture embolic material while maintaining distal perfusion. Several filters are currently available, which can be distinguished from each other based on porosity and landing zones. Table 24.1 lists the filters currently approved by the US Food and Drug Administration (FDA).

Table 24.1 Filters Approved by the US Food and Drug Administration (FDA) for Distal Embolic Protection in Carotid Artery Stenting

Type of distal filters	Manufacturer	Trial	Number of patients	30-day stroke rate	Landing zone (MM)	Porosity (μM)	Year approved by FDA
Angioguard RX	Cordis Corporation, Miami Lakes, FL	SAPPHIRE [21]	167	3.6%	5.9	100	2004
Rx Accunet	Abbott Vascular, Abbott Park, IL	ARCHeR [22]	581	5.5%	15.1	150	2004
FilterWire EZ	Boston Scientific, Marlborough, MA	ASTI [23]	100	2%	13.4	110	2006
Emboshield nav6	Abbott Vascular, Santa Clara, CA	PROTECT [24]	220	1.2%	19–22.5	140	2005
SpiderFX	Ev3, Plymouth, MN	CREATE SpideRX [25]	160	3.1%	17.3	50–300	2006
FiberNet	Lumen Biomedical, Plymouth, MN	EPIC [26]	237	2.1%	15	40	2008

Prior to using a filter, the operator must review the patient's anatomy to determine an adequate length and diameter of the vessel distal to the lesion as the landing zone for the tip of the filter device. The filters come in different diameters; some come preloaded and others can be deployed on any wire. A filter that is too large for the artery can be traumatic to the intima and cause dissection. Depending on lesion characteristics and tortuosity, it is occasionally necessary to dilate the lesion prior to advancing the filter. Predilatation is associated with a small increased risk of perioperative stroke. An analysis of over 3500 carotid artery stents in the Vascular Quality Initiative (VQI) database demonstrated that dual pre-stenting and post-stenting angioplasty was associated with a stroke risk twice that with predilatation alone [20].

Figure 24.5 shows some of the filter-type devices. Most studies that have evaluated the safety of various filter types were single-arm investigations sponsored by the manufacturers. To our knowledge, no study has been conducted to compare the superiority of any specific filter type. Operators may prefer certain filter types because of their experience and comfort, but certain considerations may help determine what filter type may be most beneficial in a given clinical scenario. Operators might prefer filters with small pores to protect against microemboli, but it might be wise to consider filters with larger pores in patients with occlusion of the contralateral ICA or limited vertebral collateral flow, to ensure maximum cerebral perfusion during the procedure. Additionally, there may be difficulty in crossing a tight lesion if a filters with a large crossing profile is used. Compared with distal balloons, distal filter protection has demonstrated a lower incidence of stroke and significantly lower ischemic burden as measured by diffusion-weighted imaging (DWI) following CAS. Prior to removing a filter, an angiogram should be performed to assess the amount of debris inside it.

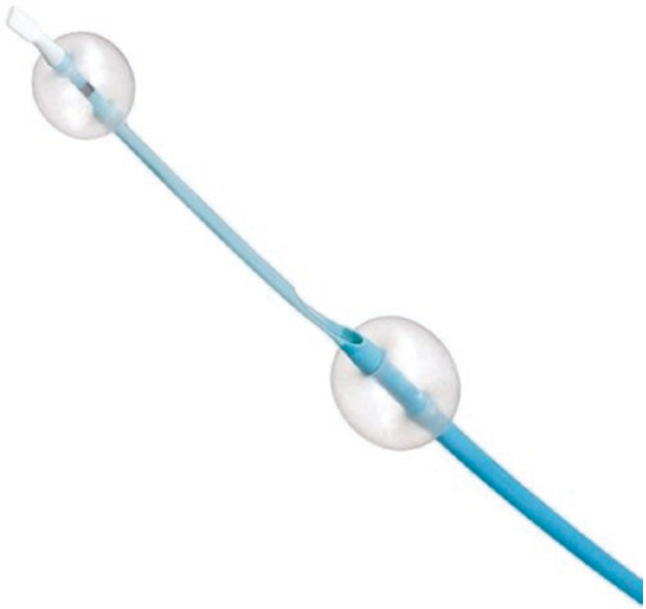

Fig. 24.5 Filter-type embolic protection devices (*From* Hicks and Malas [34]; *with permission*)

Proximal Protection

Balloon Occlusion

Proximal balloon occlusion was first proposed by Parodi et al. [27]. This model includes balloon occlusion of the CCA proximal to the lesion. The external carotid artery (ECA) is then occluded with a second balloon. This technique allows for the reversal of flow in the ICA. A guiding catheter placed in ICA allows retrograde flow from the ICA to be directed via a blood-filtered line to a femoral vein introducer in the contralateral femoral vein. A working channel allows for stent deployment. Intraoperative arteriography is performed to show that both the CCA and ECA balloons

are inflated and contrast material is retained in the ICA before being cleared through the guiding catheter. The only FDA-approved proximal balloon occlusion device is Mo.Ma™ Ultra by Medtronic (Fig. 24.6) since the Gore Flow Reversal system has been withdrawn from the market. The Mo.Ma Ultra proximal cerebral protection device (approved in 2009) involves temporary balloon occlusion of the CCA and ECA. In this system, a work channel allows for stent deployment and aspiration. A 0.035-inch guidewire is recommended for the use of this system. CCA balloons are available in sizes of 5 to 13 mm in diameter, with ECA balloons 3 to 6 mm in diameter. The Gore Flow Reversal system was also FDA-approved in 2009. It has three components: balloon sheath, balloon wire and external filter. The balloon sheath is placed in the CCA to stop antegrade flow. The balloon wire is placed in the ECA to prevent collateral flow to the ICA. The external filter is located outside the body between the balloon sheath and the venous circulation in order to create an arteriovenous shunt. Flow reversal is then initiated by inflation of both balloons. The pressure gradient across the arteriovenous shunt will drive blood flow from the ICA to the venous system in a retrograde fashion through the balloon sheath and then through the external filter into the venous circulation. The ARMOUR [28] and the EMPIRE [29] trials were involved in the approval of Mo.Ma Ultra and Gore Flow Reversal system, respectively.

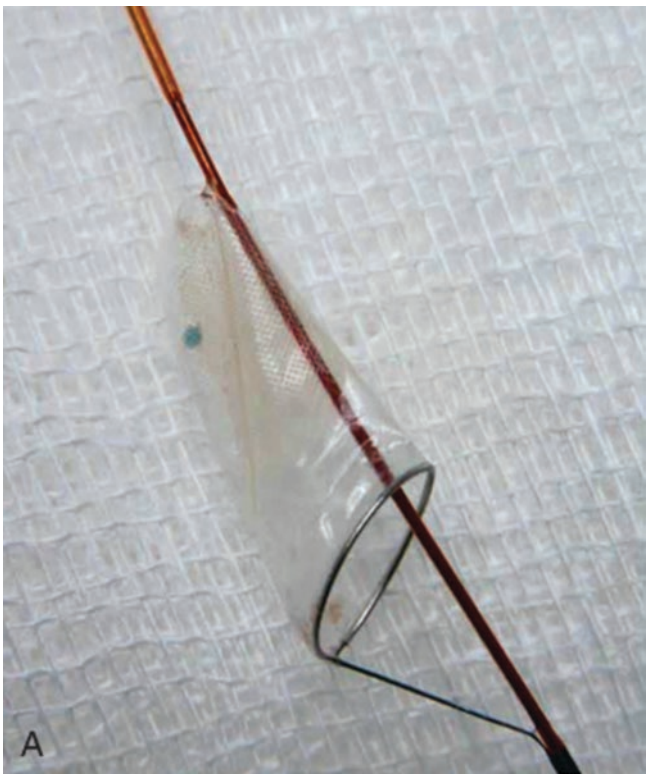

Fig. 24.6 Mo.Ma™ Ultra proximal cerebral protection device, a proximal balloon occlusion system

Unlike distal protection, proximal protection does not require a landing zone, which is particularly important in lesions within a tortuous vessel. In addition, proximal protection devices have been shown to be safer than distal protection devices. The PROFI [30] randomized clinical trial compared both approaches and reported a reduction in the incidence of new cerebral ischemic lesions (45.2% versus 87.1%) and a smaller volume of lesions in the proximal protection group. A systematic review confirmed that proximal protection was associated with reduction in microemboli but not in the risk of periprocedural stroke or death.

Transcarotid Artery Revascularization

A great advantage provided by transcarotid artery revascularization (TCAR), when compared with transfemoral CAS, is that it allows the operator to avoid manipulating the aortic arch, which may be calcified and tortuous in patients with atherosclerosis (Fig. 24.7). The ROADSTER trial [19] evaluated the ENROUTE neuroprotection system [31] and demonstrated the lowest 30-day stroke risk (1.4%) to date in any prospective multicenter clinical trial of CAS. The mid-term results were recently published and showed a 0.6% 1-year risk of stroke [32]. This procedure is unique in that it is performed through an incision between the heads of the sternocleidomastoid muscle. A 3-cm to 4-cm segment of the proximal CCA is dissected and a purse-string or U-stitch is secured. A 5F stiff micropuncture set is used, and the micropuncture wire is advanced 2–3 cm. The needle is removed, and the micropuncture sheath is advanced 1.5–2 cm into the

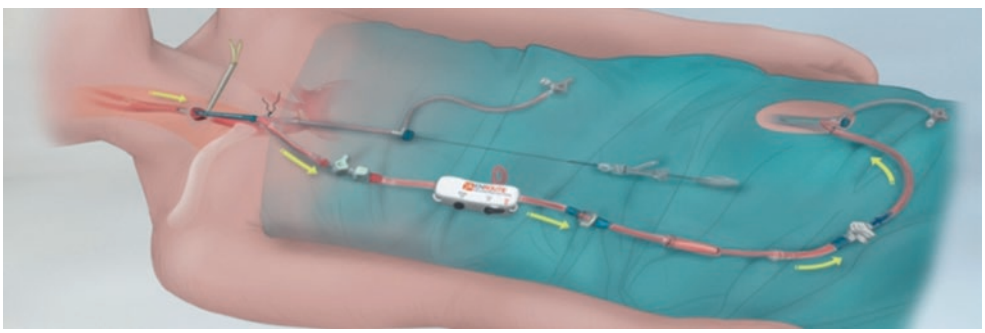

Fig. 24.7 Transcarotid artery revascularization (TCAR) (*From* Hicks and Malas [34]; *with permission*)

CCA. After removal of the micropuncture sheath, the arterial access sheath is advanced to the 2.5-cm marker. Sheath placement is then confirmed under fluoroscopy. Blood is aspirated, and the sheath is flushed by heparinized saline. The femoral vein, typically contralateral to the carotid, is accessed and the venous return sheath is advanced over a 0.035-inch wire. A flow controller is connected to the arterial access sheath, passively allowing a column of blood to fill the line, and is connected to the venous return system. Inflow to the CCA is occluded with either gentle traction proximal to the arteriotomy or with an atraumatic vascular clamp. Two flow settings are available, low and high. A flow-stop button is also available to allow for temporary cessation of flow reversal for contrast injection. The ENROUTE system is compatible with all FDA-approved stents. Intolerance to flow reversal has been reported, which may manifest as agitation, confusion, or decline in mental status. Flow can be put to a low setting or stopped if symptoms do not improve with elevation of the mean arterial pressure.

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The Use of Preoperative Imaging for Planning Endovascular and Hybrid Procedures

25

Jeanette H. Man, Crystal N. Rodriguez, and Mel J. Sharafuddin

Endovascular and hybrid procedures have become the mainstay minimally invasive treatment options for complex vascular disorders. Advanced imaging is crucial for planning and followup of such procedures. The most common preoperative imaging modalities for this planning are ultrasound (US), computed tomography angiography (CTA), and magnetic resonance angiography (MRA). This chapter focuses on the relative practical value and benefits of these modalities in common vascular surgical indications. The physical principles on which these modalities are based and other technical details are well described elsewhere [1] and are not discussed in this text.

Ultrasound

Ultrasonography enables live imaging for both diagnosis and real-time guidance of interventions in various disease processes. Ultrasonography's advantage in vascular diseases relates to its ability to assess vascular flow patterns using spectral and color Doppler imaging, in addition to gray-scale cross-sectional imaging and real-time guidance, which is of crucial importance in vascular interventions. Though simple in principle, its potential has greatly expanded with advancements in technology.

Surface Ultrasonography

The most commonly used ultrasound modality is in the form of a hand-held surface probe. The probe comes in a variety of shapes, the most common of which are curvilinear, phased array, and linear probes. Low-frequency probes (1–5 MHz) are better suited for evaluating deeper structures such as intraabdominal organs. High-frequency probes (5–10 MHz) are better adapted for examining superficial vascular structures. Several imaging modes—including two-dimensional (2D), three-dimensional (3D), spectral Doppler, color flow, and power mode—provide the user with different information. The 2D mode allows for soft-tissue characterization, including anatomic assessment of aneurysmal and atherosclerotic disease. Ultrasound imaging can provide crucial information pertaining to vascular anatomy, relationships, and orientation of the territory being imaged. The spectral Doppler mode allows for the quantitative assessment of velocities, allowing for detection of significant stenosis. The color flow mode detects the direction of blood flow.

Because of its versatility, noninvasiveness, portability, and relatively low cost, ultrasound has become a key imaging modality in vascular surgery. It can be used to diagnose vascular disease, such as stenosis, occlusions, and dissection. It also can help to characterize the lesion and determine whether the morphology is better suited for endovascular or open repair. Intraoperatively, ultrasound is also beneficial in ensuring safe vascular access into vessels can be instrumental when obtaining access into a pulseless vessel, in scarred groins, or in heavily diseased or calcified access vessels. It can help reduce the risk of complications in difficult and variant anatomy by locating the level of the femoral bifurcation, to ensure that the puncture is into a non-diseased segment of the common femoral artery. Its use also can enhance the safety of vascular closure devices, especially in patients with hostile or distorted anatomy. Post-procedure, surface ultrasound is routinely used on followup to detect any recurrent disease. As a result, the use of surface ultrasound allows versatility preoperatively, intraoperatively, and postoperatively. Ultrasound can also be helpful in deciding on making a targeted incision over a diseased vessel, sometimes referred to as *precision surgery*. For example, by marking the location of the carotid bifurcation, it becomes possible to make a small incision instead of a large incision from ear to sternum.

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A similarly small groin incision can be used to tackle an occluded common femoral artery.

Using surface ultrasound through a hand-held probe has numerous advantages. It is an accessible, quick, and portable modality with many modes and settings that equip skilled users with real-time imaging and knowledge. It is also an inexpensive and benign method of imaging, without the radiation exposure of CT scans. Disadvantages include limitations from the anatomy itself, such as when there are significant differences in acoustic impedance in tissues. Deeper structures, especially in obese patients, also are not as easily penetrated by ultrasound probes with a restricted range of frequencies. Most importantly, its use is operator-dependent. A high level of skill and experience are needed to obtain good-quality diagnostic images, but these are certainly obtainable with training and practice.

Several studies have shown the role of contrast-enhanced ultrasound in surveillance following endovascular aortic repair (EVAR). Compared with CT angiography, it showed very good diagnostic performance, absence of renal impairment, absence of radiation exposure, and low costs [2, 3].

Ultrasound is a versatile tool in vascular surgery, which can be employed both extravascularly and intravascularly to assist with diagnosis, treatment, and surveillance of vascular disease. With the constant advancements in technology, the use of ultrasound will continue to expand, and vascular surgeons will need to keep up with technology in order to take advantage of its full potential in treating patients.

Intravascular Ultrasound

Intravascular ultrasound (IVUS) has gained popularity, especially for complex aortic dissections [4]. It enables continuous real-time characterization of the vessel from within the vessel itself. There are two types of catheters: a multi-element phase-array catheter and a catheter with a mechanically rotating element. The multi-element phase-array catheter utilizes a miniature integrated circuit at its tip, whereas the mechanically rotating type employs a rotating transducer at the tip. During intraoperative use, the catheter allows evaluation of vessel wall integrity, angulation of vessels, branching points, ostial disease, thrombus, or dissection.

IVUS is employed most frequently as an adjunct during endovascular cases. When treating atherosclerotic disease, IVUS provides accurate measurements of luminal dimensions and lengths of landing zones. With an accurate assessment of anatomy, IVUS enables proper stent selection, sizing, and placement to treat atherosclerotic vascular disease. It also can be used to evaluate stent-to-vessel apposition. When optimized, all these factors promote long-term patency, which is supported by the literature. IVUS is now considered a mainstay diagnostic tool in managing iliac venous compression syndrome and guiding associated interventions. It also has become a key imaging modality during endovascular management of aortic dissections. It can provide precise information regarding the extent of the dissection and can help differentiate between the true and false lumens. This information in turn dictates whether the anatomy is conducive to endovascular repair, maps out how to do so, aids in the selection of disease-free fixation points, and ensures that other branching vessels have not been compromised. The IVUS-tipped catheter is fed over the guidewire and advanced past the area of evaluation. Then it is gradually pulled back through the area of interest, usually a stenosis or dissection flap. Images taken with the transducer are delivered to an external computer for real-time display of the endovascular and wall morphology.

The main advantages of IVUS include real-time visualization of vessel luminal anatomy and lesion-specific features not evaluable on fluoroscopic imaging or preoperative cross-sectional imaging. IVUS is also a useful intervention-guidance modality that can be used to guide many endovascular interventions. It also serves as an accurate modality for vessel diameter sizing and for post-intervention assessment, including assessment of dissection after percutaneous transluminal angioplasty (PTA) or assessment of stent expansion and stent-wall apposition, all of which have important implications for procedural outcome and long-term patency [5, 6]. The ability to perform intraluminal measurements is critical in choosing the right equipment for treating the disease. Studies have reported accuracy of luminal dimensions and wall thickness to within 0.05 mm [7, 8]. With direct visualization using IVUS, the amount of contrast and time of fluoroscopy can be decreased significantly. The use of IVUS and a standalone guidance modality during thoracic EVAR (TEVAR) and EVAR enables these procedures to be performed safely and eliminates or minimizes the need for iodinated contrast agents [9, 10]. One study demonstrated that that actual vessel size and lumen diameter were underestimated 62% of the time by arteriography, and that 40% of stents placed in the iliac arterial system were under-deployed, which may be related to treatment failure [11, 12]. Disadvantages of IVUS include its high expense and lengthening of procedure time. As with other ultrasound devices, it is operator-dependent and should be used cautiously even in the hands of a skilled interventionalist, to avoid potential embolization of plaque, dissection, or rupture of the vessel. Moreover, the accuracy of cross-sectional measurements may sometimes be limited, with underestimation in the elliptical lumens present in severely diseased vessels, in thoracic aneurysms, or in tortuous vessels [13–16].

Computed Tomography Angiography

CT angiography (CTA) is currently the imaging modality most commonly used for planning vascular procedures and assessing their outcomes. Optimal technique for CTA requires thin beam collimation (slice thickness of 1.5 mm or less) in order to allow high-resolution reformatting and segmentation needed for modern 3D imaging. Typically, a sub-second spiral scanning is the recommended means of obtaining the imaging, given that it allows for the same thickness of imaging while also allowing more information to be obtained in the cranial to caudal direction, which is optimal for angiography when imaging the aorta or peripheral vessels [1, 17, 18]. There are three different means for processing the information: surface rendering, maximum intensity projection (MIP), and volume rendering. Of these imaging processing techniques, volume rendering is generally the best option, as it is the most advanced and incorporates more of the raw data. Surface rendering is computed by analyzing the individual voxels and focusing on the intensity that is similar to the area of interest to determine the surface of the vessel. The drawback of this technique is heterogeneity of the vessel; the surface can be difficult to differentiate, and surrounding structures may have similar intensities. MIP is similar to surface rendering, but it analyzes each individual voxel and displays the data on the basis of how it compares to the voxel with the greatest intensity. The drawback of this technique is that it makes bone and calcification difficult to differentiate from intraluminal contrast. Volume rendering, a technique initially created for special effects in movies, was later applied to CT scans. It works by analyzing each individual voxel and comparing it to the data in a similar projection ray over a certain rotational range (typically 180° or 360°). 3D data projects in the visualization plane the voxels with maximum intensity that fall in the way of parallel rays traced from the viewpoint to the plane of projection. This more complex analysis enables better differentiation of asymmetric anatomy, abnormalities, or lesions, as illustrated in Fig. 25.1.

MIP reformatted CTA can blur out focal lesions, which are best visualized using oblique or centerline reformatted multiplanar reconstruction (MPR) (Fig. 25.2). Likewise, calcified lesions are exaggerated on MIP projections and require thin-cut MPR with proper windowing to demonstrate the residual lumen and distinguish volume averaging, blooming, and high-attenuation artifacts from true stenosis [19]. Calcification-related artifacts are highly detrimental in peripheral CTA, especially in patients with diabetes or end-stage renal disease, who have a predilection for heavy vascular calcification. Newer developments, notably dual-energy CTA, can be used to reduce artifact caused by plaque calcifications and may even suppress vascular calcifications altogether [20].

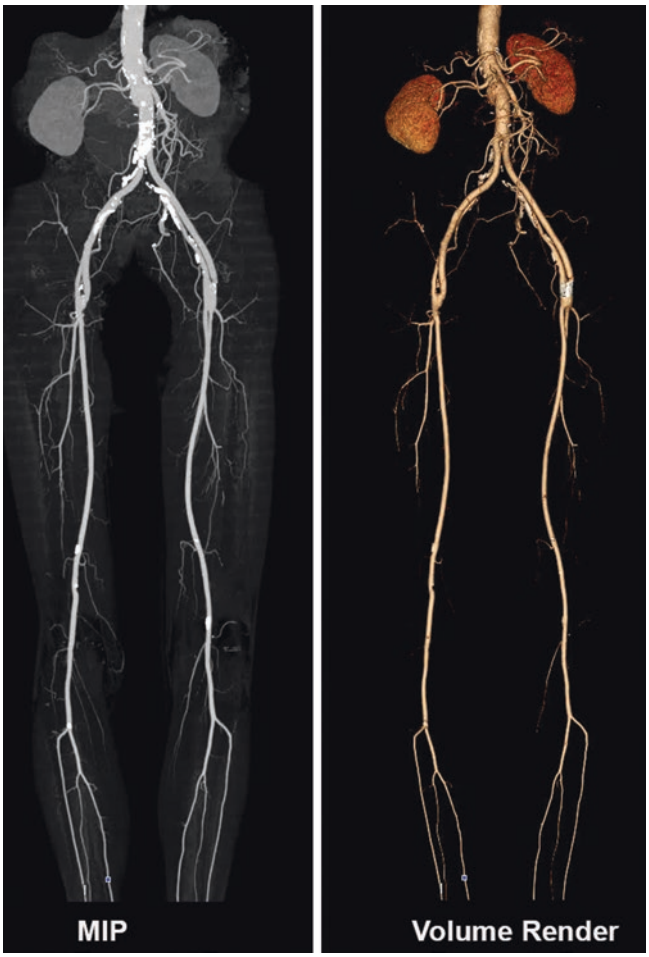

Fig. 25.1 Commonly used volumetric reformatting methods in CT or MR angiography: maximum intensity projections (MIP) and volume rendering

Neurovascular Circulation

Carotid disease is most commonly evaluated and monitored with ultrasound, but its limitations in the setting of recurrent stenosis, high bifurcation, or heavy calcifications may warrant the use of CTA or MRA. Measurement of stenosis can be done in one of two ways: by the North American Symptomatic Carotid Endarterectomy Trial (NASCET) algorithm [21], or by measuring the lumen size to determine the percent of stenosis, as illustrated in Table 25.1 [22].

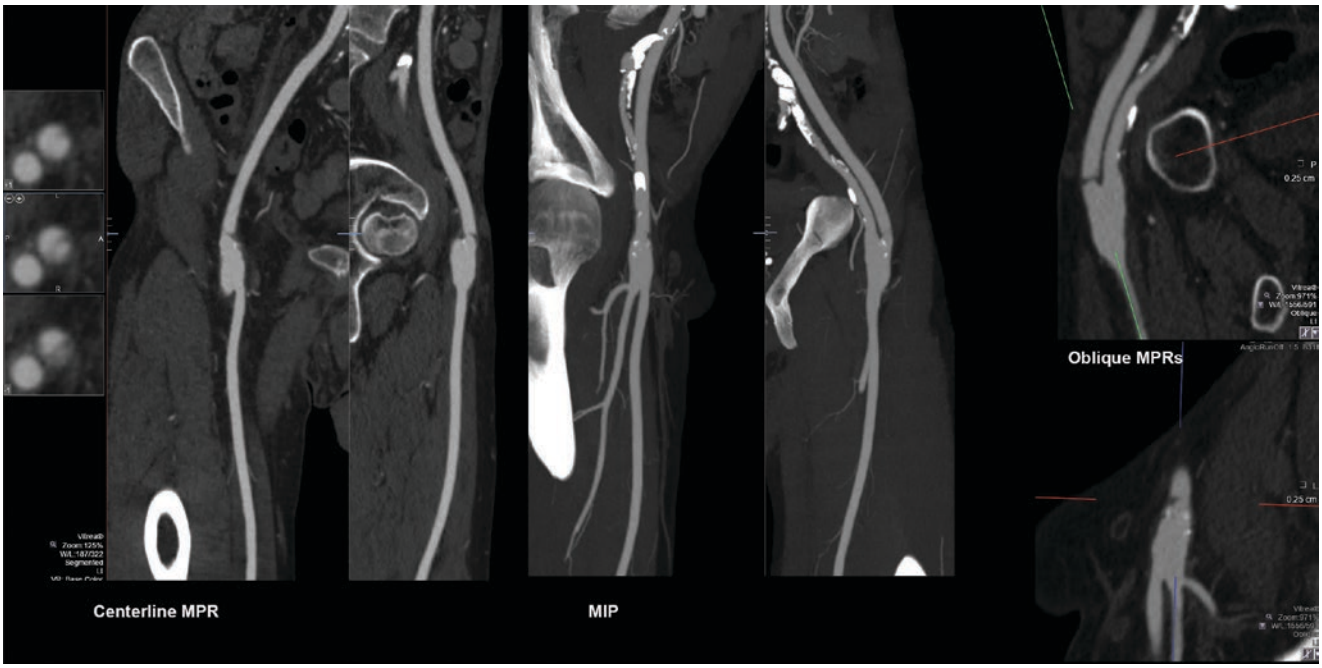

Fig. 25.2 MIP versus multiplanar reconstruction (MPR) in visualization of a focal, non-occlusive, web-like stenosis in the distal left limb of an aortobifemoral bypass. Volume averaging in MIP results in blurring of focal details; the lesion becomes obscured

Table 25.1 Prediction of Carotid Stenosis Using CT Angiography

Severity	Lumen Diameter	Stenosis	Sensitivity	Specificity
Mild	>2.2 mm	<50%	95.2%	93.2%
Moderate	2.2 – >1.3 mm	50–69%	75.0%	93.8%
Severe	≤1.3 mm	≥70%	88.2%	92.4%

Data from Barrett et al. [22]

Peripheral Vasculature

Compared with angiography, CTA has high sensitivity, identifying 86.3% of all infrainguinal lesions. When separating the lesions into those above or below the popliteal trifurcation, the accuracy of CTA was 87.3% and 80.2% [23]. CTA can be used for preoperative planning of endovascular interventions by assessing appropriate access sites and target vessel intervention; in open interventions, it can help to decide appropriate inflow and outflow for peripheral bypass. CTA is often used in conjunction with ultrasound for peripheral arterial disease; it is comparable to angiography but is less invasive.

Aorta and Viscera

Ultrasound surveillance is generally recommended for monitoring of aortic disease, but if there is concern that the size of an abdominal aortic aneurysm (AAA) is approaching 5.0 cm or greater, CTA may be used for further evaluation to determine whether surgical intervention is appropriate [24]. CTA also can be appropriate for monitoring if the patient is obese and ultrasound imaging cannot be obtained or is unreliable.

If open repair is planned, imaging is important to assess the aneurysm to determine the operative approach, extent, and clamp location. For endovascular repair, CTA imaging is used in both the preoperative and postoperative settings. In the preoperative setting, it is used for operative planning to determine suitability for endovascular repair and the type of endovascular repair (infrarenal EVAR or fenestrate/branch EVAR), depending on whether the aneurysm is infrarenal, juxtarenal/pararenal, or suprarenal. CTA yields important variables such as the length of the aneurysm, the diameter of the proximal and distal seal and fixation sites, and qualities of landing zones, such as calcification, thrombus, and non-parallel wall configuration. These measurements are used to select the size of the endograft. CTA also can contribute to preoperative planning by evaluating hypogastric patency, evaluating for synchronous aneurysmal disease, and evaluating access sites. In the postoperative setting, CTA is utilized to monitor for stent failure and to help with preoperative planning should the patient require an additional intervention, but research and evidence indicate that ultrasound plays an important and appropriate role in postoperative monitoring, particularly once the aneurysm sac has stabilized, as CTA is associated with radiation and risk from contrast.

Magnetic Resonance Angiography

Magnetic resonance angiography (MRA) has usually required the administration of diamagnetic or ferromagnetic contrast agents to outline the vascular lumen, much like the iodinated contrast agents used in CTA [18, 25–27]. MRA also can be obtained without intravascular contrast, however, by utilizing flow-based techniques. Recent advances in MR imaging has allowed these flow-based enhancement techniques to offer alternative vascular imaging options in patient who cannot tolerate iodinated contrast agents or magnetic contrast agents [28–30]. Drawbacks include the susceptibility of MRI to motion artifact and the inability to use it in patients who have pacemakers or automatic defibrillators. Metal-related artifacts also limit its value in proximity to metallic implants.

The imaging processing of MRA is similar to that of CTA and includes both MIP and volume rendering [1, 18]. With MIP, the data can be manipulated to analyze maximum intensities along different rays, similar to volume rendering. The problem with this technique is that there are not as many rays, so there is potential for missing small differences like stenoses or dissections [31].

Neurovascular Circulation

Opinions are mixed as to the appropriateness of MRA as a confirmatory test. Studies have identified varying sensitivity and specificity of MRA for carotid disease; Layton *et al.* demonstrated that the sensitivity of MRA for identifying carotid stenosis was highly dependent upon how many normal carotid arteries were included in the study [32]. Another concern regarding MRA (although controversial) is that it may overestimate stenosis in carotid disease.

Peripheral Vasculature

MRA is a well-recognized modality for preoperative planning in patients with peripheral vascular disease [33]. MRA is also accurate for postoperative bypass assessment after bypass surgery, though it suffers from moderately lower specificity than CTA; when assessing stenosis within the native artery, its sensitivity was 96.0% and its specificity was 87.6%. MRA is also less helpful for preoperative assessment of vascular calcification, but this drawback can be advantageous in allowing better assessment of the flow lumen (compared with CTA) in the presence of heavy calcifications. MRA is appropriate for postoperative monitoring or as an adjunct to preoperative evaluation for patients requiring an additional intervention to improve the secondary patency rate of a bypass.

Aorta and Visceral Arteries

Currently there are no well-established guidelines regarding MRA use to evaluate aortic disease in the surveillance period or the preoperative or postoperative setting, though some studies do support MRA. Gadolinium-enhanced MRA allows imaging of the abdominal aorta down to the groins using a breath hold. MRA imaging has been shown to be inferior to CTA for evaluating the renal arteries, with a tendency to exaggerated stenosis severity and susceptibility to motion artifact [34]. MRA is particularly useful, however, in patients with contrast allergies who are unable to undergo CTA or angiography; it has been shown to be superior to CO_2 angiography.

Conclusions: Preoperative Imaging Modalities

CTA is an appropriate modality for imaging of the vascular system and is crucial to preoperative and postoperative evaluation of carotid, aortic, and peripheral vascular disease [22, 23, 35–38]. However, CTA is inappropriate for the many patients who have concurrent renal disease resulting in a significant risk of kidney injury.

MRA can be an alternative option if CTA imaging is not appropriate. Though MRA is not widely used, there is evidence of its efficacy and reliability for the preoperative and postoperative evaluation of carotid, aortic, and peripheral vascular disease [32–34, 39–44]. Some negatives to using MRA include its cost, lack of accessibility, lack of previous operator use, and potential overestimation of stenotic lesions, as previously described.

The gold standard for any vascular imaging remains digital subtraction angiography, but this modality is invasive, depends upon contrast, and must be performed by an interventionalist. Thus, it is worth considering the other good options that are now available.

Advanced Adjuncts

Three-Dimensional Imaging

Three-dimensional (3D) imaging uses advanced image analysis to enable accurate multidimensional assessment of vascular anatomy and dimensions. It also can reveal key relationships to other relevant anatomic landmarks. The analysis of 3D vascular imaging has become key in presurgical analysis to help plan complex endovascular interventions. It is particularly indispensable for the planning of aortic aneurysm repair, especially for procedures requiring custom stent-graft designs or in fenestrated/branched endovascular aortic repair (F/BEVAR).

The process of 3D imaging is accomplished through a computer workstation that utilizes data obtained from CTA and MRA to reconstruct 3D vessel anatomy with accuracy. This enables assessment of vascular anatomy through multiple views, such as orthogonal and oblique sections, as well as curved planar reformatting that allows depiction of the lumen as a single plane. Multiple programs are available, each with its own advantages and disadvantages. Among the more popular platforms are TeraRecon (TeraRecon; Foster City, CA), Vitrea (Vital Images, Minnetonka, MN), 3Mensio (Pie Medical Imaging, Maastricht, the Netherlands), and OsiriX (Aycan Medical Systems, Rochester, NY). These programs can be either server-based or workstation-based and enable automated segmentation and centerline reformatting in customizable protocols depending on the specific application. Most of these programs allow the operator to correct segmentation and centerline errors that occur in the automated process. These programs enable accurate diameter measurements, centerline or greater-curvature lengths, clock-face vessel origin angulation, and arc length measurements, as well as indices of aortic angulation and curvature or tortuosity. These measures are vital to the selection and sizing of endovascular devices used for the endovascular treatment of many aortic conditions [45–47]. Specifically, planning of F/BEVAR depends on accurate measurement and sizing, which can be generated only with specialized 3D imaging software (Fig. 25.3).

The use of 3D imaging for complex aortic and other endovascular imaging relies on the following key prerequisites:

- The measurement process must take a centerline reference path in the vessel lumen. Centerline is helpful in analyzing highly tortuous aortas by generating an unfolded, straight projection along the main medial axis. This enables consistent and better visualization of the origin of branches, as well as accurate determination of longitudinal separation of various visceral branches along the centerline axis, which is essential for the planning of fenestrated and branched devices.
- Resulting aortic tree lumen segmentation from centerline measurements should be accurate and reproducible. The measured diameters, lengths, and angles are important to ensure optimal endograft apposition at the proximal and distal landing zones. When fenestrations or branched grafts are employed, these measurements are even more critical.
- The output must be modifiable by the user. The final centerline course or other operator-selected pathway (such as the outer curvature line) should be customizable by the operator to each patient's anatomical and clinical criteria, based on the specific clinical need. Interactive tools should allow for these changes in a user-friendly fashion (Figs. 25.4 and 25.5).

Fusion Imaging

Although 3D imaging is most helpful for pre-procedural planning and selection of endografts, fusion imaging is help-

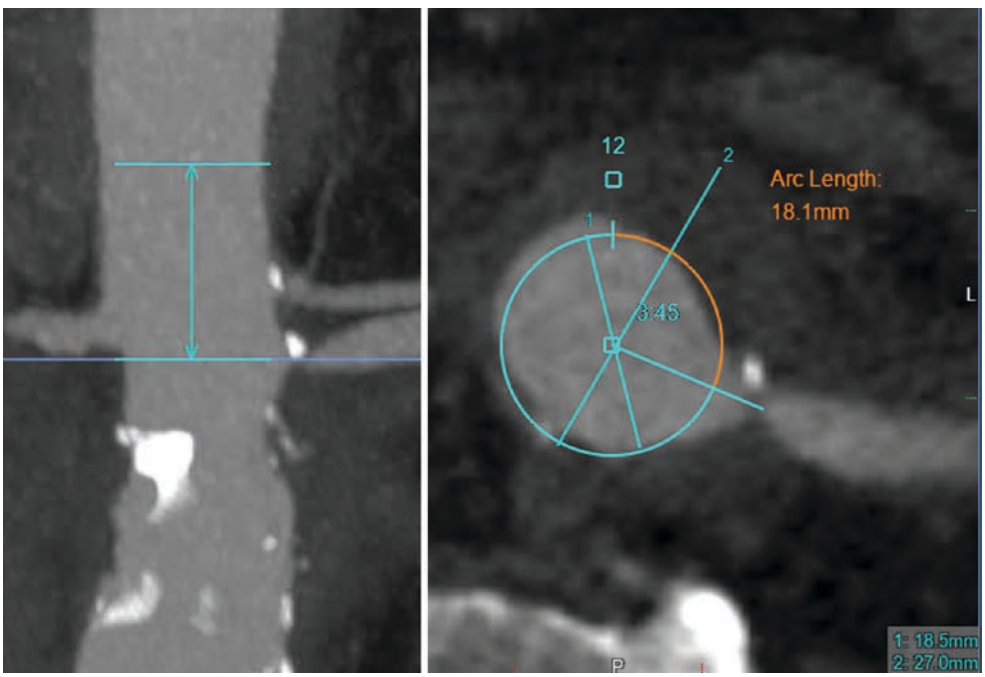

Fig. 25.3 Aortic diameters, longitudinal axial position of visceral branches, clock-face position, and arc length are readily generated on most 3D workstations. These measurements are crucial for planning of fenestrated/branched endovascular aortic repair (F/BEVAR) procedures

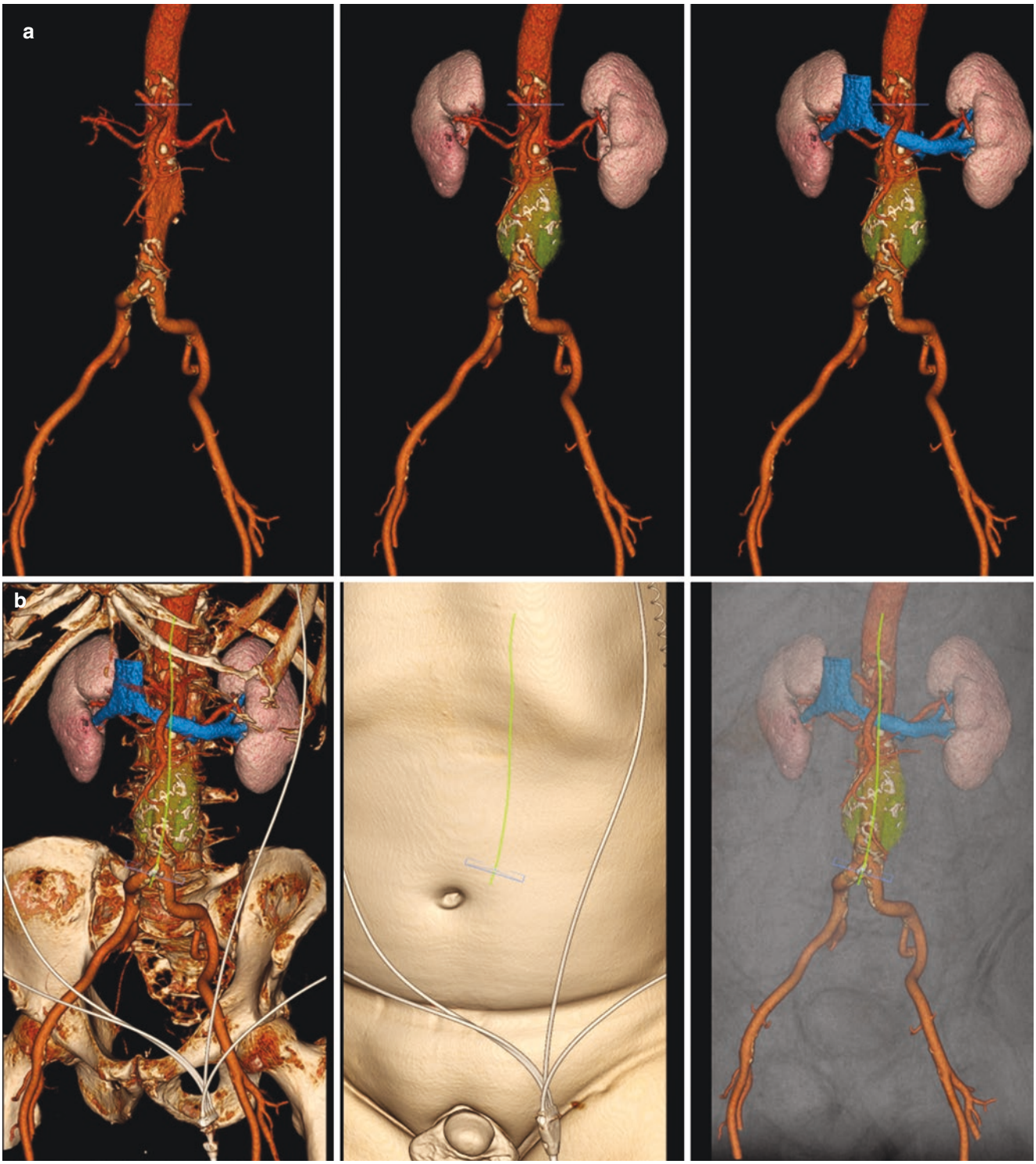

Fig. 25.4 Semi-automated tissue segmentation can be generated on most high-end 3D workstations. This allows assignment of various tissue tags to each voxel in the imaging data set. (**a**) This example is a 3D segmented, volume-rendered arterial phase from CTA of the abdomen and pelvis in a patient with abdominal aortic aneurysm (AAA). The reconstruction enables visualization of the various elements in the aorta (aneurysm, laminated mural thrombus, mural calcification, plaque). (**b**) The reconstruction also demonstrates the 3D relationship to key adjacent structures such as the renal veins, bony structures, and surface landmarks

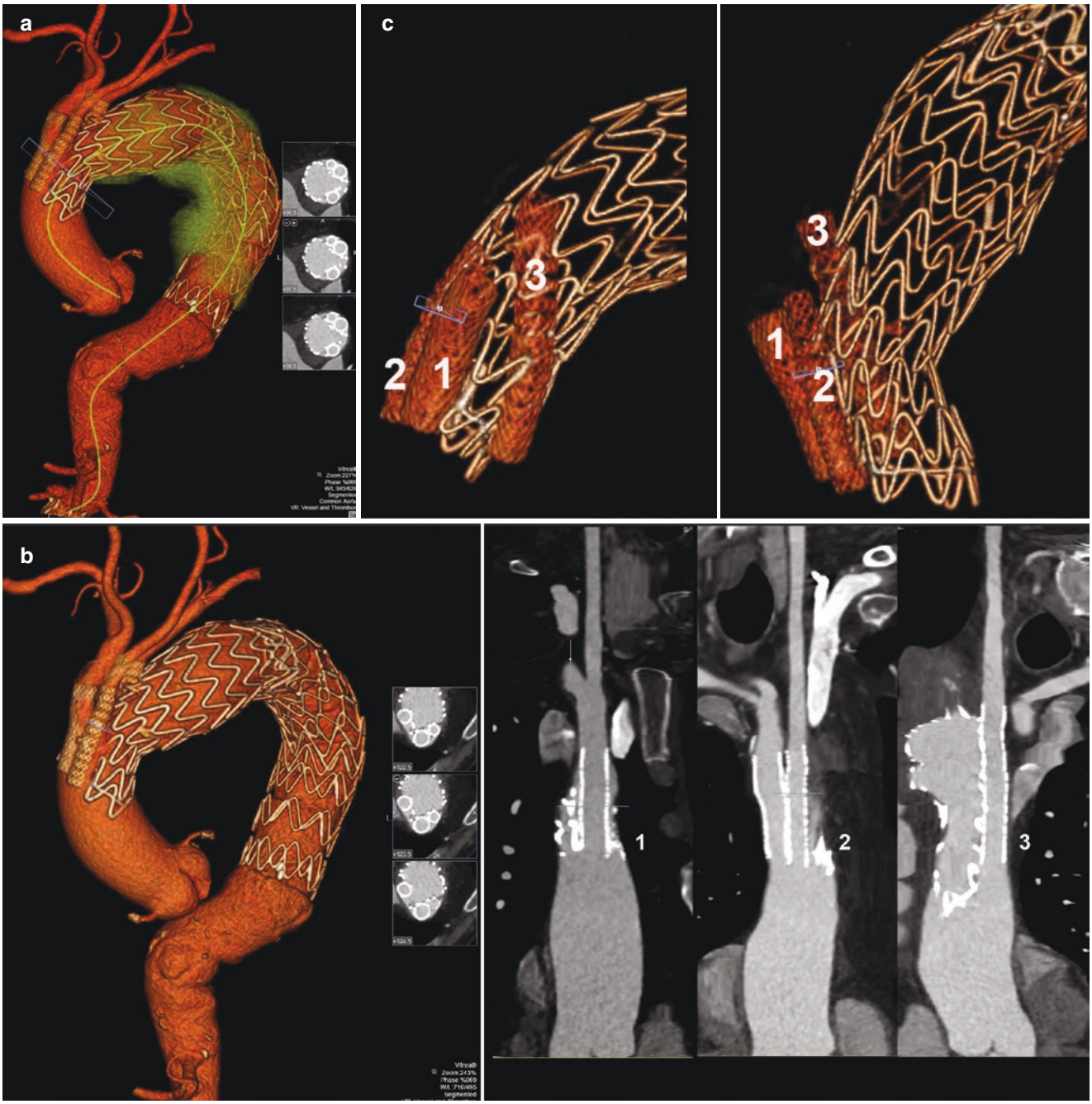

Fig. 25.5 3D reconstruction of the thoracic aorta after parallel multi-branch reconstruction to treat a zone-1 aortic arch pseudoaneurysm. (**a**) Volumetric rendering demonstrated the metallic elements of the stent-grafts, the flow lumen, and the thrombosed pseudoaneurysm. (**b**) Centerline MPR documents wide patency of all three branches stent-grafts. (**c**) Differential windowing allows visualization of solely the metallic elements of the rendered volume, which enables assessment of the main aortic endograft and the snorkeled side branches, to assess position and detect any problematic kinking or crushing

ful to enhance the safety and accuracy of intra-procedural guidance. Fusion imaging is defined as the merging of preoperative imaging with intraoperative imaging to provide a 3D vascular mask that optimizes visualization. Fusion imaging in vascular surgery is often utilized by fusing live fluoroscopy with preoperative CTA or MRA imaging to guide device deployment intraoperatively. With advances in technology, it can also be used with postoperative CTA or ultrasound imaging for postoperative monitoring in select endovascular cases.

The advantage of fusion imaging is its ability to visualize the anatomy from several modalities during the intervention and postoperative monitoring. The viewer can make more informed decisions from multiple perspectives while using

less contrast and radiation. Either hardware-based or image-based tracking technology can be used to register and place a fusion mask [48]. Moreover, recent developments have allowed virtual navigation systems that can also fuse real-time ultrasound with reconstructed 3D CT imaging [49, 50]. The accuracy of the fusion model can be verified and enhanced through the recalibration of fluoroscopic landmarks and the use of a limited-contrast angiographic run or ultrasound-based correlation to enhance its diagnostic accuracy.

The main disadvantages of fusion imaging are the need for access to this new technology and the time it takes to achieve adequate alignment, though automatic image analysis has helped greatly. Though beneficial in principle, the benefits of fusion imaging using ultrasound are still being explored, and its potential will expand as technology advances. For now, it remains a niche option that is not always clinically employed but can be helpful in selected scenarios.

Conclusions

3D imaging and fusion imaging are helpful advanced adjuncts that we can add to our arsenal of tools to treat complex vascular pathologies [51, 52]. They can add an immense amount to preparations for endovascular intervention, design of customized endografts, accurate intraoperative deployment of devices, and postoperative surveillance.

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Aortoiliac Occlusive Disease: Endovascular Management

26

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Aortoiliac occlusive disease (AIOD) is a form of peripheral artery disease (PAD) characterized by the development of atherosclerotic plaques specifically within the abdominal aorta and iliac arteries. The disease process is progressive in nature, and patients may range from asymptomatic individuals to those with critical limb ischemia in the form of rest pain or tissue loss. Patients may also present with Leriche syndrome, with buttock claudication and erectile dysfunction due to poor perfusion of the internal iliac arteries. The diagnosis of AIOD is often considered following abnormal lower extremity arterial doppler studies, and ultimately is confirmed by contrast-enhanced cross-sectional imaging or fluoroscopic angiography. Early risk factor reduction and medical management has a role in reducing the progression of disease in all patients, but endovascular and open surgical intervention may be required for those with critical limb ischemia or symptoms that are severely limiting.

Risk Factor Reduction and Medical Management

As with other forms of atherosclerotic disease, risk factor modification is critical in stabilizing the disease process to prevent limb loss or associated cardiovascular mortality and morbidity. In patients who have no significant limitations of the quality of life, noninterventional treatment options of smoking cessation and regimented exercise should be considered, as these have demonstrated the greatest benefit for those with early atherosclerotic changes. Other beneficial steps include adequate control of diabetes mellitus, hypertension, and hyperlipidemia.

Two types of agents in particular have demonstrated the greatest benefit with regards to medical management: antiplatelet and cholesterol-lowering medications. The consensus guidelines of the Society for Vascular Surgery recommend the use of aspirin for all patients with PAD, given its demonstrated reduction in myocardial infarction, stroke, and all-cause mortality [1, 2]. Also recommended are statin medications. The Heart Protection Study Collaborative Group has demonstrated significantly reduced mortality in patients with PAD taking a high-dose statin, so it is recommended unless otherwise contraindicated [3].

Endovascular Repair

Indications

Endovascular repair is considered an attractive treatment option for many patients, and it may be a primary option for those in whom open surgery poses significant risk. Severe disease burden including total occlusion may make endovascular repair technically challenging, however, so it is most commonly reserved for those with significant unilateral or bilateral iliac artery disease burden without the presence of aortic occlusion. But with the evolution of endovascular technology, it is no longer unusual to consider treating even more complex proximal occlusion, including Infrarenal aortic occlusion, with this approach. Benefits of an endovascular approach include reduction in perioperative mortality and the opportunity to treat distal lesions during the same procedure. Although the 2- to 5-year primary patency rates as low as 60% are considerably inferior to the rates for open bypass, assisted primary patency and secondary patency are almost similar to those achieved by open reconstructions, so these percutaneous interventions should be reserved for select patients [4–7].

Complications of endovascular interventions include those related to access, contrast use, and radiation, as well as the specific complications related to the treatment of the arteries themselves. Major complications such as bleeding,

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embolization into visceral arteries causing end organ damage, or rupture of the vessel can be devastating.

Any consideration of endovascular therapy for AIOD should address the inflow and outflow disease. It may be advantageous to employ a totally endovascular approach or a hybrid approach using a combination of endovascular and open techniques. The major advantage of endovascular therapy is the limitation of the morbidity and mortality resulting from an open approach. For a hybrid approach, inflow is generally established with an endovascular strategy, whereas the outflow through the femoral arteries may need either a femoral endarterectomy or profundaplasty.

Iliac Artery Stenting

Definitive endovascular management of iliac disease is traditionally accomplished with bilateral iliac stenting, often referred to as "kissing iliac stents." The stenting is completed via bilateral retrograde common femoral artery (CFA) access and requires 6- to 8-French sheaths. Both balloon-expandable and self-expanding stents have demonstrated technical success, though covered stents demonstrated long-term superiority in the COBEST trial [8]. Normal common iliac artery size ranges from 8 mm to 14.5 mm in males and 8 mm to 10.5 mm in females, so standard iliac stents range from 6 to 10 mm in diameter [9, 10]. Simultaneous expansion of stents is recommended to prevent malalignment and stent occlusion. Extension into the distal aorta is also recommended. Percutaneous transluminal angioplasty (PTA) alone has demonstrated similar rates of technical success, but because of its poor rates of primary and secondary patency (as low as 50% at 4 years), it is no longer recommended [11].

Several configurations for endovascular reconstructions for aortoiliac arteries are shown in Fig. 26.1. The choice depends on the anatomy of the segment that need to be treated.

Following are steps for an iliac artery angioplasty and stent exclusively addressing the common iliac and external iliac arteries:

1. Obtain ultrasound-guided or fluoroscopic-guided access to the femoral arteries, followed by placement of working access sheaths. Bilateral access is required when addressing stenosis or occlusion at the origin of common iliac arteries.
2. Traverse the lesion using a hydrophilic wire, and maintain the wire access in the true lumen.
3. Perform adequate intravenous heparinization (100 IU per kg body weight).
4. Exchange the wires for stiff wires.
5. If the patient has total occlusion, perform predilation with at least a 3- to 4-mm balloon, to help advance the delivery sheaths and placement of stents across the diseased segments. In heavily calcified lesions, it is helpful to advance a sheath through the lesion and place the stent in the sheath in order to protect the stent.
6. Balloon-mounted stents (either bare-metal or covered stents) are used for treatment at the origin of common iliac arteries; self-expanding stents are used for treatment of external iliac arteries.
7. Intravascular ultrasound may be used to assess adequate coverage of the lesion, stent size selection, and stent apposition to the arterial wall.
8. Perform completion angiographic evaluation to demonstrate technical success, identify any flow-limiting lesions (both proximal and distal to the treated segments), and recognize any embolic complications.
9. Use closure devices or manual compression to obtain hemostasis at the access sites.

For patients with complex lesions, one can consider Iliac stenting using subintimal iliac artery recanalization. This may be required in the event of chronic iliac artery occlusion. Intraluminal passage of the wire through the area of occlusion is preferred but is often difficult or impossible. The presence of calcific plaque material or total occlusions make the maintenance of wires in the true lumen a challenge. In these cases, subintimal crossing of the lesion may be required, which can be performed in either an antegrade or retrograde fashion. With subintimal technique, challenges can be anticipated with luminal re-entry proximally at the aortic bifurcation. If an antegrade approach is intended, then access should be obtained in the contralateral CFA or left brachial artery. Multiple devices are currently available to facilitate luminal re-entry, with differences in these devices involving use of intravascular ultrasound-guidance (Fig. 26.2) or fluoroscopic guidance (Fig. 26.2). These devices have demonstrated similar efficacy, and their use often depends on operator preference and experience [12–14].

Bleeding and rupture are well-documented complications of recanalization, occurring in up to 15% of patients; these can be treated with a covered stent and rarely require conversion to an open operation [12]. Patients requiring isolated iliac artery and distal aortic reconstruction should have a good outflow with no disease in the femoral arteries. The presence of unattended femoral artery disease can impact the patency of iliac stents. Increasingly, stent grafts are employed in the recanalization of iliac arteries, but use of these stent grafts requires delivery sheaths of larger caliber than the Nitinol-based self-expandable stents. If the internal iliac artery is patent, caution should be exercised in covering internal iliac arteries; the consequences can be colonic and gluteal ischemia, with a remote potential for paraplegia.

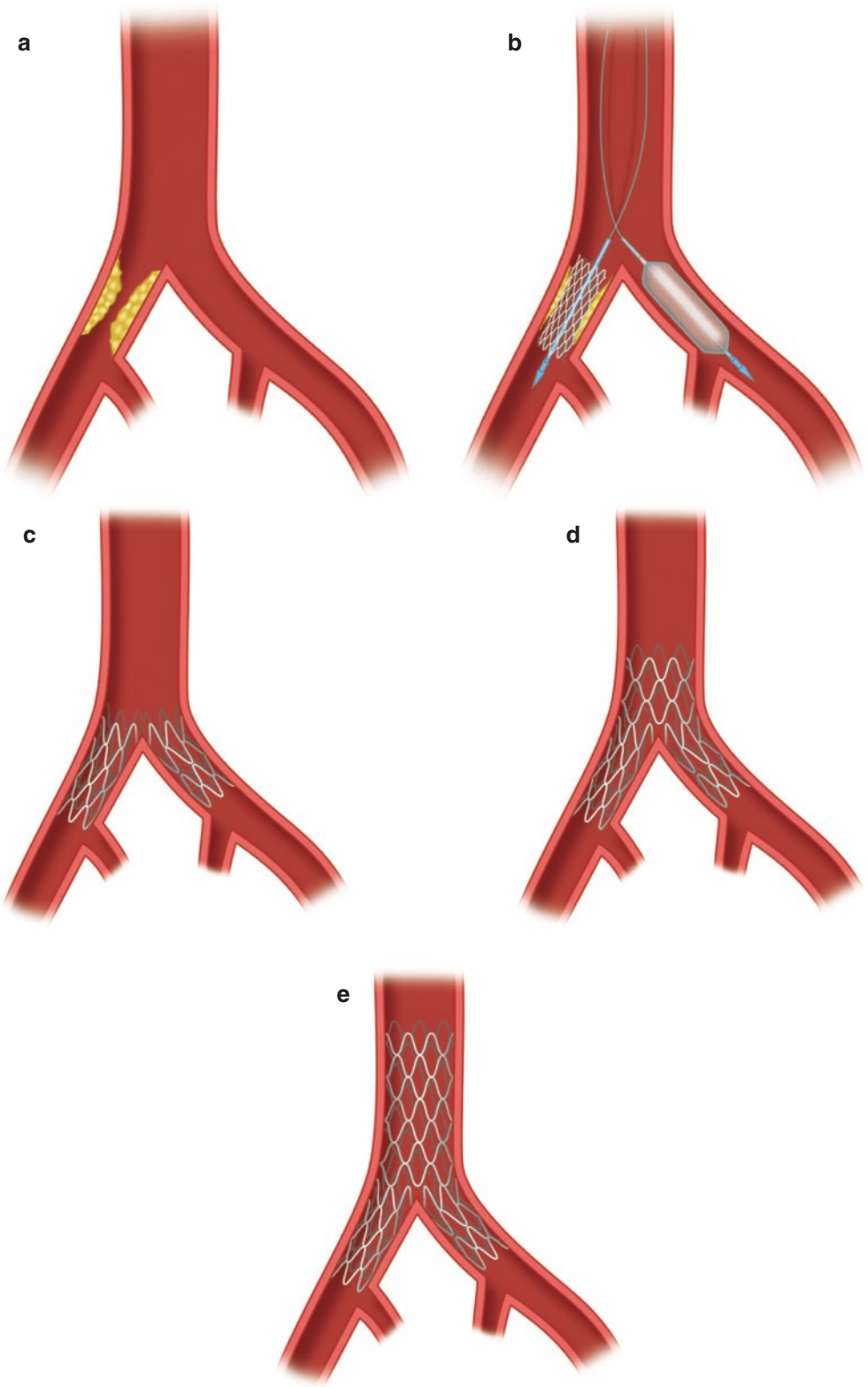

Fig. 26.1 Configurations for aorto-iliac reconstructions

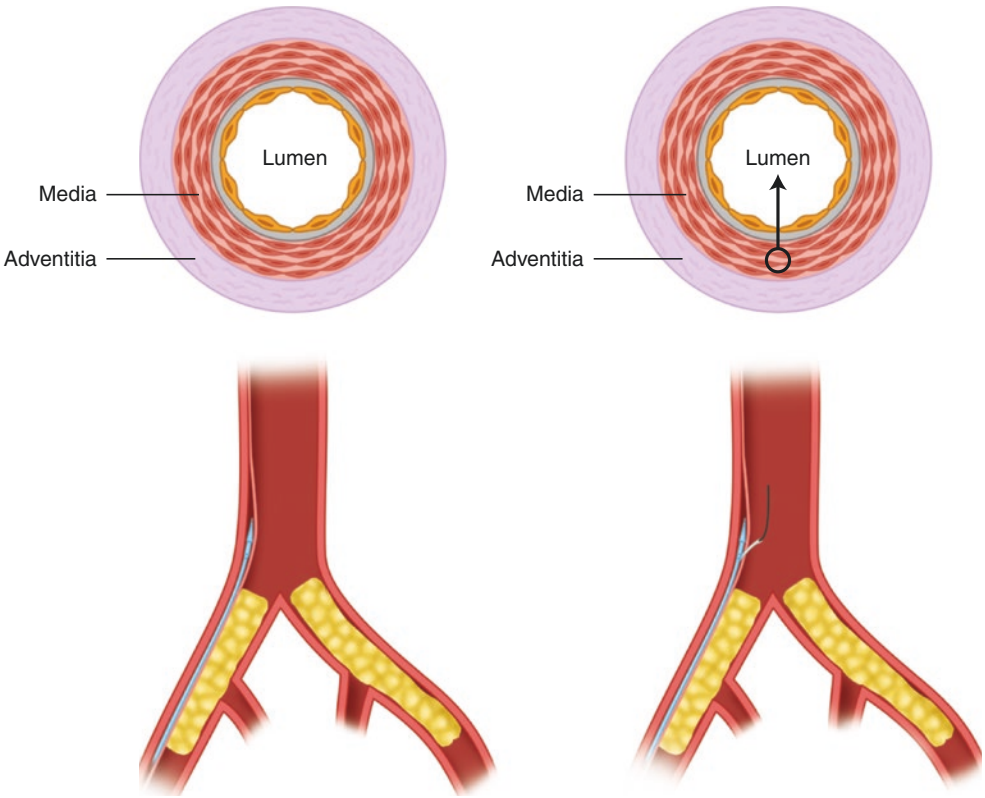

Fig. 26.2 Intravascular Ultrasonography guided true luminal reentry

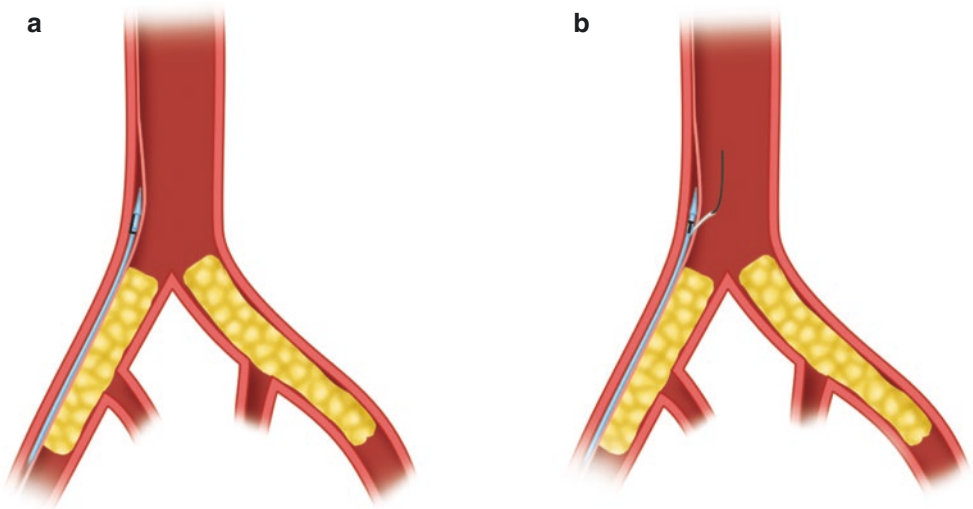

Fig. 26.3 Fluoroscopy Guided true luminal reentry

Endovascular Aortoiliac Reconstruction

Given the presence of significant disease burden in the distal aorta extending into the iliac arteries, stent grafts are increasingly used in the management of AIOD. Patients with associated aneurysmal disease along with occlusive disease are best treated with use of stent grafts (Fig. 26.3). All the FDA-approved stent grafts for aneurysmal disease have been employed in the treatment of combined AIOD with aneurysms. Unibody grafts are suited to this complex anatomy, given the unique stent design and delivery system. The Endologix AFX® unibody graft (Endologix Inc.; Irvine, CA) provides a configuration similar to an aortobifemoral bypass. Caution should be exercised in patients with a large patent Inferior mesenteric artery, as it may be an important collateral in patients with AIOD. Care should be taken to avoid covering the internal iliac arteries to reduce the risk of pelvic claudication, though this can be

done safely on one side without a demonstrated increase in the rate of morbidity [15].

Initial trial data have been promising regarding outcomes with endovascular aneurysm repair (EVAR) stent grafts. Technical success was achieved in 100% of patients, despite the presence of chronic aortic occlusion in up to 20% of patients studied [16]. Three-year primary-assisted patency rates greater than 97% rival the rates for open repair options [16].

A further endovascular technique recently described is the covered endovascular reconstruction of aortic bifurcation (CERAB). First described in 2013, this technique utilizes stent grafts similar to those found in endovascular aneurysm repair (EVAR). Three separate stent grafts are deployed: an aortic graft followed by two separate iliac grafts. These components are overlapped but differ in the stent configuration. Initial reports have demonstrated technically good outcomes at 3 years, with patency rates of 82% primary, 87% primary-assisted, and 97% secondary [17, 18]. Long-term data are still inadequate, given the novelty of this approach.

Hybrid Procedures

A final consideration in the treatment of AIOD is use of hybrid procedures, combinations of the aforementioned treatment options. These are most commonly used to minimize perioperative risk while also using techniques that will assist with long-term patency.

One such hybrid procedure is the use of unilateral iliac stenting or an aortounifemoral stent graft with concomitant femorofemoral bypass. This technique may be indicated in the setting of unilateral iliac occlusion with contralateral stenosis; the risk of a more invasive aortoiliac reconstruction would be obviated.

Another hybrid option is bilateral iliac artery stenting combined with femoral endarterectomies. This is performed utilizing bilateral CFA cutdown. Although initial reports suggest outcomes comparable to those of simple endovascular repair, one recent study has shown improved patency with this hybrid option, hypothesized to be due to the improved arterial outflow provided by the endarterectomy [19–22]. Although the primary patency for iliac stents with femoral endarterectomy is slightly inferior, assisted primary patency and secondary patency are similar to those of aortobifemoral bypass.

For a hybrid procedure, exposure of an adequate segment of femoral artery and bifurcation is important. The profunda femoris artery should be exposed beyond the first- or second-order branch points (extensive profundaplasty) to establish a good flow and also to facilitate clamp placement on a healthier segment of the vessel. Exposure can be performed with either a transverse or a vertical groin incision, depending on the anatomy and the body habitus of the patient. In patients with redo groin incisions, vertical incision may provide adequate exposure. Extensive plaque burden in the common femoral arteries and in the proximal deep femoral arteries may require a vertical incision. Care should also be taken to prevent extensive lymphatic dissection, for complications of seroma and wound complications. All the branch points should be preserved and controlled with vessel loops.

Once the outflow vessel is exposed, we adequately heparinize the patient and proceed with recanalization of the iliac arteries, using any of the techniques described above. In total occlusions, we prefer to use a combination of covered

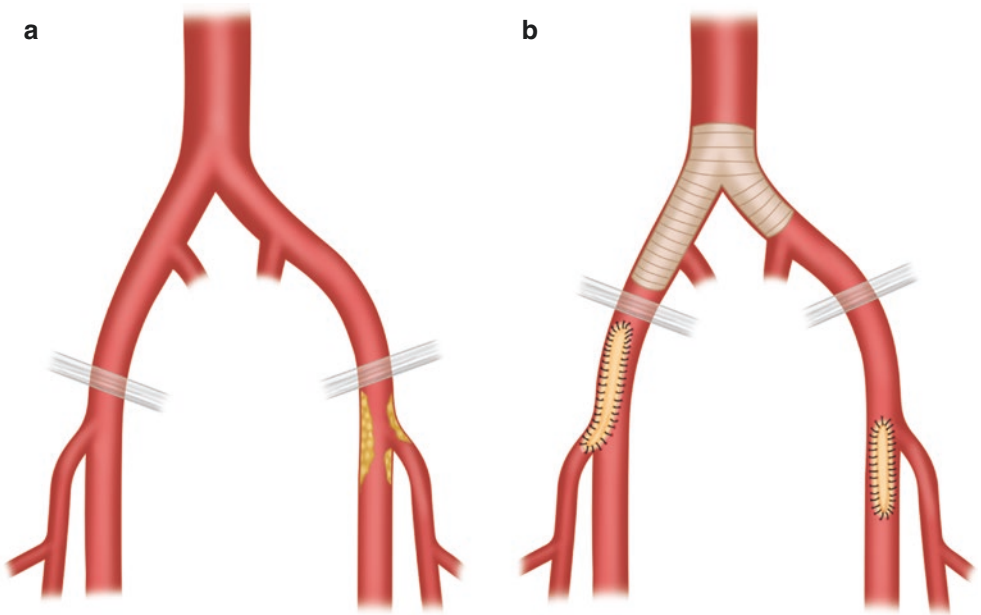

Fig. 26.4 Hybrid revascularization of aorto iliac arteries with iliac stents and femoral endarterectomy, Profundoplasty

balloon-mounted stents for proximal common iliac lesions and self-expanding covered stents for the distal/external iliac disease. We use bare-metal stents in cases of patent internal iliac arteries. Once the stents are placed in the iliac arteries, we use a balloon to control the inflow, and vascular clamps/vessel loops for distal control. Endarterectomy is then carried to the distal end of the stent, which is generally to the origin of the lateral circumflex arterial branch or inferior epigastric artery origin, allowing the stent to stay away from the inguinal ligament, to avoid external compression. Figure 26.4 depicts the presence of a balloon and a stent in the distal external iliac artery, with extensive plaque in the common femoral artery requiring femoral endarterectomy. We use a 1-cm–wide bovine pericardial patch or a saphenous vein patch, which is sewed onto the common femoral artery, extending into the deep femoral artery. Before closure of the arteriotomy, the femoral artery is flushed in order to remove any embolic debris.

In summary, the choice of a revascularization technique for AIOD depends on the patient's symptoms, underlying comorbidities, and variables related to anatomy. Challenges are related to inflow and outflow vessel selection.

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Peripheral Vascular Disease II: Infrainguinal Disease and Atherectomy

27

Naveed U. Saqib

Introduction

Peripheral vascular disease (PVD) or peripheral artery disease (PAD) is a clinical manifestation of systemic atherosclerosis that presents with symptoms ranging from claudication to rest pain, progressive ulceration, extensive tissue loss, or gangrene. PVD affects 200 million people worldwide and is associated with significant morbidity and mortality [1]. Treatment for PAD is dictated by the symptoms and severity of disease. Treatments include medical therapy, endovascular interventions, open surgical bypass procedures, or hybrid procedures [2]. Endovascular therapy with percutaneous transluminal angioplasty (PTA) and adjunctive stenting has recently become a primary treatment for lower extremity PVD [3]. However, there has been concern regarding the long-term patency of endovascular interventions and the increased need for reinterventions. PTA and stent placement, which is based on mechanical plaque disruption and displacement within the arterial wall, has not been able to become default therapy on its own because of inconsistencies from lesion to lesion, lack of significant durability in longer lesions, and reduced vessel compliance in the presence of heavy calcification, which results in suboptimal angioplasty and/or significant differential expansion that potentially may lead to significant dissections. Without exception, placement of intravascular prostheses—bare-metal, covered, or drug-eluting stents—has proven better than PTA alone in the lower extremity. The principal limitation with stenting is the process of in-stent restenosis. Moreover, stent placement is not advisable in certain anatomical locations such as the distal foot arterial system, and flexion points such as the hip and knee joints could provoke stent deformation or fracture, leading to acute arterial occlusion.

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Advancements in technology have provided vascular surgeons with more options for endovascular revascularization. *Atherectomy* refers to the endovascular obliteration of atheromatous plaque by cutting, shearing, drilling, or pulverization by sanding, resulting in luminal gain (debulking) and relieving the need for a scaffold or stent placement to obtain long-lasting patency. The debulking effects of its mechanism of action may theoretically allow for a more uniform angioplasty with minimal vessel barotrauma and improved luminal gain, thereby decreasing the risk of plaque recoil and dissection and allowing effective administration of antiproliferative drug to prevent negative remodeling and neointimal hyperplasia. Atherectomy has emerged as a novel endovascular technology for atheroma removal, with both the benefits of surgical endarterectomy and a minimally invasive modality.

Classification of Atherectomy Devices

Based upon their mechanism of action, atherectomy devices are classified into four categories, the uses of which are detailed in the rest of this chapter:

- Directional atherectomy (DA)
- Orbital atherectomy (OA)
- Excimer laser atherectomy (ELA)
- Rotational atherectomy (RA)

Basic Steps of Endovascular Interventions

Endovascular interventions such as atherectomy are performed with patients under local anesthesia and moderate conscious sedation, using fixed imaging in hybrid operating rooms or interventional radiology suites or a C-arm in an office-based laboratory (OBL). All interventions are performed after systemic heparinization (100 units/kg).

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Most commonly, interventions are performed through contralateral retrograde femoral artery access, whereas ipsilateral antegrade common femoral and left transbrachial access can be used selectively.

A catheter is then used to steer guidewires up to the aortic bifurcation and over to the common iliac artery. A baseline angiogram is then completed in order to clearly define the extent and severity of the target lesion(s), identify the location of the distal vessel reconstitution, and identify important collaterals.

Before a treatment modality is chosen, a guidewire must be used to traverse the target lesion. This most often can be done intraluminally, but in circumstances such as chronic total occlusions, special techniques such as subintimal crossing can be performed.

Once the target lesion has been traversed and re-entry is confirmed, a decision is then made to use either balloon angioplasty or atherectomy as the primary initial treatment. The contraindications to atherectomy are reviewed on a case-by-case basis; these include subintimal dissection, evidence of perforation of the vessel, size of the vessel outside the instructions for use (IFU) of the particular device, and the patient's comorbidities and condition.

Post-intervention adjunct balloon angioplasty, drug-coated balloon (DCB) angioplasty, or bailout stenting is performed on case-by-case basis.

Completion angiography is performed to assess the technical success of the intervention and to rule out, diagnose, and treat embolization and its complications.

Antiplatelet therapy is instituted to prevent restenosis. Surveillance of the treated segment is performed; clinical follow-ups use noninvasive arterial studies.

Directional Atherectomy

Directional atherectomy (DA) refers to active removal of plaque in a controlled and directional fashion. The atheromatous plaque is removed by guiding the cutting device on a catheter directly to the plaque. By rotating the catheter, the cutter is placed in the preferred direction to accomplish targeted plaque removal, and the excised plaque is packed into a nosecone.

The SilverHawk™, TurboHawk™, and the latest HawkOne™ directional atherectomy plaque excision systems (Medtronic, Minneapolis, MN, USA) have received approval from the US Food and Drug Administration (FDA). These are side-cutting cutting devices. The catheter is equipped with a rotating blade within a tubular cover that ends at a nose-cone (collection area). The rotating blade is powered by a motor.

Pantheris Lumivascular™ atherectomy device (Avinger Inc., Redwood City, CA, USA), a new directional atherectomy device, received FDA clearance in 2016. The Pantheris over-the-wire catheter is equipped with optical coherence tomography technology to enhance directional atherectomy efficacy and safety by allowing targeted removal of eccentric plaque (characteristic of directional atherectomy and minimizing the risk of trauma to non-diseased vessel wall as the cutter is placed under ultrasound guidance).

Case

Endovascular intervention is being performed in a patient with lifestyle-limiting claudication despite medical therapy. The patient is under local anesthesia and moderate conscious sedation. Contralateral (left) femoral artery retrograde access was obtained.

Omni flush catheter is then used to steer the guidewire up to the aortic bifurcation and over to the right common iliac artery.

A baseline angiogram reveals complete total occlusion (CTO) of the right superior femoral artery (SFA); the right above-the-knee popliteal artery (P1) reconstitutes from collateral arising from right profunda femoris artery (Fig. 27.1a, b).

Systemic heparinization (100 units/kg) is performed. A 7 Fr guide sheath is advanced to the right external iliac artery for support—the size most commonly used for the larger device (HawkOne L). Meanwhile, a 6 Fr sheath is selected for tibial atherectomy and the smaller-diameter popliteal artery (HawkOne M & S).

The CTO is traversed and reentry into the true lumen is confirmed. Patency of the runoff in the right anterior tibial artery, posterior tibial artery, and peroneal artery is confirmed (Fig. 27.1c).

A distal embolic protection device (Spider AFX® 6 mm) is placed in the distal right popliteal artery to prevent embolization (Fig. 27.1f). The Spider AFX® filter device has been FDA-indicated for use with the SilverHawk in calcified lesions, and I routinely use it in all directional atherectomy cases.

A HawkOne L device is used for atherectomy of this right SFA. The hinge of the catheter deflects the rotating blade away from the center of the vessel toward the target plaque. With the torque on the catheter, the cutting blade is directed towards the plaque. The conical cutter engages plaque and spins at 8000–12,000 rpm to perform longitudinal excision of the plaque.

The cutter is advanced gently in one place for the distance of the nosecone. Then it is halted and the plunger is advanced, to pack the excised atheroma into the nosecone. Atheroma is excised longitudinally and is collected and

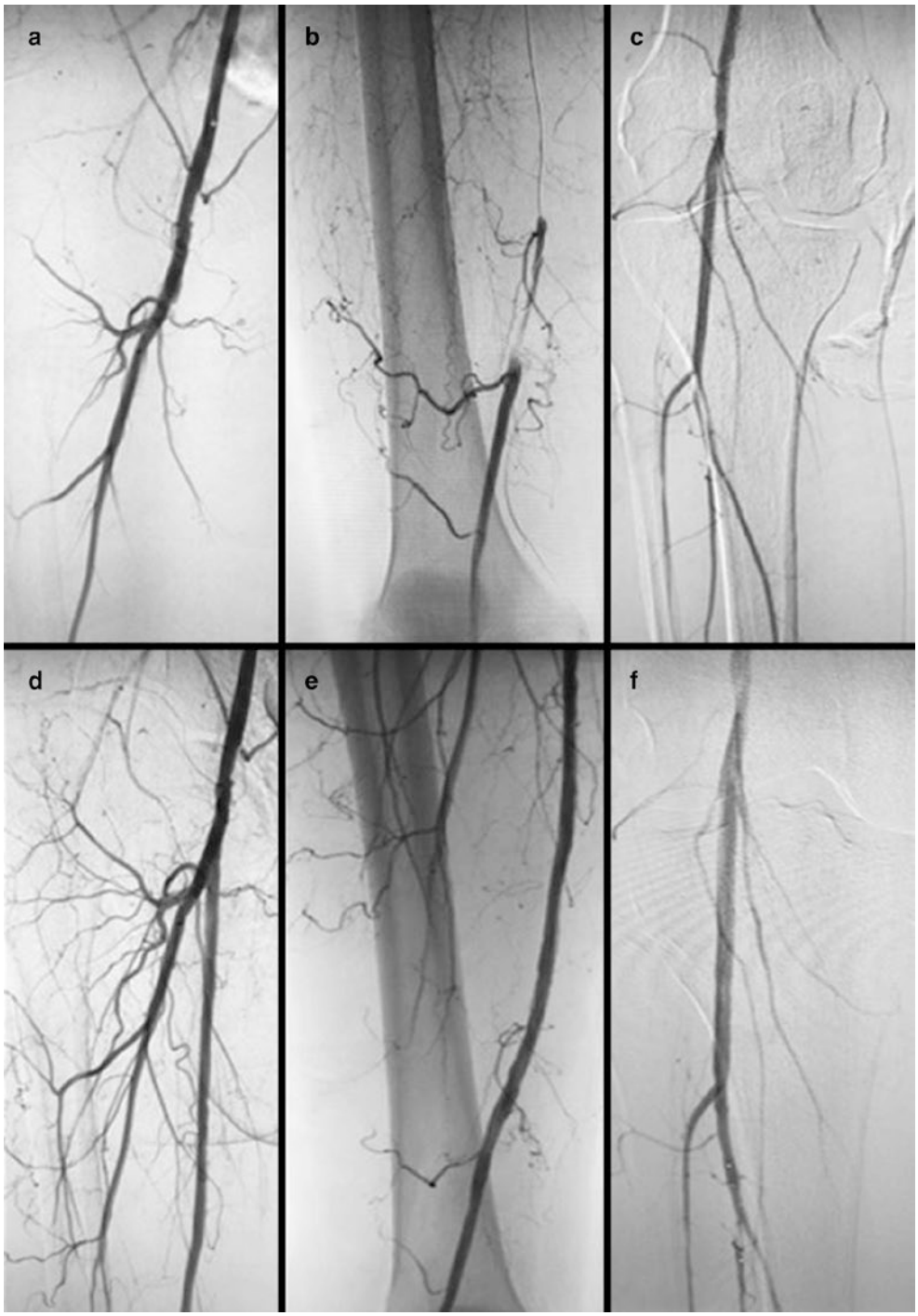

Fig. 27.1 Directional atherectomy. Preintervention angiogram of right lower extremity reveals: (**a**) Patent right CFA, patent right PFA, and CTO (complete total occlusion) of right SFA; (**b**) Reconstitution of popliteal artery; (**c**) Patent three-vessel runoff with patent P1, P2, P3, AT, PT and peroneal arteries. Post-atherectomy angiogram reveals: (**d**) Patent right CFA, right PFA and right SFA with no residual stenosis or dissection; (**e**) Patent right SFA and right popliteal artery; (**f**) Patent P1, P2, P3 and patent 3 vessel runoff

stored in the nosecone, which is located distal to the cutter window.

The same procedure of atherectomy is repeated in at least four planes. To reduce embolization, it is crucial to advance the cutter very slowly and gently.

The device is exteriorized to facilitate emptying of the nosecone before it is full (Fig. 27.2a), in order to avoid inadvertent embolization of the excised plaque.

Post-intervention angiogram is obtained, which reveals adequate luminal gain. I decided to proceed with DCB angioplasty to prevent restenosis.

Completion angiogram reveals no residual stenosis, and no evidence of distal embolization (Fig. 27.1f), so the distal embolic protection device is removed. Inspection of the device shows that an embolic atheroma is present (Fig. 27.2b).

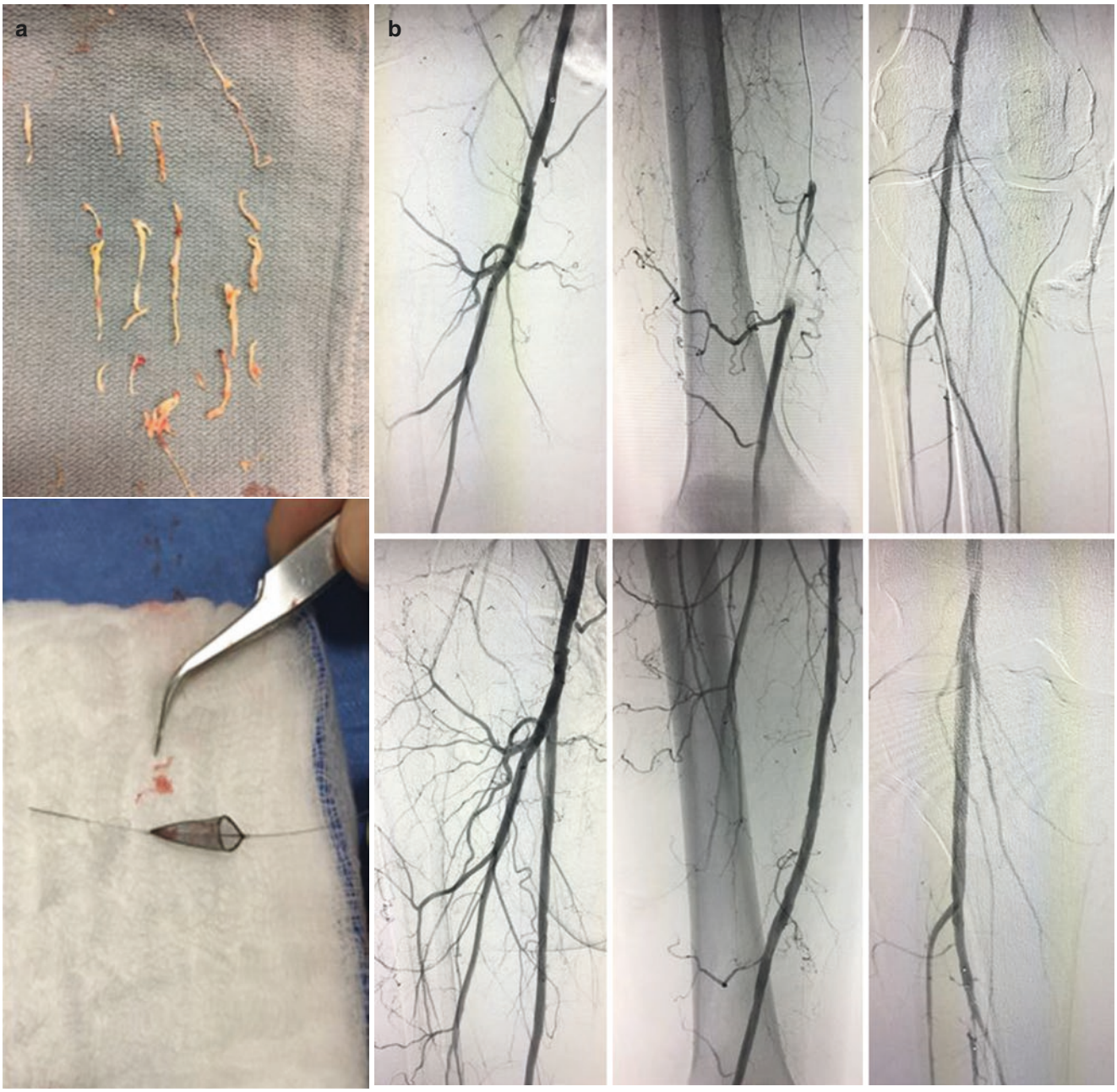

Fig. 27.2 (**a**) Atheroma excised by directional atherectomy; (**b**) Embolic atheroma captured by distal embolic protection device, Spider AFX$^{\text{Ò}}$

After the procedure, the patient was continued on dual antiplatelet therapy and statin therapy.

Evidence

The DEFINITIVE LE study (Determination of EFfectiveness of the SilverHawk® Peripheral Plaque ExcisioN System for the Treatment of Infrainguinal VEssels/Lower Extremities) reported 12-month overall primary patency (PP) to be 78% in claudicants (95% CI, 74–81%). The rate of freedom from major unplanned amputation of the target limb at 12 months in subjects with critical limb ischemia (CLI) was 95% (CI, 90.7–97.4%). Periprocedural adverse events included embolization (3.8%), perforation (5.3%), and abrupt closure (2.0%). The bailout stent rate was 3.2%. Safety and efficacy of DA was established in diabetics (53%) enrolled, with 12-month PP comparable to nondiabetics (77.0% vs 77.9%; superiority $P = 0.98$; non-inferiority $P < 0.001$) and freedom from target-lesion revascularization (TLR, 83.8% *vs*. 87.5%; $P = 0.19$) [4].

DEFINITIVE Ca^{++} established both the efficacy and safety of a DA device along with distal embolic protection (Spider FX) in 133 subjects with moderate to severely calcified lesions in the superficial femoral and/or popliteal arteries. The overall 30-day rate of freedom from major adverse event (MAE) was 93.1% [5].

The DEFINITIVE AR study (Directional Atherectomy Followed by a Paclitaxel-Coated Balloon to Inhibit Restenosis and Maintain Vessel Patency—A Pilot Study of Anti-Restenosis Treatment) was a multicenter, randomized trial designed to estimate the effect of DA before a DCB to facilitate the development of future end point–driven randomized studies. The 1-year primary outcome of angiographic percent diameter stenosis was 33.6 ± 17.7% for DA + DCB *versus* 36.4 ± 17.6% for DCB (P = 0.48), and the clinically driven target lesion revascularization was 7.3% for DA + DCB and 8.0% for DCB (P = 0.90). Duplex ultrasound patency was 84.6% for DA + DCB, 81.3% for DCB (P = 0.78), and 68.8% for calcified lesions. Freedom from MAE at 1 year was 89.3% for DA + DCB and 90.0% for DCB (P = 0.86) [6].

Two randomized trials are currently ongoing to evaluate the adjunctive use of DA and DCB treatment. REALITY STUDY is for long, calcified SFA and/or popliteal artery lesions; ADCAT (Atherectomy and Drug-Coated Balloon Angioplasty in Treatment of Long Infrapopliteal Lesions) is studying tibial arteries.

Orbital Atherectomy

Orbital atherectomy (OA) consists of high-speed rotational spin of the shaft and the orbital rotation (eccentric) of a specially designed debulking, diamond-coated crown. Atheromatous and calcified plaque is removed by the orbital movement of the crown. The debulking area increases with the increase of the rotational speed of the crown. OA modifies the surface of calcified plaques by preferentially cutting or sanding the atheroma plaque while avoiding the elastic arterial wall. All debris generated is considered to be smaller than a red blood cell, so the embolization risk hypothetically is reduced, though it cannot be excluded.

The only approved OA device is the Diamondback 360° Peripheral Orbital Atherectomy System (Cardiovascular Systems; St. Paul, MN, USA). It consists of an orbiting eccentric diamond-coated crown, mounted at the end of a shaft, and a saline pump. Three types of crowns are available: A solid micro-crown is recommended for tortuous vessel anatomy, tight bends, and distal below-the-ankle lesions; a solid crown is recommended for calcified lesions and maximum plaque removal in short atherectomy time (additional diamond-coated surface area); the classic crown (the most flexible) is recommended for below-the-knee lesions [7].

Case

In a patient with critical limb ischemia and tissue loss, the baseline angiogram reveals patent inflow and no significant femoropopliteal disease. There is distal stenosis of the posterior tibial artery and multifocal calcified plantar artery stenosis (Fig. 27.3a).

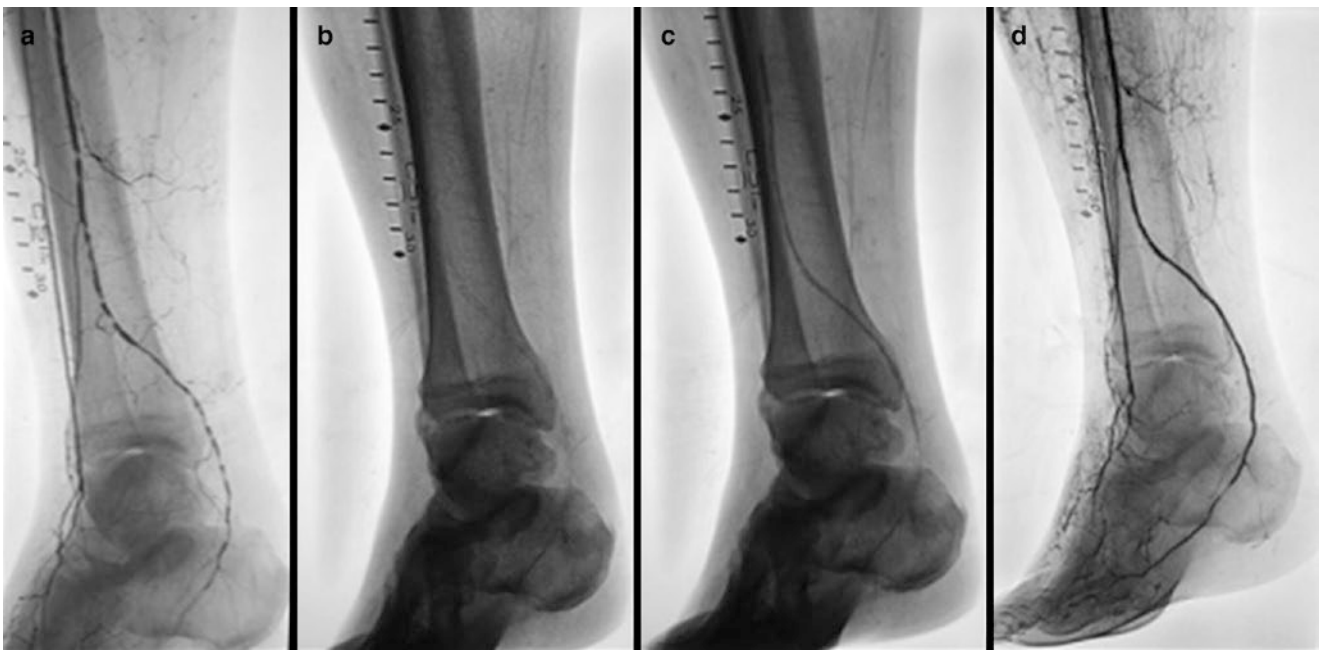

Fig. 27.3 Orbital atherectomy (OA) and percutaneous transluminal angioplasty (PTA) for limb salvage in setting of critical limb ischemia (CLI). (**a**) Preintervention selective right lower extremity angiogram reveals highly calcified right posterior tibial artery and multifocal short occlusions in the right plantar artery. Right anterior tibial artery is patent but heavily calcified and small in calibre; (**b**) Micro Diamondback CSI Orbital atherectomy identified in the distal plantar artery; (**c**) Post-atherectomy balloon angioplasty; (**d**) Postintervention angiogram reveals considerable improvement with no residual significant stenosis except mid plantar artery

Systemic heparinization (100 U/kg) is performed. A 6 Fr long arterial sheath is advanced to the right popliteal artery for support. I usually use a 6 Fr sheath for OA, but it is important to point out that OA is the only atherectomy system compatible with 4 Fr sheaths (allowing use with pedal access) and up to 7 Fr.

Selective catheter is placed in the right posterior tibial artery, and a specialty 0.014-inch over-the-wire proprietary guidewire (the ViperWire™) is placed (Fig. 27.3b). The Diamondback 360° using the 1.25-mm classic crown is used for tibial OA.

I perform OA at low rotational speed for the initial pass through the stenotic segment, in order to prepare the vessel. The crown is advanced slowly over the wire 0.014-inch system using the ViperWire™ guidewire. A second pass is performed at medium rotational speed. The same procedure of atherectomy is repeated at high speed in larger vessels. While advancing the crown, ViperSlide lubricant is administered by the OAS pump.

Post-intervention angiography reveals adequate luminal gain. I perform adjunct balloon angioplasty in all OA procedures (Fig. 27.3c).

Completion angiogram reveals minimal residual stenosis and no evidence of distal embolization (Fig. 27.3d).

Evidence

Patients with PAD who were treated with OA were followed in large, multicenter, nonrandomized, all-comer registries in CONFIRM I, II, and III [8]. The CONFIRM series revealed that severely calcified lesions (compared with soft plaque) were easily removed by OA. Adjunctive treatment with low-pressure balloon inflation (5.4–5.9 atm) was performed for 73.3% of lesions, and stenting in 5.7%. Compared with other studies, the complication rate was low (dissection, 11.3%; spasm, 6.3%; slow flow, 4.4%; embolism, 2.2%; and perforation, 0.7%) [8].

In two small, randomized pilot studies (CALCIUM 360 and COMPLIANCE 360), OA plus PTA was shown to have a lower incidence of complications and bailout stenting, and greater freedom from target-lesion revascularization (TLR) compared with PTA alone in femoropopliteal and Infrapopliteal lesions [9, 10].

Preliminary 30-day data from the LIBERTY 360 registry showed positive outcomes regardless of the severity of PAD. The 30-day freedom from MAE rates were 99% (Rutherford 2–3), 95.7% (Rutherford 4–5), and 90.7% (Rutherford 6). More than two thirds of patients were treated with Diamondback 360° OA (45% in Rutherford 2–5 and 60% in Rutherford 6) [11].

Excimer Laser Atherectomy

Laser atherectomy utilizes excimer laser (Light Amplification by Stimulated Emission Radiation) technology to perform photochemical and photomechanical ablation of atheromatous plaque. Laser atherectomy is indicated for both de novo and in-stent restenosis.

Excimer laser atherectomy (ELA) catheters (Turbo-Elite, Turbo-Power, and Turbo-Tandem (Spectranetics Corporation, Colorado Springs, CO, USA) use ultraviolet radiation to ablate the atheroma with a thickness of 10 μm with each pulse of energy. The device is powered by an external generator (CVX-300 excimer laser ablation system). Episodes of micro- and macro-embolization have been described with ELA, so the use of a protection filter while performing ELA is advisable.

Case

In a patient with a history of left SFA stenting and recurrence of claudication, the baseline angiogram reveals de novo and in-stent SFA occlusion and reconstitution of the popliteal artery with three-vessel runoff (Fig. 27.4a).

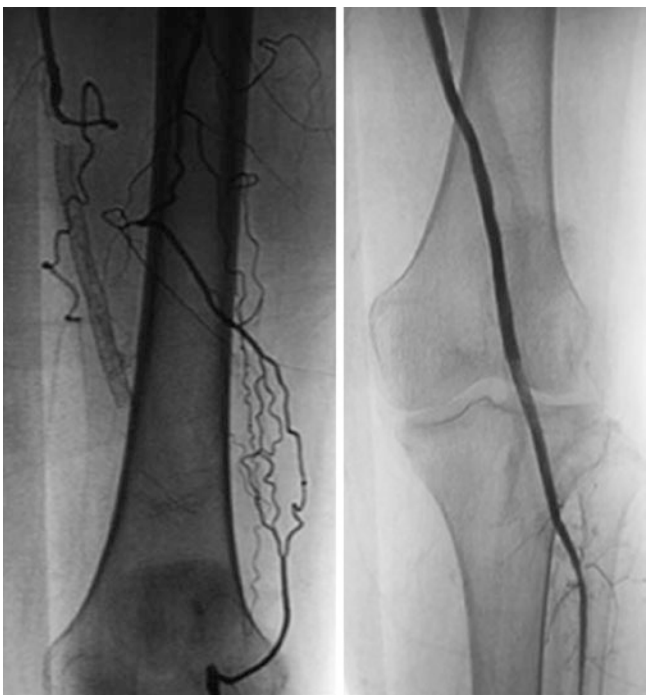

Fig. 27.4 **Left,** Left superior femoral artery (SFA) in-stent occlusion and de novo SFA complete total occlusion; **Right,** Excimer laser atherectomy (ELA) and PTA result in patent left SFA and popliteal artery without residual stenosis

Systemic heparinization (100 U/kg) is performed. A 6 Fr guide sheath is advanced to the right popliteal artery for support. (I mostly use a 6 Fr sheath for ELA.)

The in-stent and de novo left SFA complete total occlusion (CTO) is traversed, and reentry into the true lumen is confirmed. Patency of the runoff in the right anterior tibial artery, posterior tibial artery, and peroneal artery is confirmed.

When selecting the catheter for ELA, it is important to understand that Turbo-Tandem is not designed to be used in total or subtotal occlusions, whereas the Turbo-Elite catheter is capable of crossing occlusions without the need for a guidewire.

Catheter advancement is also important in delivering the appropriate amount of energy to the lesion; it should be performed slowly, at a rate no more than 1 mm per second, so as to remove plaque effectively and uniformly.

Laser should never be used in the presence of contrast media, as this increases energy absorption, leading to dissection or perforation. As blood also absorbs laser energy, saline flushing during laser atherectomy is essential in order to remove blood and contrast from the treated vessel.

Post-intervention angiography reveals adequate luminal gain. I perform adjunct balloon angioplasty in all ELA procedures.

The completion angiogram reveals a patent stent and no evidence of distal embolization (Fig. 27.4b).

Evidence

The Laser Angioplasty for Critical Limb Ischemia (LACI) prospective, multicenter trial reviewed 145 patients with 155 critically ischemic limbs who were poor candidates for bypass surgery. Success rates for delivery of laser treatment (99%) and balloon angioplasty (90%) were high. A 6-month limb salvage rate of 92% was achieved among survivors, and only 2% of LACI patients required surgical revascularization [12].

The EXCITE ISR (EXCImer Laser Randomized Controlled Study for Treatment of FemoropopliTEal In-Stent Restenosis) trial led to the FDA approval of laser atherectomy for the treatment of femoropopliteal in-stent restenosis. ELA plus PTA achieved superior procedural success (93.5% *vs* 82.7%; $P = 0.01$) with significantly lower 30-day MAE rates (5.8% *vs*. 20.5%; $P < 0.001$) and a 52% reduction in TLR (hazard ratio, 0.48; 95% CI, 0.31–0.74) when compared with PTA alone [13].

PHOTOPAC (Photoablative Atherectomy Followed by a Paclitaxel-Coated Balloon to Inhibit Restenosis in In-Stent Femoropopliteal Obstructions), a large, prospective, randomized, two-arm study, is underway to compare the safety and efficacy of laser debulking plus a DCB versus DCB alone

Rotational Atherectomy

Rotational atherectomy is a plaque-modifying technology in which the plaque is excised by a concentrically rotating specialty tip (burr). The luminal gain matches the size of the tip/burr used and is not dependent on the rotational speed (as with OA).

The Jetstream™ Atherectomy System (Boston Scientific; Marlborough, MA, USA) is a cutting rotational atherectomy device with active aspiration. It is a 7 Fr sheath, over-the-wire system with two types of catheters: the SC catheter, with a single set of front cutting blades, and the larger XC catheter, equipped with a second set of larger blades. An aspiration port and proximal infusion ports are also present. The Jetstream console is designed to enable atherectomy, active aspiration, flushing, and monitoring of the volume of blood products removed. Despite active aspiration ability, the use of a distal embolic protection filter is still advisable, as micro- and macro-embolization may occur. The device has been approved for both acute thrombus removal and atherectomy of chronic lesions [14, 15].

The Peripheral Rotablator™ system (Boston Scientific) rotates concentrically a 5-micron diamond-coated catheter tip (burr) (Fig. 27.5). The catheter requires 4 Fr to 8 Fr arte-

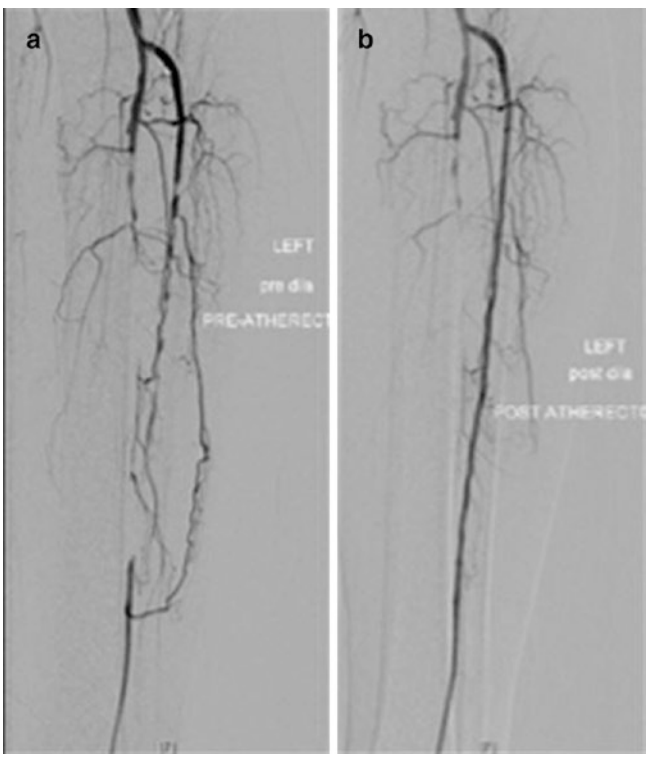

Fig. 27.5 Rotablator atherectomy for a patient with tibial artery CLI. (**a**) Pre-atherectomy angiogram reveals occlusion of mid left anterior tibial artery which is the single vessel runoff in left leg; (**b**) Post-atherectomy angiogram reveals patency of left anterior tibial artery with no evidence of dissection or residual stenosis

rial sheaths and is compatible with a specific 0.009″ guidewire. The maximum atherectomy time recommended for a single catheter is 15 minutes; after that, the burr is considered ineffective. Active aspiration is not available and distal embolic protection is advisable.

The Phoenix rotational atherectomy system (Philips; Cambridge, MA, USA) consists of two main components: a single-use catheter without capital equipment and the Phoenix atherectomy handle. The rotating torque shaft enables rotational atherectomy by the cutter. The excised plaque is mechanically transported within the catheter using an Archimedes screw fixed on the outer surface of the shaft and extended though the entire length of the catheter, with a port on the handle connected to an external bag. It is compatible with 0.014 inch, 260 cm length guidewire and 5 Fr to 7 Fr sheaths.

Summary

Atherectomy and DCB angioplasty with a "leave nothing behind" approach is promising and shown to be safe and effective in various infrainguinal anatomic locations. Data to support this approach as a primary modality is still lacking but ongoing clinical trials studying the implications of atherectomy and DCB are promising. The results from these trials will help in determining the long-term effect. Atherectomy remains one tool in the armamentarium of vascular surgeons for the treatment of patients with PVD.

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Renal Artery and Visceral Artery Endovascular Interventions

28

Ranjith Dodla, James Bemis, and Mark A. Mattos

To provide the best endovascular treatment for each patient, it is vitally important to know the unique anatomy and variant pathology of each arterial bed. Therefore, the vascular interventionalist must have a working knowledge of the endovascular procedures to be performed and should, at the very least, have a basic understanding of the steps of each procedure and the basic catheter and guidewire skills necessary to independently complete the renal and visceral artery endovascular procedures with proficiency. Therefore, the content of this chapter has been designed using a "How I Do It" approach, with simple, straightforward black-and-white drawings to help the interventionalist better understand the distinct endovascular procedural steps and interventional techniques in the performance of contrast-based diagnostic angiography and endovascular interventions for the management of patients with renal and visceral artery occlusive disease.

Preoperative Diagnostic Imaging

The clinical diagnosis and treatment pathways for renal artery and visceral artery occlusive disease are supported and confirmed using duplex ultrasound, computed tomographic (CT) angiography and catheter-based contrast angiography. Duplex ultrasound is usually the initial noninvasive diagnostic modality employed to determine presence or absence of disease in the renal and visceral arteries. Duplex ultrasound has excellent overall accuracy in the detection of renal artery occlusive disease and is used to determine whether a patient should undergo further evaluation and endovascular treatment. Duplex ultrasound has been shown to be less accurate for the assessment of the presence of visceral artery occlusive disease and for the determination of its severity. CT angiography is considered the noninvasive gold standard in most instances for identifying the presence, location, type, severity, and extent of occlusive disease of the aorta and renal and visceral arteries. It provides a diagnostic roadmap allowing vascular surgeons or other treating interventionalists to offer the best possible treatment plan.

Renal Artery Atherosclerotic Occlusive Disease

Nonselective Diagnostic Abdominal Aorta–Renal Artery Angiogram and Selective Diagnostic Renal Artery Angiogram

When preparing to perform a diagnostic angiogram of the aorta and renal arteries, it is important to place the patient on the fluoroscopy table supine with both arms at his or her sides. The primary operator should stand on the right side of the patient at the groin area. Both groin areas should be prepped sterile and prepared for bilateral common femoral artery (CFA) access if necessary, though it is seldom required.

Arterial access to the CFA (in this case, the right CFA) is obtained at its midpoint, using the Seldinger technique under ultrasound guidance. Prior to cannulation, it is important to scan the entire length of the CFA from the inguinal ligament to the bifurcation of the superficial femoral and profunda femoral arteries. In this way, one can avoid either too high of a cannulation in the external iliac artery, which could result in a retroperitoneal bleed, or too low of a cannulation in either the superficial femoral or profunda femoral artery, leading to the development of a pseudoaneurysm.

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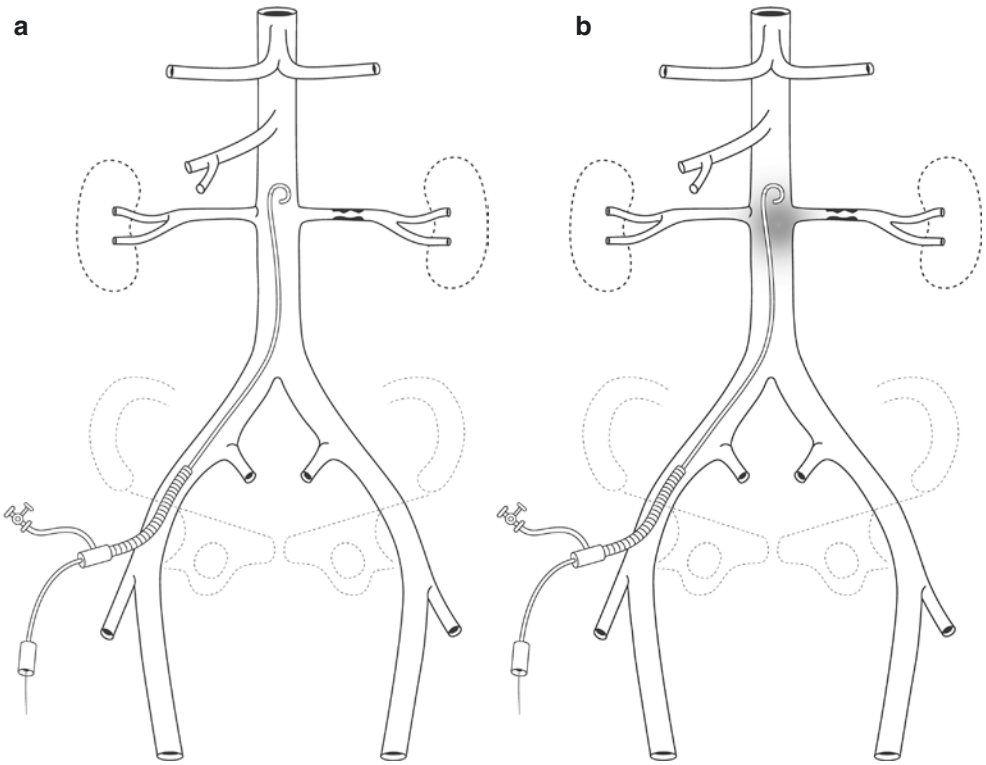


Fig. 28.1 Nonselective diagnostic abdominal aorta–renal artery angiogram. (**a**) The tip of the guidewire is positioned in the aorta proximal to the renal arteries. The guidewire is then removed and the catheter resumes its original shape at or just proximal to the level of the renal arteries. (**b**) The angiogram is performed in a straight anterior-posterior (AP) view or slight (7–10°) ipsilateral left anterior oblique (LAO) view projection

Access to the CFA and access sheath placement is performed using either a micropuncture technique (21 g needle, 0.018″ access wire, 4 Fr/5 Fr microcatheter, 0.035″ access j-wire, 5 Fr × 10 cm access sheath) or standard technique (18 g needle, 0.035″ access j-wire, a 5 Fr × 10 cm access sheath). A guidewire is then tracked through the 5 Fr access sheath and the wire tip is positioned in the aorta proximal to the renal arteries. A 5 Fr diagnostic multi-hole flush catheter is tracked over the guidewire to the level of (or just above) the orifices of the renal arteries. The guidewire is then removed from the shaped catheter, and the catheter resumes its original shape at or just proximal to the level of the renal arteries (Fig. 28.1a). A nonselective abdominal aorta-renal artery angiogram is performed in a straight anterior-posterior (AP) view or slight (7–10°) ipsilateral left anterior oblique (LAO) view projection (Fig. 28.1b).

This type of angiogram is performed with a power injector to ensure proper distribution of the contrast dye to the aorta and renal arteries. Injection rates can vary depending on patient abdominal habitus and renal function, from high-volume rates of 15 mL per second for a total of 30 mL ("15 for 30") to low-volume rates of 10 mL per second for a total of 15 mL ("10 for 15"). Higher-pressure injections (PSI 700–900) can help facilitate better distribution of the contrast within the aorta.

The multi-hole flush catheter is then exchanged over a wire for a selective angled or shaped diagnostic catheter (i.e., renal curve, cobra, Sos 1 or 2, renal double curve Simmons 1). The selective catheter is positioned proximal to the renal arteries (Fig. 28.2a). The guidewire is then removed, allowing the selective angled or /shaped diagnostic catheter to assume its intended shape. The tip of the catheter is carefully moved distally toward the orifice of the left renal artery (Fig. 28.2b).

If the ostium of the renal artery is free of disease, the tip of the selective catheter is then gently allowed to move passively into the orifice of the left renal artery without using a wire. This is known as a "blind cannulation" or "direct engagement" technique (Fig. 28.2c). Alternatively, a 0.014″ to 0.035″ angled wire can be used to cannulate the ostium of the left renal artery to allow for over-the-wire advancement of the catheter into the ostium of the left renal artery (but no further). This is known as the "no-touch" technique. A selective left renal artery angiogram is performed. This can be completed using the power injector at lower-volume rates of 4–5 mL per second for a total of 8 mL and lower PSI (400–500) (Fig. 28.2d). Alternatively, hand injections can be performed with the same volume of contrast, albeit diluted to 50–70% concentration to allow for ease of injection.

Care is taken to avoid crossing and cannulating the stenosis unnecessarily when just performing a diagnostic study. If the ostium of the left renal artery is severely stenotic, then the tip of the diagnostic catheter is positioned just at the ostium but does not physically engage the ostium for fear of causing a dissection, embolization, or complete occlusion of the left renal artery.

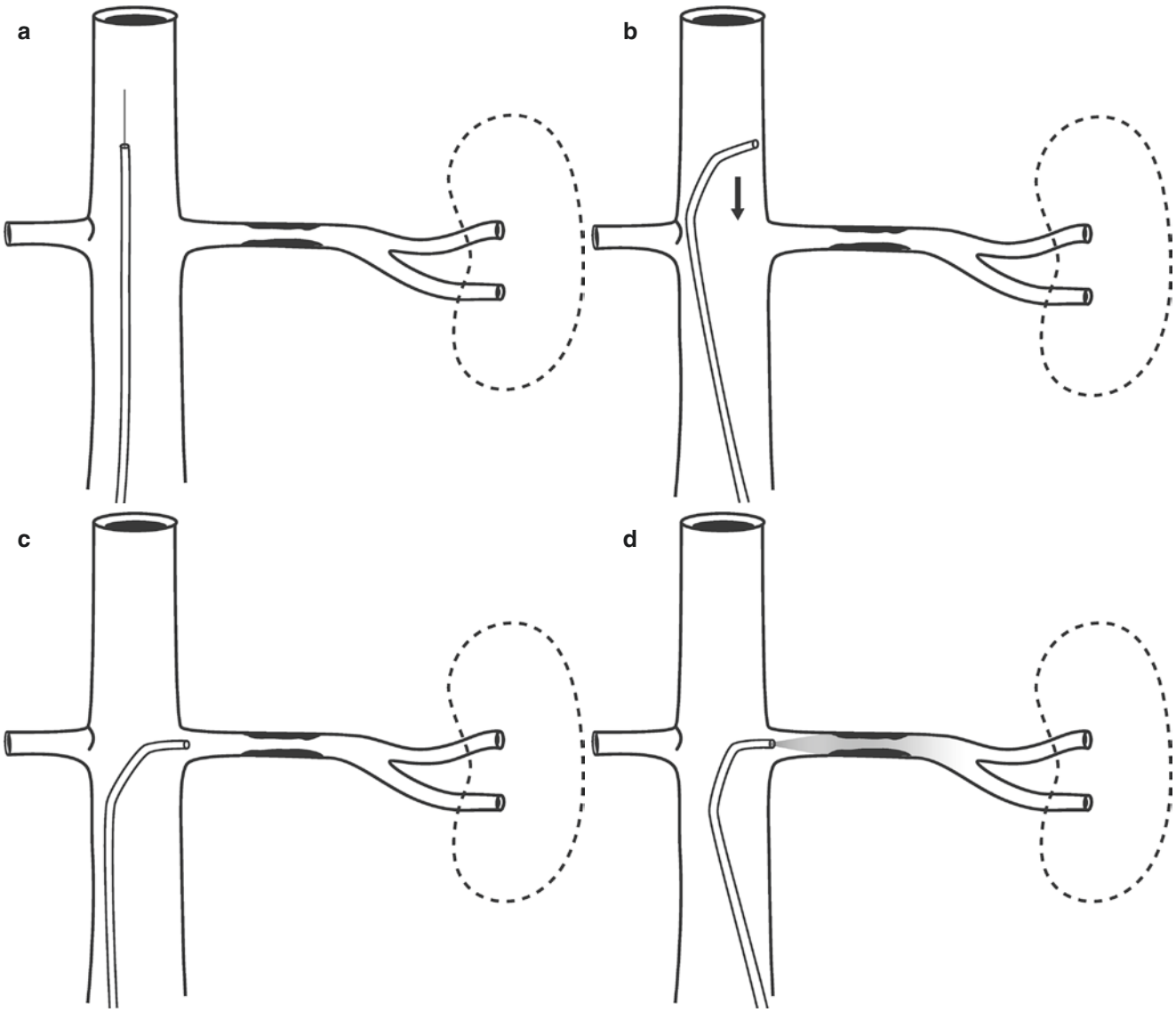


Fig. 28.2 Selective diagnostic renal artery angiogram. (**a**) The multihole flush catheter is then exchanged over a wire for a selective angled or shaped diagnostic catheter, which is positioned proximal to the renal arteries. (**b**) The guidewire is then removed, allowing the diagnostic catheter to assume its intended shape. The tip of the catheter is carefully moved distally toward the orifice of the left renal artery (*arrow*). (**c**) The tip of the selective catheter moves passively into the orifice of the left renal artery without using a wire. This is known as a *"blind cannulation" or "direct engagement"* technique. (**d**) Once the orifice of the left renal artery is cannulated with the tip of the catheter, a selective left renal artery angiogram is performed

Following completion of the selective left renal artery angiogram, the tip of the selective diagnostic catheter is moved out of the left renal artery orifice and back into the lumen of the aorta. A guidewire is inserted through the catheter and both are removed as a single unit, leaving the 5 Fr access sheath in place (Fig. 28.3).

To establish hemostasis at the puncture site, an approved, appropriately sized closure device (MYNX, Cardinal Health-Cordis; Perclose ProGlide, Abbott; Angio-Seal, Terumo) is deployed, and hemostasis is achieved as per the device protocol. Alternatively, the sheath is removed and pressure is applied directly over the CFA puncture site for 15 to 20 minutes to create hemostasis.

Stenosis of the Proximal to Mid Renal Artery

A nonselective diagnostic abdominal aorta–renal artery angiogram and selective diagnostic left renal artery angiogram are performed, as shown in Figs. 28.1, 28.2 and 28.3.

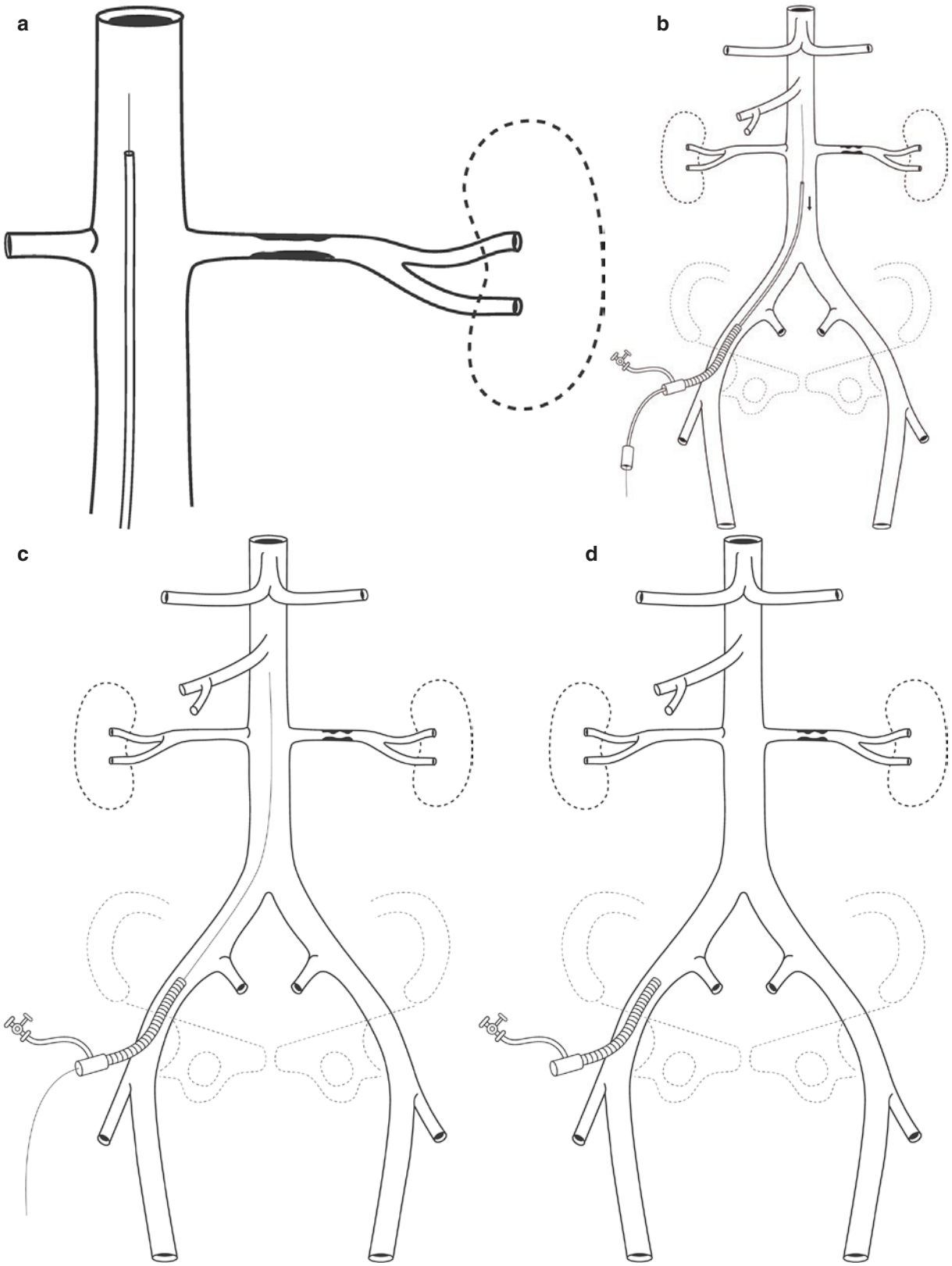


Fig. 28.3 Completion of the angiogram process. (**a**) The tip of the selective diagnostic catheter is moved out of the renal artery orifice and back into the lumen of the aorta. (**b**) A guidewire is inserted through the catheter and the catheter is removed over guidewire (*arrow*). (**c**) The guidewire remains in the aorta through sheath. (**d**) The guidewire is removed, leaving the 5 Fr access sheath in the right common femoral artery (CFA)

A decision is then made either to terminate the procedure or to proceed with endovascular treatment if clinically indicated. If the decision is to proceed with endovascular intervention for left renal artery stenosis, the 5 Fr access sheath and guidewire remain in place. A stiffer 0.035″ wire is used to facilitate exchange for a larger, longer guide (destination) sheath.

The Fr size (5–7 Fr) and shape of the guide sheath (Ansel, Raabe) used will depend on the anatomy of the aorta and renal artery and on what wire-catheter-balloon-stent platform type (0.014″–0.035″) is selected to perform the procedure. Alternatively, a guide catheter platform (renal standard curve, IMA, renal double curve, hockey stick, SOS Omni) may be used instead of a guide sheath platform. Each platform has its advantages and disadvantages. This chapter shows the use of a guide sheath platform.

The 5 Fr access sheath is then exchanged for a longer (45–55 cm) guide sheath (5–7 Fr) (Fig. 28.4a). Once the guide sheath is inserted, 2000 units of heparin is given intravenously. The tip of the guide sheath is positioned distal to the orifice of the renal artery being treated. Once the sheath is in place, an angled or shaped selective diagnostic catheter is tracked over the guidewire. The shape or angle of the diagnostic catheter selected is based on the anatomy and location of the left renal artery. The tip of the diagnostic catheter moves beyond the end of the sheath and is directed towards the orifice of the renal artery. If the ostium of the renal artery is free of disease, the tip of the diagnostic catheter is then gently allowed to move passively into the orifice of the renal artery without using a wire. This is known as a "blind cannulation" or "direct engagement" technique. Alternatively, if the ostium of the renal artery has mild atherosclerotic disease, the tip of the diagnostic catheter is positioned just at the ostium but does not physically engage the ostium for fear of causing a dissection, embolization, or complete occlusion of the artery. An 0.014″ to 0.035″ angled wire can be used to cannulate the ostium of the renal artery to allow for over-the-wire advancement of the catheter into the ostium of the left renal artery, but no further. This is known as the "no-touch" technique (Fig. 28.4b).

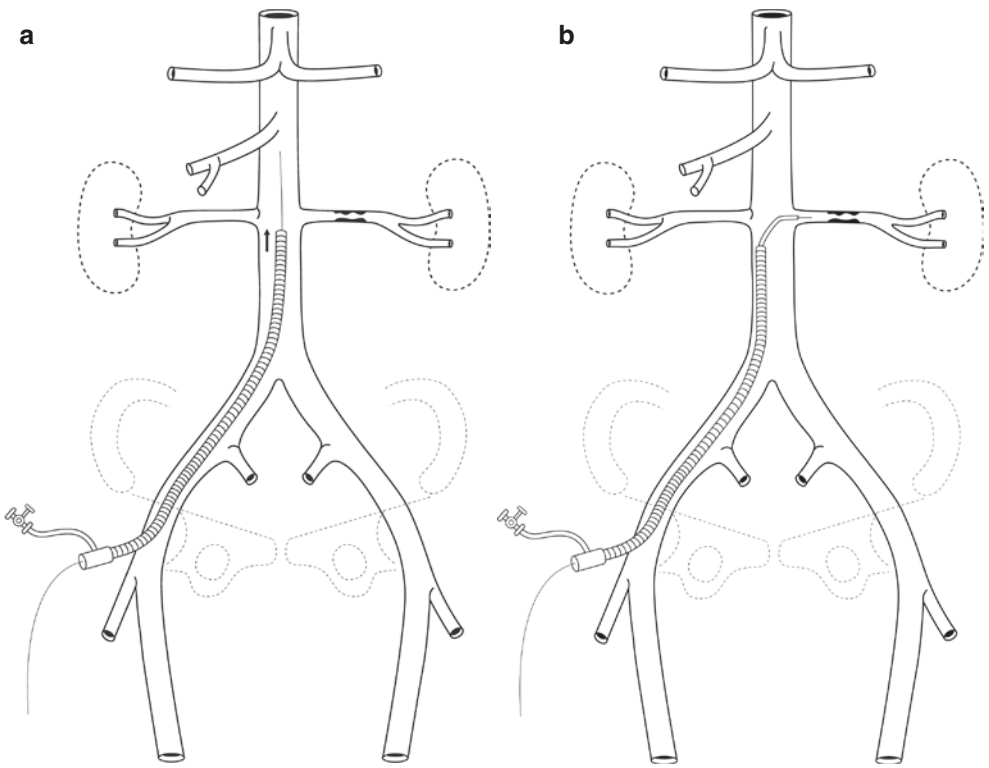


Fig. 28.4 Endovascular intervention for stenosis of the proximal to mid left renal artery: diagnostic angiography. (**a**) The 5 Fr access sheath is exchanged for a longer (45–55 cm) guide sheath (5–7 Fr). (**b**) The tip of the guide sheath is positioned distal to the orifice of the renal artery being treated. The tip of the diagnostic catheter moves beyond the end of the sheath and is directed towards the orifice of the renal artery. (**c**) The 0.014″–0.035″ wire is used to cross the proximal–mid renal artery stenosis. The wire tip is placed in a first- or second-order branch of the renal artery. A "telescoping technique" is used to advance the diagnostic catheter over the wire and the guide sheath is advanced over the diagnostic catheter at or just into the ostium of the renal artery but proximal to the stenotic lesion. (**d**) The diagnostic catheter is removed over the wire, keeping the wire in place across the stenosis, and the tip of the guide sheath in or at the orifice of the renal artery. (**e**) A selective left renal artery angiogram is then performed through the guide sheath to determine the degree of stenosis severity, stenosis length, and the diameter and length of the renal artery

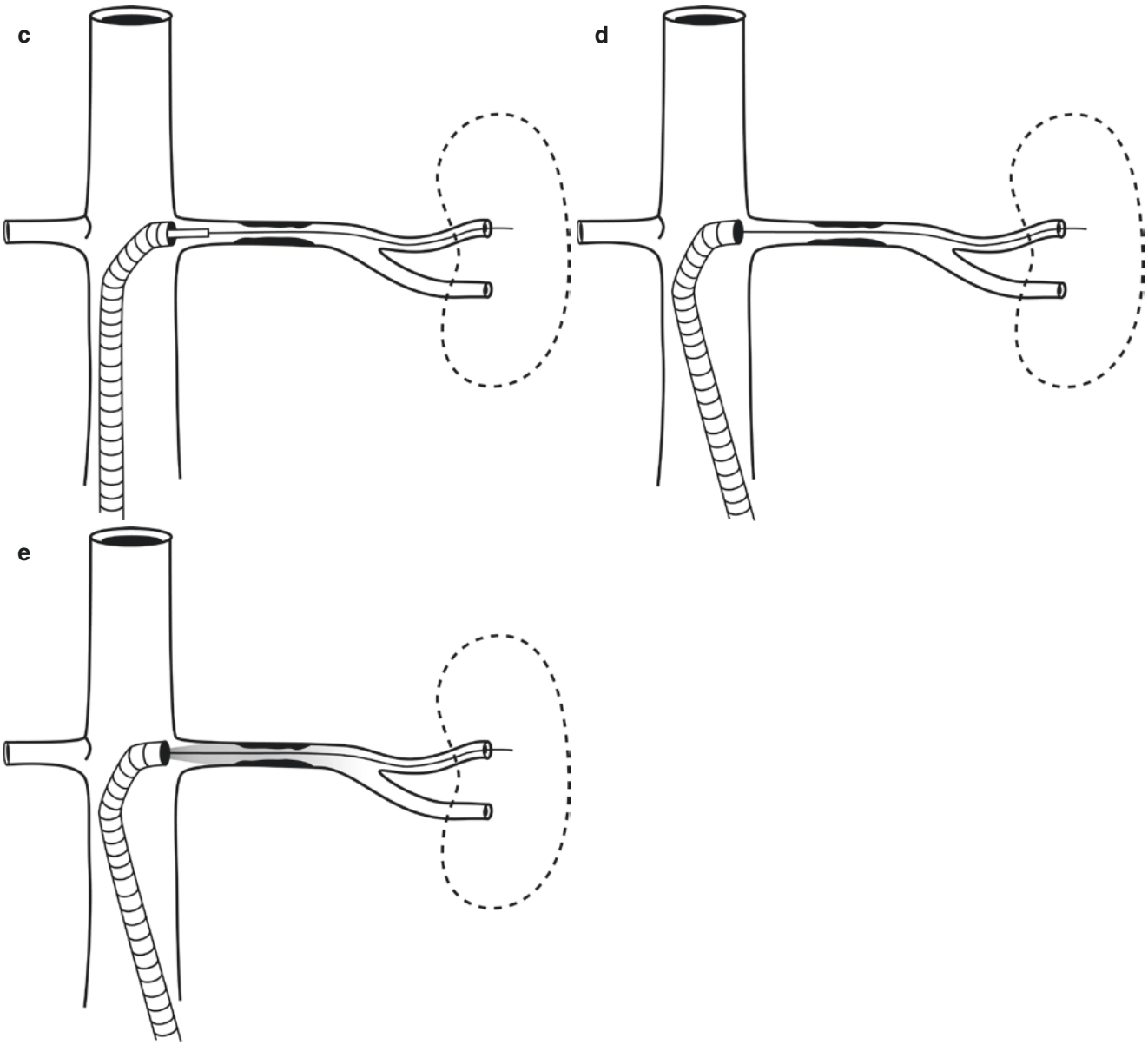


Fig. 28.4 (continued)

The 0.014″-0.035″ wire is used to cross the area of stenosis, and the wire tip is placed in a first- or second-order branch of the renal artery. Using a telescoping technique, the diagnostic catheter is then advanced over the wire into the proximal renal artery but not through the lesion (Fig. 28.4c). The guide sheath is then advanced proximally over the diagnostic catheter and wire proximally, just into or right at the orifice of the renal artery.

Once the wire, catheter, and sheath positions are stabilized, a full dose of heparin (75–100 IU/kg) is given intravenously. The diagnostic catheter is removed over the wire, keeping the wire in place across the stenosis and tip of the guide sheath in or at the orifice of the renal artery (Fig. 28.4d). A selective left renal artery angiogram is then performed through the guide sheath to determine the degree of stenosis severity, stenosis length, and renal artery diameter and length (Fig. 28.4e).

A balloon angioplasty catheter is selected, inserted into the sheath, tracked over the wire, and positioned across the lesion. The balloon is then inflated to its full diameter profile (Fig. 28.5a–c).

The balloon is then deflated and removed over the wire. A completion selective left renal artery angiogram is performed through the sheath (Fig. 28.6a). If the residual stenosis is less

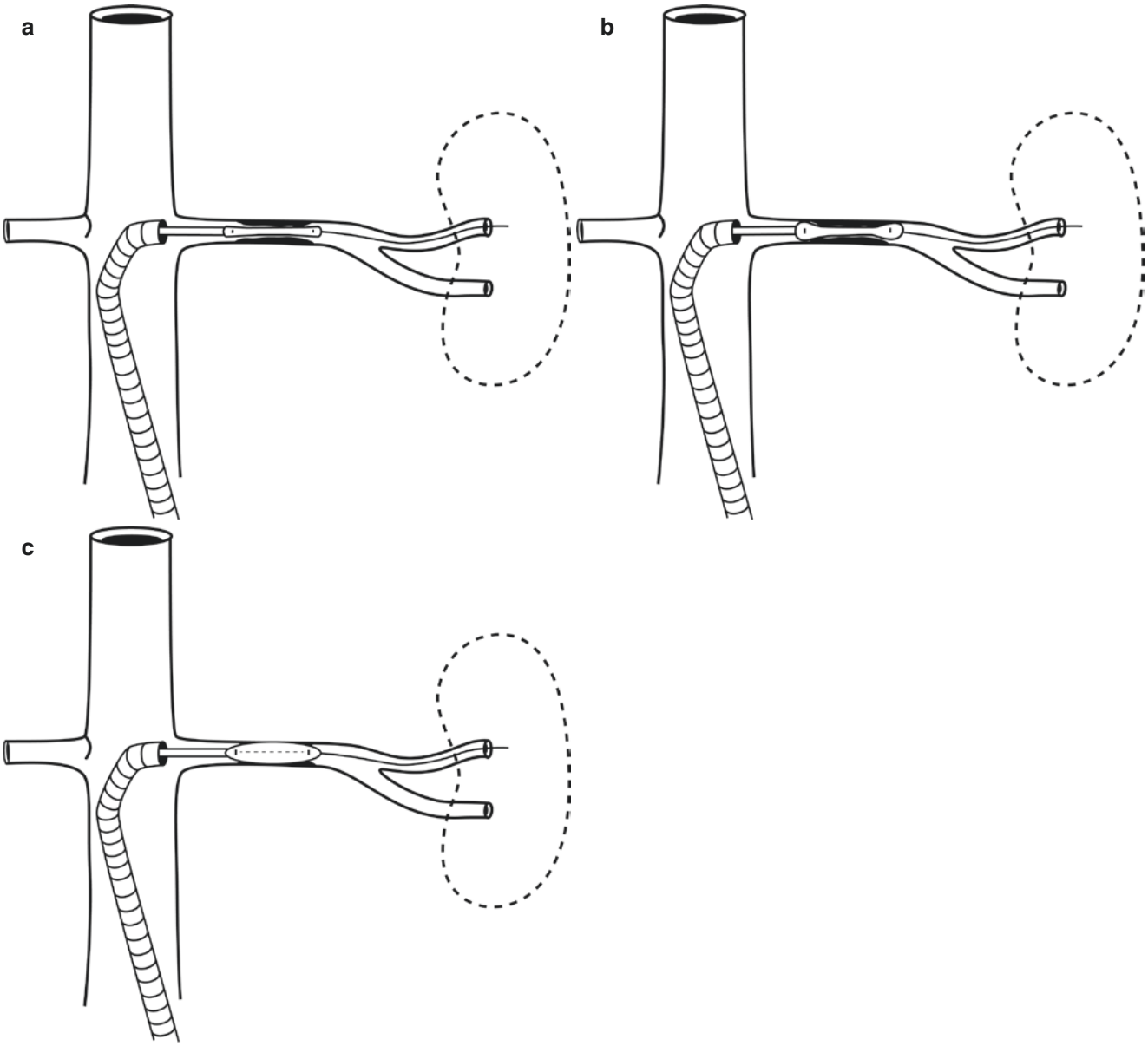


Fig. 28.5 Endovascular intervention for left renal artery stenosis. (**a**) A balloon angioplasty catheter is positioned across the lesion. (**b**) The "dog-bone" effect is seen as the balloon is partially inflated. (**c**) The balloon is fully inflated to its full diameter profile, covering the entire lesion

than 30%, the procedure is considered a success and no stent is required. If the residual stenosis is greater than 30%, we proceed with the deployment of a stent (Fig. 28.6b).

A balloon-expandable stent is preferred because of its precise deployment and good radial force. A bare metal balloon-expandable stent catheter is selected and tracked over the wire and through the sheath. The stent is positioned across the residual stenosis. The balloon is inflated, and the stent is then deployed with full apposition against the walls of the renal artery (Fig. 28.7a–c).

Following stent deployment, the catheter is removed over the wire, and a completion selective left renal artery angiogram is performed. If no residual stenosis is identified, the procedure is determined to be a success and the long guide sheath is exchanged for a short access sheath (Fig. 28.8a–c).

An activated clotting time (ACT) is checked. If the ACT is less than 200 seconds, typically a closure device (MYNX, Cardinal Health-Cordis; Perclose ProGlide, Abbott; Angio-Seal, Terumo) is then deployed for hemostasis. Alternatively, if a closure device is not used, the sheath is removed and pressure is applied over the CFA puncture site for 20 to 30 minutes to create hemostasis.

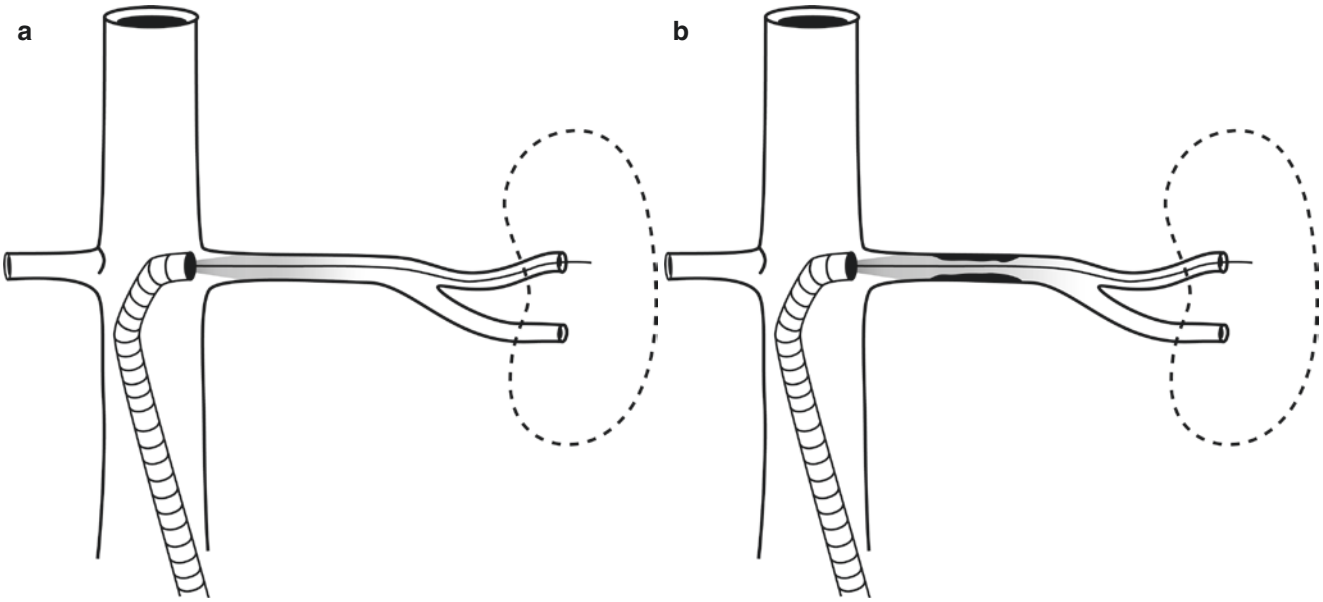


Fig. 28.6 Selective completion left renal artery angiogram following balloon angioplasty, performed through the sheath. (**a**) With less than 30% residual stenosis, the procedure is considered a success and no stent is required. (**b**) If the angiogram shows >30% residual stenosis, the deployment of a stent is indicated

Distal Renal Artery Stenosis

A nonselective diagnostic abdominal aorta–renal artery angiogram and selective diagnostic renal artery angiogram are performed, as illustrated in Figs. 28.1, 28.2 and 28.3. A decision is then made to either terminate the procedure or proceed with endovascular treatment if clinically indicated. If the decision is to proceed with endovascular intervention for the renal artery stenosis, the 5 Fr access sheath and guidewire can remain in place. A stiffer 0.035″ wire can be used to facilitate exchange to a larger, longer guide (destination) sheath. The Fr size (5–7 Fr) and shape of the guide sheath (Ansel, Raabe) used will depend on the anatomy of the aorta and renal artery and what wire-catheter-balloon-stent platform type (0.014″–0.035″) is selected to perform the procedure. Alternatively, a guide catheter platform (renal standard curve, IMA, renal double curve, hockey stick, SOS Omni) may be used instead of a guide sheath platform. Each platform has its advantages and disadvantages. A guide sheath platform is used in this chapter.

As shown in Fig. 28.9a, the 5 Fr access sheath is then exchanged for a longer (45–55 cm) guide sheath (5–7 Fr). Once the guide sheath is inserted, 2000 units of heparin is given intravenously. The tip of the guide sheath is positioned distal to the orifice of the renal artery being treated. Once the sheath is in place, an angled or shaped selective diagnostic catheter is selected and tracked over the guidewire. The shape or angle of the diagnostic catheter selected is based on the anatomy and location of the renal artery. The tip of the diagnostic catheter moves beyond the end of the sheath and is directed towards the orifice of the renal artery. If the ostium of the renal artery is free of disease, the tip of the diagnostic catheter is then gently allowed to move passively into the orifice of the artery without using a wire. This technique is known as “blind cannulation” or “direct engagement”. Alternatively, if the ostium of the renal artery has mild atherosclerotic disease, then the tip of the diagnostic catheter is positioned just at the ostium but does not physically engage the ostium, for fear of causing a dissection, embolization, or complete occlusion of the renal artery. An angled wire (0.014″ to 0.035″) can be used to cannulate the ostium of the renal artery to allow for over-the-wire advancement of the catheter into the ostium of the artery but no further. This is known as the “no-touch” technique (*see* Fig. 28.9a, b).

The 0.014″–0.035″ wire is used to cross the distal renal artery stenosis. The wire tip is placed in a first-order or second-order branch of the renal artery. Using a telescoping technique, the diagnostic catheter is then advanced over the wire into the proximal renal artery, but not through the lesion. The guide sheath is then advanced proximally over the diagnostic catheter and wire just into or right at the orifice of the renal artery. The diagnostic catheter is removed over the wire, keeping the wire in place across the stenosis and keeping the tip of the guide sheath in or at the orifice of the renal artery (*see* Fig. 28.9c, d).

In an effort to protect both first-order branches from becoming occluded during angioplasty and stenting of the distal renal artery stenosis, an 0.014″ wire is introduced into the sheath and advanced across the distal stenosis; the tip of the wire is placed into the other at-risk renal branch.

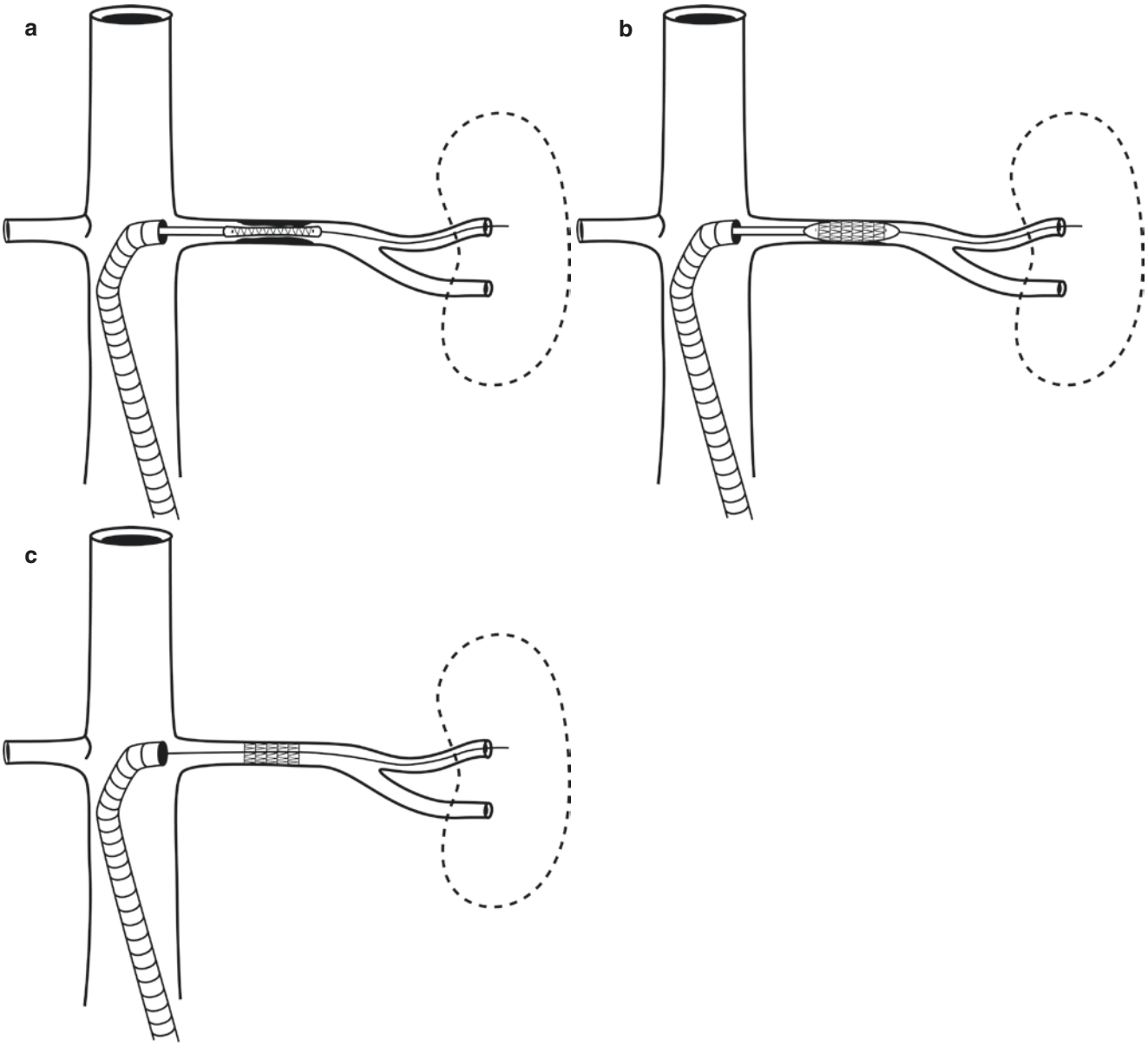


Fig. 28.7 Placement of a balloon-expandable stent. (**a**) A bare metal balloon-expandable stent catheter is selected and tracked over the wire and through the sheath. The stent is positioned across the residual stenosis, (**b**) The balloon is fully inflated within the stent. (**c**) The fully deployed stent after the balloon catheter is removed

Sometimes a diagnostic catheter is needed to help direct the second wire into the proper position. Once the second wire is safely stabilized in the second first-order branch, the diagnostic catheter is removed and a full dose of heparin (75–100 IU/kg) is given intravenously (*see* Fig. 28.9e–g).

Alternatively, an 0.014″ wire can be introduced from the opposite CFA through a 5 Fr access sheath and using a diagnostic catheter cannulate the left renal artery and distal stenosis with positioning and stabilization of the wire tip in the other at-risk first order branch (Fig. 28.10).

A selective left renal artery angiogram is then performed through the guide sheath. The degree of stenosis severity, stenosis length, and renal artery diameter and length measurements are determined (Fig. 28.11).

A balloon angioplasty catheter is selected, tracked over one of the wires, inserted into the sheath, and positioned across the lesion. Care is taken to avoid encroaching on the first-order branches with the distal end of the balloon, as doing so may cause branch occlusion or even frank rupture. The balloon is then inflated to its full diameter profile (Fig. 28.12a–c).

The balloon is then deflated and removed over the wire. A selective completion angiogram of the artery is performed through the sheath. If there is less than 30% residual ste-

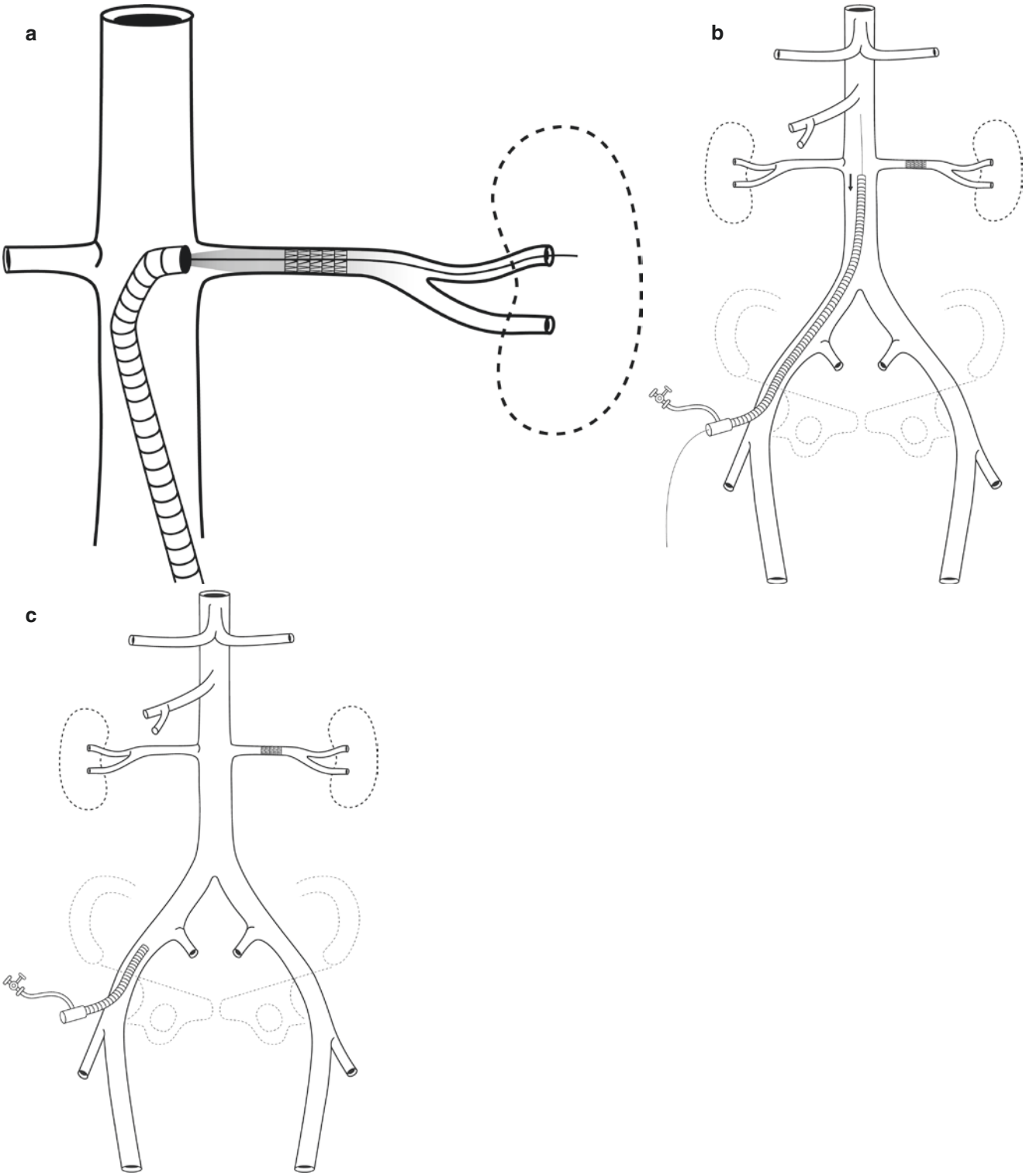


Fig. 28.8 Procedure after stent deployment. (**a**) A selective completion renal artery angiogram is performed. This angiogram shows stent patency with no residual stenosis, with full apposition against the walls of the renal artery. (**b**) The balloon-stent catheter is removed over the wire. (**c**) The long guide sheath is exchanged for a short access sheath

nosis, the procedure is considered a success and no stent is required, but if more than 30% residual stenosis is measured, then we proceed with the deployment of a stent (Fig. 28.13).

A balloon-expandable stent is preferred, because of its precise deployment and excellent radial force. A bare metal balloon-expandable stent catheter is selected and tracked over the wire and through the sheath. The stent is positioned across the residual stenosis (Fig. 28.14). Care is taken to not encroach too closely on the smaller first-order branches with the distal end of the balloon or stent, as doing so may cause branch occlusion or even frank rupture. The balloon is inflated, and the stent is then deployed with full apposition against the walls of the renal artery. The balloon-stent catheter is the removed over the wire, while maintaining both wires in the first- order arterial branches. A selective completion post-stent deployment left renal artery angiogram is performed (Fig. 28.15).

Once the patency of the stent and lack of residual stenosis are confirmed and the patency of both first-order arterial branches is visualized, the procedure is determined to be a success. One of the 0.014″ wires is removed and the other 0.014″ wire is exchanged for a larger, stiffer 0.035″ wire. The long guide sheath is removed and exchanged for a short access sheath (Fig. 28.16).

An activated clotting time (ACT) is checked. If the ACT is less than 200 seconds, typically a closure device (MYNX,

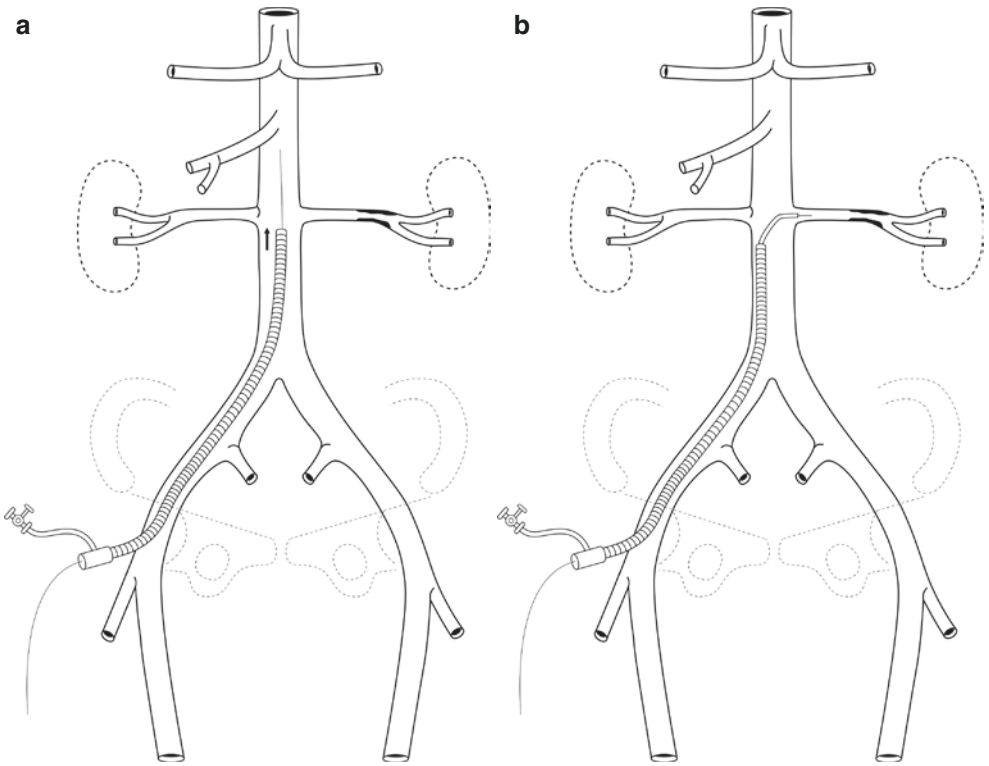


Fig. 28.9 Preparing for diagnostic angiography for distal renal artery stenosis. (**a**) The 5 Fr access sheath is exchanged for a longer (45–55 cm) guide sheath (5–7 Fr). (**b**) The tip of the guide sheath is positioned distal to the orifice of the renal artery being treated. (**c**) The 0.014″–0.035″ wire is advanced through the catheter and directed to cross the distal renal artery stenosis. The wire tip is placed in a first- or second-order branch of the renal artery. The tip of the diagnostic catheter moves beyond the end of the sheath and is directed towards the orifice. A "telescoping technique" is used to advance the diagnostic catheter over the wire, and the guide sheath is advanced over the diagnostic catheter at or just into the ostium of the renal artery, but proximal to the distal renal artery lesion. (**d**) The diagnostic catheter is removed. (**e**) A second wire (0.014″) is introduced through the sheath and diagnostic catheter. (**f**) The wire is advanced across the distal renal artery stenosis, and the tip of the wire is placed into the other at-risk renal branch, to protect both branches from becoming occluded during angioplasty and stenting. (**g**) The diagnostic catheter is removed from the second wire while maintaining both wire accesses and the sheath tip position

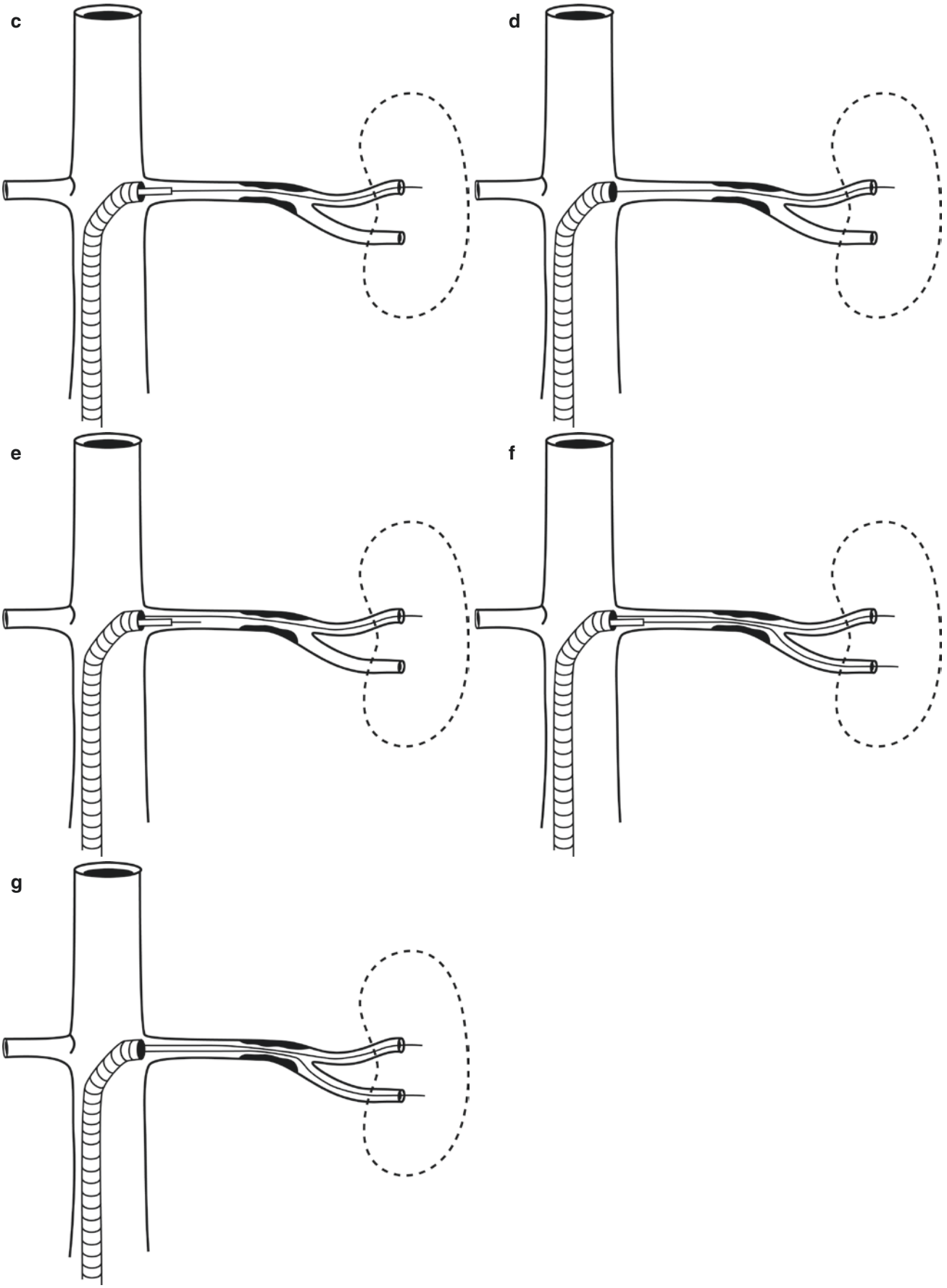


Fig. 28.9 (continued)

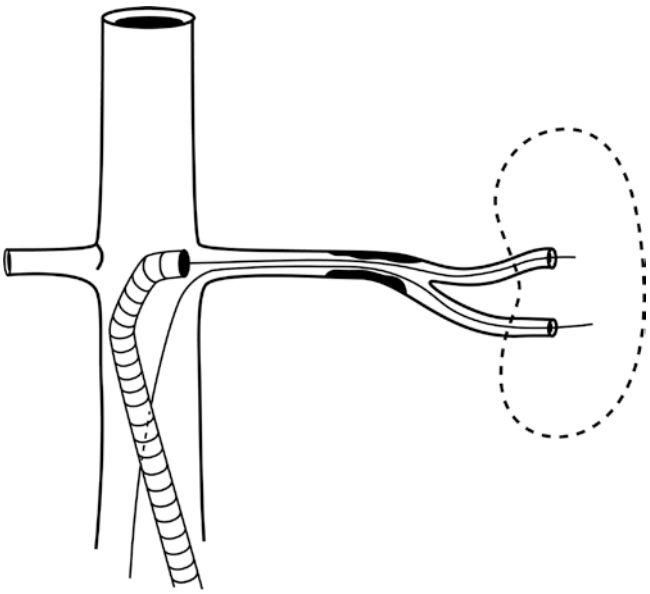


Fig. 28.10 An alternative approach is to introduce an 0.014″ wire from the opposite common femoral artery (CFA) through a 5 Fr access sheath. A diagnostic catheter is used to cannulate the renal artery and distal stenosis, positioning and stabilizing the wire tip in the other at-risk first-order branch

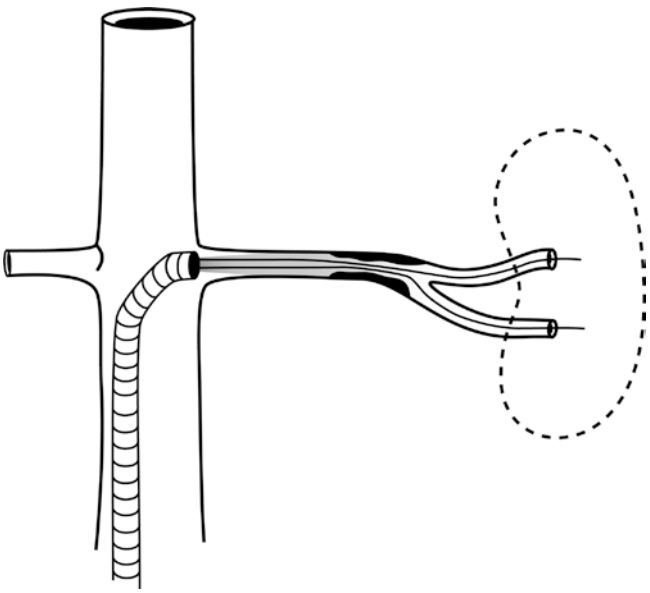


Fig. 28.11 A selective renal artery angiogram is then performed through the guide sheath, to determine the degree of stenosis severity, stenosis length, and the diameter and length of the renal artery

Cardinal Health-Cordis; Perclose ProGlide, Abbott; Angio-Seal, Terumo) is then deployed for hemostasis. If no closure device is used, the sheath is removed and pressure is applied over the CFA puncture site for 20 to 30 minutes to create hemostasis.

Ostial Renal Artery Stenosis

As described previously, arterial access is obtained with a short 5 Fr access sheath placed into the CFA (*see* Figs. 28.1, 28.2 and 28.3). A guidewire is then tracked through the 5 Fr access sheath, and the wire tip is positioned in the aorta proximal to the renal arteries. A shaped 5 Fr diagnostic multi-hole flush catheter (Pigtail or Omni) is tracked over the guidewire to the level of or just above the orifices of the renal arteries. The guidewire is then removed from the shaped catheter, and the catheter resumes its original shape at or just proximal to the level of the renal arteries (Fig. 28.17a–c). A nonselective abdominal aorta–renal artery angiogram is performed (Fig. 28.17d) in either a straight anterior-posterior (AP) view or slight (7–10°) left or right anterior oblique (LAO, RAO) view, using the technique described previously.

A decision is then made to either terminate the procedure or proceed with endovascular treatment if clinically indicated. If the decision is to proceed with endovascular intervention, the multi-hole flush catheter is removed over a stiffer wire through the 5 Fr access sheath, leaving the stiffer wire in the aorta. The stiffer wire is used to facilitate the exchange of a longer guide (destination) sheath (Ansel, Raabe). The Fr size (5–7 Fr) and shape of the guide sheath used will depend on the anatomy of the aorta and renal artery and on the wire-catheter-balloon-stent platform type selected for the procedure. Alternatively, a guide catheter platform (renal standard curve, IMA, renal double curve, hockey stick, SOS Omni) may be used instead of a guide sheath platform. Each platform has its advantages and disadvantages. This chapter uses a guide sheath platform. The 5 Fr access sheath is then exchanged for a longer (45–55 cm) and larger (5–7 Fr) guide sheath. The tip of the guide sheath is positioned distal to the orifice of the renal artery being treated (Fig. 28.18). At this point, 2000 units of heparin may be given intravenously. The patient is not fully heparinized until wire access cannulation of the stenosis is accomplished.

With tip of the guide sheath positioned distal to the orifice of the renal artery, an angled or shaped diagnostic catheter is selected based on the anatomy and location of the ostium of the renal artery. The diagnostic catheter is tracked over the wire within the sheath, and its tip is placed in the aorta and directed towards the orifice of the renal artery (Fig. 28.19). Because the angiogram has shown the ostium of the artery to be severely stenotic, the tip of the angled or shaped diagnostic catheter is positioned just at the ostium; it does not physically engage the ostium for fear of causing a dissection, embolization, or complete occlusion of the renal artery.

The renal artery ostial stenosis can now be cannulated using a “no touch” technique. In this method, the diagnostic

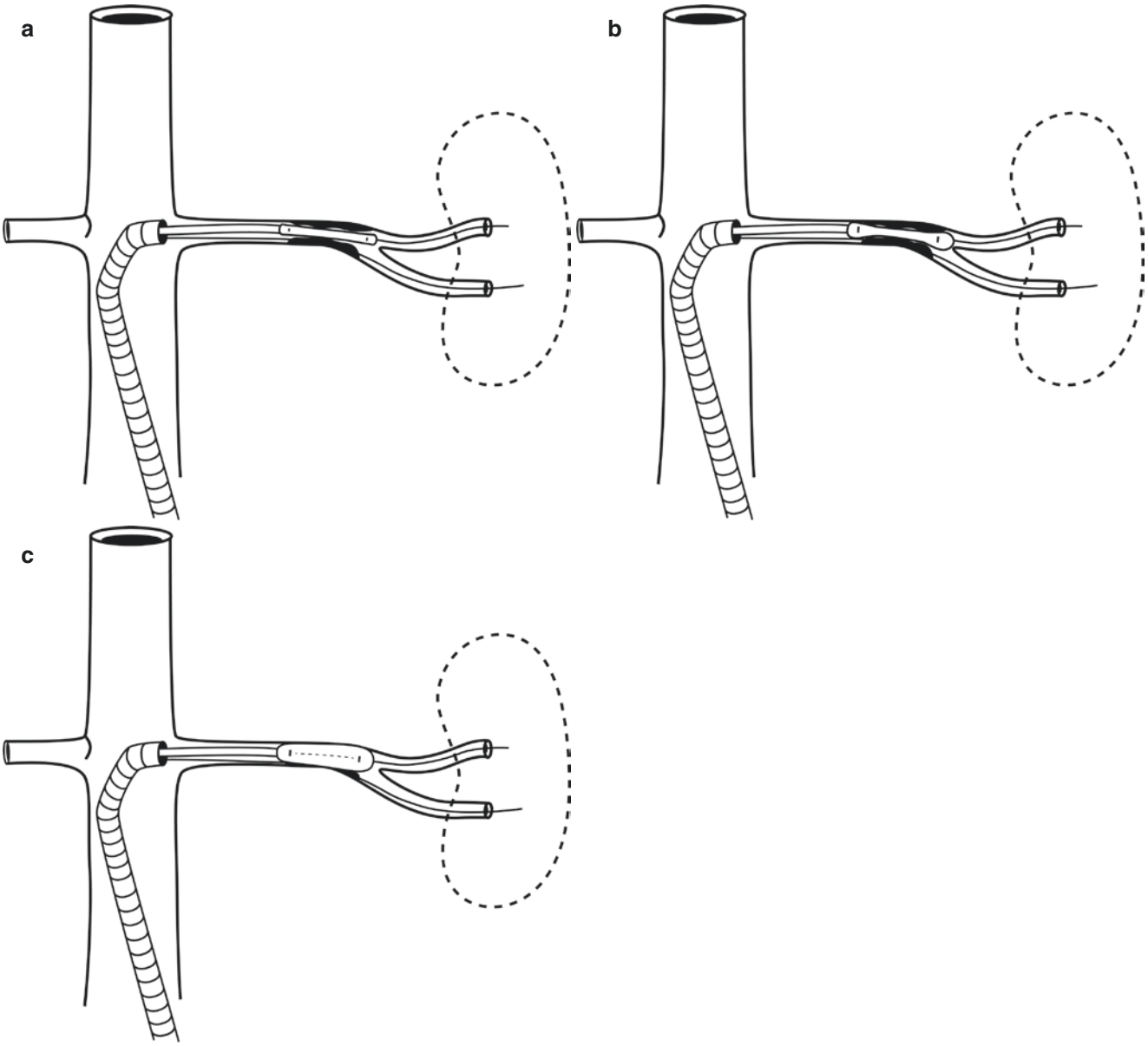


Fig. 28.12 Balloon angioplasty of distal renal artery stenosis. (**a**) A balloon angioplasty catheter is positioned across the lesion, taking care to avoid encroaching on the first-order branches. (**b**) When the balloon is partially inflated, it shows a "dog-bone" effect. (**c**) The balloon is fully inflated to its full diameter profile, covering the entire lesion

catheter directs the 0.014″–0.035″ angled guidewire towards the ostium of the renal artery. The ostial stenosis is cannulated by the wire, using a torque device to carefully direct the wire tip across the stenosis, into the renal artery proper, and then into a first- or second-order arterial branch (Fig. 28.20). Determination of wire length will depend on whether the intervention will be performed using a rapid exchange (RX) or monorail or an over-the-wire (OTW) platform.

Care is taken to position the wire in a first- or second-order arterial branch for support and stabilization of the wire across the stenosis. Avoid placing the wire in a more distal third- or fourth-order renal artery branch to prevent occlusion or perforation. Full heparin anticoagulation (75–100 IU/kg) can now be given.

A "telescoping technique" is now used to advance the guide sheath over the diagnostic catheter wire proximally within the aorta so that the guide sheath tip is at the level of the renal artery ostium but does not pass through the ostial stenosis. The diagnostic catheter is removed, maintaining the wire access across the stenosis (Fig. 28.21).

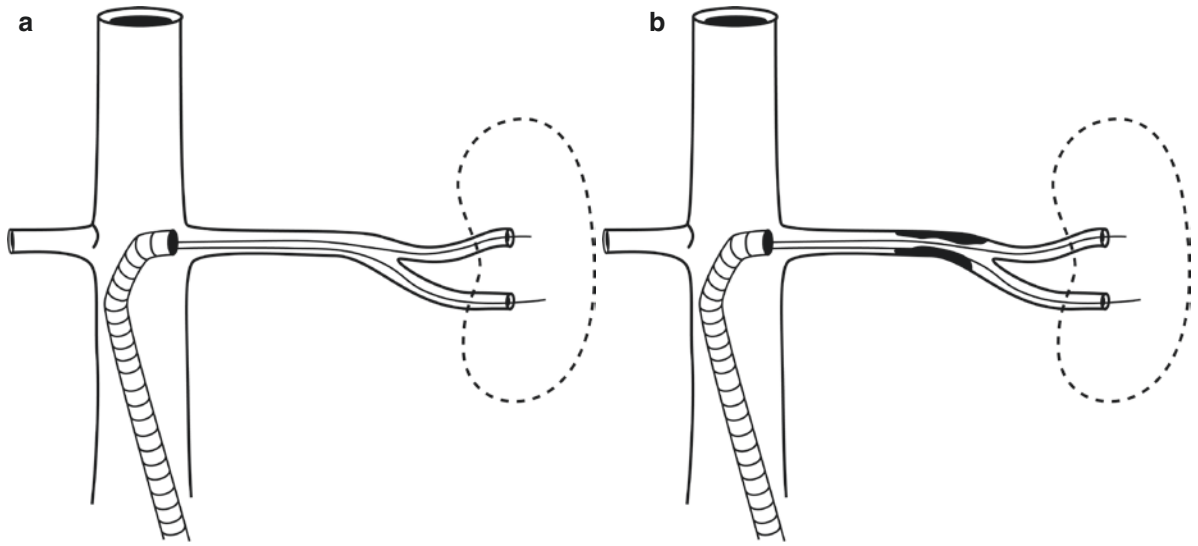


Fig. 28.13 Residual stenosis measured by a selective completion angiogram of the renal artery following balloon angioplasty. (**a**) Less than 30% residual stenosis, indicating that no stent is required. (**b**) Greater than 30% residual stenosis, which requires stent placement

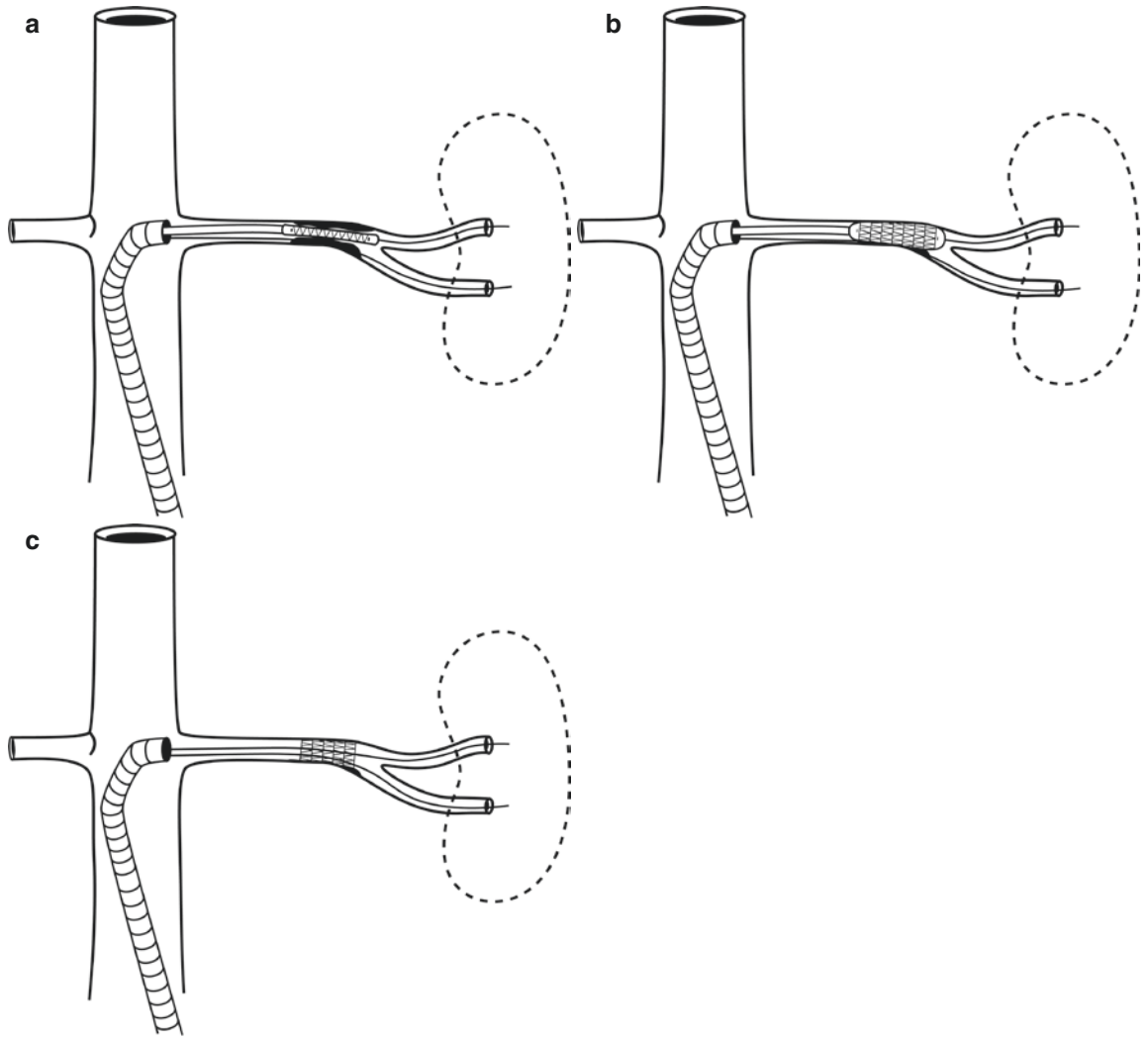


Fig. 28.14 Placement of a balloon-expandable stent. (**a**) A bare metal balloon-expandable stent catheter is selected and tracked over the wire and through the sheath. The stent is positioned across the residual stenosis. (**b**) The balloon is fully inflated within the stent. (**c**) The fully deployed stent after removal of the balloon catheter

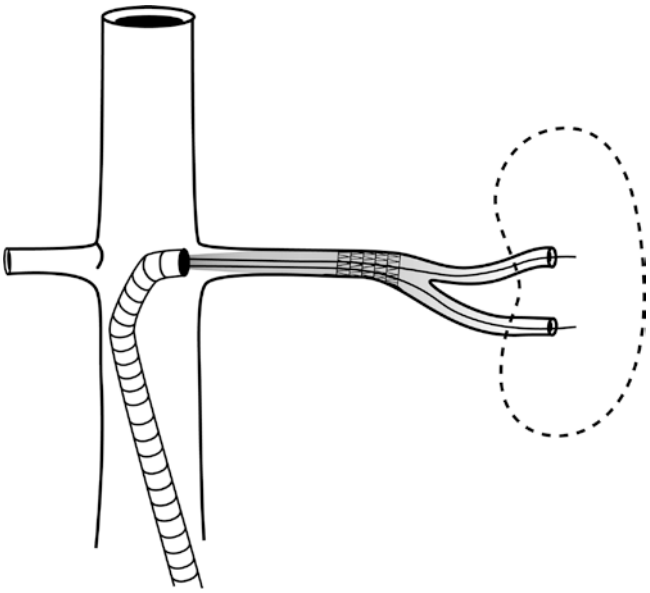


Fig. 28.15 Following stent deployment, a selective completion renal artery angiogram is performed through the sheath, showing stent patency with no residual stenosis and full apposition against the walls of the artery. Note also the patency of the first-order branches

A directed nonselective renal artery angiogram is performed through the guide sheath to determine the degree of stenosis severity, stenosis length, and the renal artery diameter and length (Fig. 28.22).

Primary stenting is recommended for the treatment of ostial renal artery stenosis because the rate of residual and recurrent stenosis is at least 40–50% with the use of balloon angioplasty alone. A balloon-expandable stent is preferred, owing to its precise deployment and good radial force. If decreased pressure and flow make it impossible to accurately determine the renal artery diameter distal to the ostial stenosis (for stent sizing), pre-dilation balloon angioplasty prior to stent deployment is recommended.

Once accurate measurements of the renal artery diameter and the lesion length have been obtained, a bare metal balloon-expandable stent catheter is selected and tracked over the wire through the guide sheath (Fig. 28.23a). The stent is positioned across the ostial renal artery stenosis for complete coverage of the lesion and dilation of the ostium. The stent should be long enough to cover the stenosis entirely, with the proximal end protruding 2 to 3 mm into the aorta to cover and exclude the ostial disease. ("Aorta spill-over plaque" is typically associated

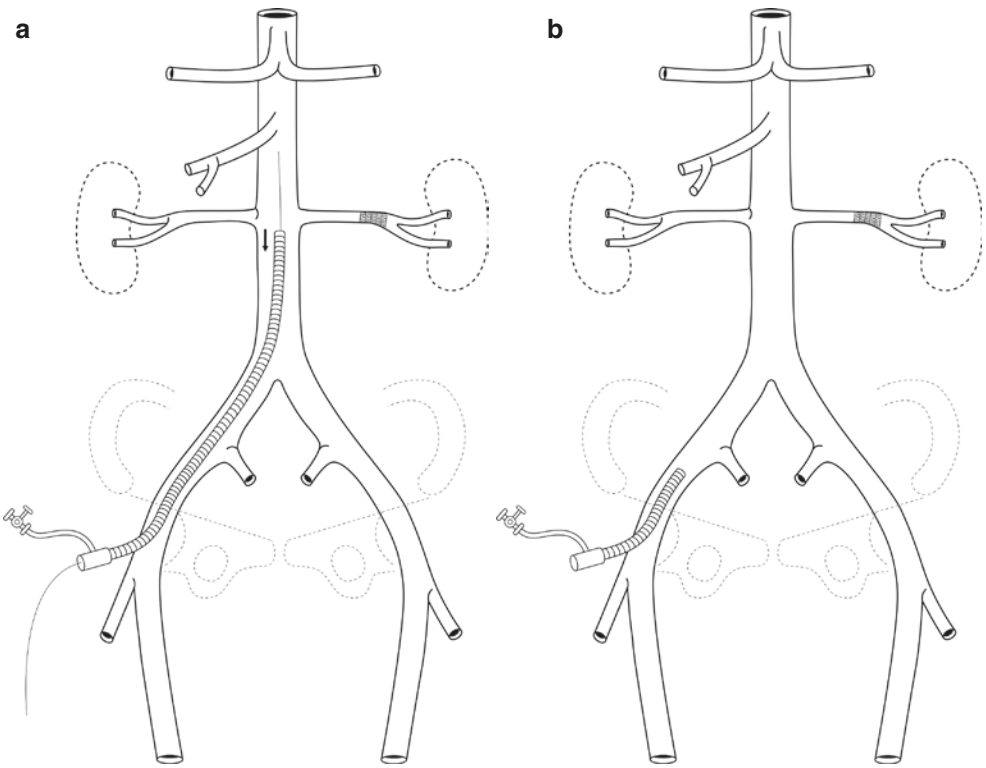


Fig. 28.16 Procedure after stent deployment. (**a**) The balloon-stent catheter is removed over the wire (*arrow*). (**b**) The long guide sheath is exchanged for a short access sheath

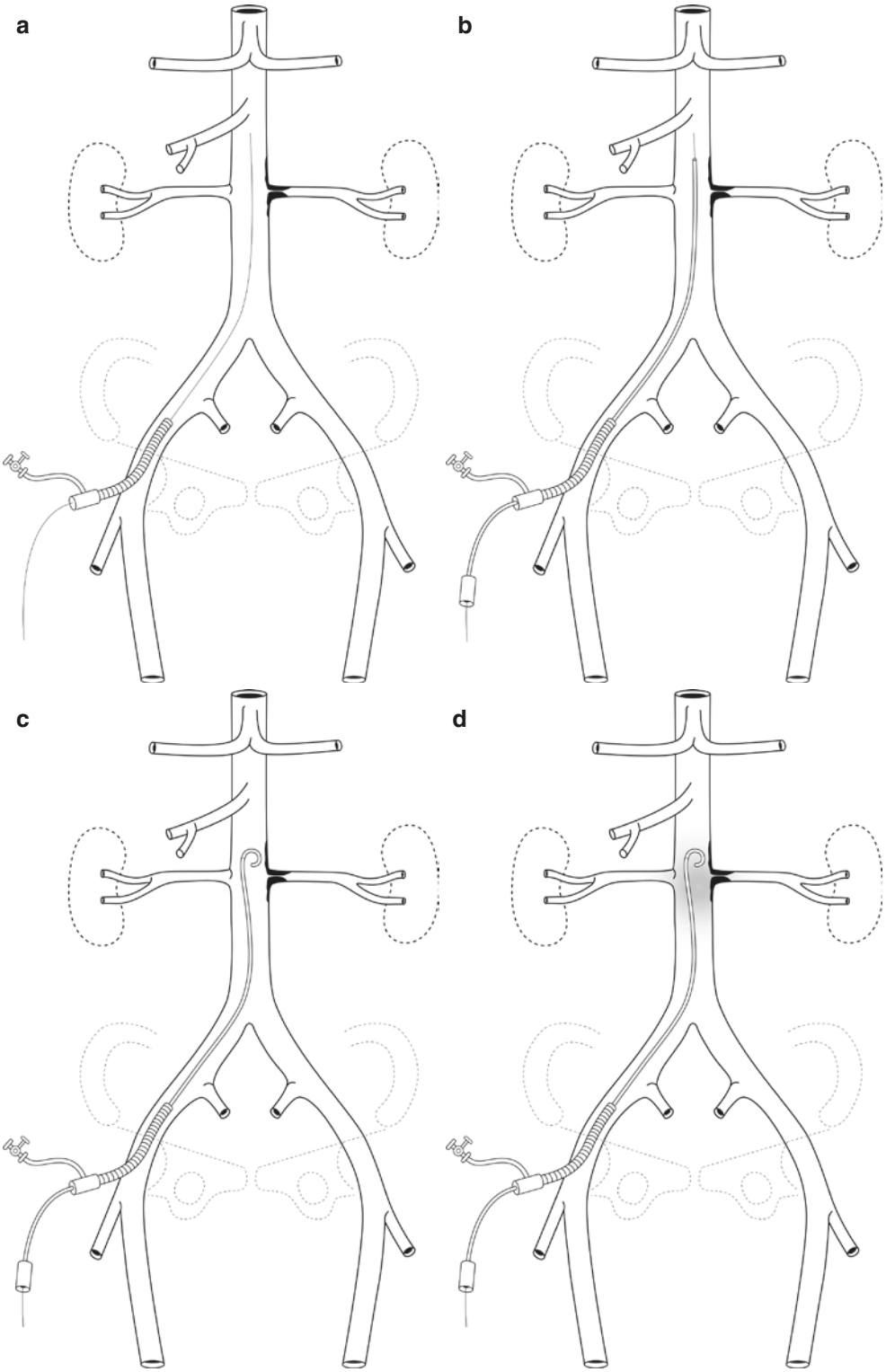


Fig. 28.17 Arterial access for ostial renal artery stenosis. (**a**) A guidewire is tracked through the 5 Fr access sheath and the wire tip is positioned in the aorta proximal to the renal arteries. (**b**) A 5 Fr diagnostic multi-hole flush catheter is tracked over the guidewire to the level of or just above the orifices of the renal arteries. (**c**) The guidewire is then removed from the shaped catheter, and the catheter resumes its original shape at or just proximal to the level of the renal arteries. (**d**) A nonselective abdominal aorta–renal artery angiogram is performed in either a straight AP view or slight (7–10°) ipsilateral LAO view

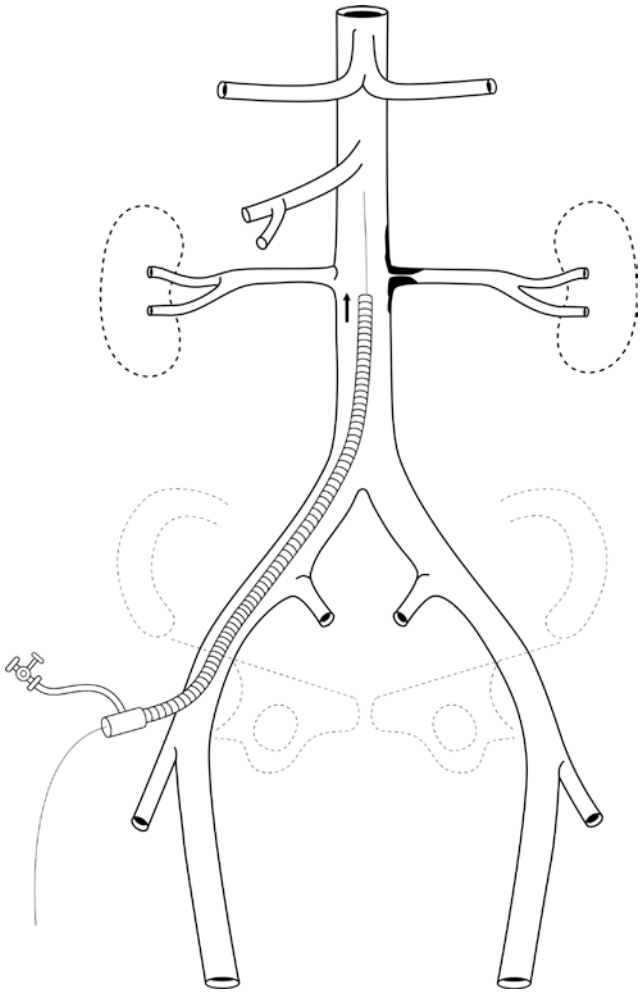


Fig. 28.18 The tip of the guide sheath is positioned distal to the orifice of the renal artery being treated

with ostial renal artery disease.) The balloon-expandable stent is dilated and deployed to full apposition against the renal artery wall, with 2 to 3 mm of the proximal end of the stent protruding into the aorta (Fig. 28.23b, c).

The balloon is withdrawn partially back into the aorta and re-inflated to help "flare" the aortic end of the stent to ensure exclusion of the "spill-over" renal-aortic ostial plaque and optimize the renal artery stent patency (Fig. 28.24a, b).

Following stent deployment, the balloon-stent catheter is removed over the wire, and a directed nonselective completion post-stent deployment renal artery angiogram is performed through the sheath to confirm stent and arterial luminal patency, perfusion of the entire kidney, and the absence of parenchymal

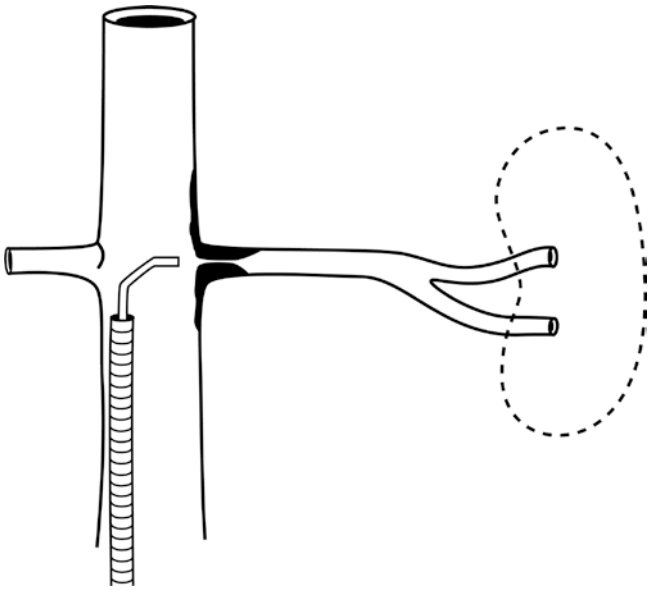


Fig. 28.19 The diagnostic catheter is tracked over the wire within the sheath and its tip is placed in the aorta and directed towards the orifice of the renal artery. Because the ostium of the renal artery is known to be severely stenotic, the tip of the angled or shaped diagnostic catheter is positioned just at the ostium and does not physically engage the ostium

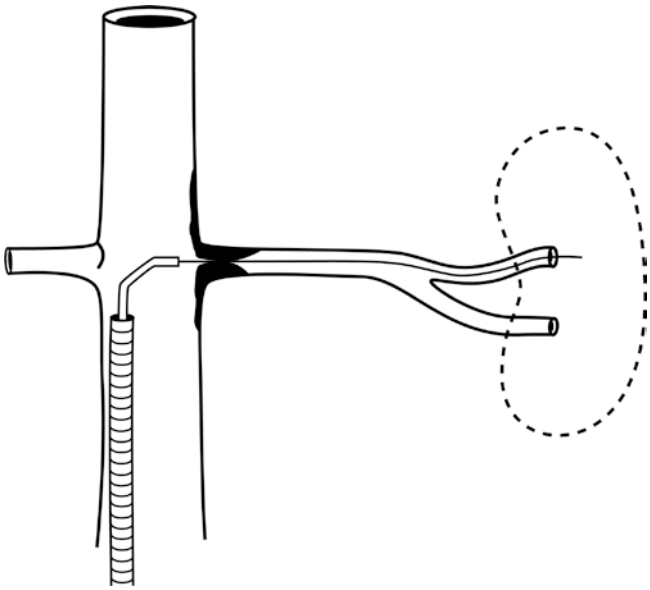


Fig. 28.20 This left renal artery ostial stenosis is cannulated by a wire using a "no touch" technique. The wire is carefully navigated through the stenosis and the main renal artery by using a torque device. For stability, the tip of the wire is positioned into a first-order renal branch

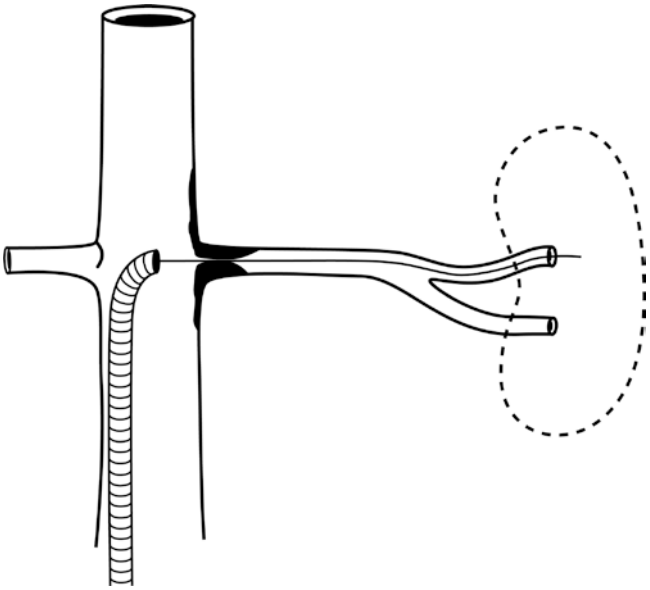


Fig. 28.21 The guide sheath is advanced proximally over the diagnostic catheter and wire so that the tip of the sheath is at the level of the renal artery ostium but does not engage the ostial stenosis. The diagnostic catheter is removed, maintaining the wire access across the stenosis

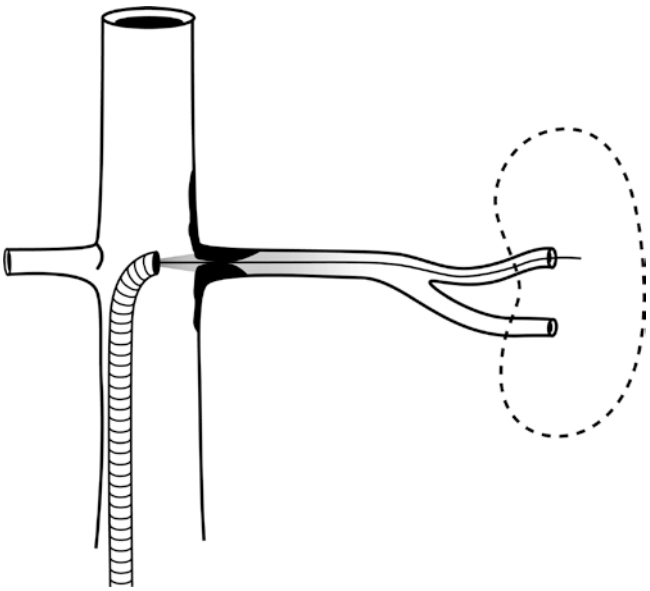


Fig. 28.22 A directed nonselective renal artery angiogram is performed through the guide sheath, determining the degree of stenosis severity, stenosis length, and renal artery diameter and length

or capsular injury (Fig. 28.25). Some interventionalists also perform a nonselective pararenal aorta–renal artery angiogram following the selective renal artery angiogram.

Once stent patency without residual stenosis or complication has been confirmed, the procedure is considered a success and the long guide sheath is exchanged for a short access sheath (Fig. 28.26a, b).

An activated clotting time (ACT) is checked. If the ACT is less than 200 seconds, typically a closure device (MYNX, Cardinal Health-Cordis; Perclose ProGlide, Abbott Vascular; Angio-Seal, Terumo) is then deployed for hemostasis. If no closure device is used, the sheath is removed and pressure is applied over the CFA puncture site for 20 to 30 minutes to achieve hemostasis.

Visceral Artery Atherosclerotic Occlusive Disease

Nonselective Diagnostic Abdominal Aorta–Visceral Artery Angiogram and Selective Diagnostic Superior Mesenteric Artery Angiogram

When preparing to perform a diagnostic angiogram of the aorta and visceral arteries, place the patient on the fluoroscopy table supine with both arms preferably extended above the patient's head. The primary operator should stand on the right side of the patient at the groin area. Both groin areas should be prepped sterile and prepared for the rare necessity of bilateral CFA access.

Arterial access is obtained, using a short 5 Fr access sheath placed into the CFA, as described previously for renal artery disease. A guidewire is then tracked through the 5 Fr access sheath, and the wire tip is positioned in the aorta proximal to the celiac artery. A 5 Fr diagnostic multi-hole flush catheter is tracked over the guidewire to the level of or just proximal to the origin of the celiac artery (CA). The guidewire is then removed from the shaped catheter and the catheter resumes its original shape at or just proximal to the level of the CA (Fig. 28.27a–c).

A nonselective abdominal aorta–celiac–superior mesenteric artery (SMA) angiogram is performed in a straight anterior-posterior (AP) view or a slight (7–10°) LAO or RAO view. These views will show distal branches of the CA and

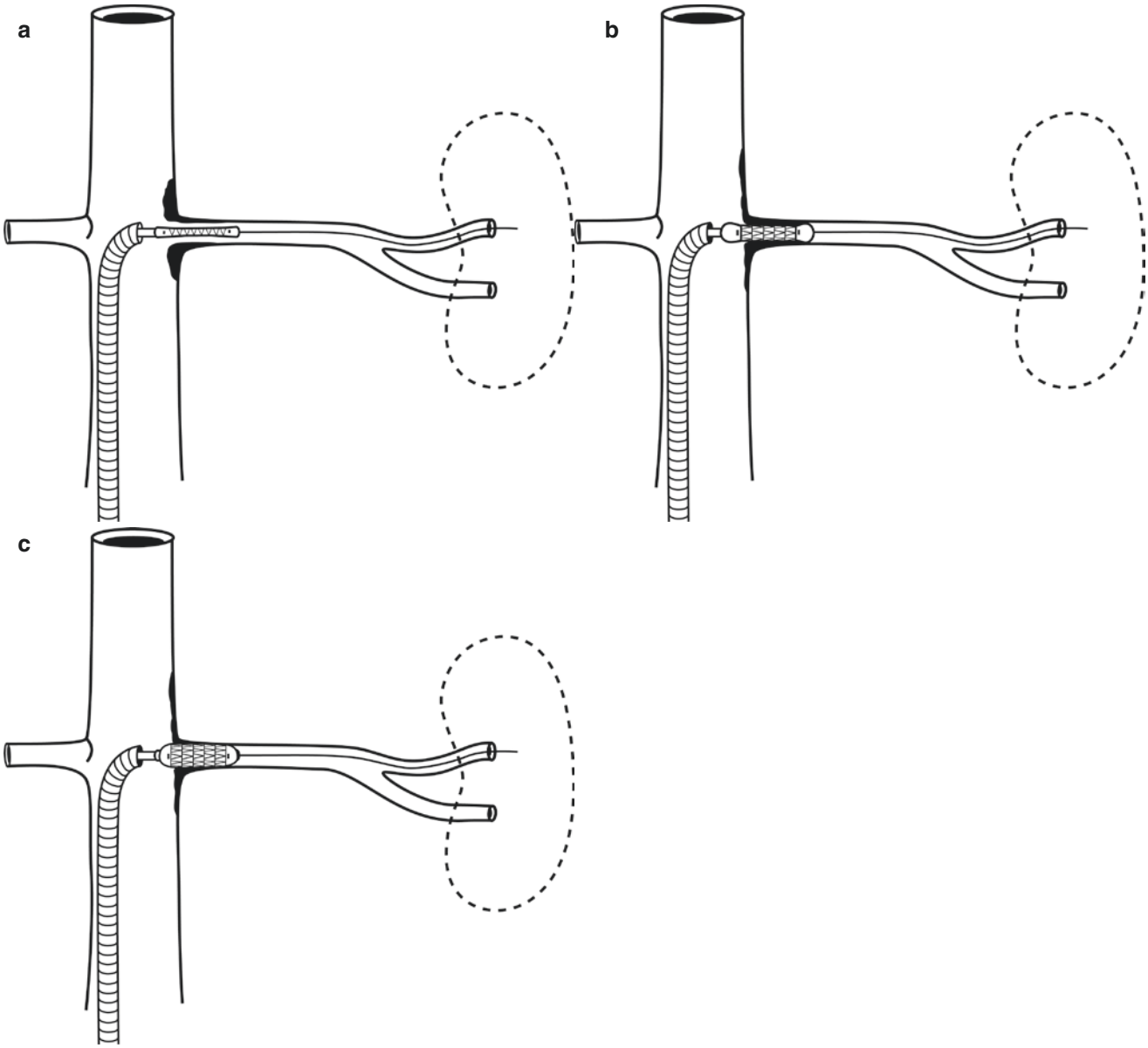


Fig. 28.23 Placement of a balloon-expandable stent for ostial renal artery stenosis. (**a**) A bare metal balloon-expandable stent catheter is selected and tracked over the wire through the guide sheath. (**b**) The stent is positioned across the ostial renal artery stenosis for complete coverage of the lesion. The stent should be long enough to cover the stenosis entirely and have the proximal end protrude 2 to 3 mm into the aorta to cover and exclude the "aorta spill-over plaque" typically associated with ostial renal artery disease. (**c**) The balloon-expandable stent is dilated and deployed to full apposition against the renal artery wall, with 1 to 2 mm of the proximal end of the stent protruding into the aorta

SMA. A second nonselective angiogram is then performed in an LAO view (>75°) or full lateral position (90°) to better visualize the origins and proximal aspect of the CA and SMA (Fig. 28.28a, b). Magnified angiographic views of the origins of the CA and SMA are obtained for definitive determination of the extent of disease and the degree of stenosis (Fig. 28.28c, d). The technique for proper nonselective distribution of contrast dye to the aorta and the CA and SMA was described previously, as related to renal arteries.

The multi-hole flush catheter is then exchanged over a wire for a selective angled or shaped diagnostic catheter (JR4, LIMA, Cobra, Sos 1 or 2, Simmons 1, or Vanchi). The selective catheter is positioned proximal to the intended targeted CA or SMA (Fig. 28.29a). The guidewire is then

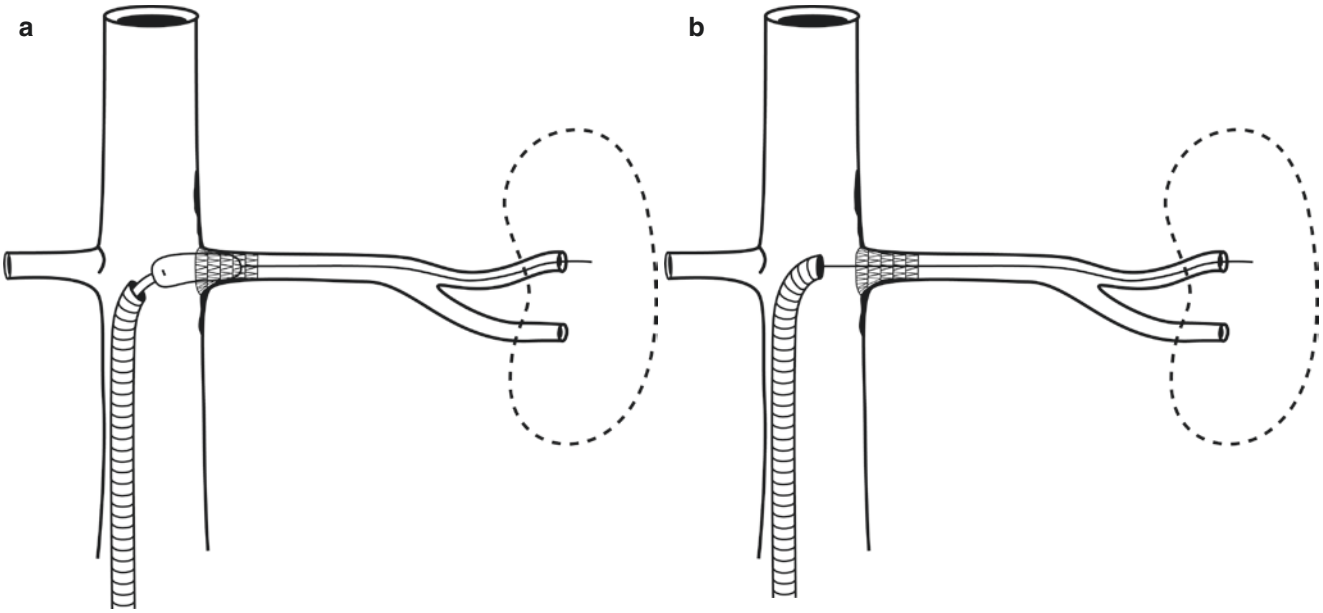


Fig. 28.24 Stent for ostial renal artery stenosis. (**a**) The balloon is withdrawn partially back into the aorta and re-inflated. (**b**) The aortic end of the stent is "flared" to ensure exclusion of the "spill-over" renal-aortic ostial plaque and optimize renal artery stent patency

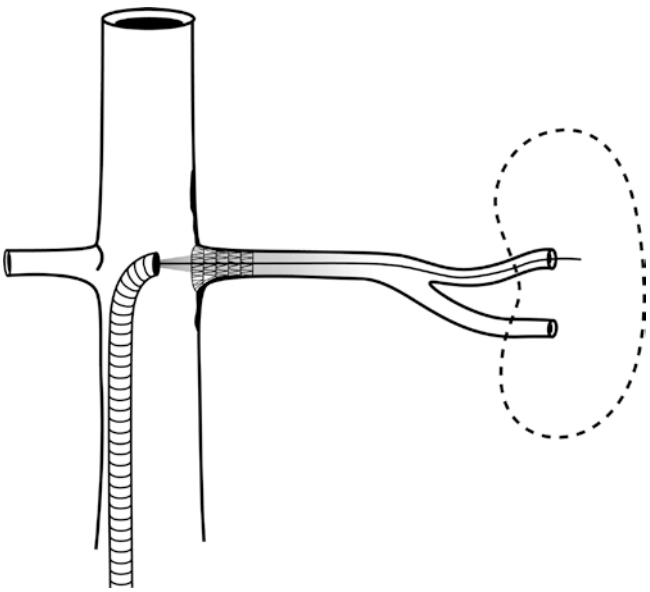


Fig. 28.25 A directed nonselective completion angiogram of the left renal artery is performed through the sheath after stent deployment to confirm patency of the stent and arterial lumen, perfusion of the entire kidney, and absence of parenchymal or capsular injury

removed, allowing the selective angled or shaped diagnostic catheter to assume its intended shape. The tip of the catheter is carefully moved distally toward the ostium of the targeted artery. Figure 28.29b, c shows an example of an SMA with a severely stenotic ostium. In such a case, the tip of the angled or shaped diagnostic catheter is positioned just at the ostium but does not physically engage the ostium, for fear of causing a dissection, embolization, or complete occlusion of the artery. A directed selective angiogram is then performed (Fig. 28.30).

Alternatively, if most of the atherosclerotic disease is located more distally and the ostium is relatively disease-free, the tip of the selective catheter is gently allowed to move passively into the orifice of the artery without using a wire, a technique known as "blind cannulation" or "direct engagement" A selective angiogram can then be performed. Another cannulation technique available is the use of an 0.014″ to 0.035″ angled wire to cannulate the ostium of the artery to allow for over-the-wire advancement of the catheter into the ostium (but no further). This is known as the "no-touch" technique. Care is taken to avoid crossing and cannulating the stenosis unnecessarily when just performing a diagnostic study.

A selective angiogram can then be completed using the power injector at lower volume rates of 5–10 mL per second for a total of 10–20 mL and lower PSI (400 to 500). Alternatively, hand injections can be performed with the same volume of contrast, albeit diluted to 50–70% concentration to allow for ease of injection.

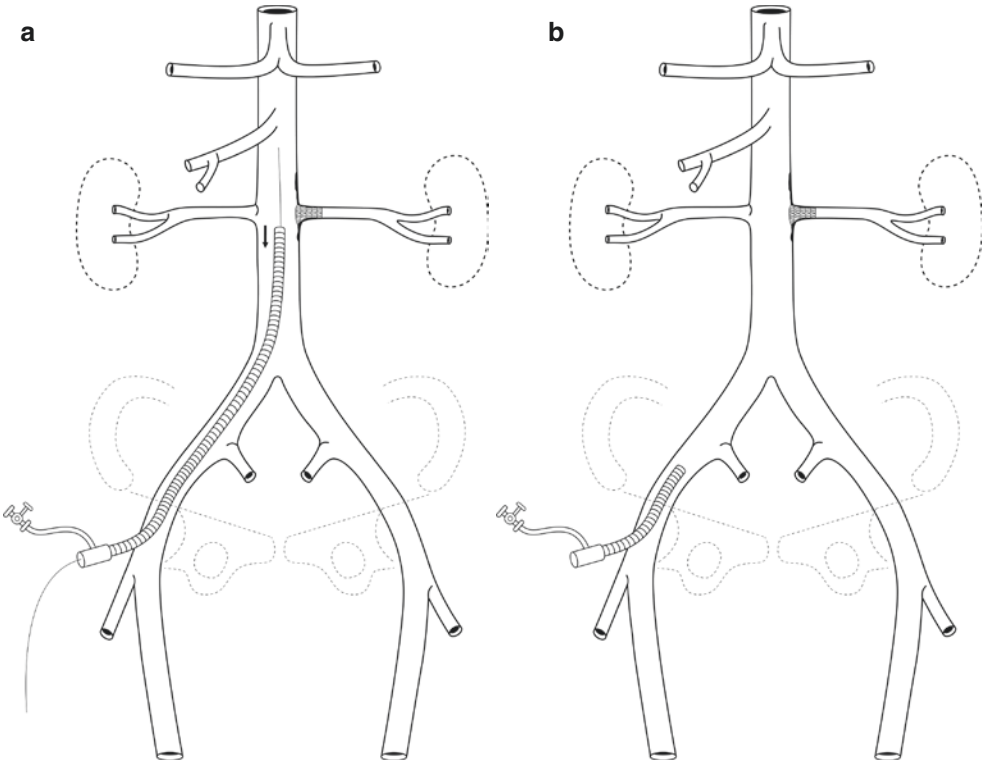


Fig. 28.26 Procedure after stent deployment. (**a**) The balloon-stent catheter is removed over the wire (*arrow*). (**b**) The long guide sheath is exchanged for a short access sheath

Following completion of the directed nonselective or selective diagnostic angiogram, the tip of the angled or shaped selective diagnostic catheter is moved away from or out of the ostium of the SMA into the lumen of the aorta. For shaped catheters (Sos, Cobra, Simmons, Vanchi), this is done by advancing the catheter proximally into the aorta; for angled catheters (JR4, LIMA), this is completed by simply withdrawing the catheter distally into the aorta. A guidewire is then inserted through the diagnostic catheter and both are removed as a single unit, leaving the 5 Fr access sheath in place.

To establish hemostasis at the puncture site, an approved, appropriately sized closure device (MYNX, Cardinal Health-Cordis; Perclose, Abbott; Angio-Seal, Terumo) is deployed, and hemostasis is achieved per the device protocol. Alternatively, the sheath is removed and pressure is applied directly over the CFA puncture site for 15 to 20 minutes to create hemostasis.

Ostial Superior Mesenteric Artery Stenosis

A nonselective diagnostic abdominal aorta–celiac–superior mesenteric artery and directed nonselective diagnostic superior mesenteric artery angiogram are performed as detailed previously. If it is decided to proceed with endovascular intervention for ostial SMA stenosis, the diagnostic catheter is removed; the 5 Fr access sheath and guidewire can remain in place. A stiffer 0.035″ wire can be used to facilitate exchange to a larger, longer guide (destination) sheath.

The 5 Fr access sheath is then exchanged for a longer (45–55 cm) guide sheath (5–7 Fr) (Fig. 28.31). The size and shape of the guide sheath used will depend on the anatomy of the aorta and the SMA and the wire-catheter-balloon-stent platform selected to perform the procedure. Alternatively, a guiding catheter platform may use instead of a guide sheath platform. Each platform has its advantages and disadvantages. This chapter uses a guide sheath platform.

Once the guide sheath is inserted, 2000 units of heparin is given intravenously. The patient is not fully heparinized until cannulation of the stenosis is achieved and wire position is stabilized.

With the tip of the guide sheath positioned distal to the orifice of the SMA, an angled or shaped diagnostic catheter (JR4, LIMA, Cobra, Sos 1 or 2, Simmons 1, Vanchi) is selected based on the arterial anatomy and the location of the SMA ostium. The diagnostic catheter is tracked over the wire within the sheath; its tip is placed in the aorta and directed towards the orifice of the SMA. Because the ostium of the SMA is severely stenotic (as shown in Fig. 28.32), the tip of the angled or shaped diagnostic catheter is positioned just at the ostium but does not physically engage the ostium for fear of causing a dissection, embolization, or complete occlusion of the artery.

The SMA stenosis can now be cannulated using a "no touch" technique. In this method, the diagnostic catheter directs the 0.014″–0.035″ angled guide towards the ostial

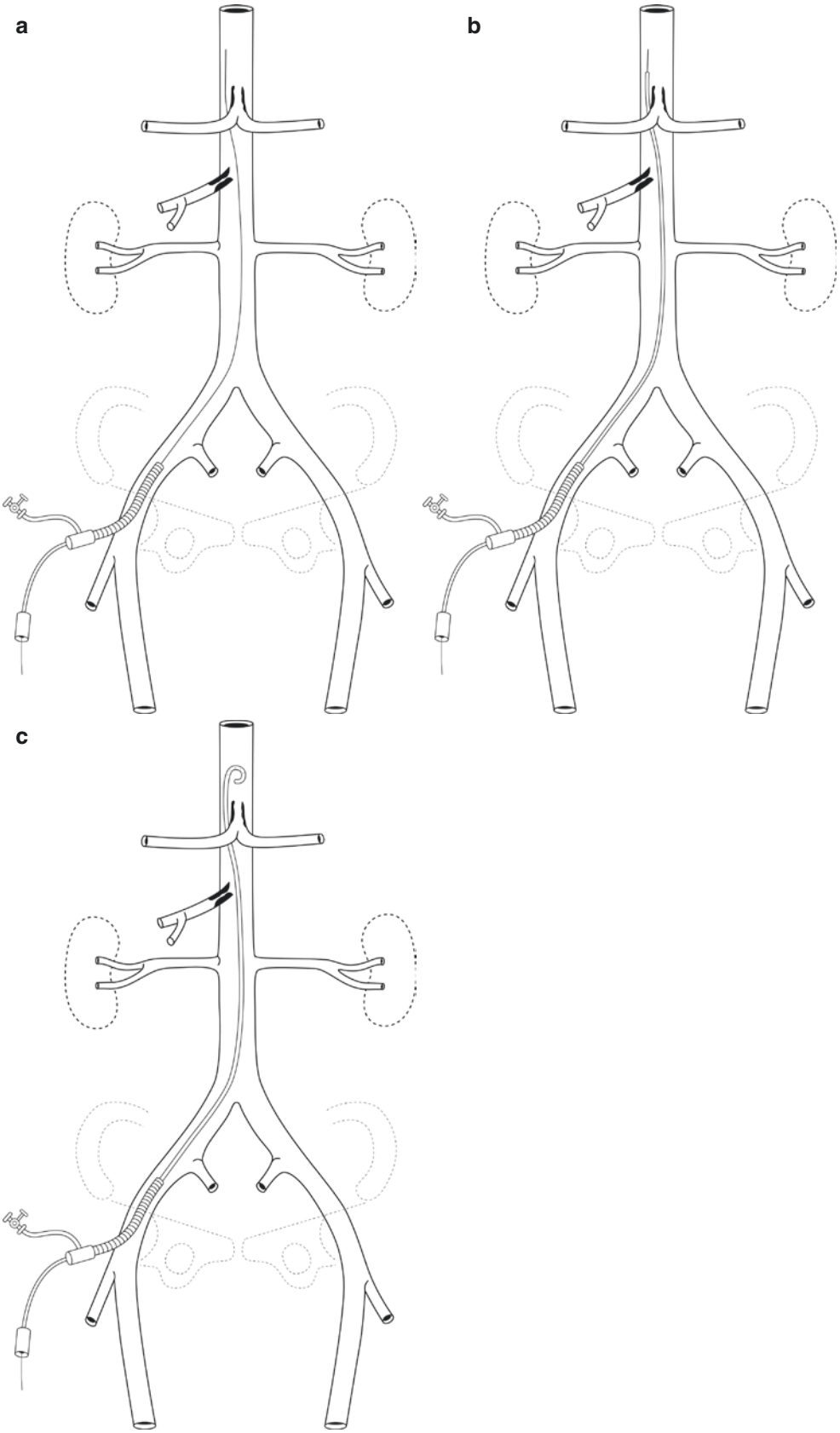


Fig. 28.27 Arterial access for visceral artery disease. (**a**) A guidewire is tracked through the 5 Fr access sheath and the wire tip is positioned in the aorta proximal to the celiac artery (CA). (**b**) A 5 Fr diagnostic multi-hole flush catheter is tracked over the guidewire to the level of or just proximal to the CA origin. (**c**) The guidewire is then removed from the shaped catheter, and the catheter resumes its original shape at or just proximal to the level of the CA

stenosis of the SMA.). The ostial stenosis is cannulated by the wire, using a torque device to carefully direct the wire tip is across the stenosis and into the mid-distal segment of the artery (Fig. 28.33). Care should be taken to position the wire tip in the main trunk of the SMA for support and stabilization of the wire across the stenosis. Avoid placing the wire in a distal secondary or tertiary mesenteric branch; doing so may lead to occlusion or perforation. Full heparin anticoagulation can now be given (75–100 IU/kg).

It is the authors' preference to exchange out the 0.014″–0.035″ guide wire for a stiffer 0.014″–0.035″ wire through a straight or angled guide catheter (Fig. 28.34). Determination of wire length will depend on whether the intervention will be performed using a rapid exchange or monorail (RX) or an over-the-wire (OTW) platform.

A "telescoping technique" is used to advance the tip of the guide sheath over the glide/diagnostic catheter and stiffer wire proximally within the aorta to the level of the SMA ostium but not through the ostial stenosis (Fig. 28.35a). The glide/diagnostic catheter is removed, maintaining the wire access across the stenosis (Fig. 28.35b). A directed but non-selective SMA angiogram is performed through the guide sheath (Fig. 28.36).

Balloon predilation (usually with a low-profile balloon) is performed in the setting of occlusion, severe pre-occlusive stenosis, or excessive calcification, and for accurate sizing of the artery for stent deployment. A balloon angioplasty catheter is selected, inserted into the sheath, tracked over the wire, and positioned across the lesion. The balloon is then inflated to its full diameter profile (Fig. 28.37).

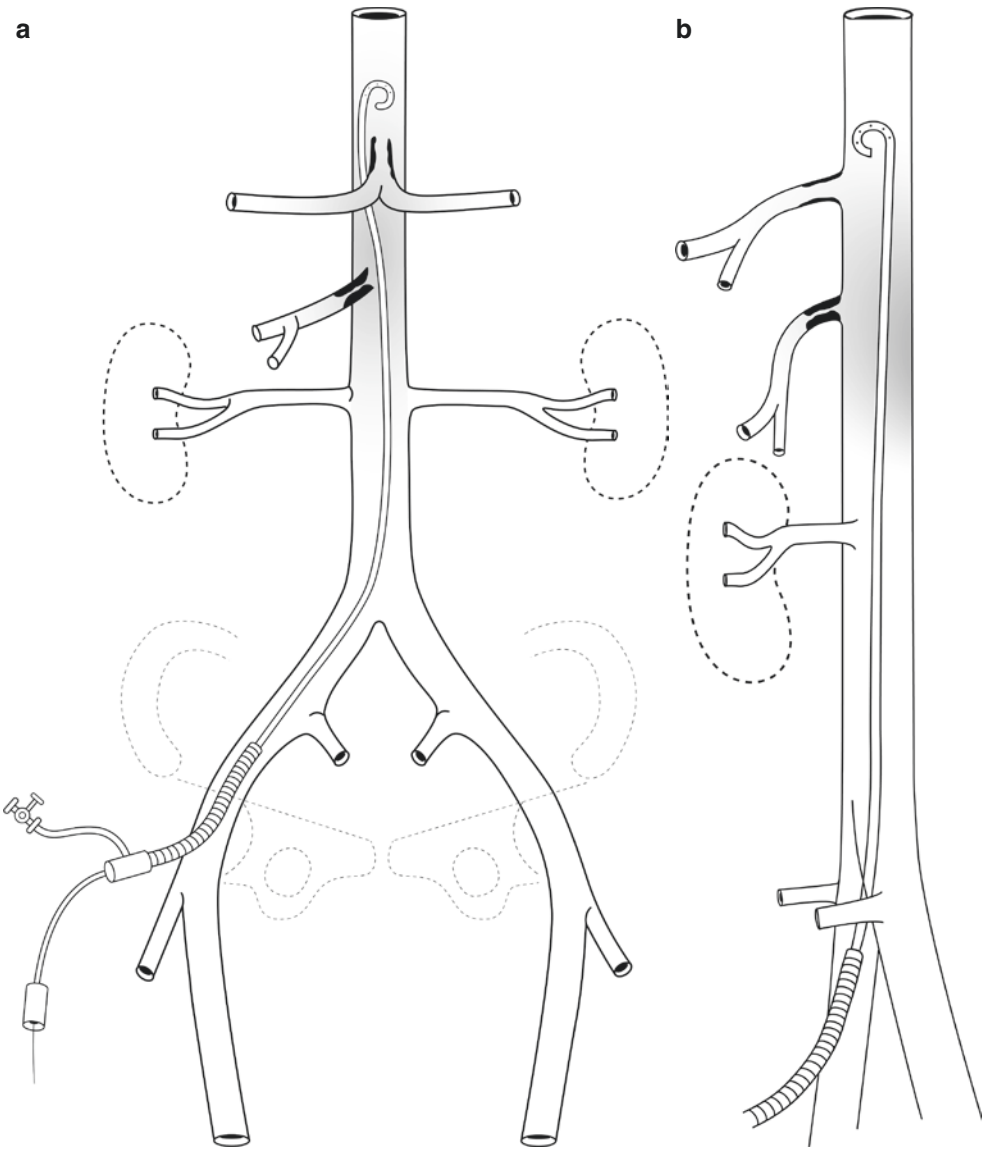
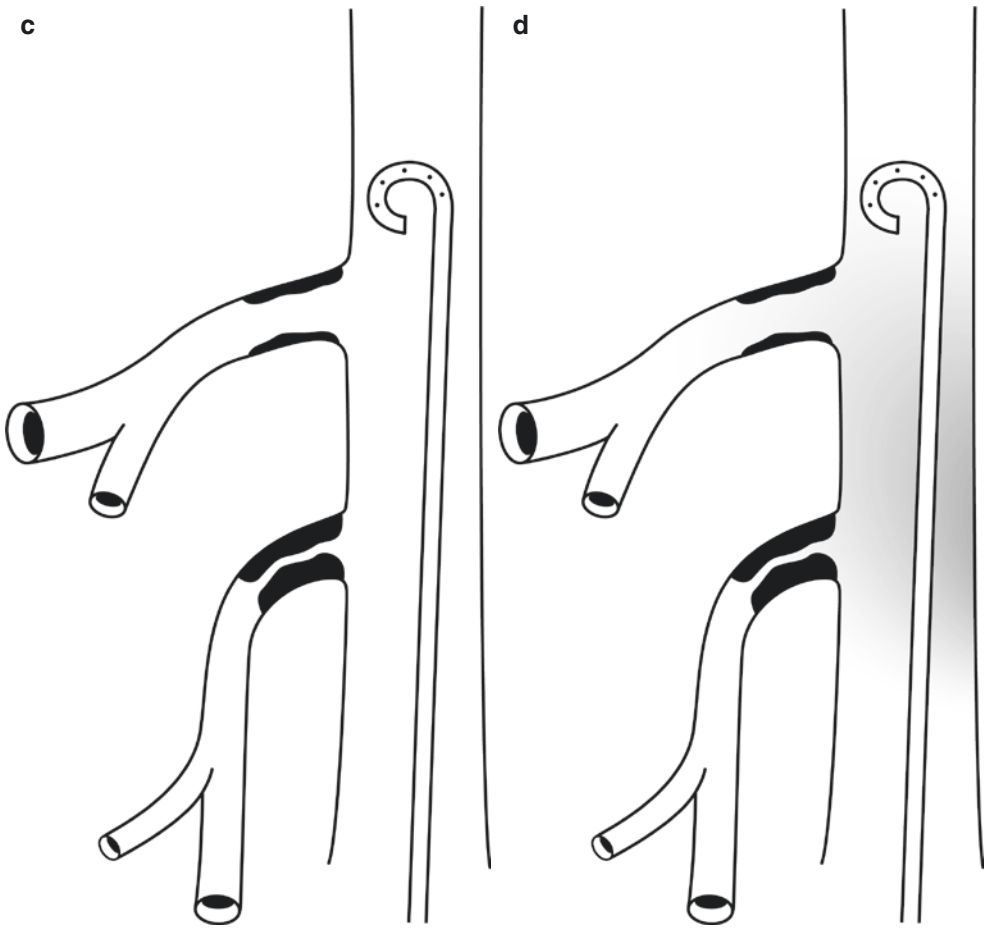


Fig. 28.28 Diagnostic angiography. (**a**) A nonselective abdominal aorta–celiac–superior mesenteric artery (SMA) angiogram is performed in AP view, showing distal branches of the CA and SMA. (**b**) Nonselective lateral angiographic view of the CA and SMA. (**c**) Magnified view of the origin of the CA and SMA in 90° lateral position. (**d**) Nonselective abdominal aorta–celiac–SMA angiogram in lateral view, showing the origins of the CA and SMA in a magnified view

Fig. 28.28 (continued)



The balloon is then deflated and removed over the wire. A directed nonselective SMA angiogram is performed through the sheath (Fig. 28.38).

Primary stenting of ostial lesions of the SMA is recommended because the rate of residual and recurrent stenosis following balloon angioplasty alone is high, upwards of 40–50%. A balloon-expandable stent is preferred owing to its precise deployment and excellent radial force. It is preferable to select the shortest possible stent that completely covers the stenosis and allows for 2 to 3 mm of the stent to extend into the aorta.

A bare metal balloon-expandable stent catheter is selected and tracked over the wire through the guide sheath. The stent is positioned entirely across the stenosis and the ostium of the SMA. The proximal end of the stent should protrude 2 to 3 mm into the aorta to ensure that the stent covers and excludes the "aorta spill-over plaque" associated with ostial disease. The balloon-expandable stent is dilated and deployed to full apposition against the wall of the SMA. The proximal end of the stent should protrude 2 to 3 mm into the aorta (Fig. 28.39a, b).

The balloon catheter is then withdrawn partially back into the aorta and re-inflated to "flare" the aortic end of the stent to ensure the exclusion of the ostial plaque and optimize the SMA stent patency (Fig. 28.40).

Following stent deployment, the balloon-stent catheter is removed over the wire. A magnified, directed nonselective completion SMA angiogram is performed through the sheath to confirm stent patency (Fig. 28.41). Note the flared end of the proximal end of the stent.

It is preferable to obtain a non-magnified aorta-mesenteric artery angiogram in both lateral and AP projections to confirm stent and to assess the distal mesenterial arterial patency (Fig. 28.42).

If the completion angiogram determines that the stent is widely patent and the stenosis has been successfully treated, the long guide sheath is exchanged for a short access sheath (Fig. 28.43a, b).

An activated clotting time (ACT) is checked. If the ACT is less than 200 seconds, typically a closure device (MYNX [Cardinal Health-Cordis], Perclose ProGlide [Abbott Vascular], or Angio-Seal [Terumo]) is then deployed

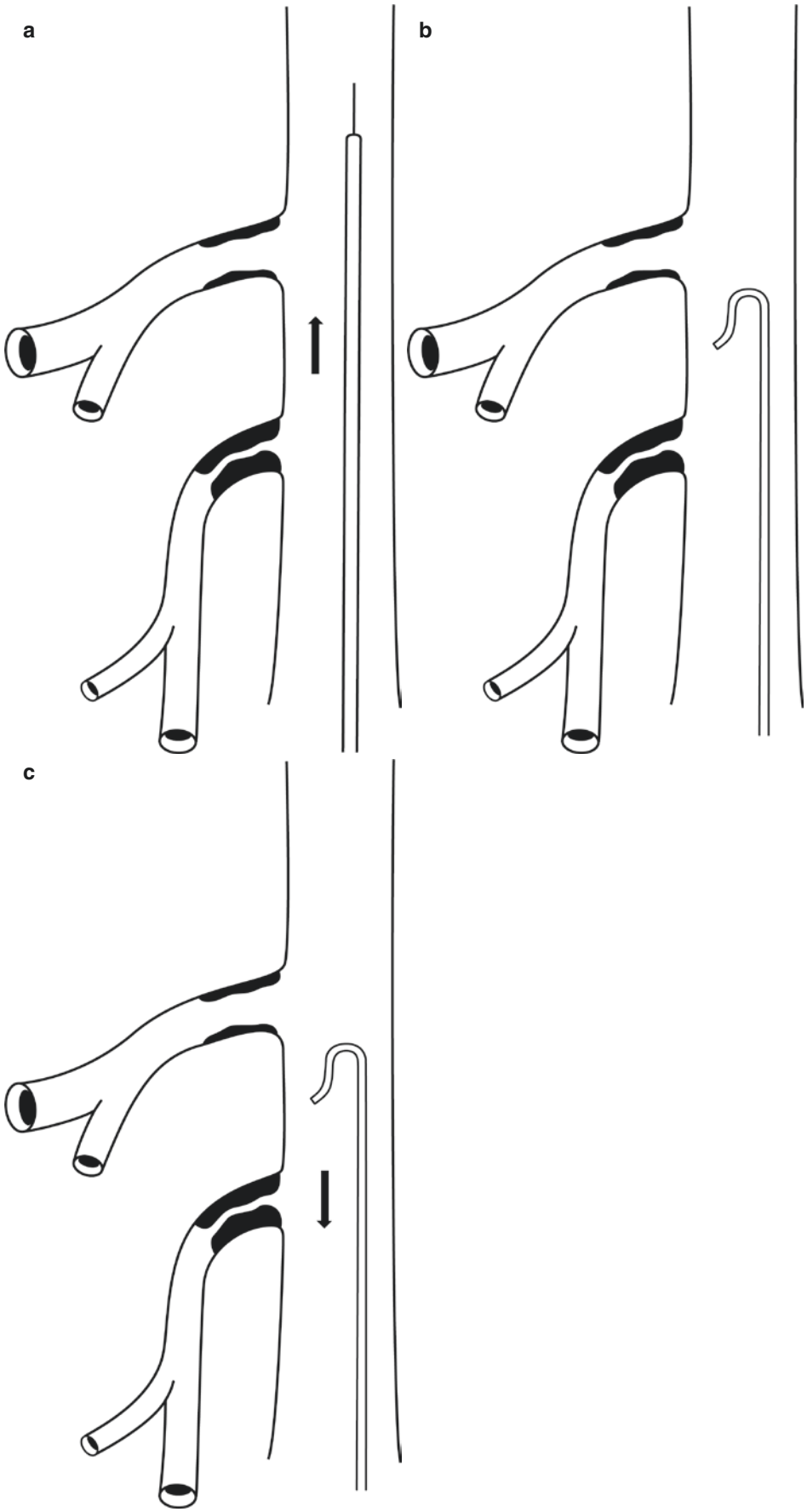


Fig. 28.29 Selective diagnostic SMA angiogram. (**a**) The multi-hole flush catheter is exchanged over a wire for a selective angled or shaped diagnostic catheter. The selective catheter is positioned proximal to the intended targeted artery (in this case, the SMA). (**b**) The guidewire is then removed, allowing the selective angled or shaped diagnostic catheter to assume its intended shape. (**c**) The tip of the catheter is carefully moved distally (*arrow*) toward the ostium of the targeted artery

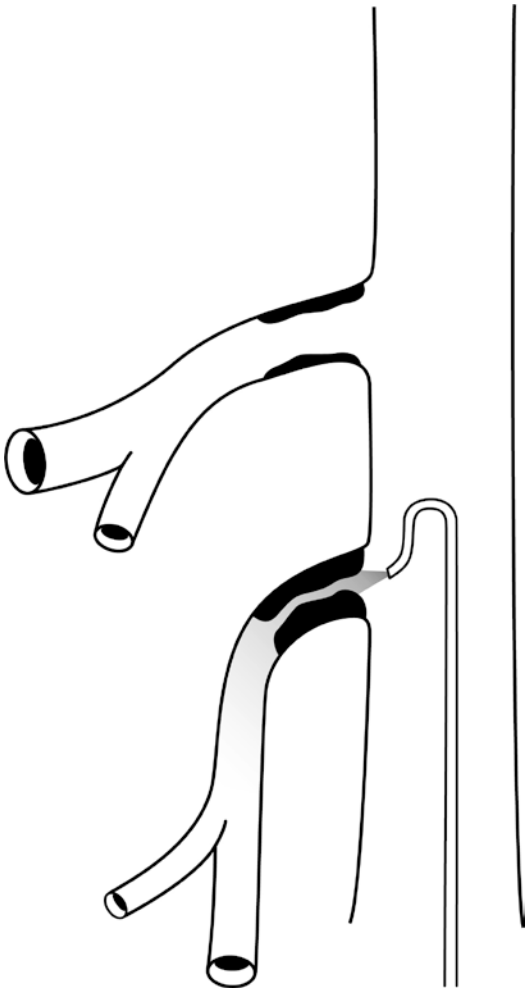


Fig. 28.30 A directed selective SMA angiogram is performed. In this example, the ostium of the SMA is severely stenotic, so the tip of the diagnostic catheter does not physically engage the ostium

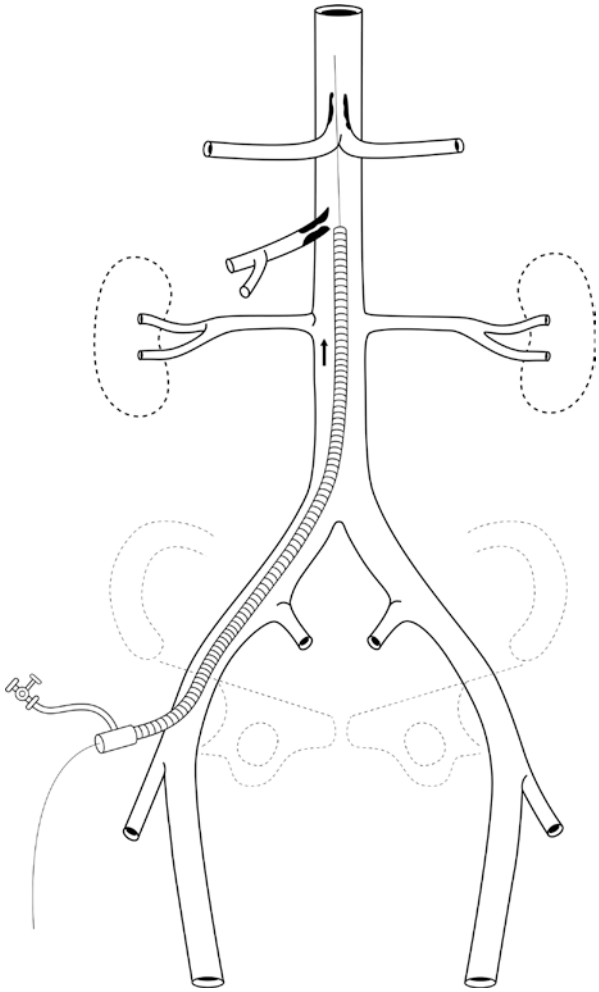


Fig. 28.31 Endovascular intervention for ostial SMA stenosis. The 5 Fr access sheath is exchanged for a longer guide sheath

for hemostasis. If no closure device is used, the sheath is removed and pressure is applied over the CFA puncture site for 20 to 30 minutes to achieve hemostasis.

Embolic protection such as a Spider Fx™ (Medtronic) filter should be considered in patients with occlusions, long-segment disease (>30 mm), severe calcification, or the presence of thrombus (Fig. 28.44a, b).

Celiac Artery Occlusive Disease

Although the technique for diagnostic and endovascular interventions of the CA is essentially like that for the SMA, some important distinctions must be identified. The guidewire takes a straighter path in the SMA than in the CA, in which the guidewire will follow a curving path that could prove to be technically challenging, depending on the path it enters. The key is to choose the appropriate CA branch so that adequate wire purchase can be made, to provide stability for the intended intervention. In some cases, the CA lesion can be very close to the branches, so it may be necessary to position more than one guidewire into the branches. The CA also is shorter than the SMA, so it is imperative that its true diameter and length are accurately determined in order to select a balloon and/or stent of the correct length and diameter.

Alternative Access Approaches

The left transbrachial approach is a commonly used alternative access site when the CFA is not available for access. The brachial artery approach is best utilized for down-slop-

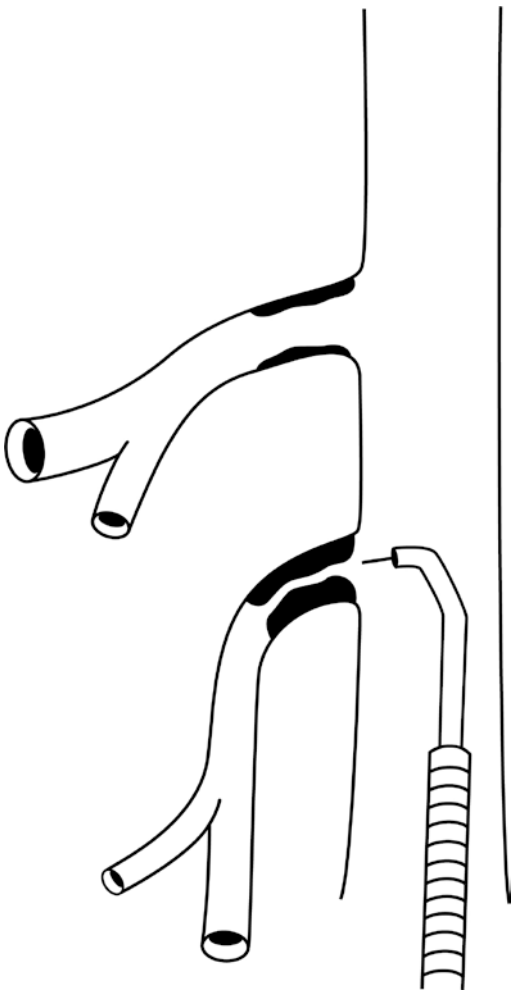


Fig. 28.32 A diagnostic catheter is tracked over the wire within the sheath and its tip is placed in the aorta and directed towards the orifice of the SMA. The tip of the angled or shaped diagnostic catheter is positioned just at the ostium but does not physically engage the ostium

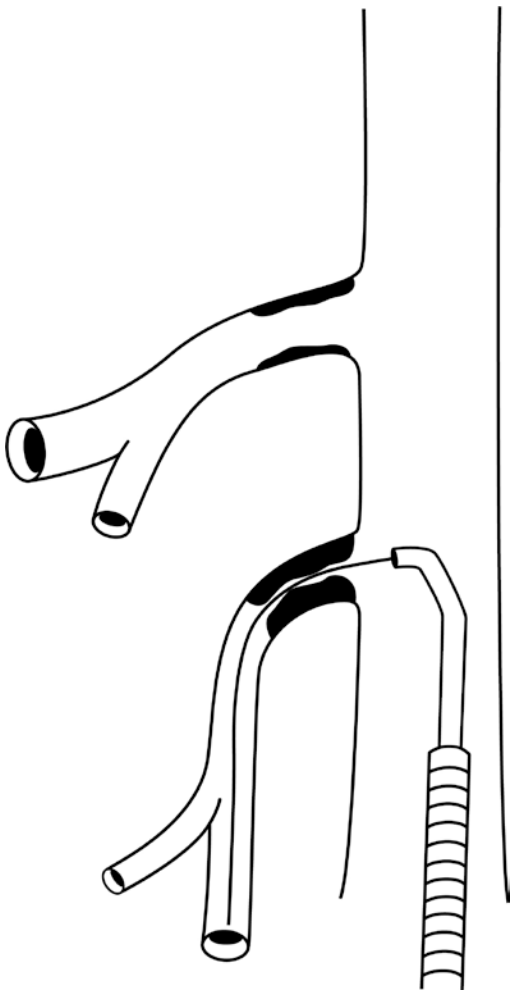


Fig. 28.33 The SMA stenosis is cannulated using a "no touch" technique. The diagnostic catheter directs the angled guidewire towards the ostium of the SMA, across the stenosis, and into the mid-distal segment of the artery

ing renal-mesenteric-celiac arteries or when CFA access is not an option because of occlusive atherosclerotic disease in the femoral and iliac arteries. The left brachial artery can be accessed in the same fashion as the CFA. Typically, smaller access sheath sizes (4 Fr, 5 Fr) are used. The challenge with left brachial artery access is being able to navigate the wire and catheter across the aortic arch and descending aorta down to the paravisceral aorta and the intended target vessels. It may be necessary to use multiple angled and shaped diagnostic catheters in order to reach the paravisceral aorta. Once wire access is achieved, both nonselective and selective diagnostic angiograms are performed. If the decision is made to proceed with endovascular intervention, then a stiffer wire is placed and the access sheath is exchanged and upsized to a long guide sheath (6 Fr). Once the long guide sheath is in the appropriate position, the endovascular procedure can be initiated. The treatment steps from this point forward are essentially the same as described previously for the transfemoral approach. The one caveat that interventionalists should remember is that all wires and catheters must be longer than those used in procedures from a CFA access.

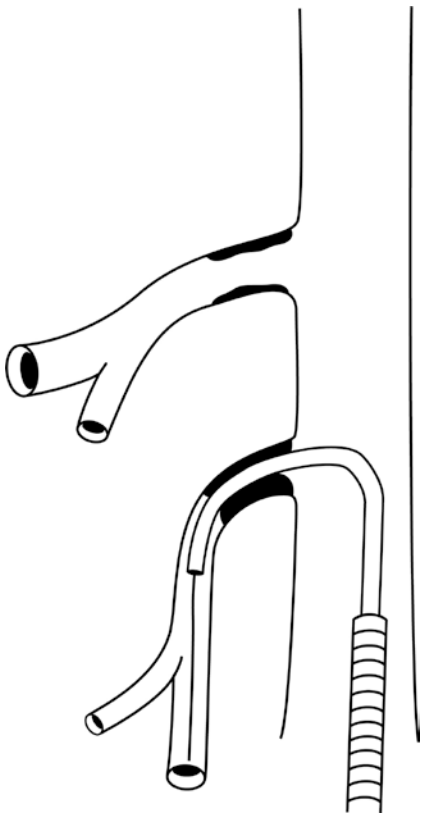


Fig. 28.34 A straight or angled guide catheter is tracked over the wire and through the stenosis into the non-diseased part of the SMA, to exchange out the 0.014″–0.035″ guidewire for a stiffer 0.014″–0.035″ wire

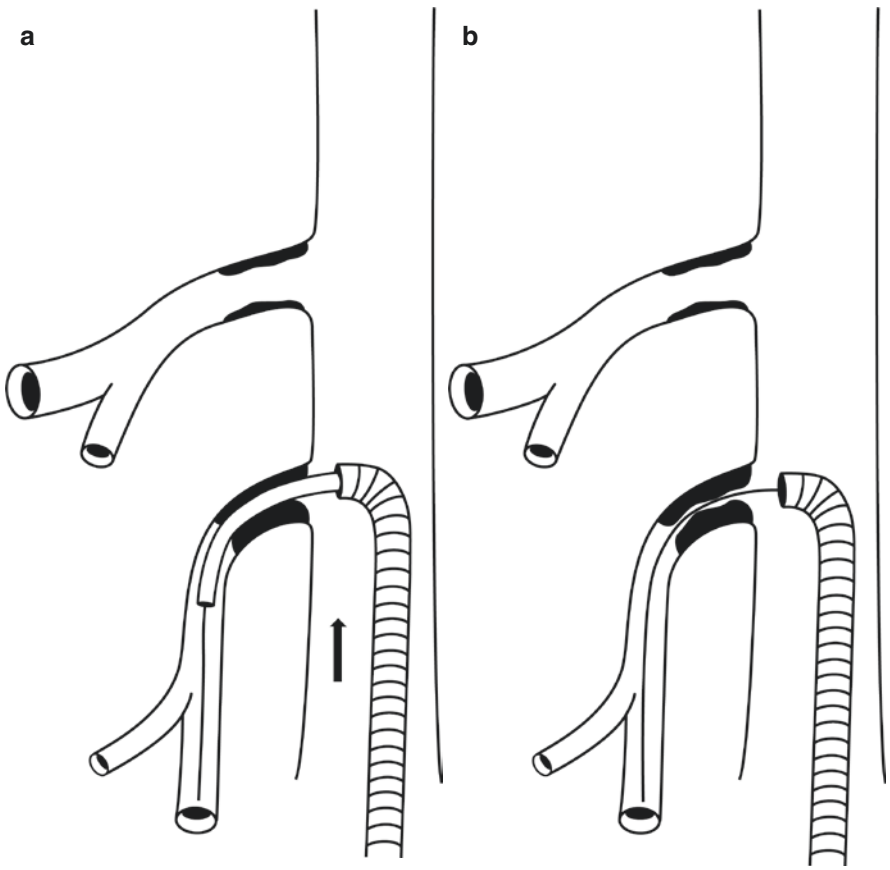


Fig. 28.35 (**a**) The guide sheath is advanced over the guide catheter and stiffer wire proximally within the aorta so that the tip of the guide sheath is located at the level of the SMA ostium but not through the ostial stenosis. (**b**) The guide catheter is removed, maintaining the wire access across the stenosis.

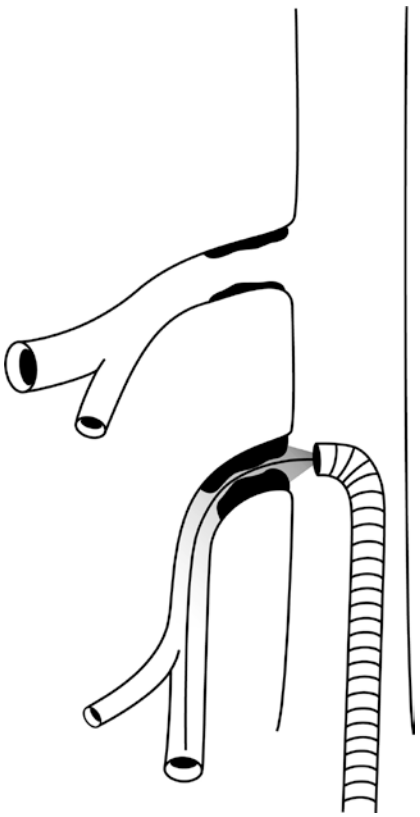


Fig. 28.36 A directed but nonselective SMA angiogram is performed through the guide sheath, determining the degree of stenosis severity, the stenosis length, and the diameter and length of the SMA

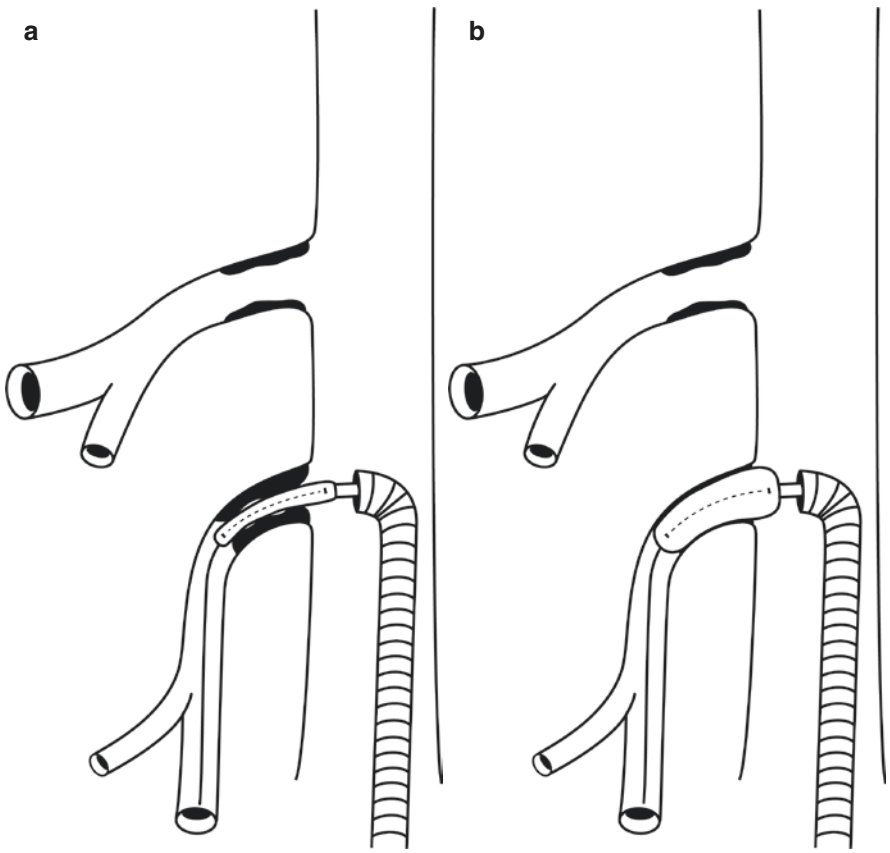


Fig. 28.37 Balloon predilation of ostial SMA stenosis. (**a**) The balloon angioplasty catheter is selected, inserted into the sheath, tracked over the wire, and positioned across the entire lesion. (**b**) The balloon is then inflated to its full diameter profile

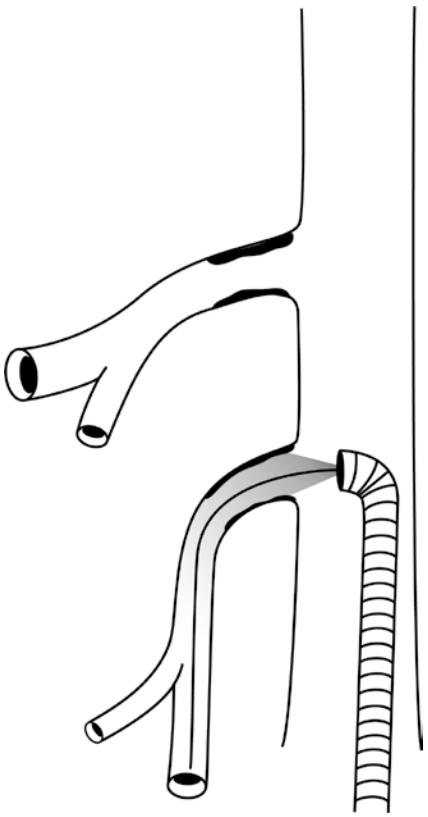


Fig. 28.38 A directed nonselective completion angiogram of the SMA is performed following the balloon angioplasty

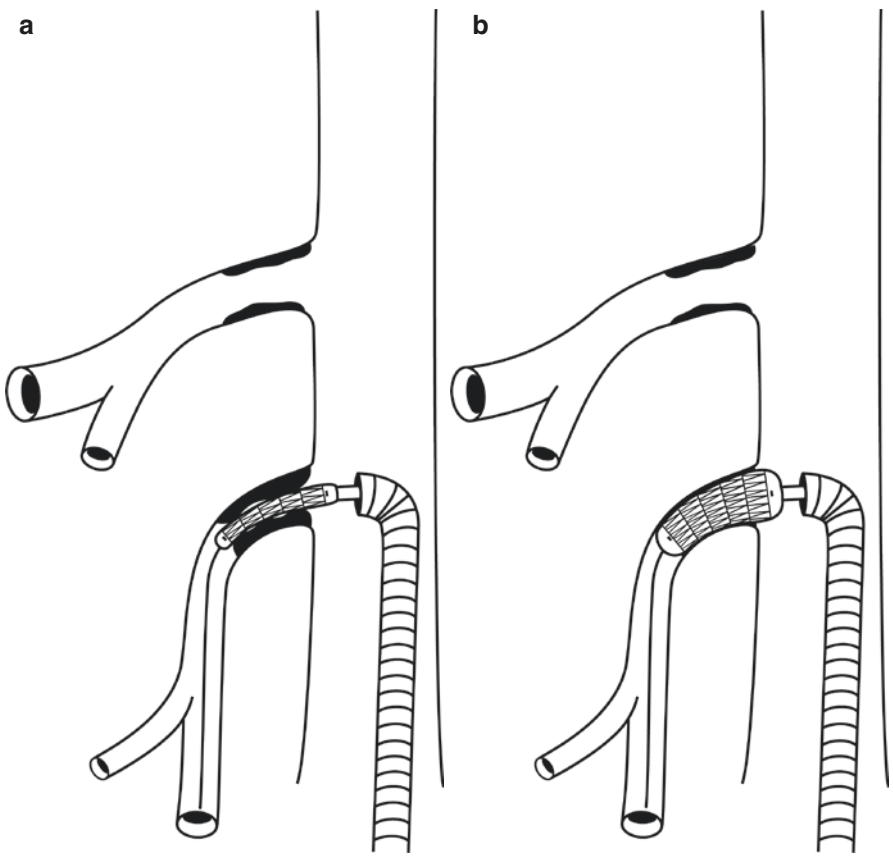


Fig. 28.39 (**a**) A bare metal balloon-expandable stent catheter is positioned entirely across the stenosis and ostium of the SMA. The proximal end of the stent should protrude 2–3 mm into the aorta. (**b**) The stent is dilated and deployed to full apposition against the SMA wall.

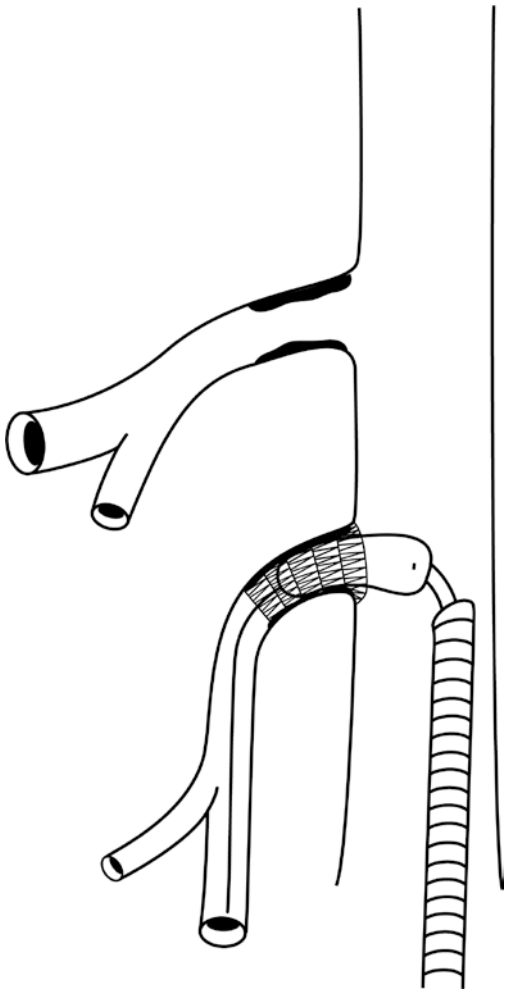


Fig. 28.40 The balloon catheter is then withdrawn partially back into the aorta and re-inflated to "flare" the aortic end of the stent

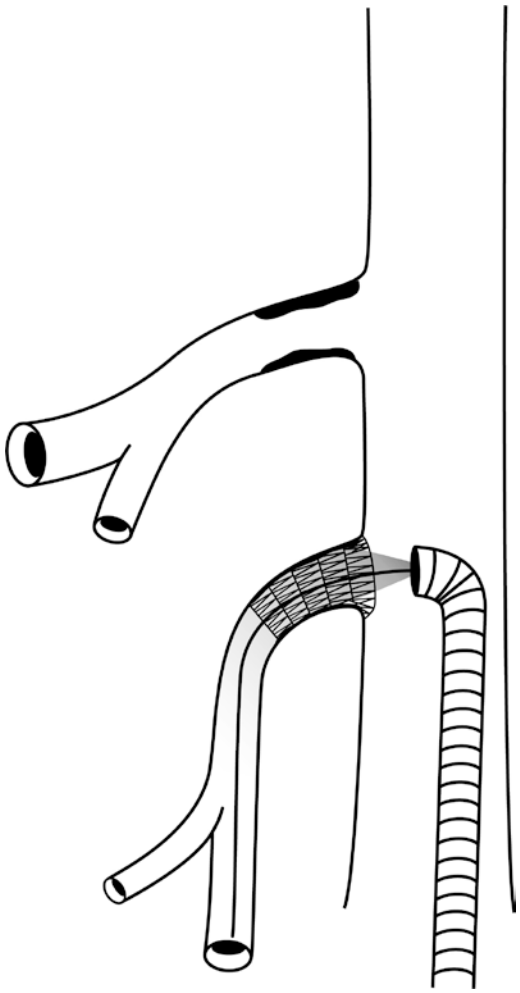


Fig. 28.41 Following stent deployment, the balloon-stent catheter is removed over the wire. A magnified, directed nonselective completion SMA angiogram is performed through the sheath to confirm the patency of the stent and the arterial lumen. Note the flared proximal aortic end of the stent

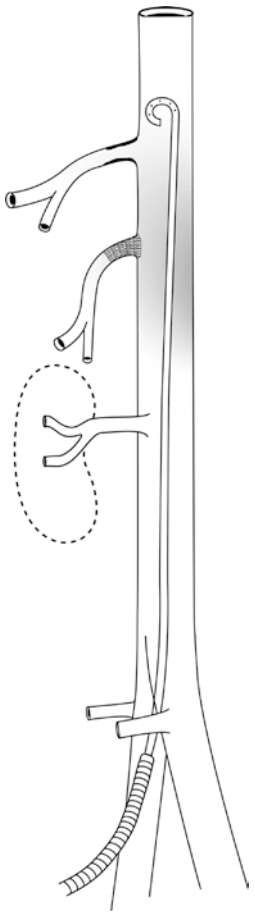


Fig. 28.42 A non-magnified lateral aorta-mesenteric artery angiogram will confirm patency of the stent and of the distal SMA lumen

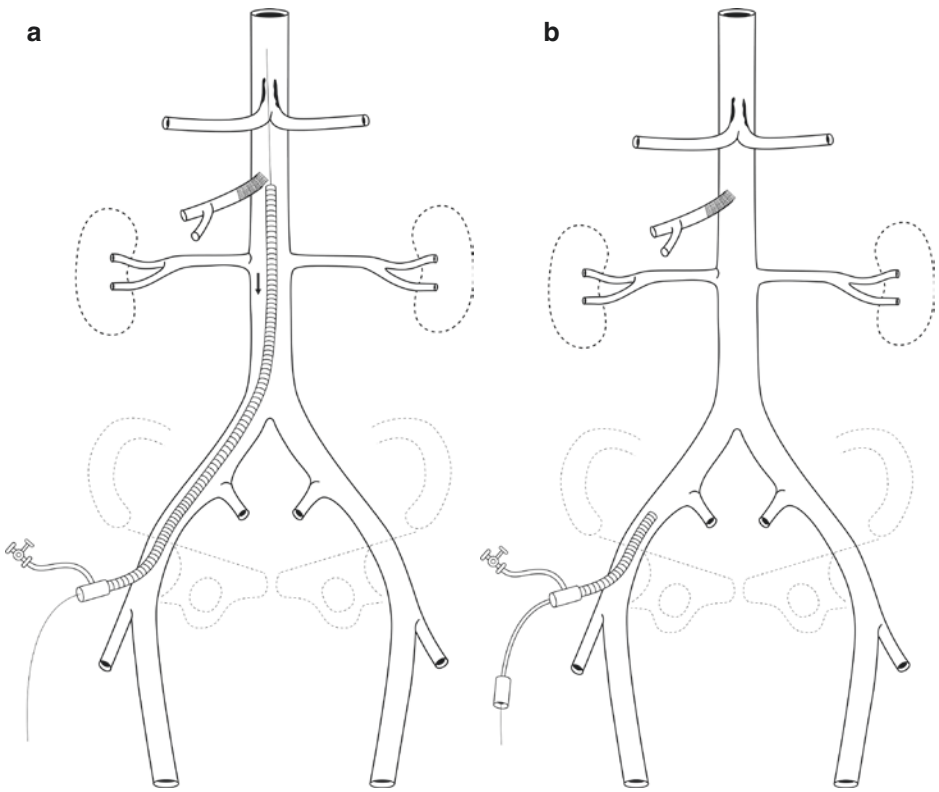


Fig. 28.43 Procedure after stent deployment. (**a**) The guide sheath is removed over the wire (*arrow*). (**b**) The long guide sheath is exchanged for a short access sheath

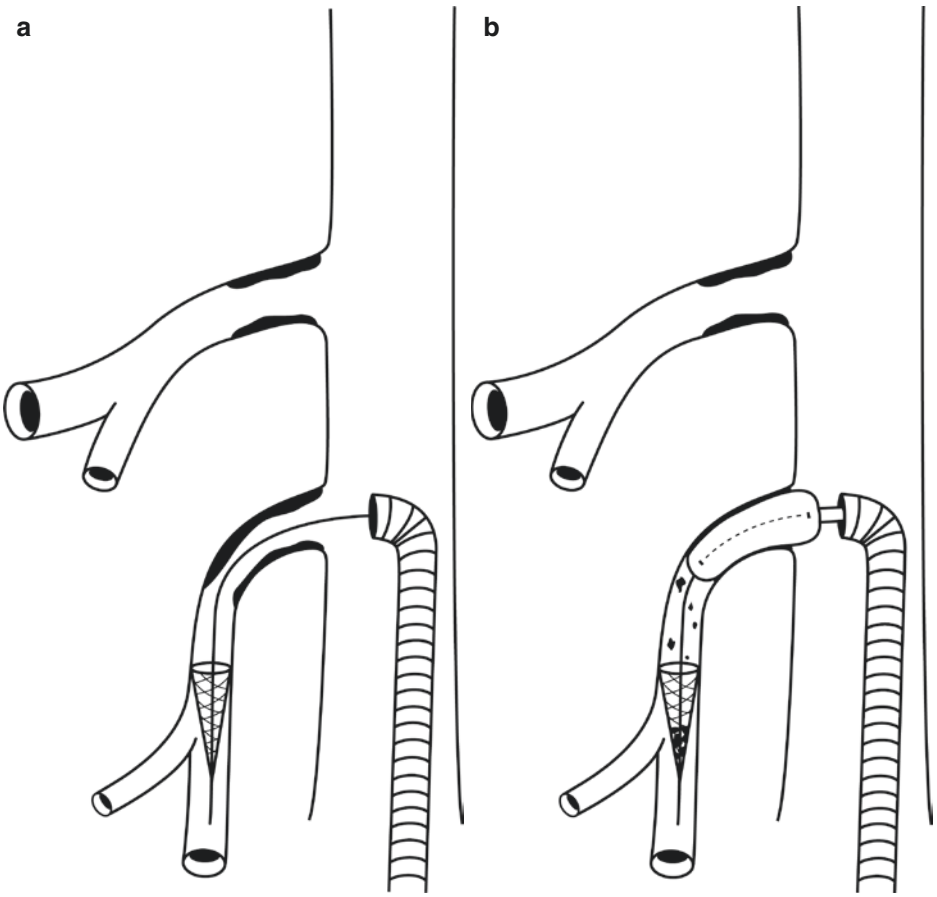


Fig. 28.44 Embolic protection. (**a**) An embolic protection device such as a Spider Fx™ filter is shown in the SMA distal to the ostial stenosis prior to balloon angioplasty, (**b**) Embolic particles are captured by the filter during balloon angioplasty

Conclusion

The goal of this chapter has been to provide the learner with straightforward instruction on how to perform basic diagnostic and interventional endovascular procedures in the renal and visceral arteries. We did not review several atherosclerotic and aneurysmal diseases of these arteries. We did not include the specific endovascular treatment for atherosclerotic disease of the celiac artery, and we did not cover bare-metal and covered stenting and embolization techniques for treatment of aneurysmal disease of the renal, hepatic, or splenic arteries. In addition, there are a myriad of advanced hybrid open-endovascular procedures that all board-certified vascular surgeons should be able to perform with independence and proficiency. The description of these complex procedures is beyond the scope of this chapter and has been left to other vascular surgery textbooks.

Suggested Reading

Bornak A, Milner R. Endovascular treatment of occlusive superior mesenteric artery disease. In: Chaikof EL, Cambria RP, editors. Atlas of vascular surgery and endovascular therapy: Anatomy and technique. Philadelphia: Elsevier Saunders; 2014. p. 491–9.

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Zayed MA, Dalman RL. Stenting, endografting and embolization techniques: celiac, mesenteric, splenic, hepatic, and renal artery disease management. In: Dalman RL, Mulholland MW, editors. Operative techniques in vascular surgery. Philadelphia: Wolters Kluwer Health; 2015. p. 156–68.

Endovascular Treatment of Carotid and Subclavian Artery Stenosis

29

James M. Chang and Yazan Duwayri

Indications for Carotid Stenting

Patients with cerebrovascular disease are at risk for thromboembolic complications from carotid stenosis. Classically, symptomatic or high-grade carotid stenosis has been treated with carotid endarterectomy (CEA). Carotid artery stenting (CAS) also offers stroke risk reduction in patients with symptomatic and asymptomatic carotid disease. It is particularly useful in patients considered high-risk for CEA because of severe cardiopulmonary disease or anatomic reasons such as high lesion location, prior neck surgery, or a history of CEA or irradiation [1].

Approach Considerations for Carotid Stenting

Preoperative Imaging

Cross-sectional imaging is useful to plan the endovascular approach. We prefer CT angiography (CTA) to assess the aortic arch characteristics and the location, dimensions, and characteristics of the carotid lesion.

The aortic arch is classified into three types, which are predictive of the difficulty of technical access of transfemoral stenting (Fig. 29.1):

- Type I: The great vessel origins are level with the upper convexity.
- Type II: The great vessel origins are between the upper and lower convexity.
- Type III: The great vessel origins are caudal to the lower convexity.

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Type I and II arches are appropriate for transfemoral stenting. Type III arches present challenges in transfemoral carotid access, so alternatives to this approach should be considered. Similarly, significant aortic arch calcifications, particularly around the ostia of the carotid artery, can result in increased periprocedural stroke risk.

When evaluating the carotid lesion itself, it is essential to look for unstable-appearing plaque, embolus, or a high thrombus burden; these are considered contraindications to CAS. Severe carotid lesion calcifications carry a risk of dissection during CAS.

If transfemoral CAS is planned, distal internal carotid artery kinks and loops should be noted, because they preclude the delivery of distal embolic protection devices.

If transcervical CAS is considered, the common carotid artery (CCA) should be evaluated to ensure the absence of anterior calcification at the point of sheath entry and the presence of an adequate length (5 cm) between the clavicle and the carotid lesion to allow for sheath stability. Carotid artery duplex can provide this information if CTA cannot be obtained.

Preoperative Medical Treatment

Patients considered for CAS should be started on statin and dual antiplatelet therapy for at least 5 days preoperatively to reduce the risk of perioperative cerebrovascular accident.

Transfemoral Versus Transcervical Approach

The previously mentioned cross-sectional imaging assists in defining the anatomy to determine whether transfemoral CAS with distal embolic protection or transcervical CAS with flow reversal (transcervical carotid artery revascularization or TCAR) is more favorable. The poten-

J. J. Hoballah, C. F. Bechara (eds.), *Vascular Reconstructions*, https://doi.org/10.1007/978-1-0716-1089-3_29

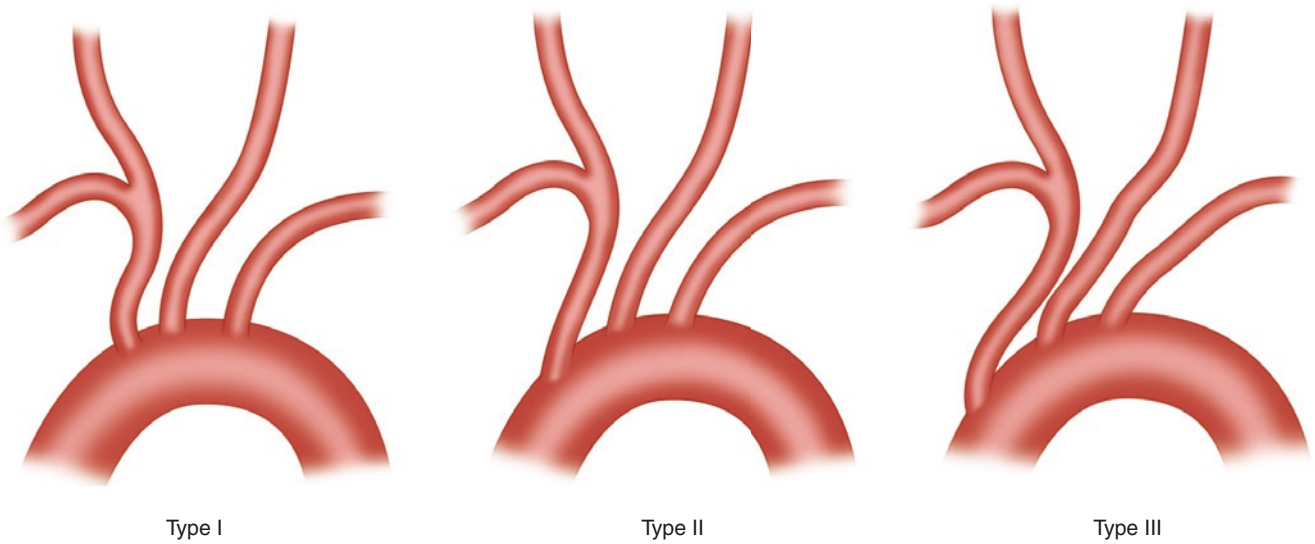

Fig. 29.1 Aortic arch types

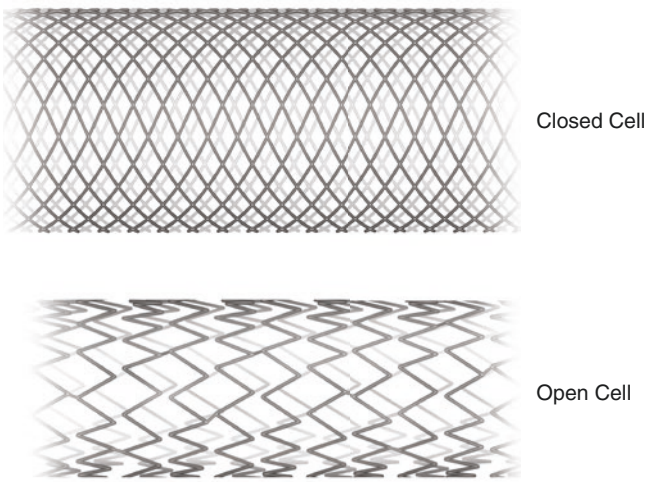

Fig. 29.2 Stent types: Closed-cell versus open-cell design

tial benefits of TCAR are the avoidance of aortic arch and carotid lesion manipulation prior to the initiation of neuroprotection. TCAR is suitable if the patient can undergo a CCA cutdown and sheath delivery proximal to the lesion. The presence of contralateral occlusion is not a contraindication to either technique. It is preferable to avoid transfemoral CAS in patients with type III aortic arch, a diseased arch, or loops or kinks in the internal carotid artery (ICA) distal to the lesion.

Stent Choice and Distal Embolic Protection

Carotid stents currently are produced in several main categories, including closed-cell, open-cell, hybrid, or membrane-covered stents (Fig. 29.2), as well as tapered and straight configurations. Closed-cell designs typically confer greater plaque stabilization characteristics, with potentially fewer or smaller embolic events. Mesh or covered stents are in development and may represent an improved design that may limit embolic events during and after the index stenting procedure. Comparisons between different stent designs have not demonstrated a clinical advantage of one over the others.

Similarly, no randomized clinical trials have compared the different embolic protection devices (EPDs). Embolic protection devices (Fig. 29.3) have improved rates of stroke and death after carotid artery stenting [2]. There are two main design types, either proximal balloon occluders or distal filters. Distal filters have gained popularity due to ease of use, the ability to maintain cerebral blood flow during the procedure, and their compatibility with other 0.014″ CAS equipment. They do have several disadvantages, including lesion crossing prior to the embolic protection and occasional difficulty in filter retrieval, particularly if it fills with procedural debris. Transfemoral proximal balloon EPDs avoid these issues, but they have not achieved widespread use because they are bulky and relatively more difficult to use, particularly because they require navigation through the aortic arch and balloon placement in the external carotid artery. Transcervical flow reversal avoids arch manipulation altogether, but requires a limited carotid exposure. Early results have revealed fewer periprocedural neurologic events with this technique than had been historically reported with other EPD devices.

Transfemoral Carotid Cannulation and Stenting

Toolkit

In CAS, minimizing procedural time is essential to decrease cerebral ischemia time or embolization due to prolonged sheath or filter presence in the carotid artery. Therefore, the

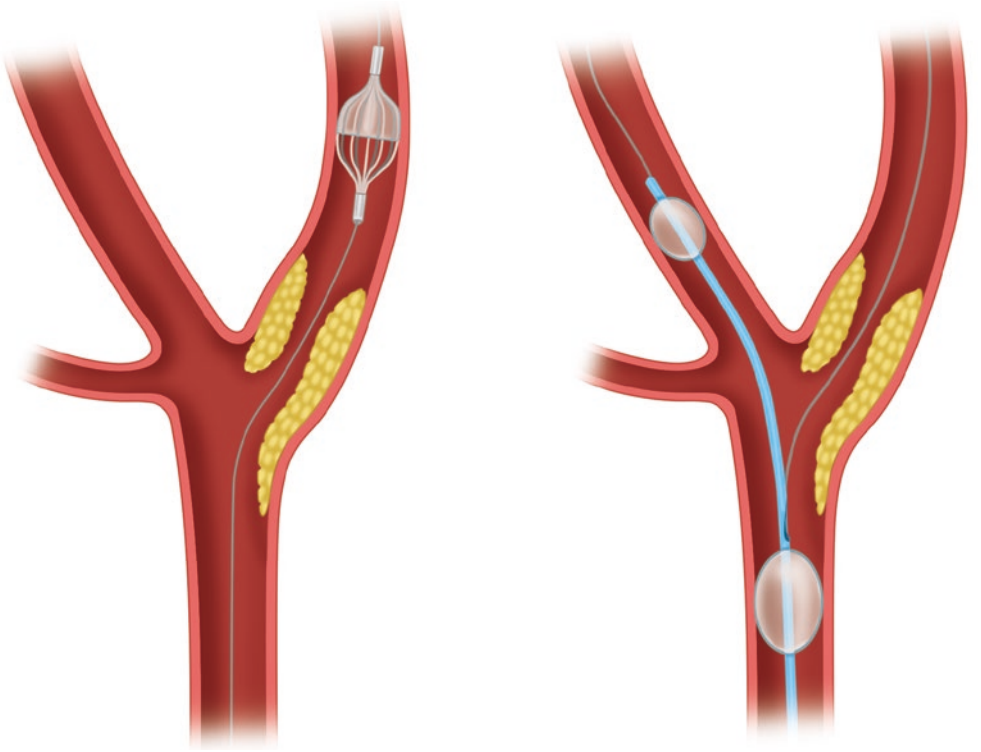

Fig. 29.3 Embolic protection devices

operator should confirm the availability of the necessary equipment prior to embarking on the procedure. The following should be available:

- Short 5–6 French sheath.
- A pigtail catheter.
- A range of selection catheters (Fig. 29.4).
- A hydrophilic coated wire such as a Glidewire (Terumo; Somerset, NJ) for vessel cannulation.
- A stiff wire such as a "carotid" Amplatz Super Stiff Guidewire with a short flexible tip (Boston Scientific; Marlborough, MA) to support proximal carotid sheath delivery.
- A long 6 French sheath, such as a 90 cm Flexor Shuttle or Raabe (Cook Medical; Bloomington, IN).
- 3 mm–5 mm predilation and postdilation 0.014 rapid exchange balloons.

To avoid waste, the stents, balloons, and EPDs may be kept in reserve until the vessel is cannulated. Wire selection

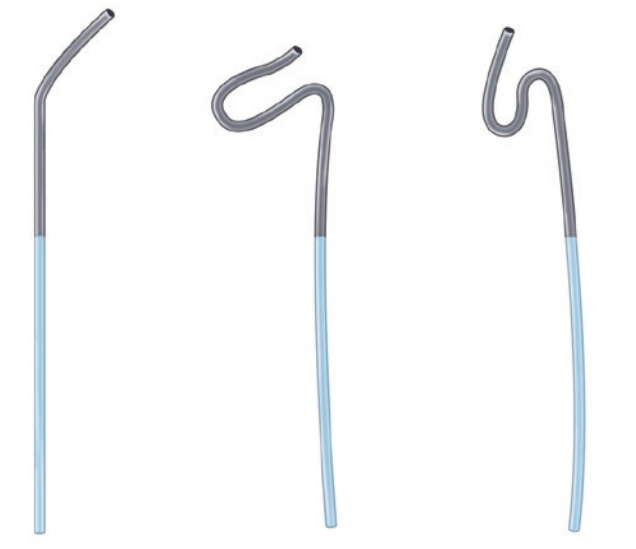

Fig. 29.4 Selection catheter types: Vertebral, VTK, Headhunter 4

for lesion crossing and stent deployment is dependent on the EPD used; some are already preloaded on a wire. All carotid stents are delivered over a 0.014 wire system.

Procedure

The procedure is preferably performed under local anesthesia to allow neurologic monitoring and minimize cardiac stress. A femoral 5–6 Fr short sheath is placed, and systemic heparin is administered prior to arch or carotid manipulation. An arch aortogram is then performed using a pigtail catheter to mark the origins of the great vessels. Optimal fluoroscopic angles may be determined preoperatively from the cross-sectional imaging, but a steep left anterior oblique (LAO) angle is usually needed. Once the CCA origin is mapped, it is selected using a combination of the selection catheter and hydrophilic coated wire (Fig. 29.5).

Particularly in a Type II or Type III aortic arch, a reverse curve catheter may be useful (Fig. 29.6). Once the CCA is cannulated, a selective angiogram can be performed. The hydrophilic wire is then advanced into the external carotid artery and exchanged with a stiff wire to support the advancement of a long sheath.

Once the long 6 Fr sheath has been delivered into the CCA, extracranial and intracranial AP and lateral angiograms should be performed to assess the lesion length and location and perfusion of the anterior and middle cerebral arteries (ACA, MCA) and the posterior circulation (Fig. 29.7). These are careful hand-injection digital subtraction angiography runs to reduce the risk of air embolus or dissection from power injection. The patient should be instructed to hold his or her breath and not to move or swallow if possible. Final sizing and stent selection may be made at this point.

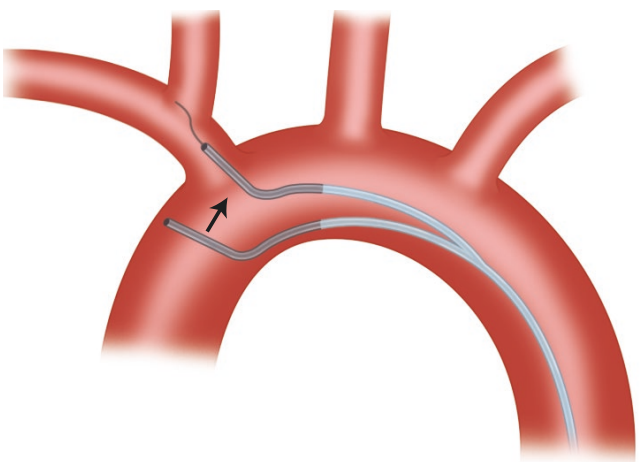

Fig. 29.5 Arch selection using vertebral catheter

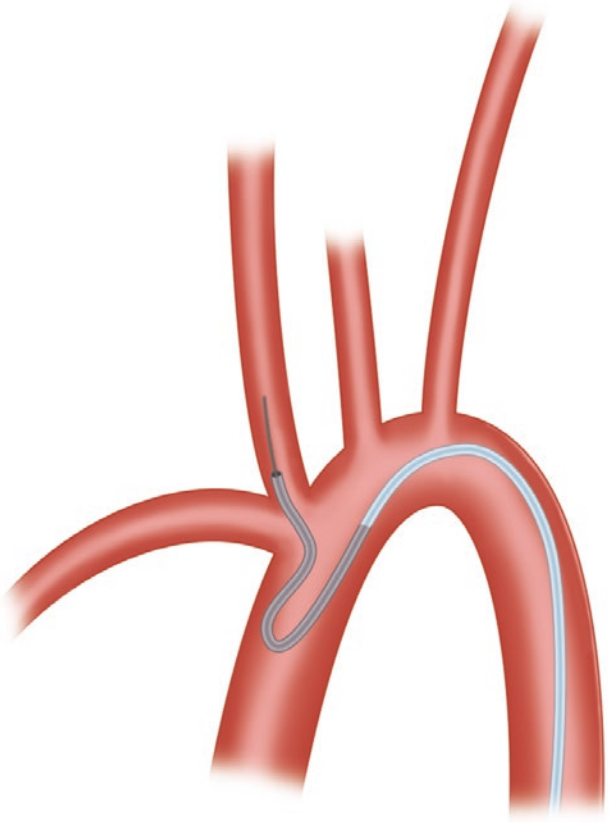

Fig. 29.6 Arch selection using reverse curve catheter

The ICA lesion should be crossed with the utmost care. The system for embolic protection and stent is on an 0.014″ platform. The wire must pass freely and effortlessly past the lesion and must not be allowed to "J," as there is no protection deployed at this point (Fig. 29.8). Creating a roadmap of the lesion can facilitate choosing the flow-channel to cross. Once the lesion is crossed, the EPD is deployed in a long, straight segment of the ICA, away from the lesion to avoid jailing by the stent. Predilation of the lesion may be required prior to stenting, but this may increase the intraprocedural embolic risk and should be used only in select cases. The stent should then be advanced and deployed, covering the entire lesion, frequently landing proximally into the normal segment of the CCA (Fig. 29.9). Balloon postdilation may be needed; if so, Anesthesia should be alerted, as severe bradycardia may result. It should be noted that the frequency of microembolism is highest during balloon inflation and deflation, so routine postdilation is not recommended unless significant stenosis (>50%) is present on post-stenting angiography. AP and lateral extracranial and cerebral angiograms should be performed to demonstrate flow within the filter and unchanged cerebral perfusion. The filter is then retrieved and can be examined for debris after the procedure. A repeat angiogram is also recommended after filter removal, to rule out dissection. The sheath is pulled back into the aor-

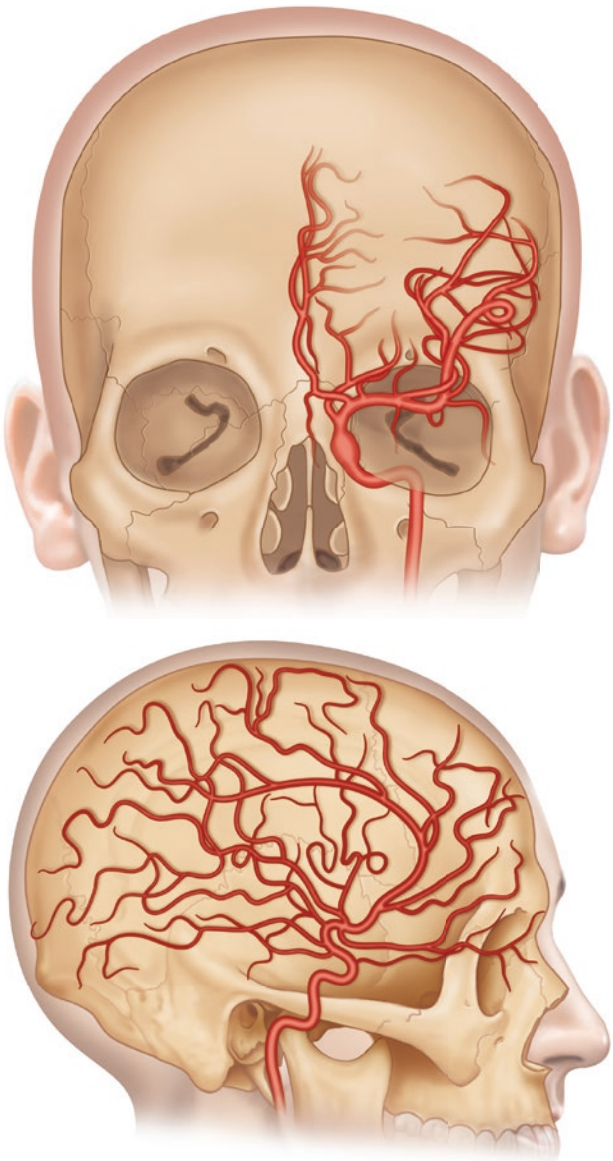

Fig. 29.7 Anteroposterior (AP) and lateral cerebral angiograms

tic arch over the wire. We do not typically reverse the heparinization. Use of a closure device is up to the operator's preference and experience.

Transcervical Carotid Artery Revascularization (TCAR)

Toolkit

Transcervical carotid artery revascularization (TCAR) has been facilitated by the commercial availability of the ENROUTE Transcarotid stent system (Silk Road Medical; Sunnyvale, CA) [3]. A 5 Fr micropuncture set is required. The set includes an arterial access sheath (8 Fr inner diameter, 10 Fr outer diameter), flow controller, and a venous sheath. The technique utilizes flow reversal driven by the difference between the mean arterial and venous pressures, so no distal EPD is required for this approach. The technique is compatible with all other carotid stents.

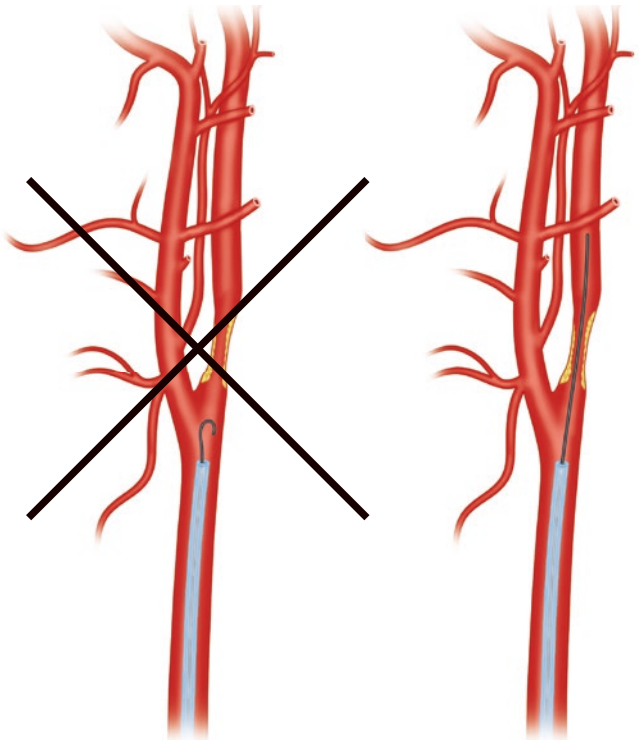

Fig. 29.8 Crossing the internal carotid lesion: The wire must not be allowed to "J"

Procedure

The procedure may be performed under local or general anesthesia. The patient should be placed in the same position as for carotid endarterectomy. The C-arm is brought in from the head and the surgeon typically stands on the ipsilateral side, with the assistant on the contralateral side. The anatomic landmarks for the exposure of the CCA are the triangle created by the sternal and clavicular heads of the sternocleidomastoid and the superior edge of the clavicle (Fig. 29.10). The dissection should remain proximal to the omohyoid down to the level of the carotid sheath. The carotid sheath is opened longitudinally, and the internal jugular vein is retracted medially. A 32–3-cm segment of the CCA is isolated, and an umbilical tape is placed as proximally as possible. A U-stitch of 5–0 polypropylene is placed in the anterior arterial adventitia to facilitate closure at the completion of the procedure.

Common femoral vein access is performed with ultrasound guidance. The venous return sheath is advanced over a 0.035″ wire. Blood is aspirated and then flushed from the

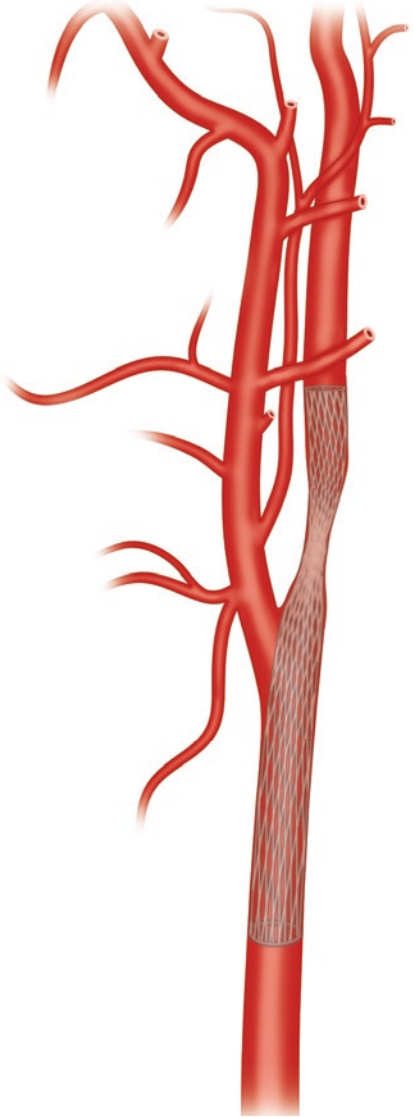

Fig. 29.9 Deployed stent

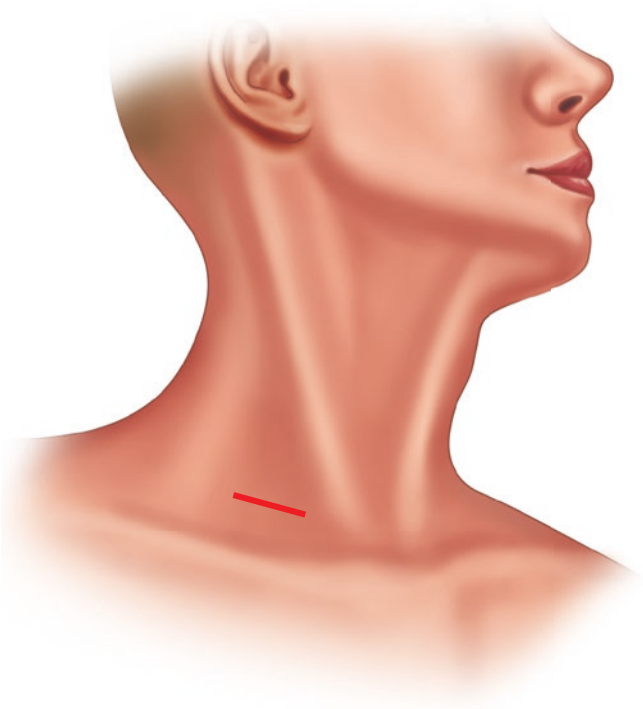

Fig. 29.10 Anatomic landmarks for transcervical carotid artery revascularization (TCAR)

flow line with heparinized saline; the line is secured to the skin with a suture.

Prior to arterial access, the patient should be heparinized to an activated clotting time of 250 to 300 seconds. A micropuncture needle is used to access the artery through the previously placed suture, taking care to avoid the back wall. The micropuncture sheath is advanced 1.5–2 cm into the CCA; pulsatile back bleeding should be present. The micropuncture sheath may be used for the initial angiograms to demonstrate the locations of the carotid bifurcation and the lesion. The stiff 0.035″ wire may be advanced up to the bifurcation, taking care not to engage the lesion at the carotid bulb. Alternatively, the micropuncture system wire and sheath may be advanced into the external carotid artery and exchanged with the stiff 0.035″ wire to gain further support.

The arterial sheath is then advanced 2–3 cm into the CCA, secured to the skin with gentle forward tension. Blood is aspirated and then flushed with heparinized saline. The arterial sheath is then connected, through the flow controller, to the venous sheath.

Before initiating reversal of flow, the CCA is clamped proximal to the arterial sheath. The flow controller has two reversal-of-flow settings and a flow-stop button to allow for contrast injection. Flow reversal may be confirmed in either of two ways: by clearing the venous return sheath with heparinized saline and then watching blood return in a reverse fashion from the flow controller, or by performing a small contrast injection near the lesion in question, with the flow-stop button held. Releasing the flow-stop button should confirm flow reversal in the artery.

Prior to initiation of flow reversal, all wires, catheters, and stents should be prepared, in order to limit the time on flow reversal. The blood pressure should be elevated to a systolic pressure exceeding 160 mm Hg. The lesion is crossed under flow reversal with a 0.014″ wire. Predilation, stent deployment, and postdilation (if needed) are then performed. Reversal of flow is stopped by releasing proximal control of the CCA and closing the outflow stopcock. Its advisable to keep the flow reversal for few minutes at the end of the case in patients with heavily diseased or calcified lesions, to allow clearing of the blood prior to establishing antegrade flow into the carotid. The arterial access sheath is then removed, and hemostasis is obtained by tying down the previously placed U stitch. The neck incision is then closed, and the venous sheath may be removed, with brief manual compression to

gain hemostasis. After the procedure, the 200-micron filter in the flow controller may be examined to look for embolic debris.

Neurologic Intolerance

A small subset of patients may not tolerate reversal of flow or CCA clamping, as evidenced by confusion, agitation, or depressed level of consciousness. In this case, the flow controller may be switched to "Low" and the procedure completed. The procedure may be halted and antegrade flow from the CCA may be restored to "precondition" the patient 5 minutes prior to reclamping and proceeding expeditiously. The patient's anesthetic plan also may be changed to a general anesthetic to lower cerebral metabolic demand, and once again the procedure may be completed expeditiously. If all these steps fail, a distal EPD may be deployed and the procedure completed under antegrade flow.

Kinking at the Clavicle

In patients with deep necks, the arterial access sheath may have a steep approach if placed directly into the wound, causing a kink in the system that inhibits working space, with reversal of flow. This may be remedied by tunneling the arterial sheath over the clavicle through a second incision below the clavicle to provide a gentler angle of approach.

Complications

Cerebrovascular Accident (CVA)

If signs of stroke occur intraoperatively, cerebral angiograms must be performed again to assess for embolic or hemorrhagic stroke. Cerebral embolic retrieval devices and neurointerventional expertise may be needed intraoperatively if embolic stroke is identified.

Hemodynamic Instability

Manipulation of the carotid bulb may cause instability due to bradycardia. This possibility should be anticipated, and atropine or glycopyrrolate should be made available for prophylaxis or treatment of these events.

Subclavian Access and Intervention

Subclavian lesions secondary to atherosclerosis or trauma (whether iatrogenic or incidental) may be rapidly approached via an endovascular route, via either the femoral artery or the ipsilateral brachial artery.

Femoral Versus Brachial Access

Most subclavian interventions can be performed with equal ease from a femoral or a brachial approach. A brachial approach may provide better sheath stability to deliver stents in the origin of the subclavian artery. Sheath size should be taken into consideration. Most interventions requiring a 6 Fr sheath can be performed safely from a percutaneous brachial approach. Open brachial cut-down should be considered for larger sheath sizes.

Toolkit

Prior to starting the procedure, confirm availability of a short sheath, longer sheath, and all anticipated stents and balloons. A hydrophilic coated wire is used to cross the lesion in question, with assistance from a directional catheter. Usually, simple-curve catheters such as a Berenstein or Multipurpose Angiocatheter (AngioDynamics; Latham, NY) are sufficient to access the subclavian vessels. Occasionally a complex-curve catheter such as a VTK (*see* Fig. 29.4) is required for transfemoral left subclavian artery (LSA) access. A long sheath may be needed, particularly if accessing from the groin.

Angioplasty/Stenting Options

The patient should be heparinized prior to arch or lesion manipulation, to reduce the chances of vertebral or carotid embolization.

When coming from the femoral approach, an arch angiogram with the fluoroscope positioned in at least 35–40 degrees of LAO is useful to determine the ostia of the left subclavian artery. From a brachial approach, backfilling of the subclavian from the vertebral artery may make the angiogram more difficult, so advancing a catheter to the occlusion and then performing a hand injection will help to delineate the anatomy. A hydrophilic coated wire may be used to cross the lesion with a crossing catheter. Once wire access across the lesion has been obtained, a bare metal or covered stent may be used, depending on the clinical situation. Orifical lesions are best addressed with balloon-expandable covered stents. Care should be taken to avoid covering the origin of the vertebral artery. If there is a concern for embolization, embolus coronary filter or small occlusive balloon can be placed in the vertebral artery.

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Endovascular Aortic Repair (EVAR and TEVAR)

30

Vy T. Ho and Jason T. Lee

Endovascular aortic repair (EVAR) and thoracic endovascular aortic repair (TEVAR) are minimally invasive modalities for the treatment of aneurysms, dissections, penetrating ulcers, and traumatic aortic injury. Aortic stent grafts can be used to exclude an aneurysm sac, encourage thrombosis of a false lumen, cover an entry tear or penetrating ulcer, or seal a transection.

Preoperative Considerations

Preoperative Testing and Procedures

EVAR and TEVAR patients should have baseline laboratory testing including serum creatinine and coagulation parameters. In the elective setting, cardiac evaluation can be undertaken. Depending on the functional status of the patient, testing may include chemical or exercise stress testing or coronary angiography, depending on risk stratification. Preoperative hydration should be considered in patients with elevated serum creatinine to avoid contrast-associated nephropathy. General anesthesia is typically employed, but sedation with local anesthesia can utilized if patients are unable to tolerate general anesthesia.

In the setting of descending thoracic aortic dissection, aggressive impulse control should be undertaken with intravenous antihypertensives. For patients with planned significant thoracic or thoracoabdominal stent coverage, placement of a prophylactic lumbar drain should be considered to help mitigate risks of spinal ischemia by reducing lumbar cerebrospinal fluid pressure and increasing spinal cord perfusion pressure. Complications of lumbar drain placement are rare but include neuraxial hematoma, subdural hematoma, catheter fracture, meningitis, intracranial hypotension, and spinal headache.

Stent Graft Sizing and Selection

Access

When available, preoperative cross-sectional imaging should be evaluated to determine the proper approach to navigating the aorta. Current sheath size ranges from 12 to 26 French, corresponding to an outer diameter of 4.7–9.5 mm, depending on the device. Vessel size and quality and tortuosity should dictate which side the main graft body is deployed over.

Evaluation of iliofemoral tortuosity, caliber, or intraluminal disease can determine eligibility for percutaneous versus open access, or the need for concurrent endarterectomy or open or endovascular conduit. Arteries with circumferential or anterior calcification are difficult to close percutaneously, and suture-mediated closure devices may have difficulty navigating a tortuous iliofemoral system.

A conduit is typically a Dacron graft that is sewn end-to-side onto either the common femoral artery or external iliac artery during open exposure, but another alternative is the endo-conduit, in which placement of an external iliac stent graft followed by serial dilation and balloon angioplasty is undertaken to treat pre-existing iliofemoral disease. Brachial access can be obtained as well, to assist in left subclavian embolization, renal artery intervention, or celiac embolization, if indicated.

Landing Zones

In general, landing zones should be at least 15–20 mm proximal and distal to the pathological aortic segment depending on the pathology as well as the quality of the landing zone. In TEVAR, anatomical boundaries include the left subclavian artery and the celiac artery, although adjunctive maneuvers

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such as embolization, bypass, or branched configurations can allow for extension beyond these vessels. In EVAR, the anatomical boundaries are the renal arteries superiorly and the hypogastric arteries inferiorly. Chimney, snorkel, branched, or fenestrated approaches can allow for extension into the suprarenal segment, and iliac branch devices allow for treatment beyond the origin of the hypogastric artery. 3D reconstruction preoperatively can assist in accurately measuring the image intensifier angles to maximize the seal zones visualized during stent graft deployment.

Landing zone length may need to be extended in the setting of non-parallel walls, tortuosity, circumferential thrombus, or extensive calcification, as these factors make it more challenging to obtain adequate seal.

Sizing

Anatomic measurements should be taken from the preoperative CT angiography (CTA) scan for appropriate stent graft sizing and selection. Three-dimensional reconstructive software is extremely useful for measurements (particularly in the setting of tortuosity) and for deciding how a device may land proximally and distally. Stent diameter is typically oversized by 10–20% at the proximal and distal landing zones in aneurysmal disease, whereas oversizing is usually not necessary in the setting of chronic dissection or traumatic injury of a previously healthy aorta.

Currently available stent grafts range in diameter from 22 to 46 mm. Given the traditional 10–20% rule of device oversizing, these devices are designed to safely treat aortas with landing zones ranging from 18 to 44 mm in diameter.

Operative Technique

Setting Up the Operating Room

The patient is positioned supine on the operating room table, with bilateral groins prepped. If the left arm is to be accessed, it can be abducted and prepped circumferentially.

Access

Percutaneous Access

In percutaneous access, the mid-common femoral artery is punctured under ultrasound guidance with a micropuncture needle, which is exchanged for a low-profile micropuncture sheath over a 0.018 wire.

Confirmation of puncture into healthy common femoral artery below the inguinal ligament and above the femoral bifurcation should be obtained with a sheathogram. A starter wire is then advanced into the abdominal aorta and the sheath is exchanged for a 7 Fr sheath.

At this point, pre-closure can be performed with a variety of techniques. We prefer the "pre-close" technique using two suture-mediated closure devices. If performed, the 7 Fr sheath is removed and the suture-mediated closure devices are serially deployed with device orientation in the 10 o'clock and 2 o'clock positions to facilitate closure of the arteriotomy at the conclusion of the procedure. The suture ends are clamped together to avoid premature cinching of the knots, and a sterile towel can be placed over them to avoid tangling. A 9 Fr sheath can then be placed to continue dilation.

Femoral Cutdown

For a femoral cutdown, a longitudinal or transverse incision can be made over the common femoral artery, which can be identified by palpation, ultrasound guidance, or anatomical landmarks (classically two thirds medially along the inguinal ligament when moving from lateral to medial). The incision is deepened through the femoral sheath and the common femoral artery is circumferentially dissected to expose adequate area for percutaneous access and proximal/distal control.

This approach is required if endarterectomy or a conduit is needed. Longitudinal endarterectomy is performed in the standard fashion and can be patched with Dacron or bovine pericardium. Then the pericardial patch is punctured with the micropuncture kit. If feasible, place the patch at the end of the case, because putting a large-bore sheath through the patch and fresh suture line might cause bleeding or even disruption of the suture line.

If a Dacron conduit is needed in the common femoral, we prefer the femoral "chimney conduit", but splitting the Dacron graft longitudinally to create cranial and caudal tapered ends much like a patch, allowing for a mobile graft that can be flipped retrograde and antegrade (Fig. 30.1). The graft is then clamped distally and punctured with the micropuncture kit, and at the end of the case the femoral chimney is transected and oversewn or stapled.

TEVAR Technique

A double-curved, stiff, 260-cm Lunderquist wire is then exchanged and advanced across the aortic arch until the apex of the curve rests against the aortic valve. To ensure that this position is maintained while fluoroscopy is directed elsewhere, the end of the wire outside the patient should be marked and efforts made to ensure that the wire stays in this position. It is preferable to associate the end of the wire to a physical landmark on the table rather than marking the sterile drape, which can crumple and move.

Serial dilation is then performed to reach the minimum required outer diameter of the sheath for the chosen device.

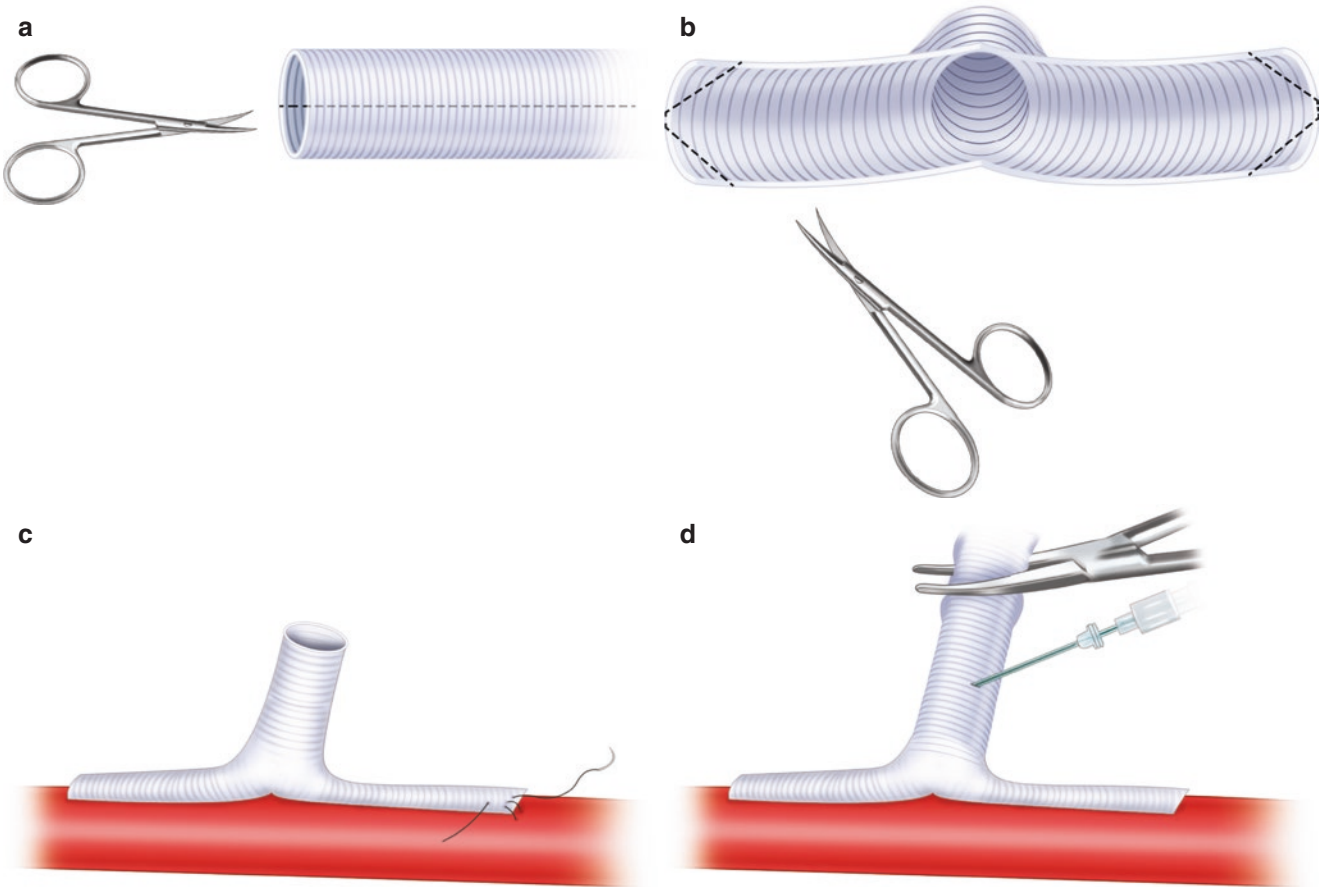

Fig. 30.1 Sewing a Dacron conduit. (**a**) Obtain an 8-mm ribbed Dacron tube graft for the common femoral artery or a 10-mm Dacron graft for the iliac artery. Using a straight, heavy scissor, make two incisions longitudinally on the graft, 180 degrees apart. (**b**) The graft can then be splayed and the corners trimmed and tapered to allow for smooth anastomosis of the patch. (**c**) The graft is then sewn over a longitudinal arteriotomy in an end-to-side fashion. (**d**) At the conclusion, the distal graft end is clamped and the graft is accessed percutaneously with the micropuncture needle

If there is no contraindication for heparin (such as active intracranial hemorrhage or gastrointestinal bleed), systemic heparin should be initiated at this time, with a goal of an activated clotting time over 250 seconds.

Initial Angiogram

A 5 French 100-cm Omni flush catheter is advanced into the aortic arch, either from contralateral femoral or upper extremity access. The thoracic endograft is then advanced over the Lunderquist wire into the thoracic aorta. The C-arm or fixed imaging system should be moved into a left anterior oblique position to allow for optimal great vessel visualization, with the ideal angle determined on preoperative 3D manipulation. The Omni flush catheter is connected to a power injector via sterile tubing and a three-way stopcock. Air is flushed from the system. If the patient is intubated, the anesthesiologist should be instructed to induce temporary apnea. Power injection is then used to obtain an initial aortogram, which can confirm measurements and locate the great vessels (Fig. 30.2).

Intravascular ultrasound (IVUS) can be used as an adjunct or replacement for the angiogram. IVUS reduces contrast use by allowing identification of branch vessels and measurements. In the setting of dissection, IVUS is particularly helpful in ensuring that the Lunderquist wire is in the true lumen and where fenestrations occur, as well as ensuring wall apposition of the stent graft.

Device Deployment

After a satisfactory angiogram is performed and the boundary vessels are marked, the graft can be deployed. Stent grafts conform to the outer curvature of the thoracic aorta, which can cause the graft to "jump" distally. Forward pressure on the Lunderquist wire will help push the wire against the outer curvature to better approximate the true path of the stent graft during deployment. This pressure can also help the apposition of the graft to the vessel wall, avoiding the "bird-beaking" effect.

Ongoing aortic blood flow can become trapped in the deploying graft and displace the stent distally, in a phenom-

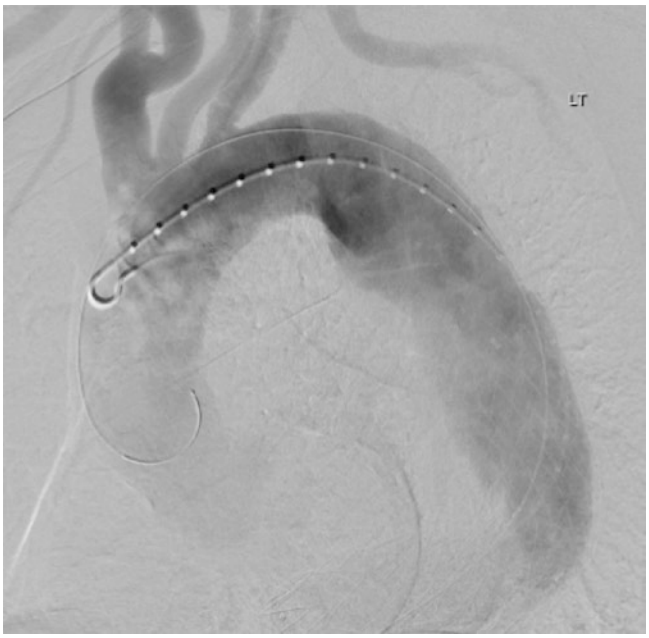

Fig. 30.2 Initial angiogram of the thoracic aorta in a left anterior oblique position. A prior stent graft had already been deployed in a distal aorta as part of a distal descending thoracic aneurysm repair

enon known as the "windsock" effect. A steady rate of deployment and a start slightly proximal to the intended landing zone can help mitigate this effect, and latest generation stent grafts incorporate newer technology to account for this. Additional stent grafts can then be deployed to obtain adequate seal, with a goal of a 5-cm minimum overlap between stents.

Graft Molding

Thoracic aortic ballooning is generally avoided in the setting of treatment for aortic dissection due to the risk of causing retrograde dissection. In aneurysmal disease, a noncompliant molding balloon can be used. Balloon molding should be performed first within the most proximal aspect of the stent graft, followed by areas of graft overlap and then the distal aspect of the graft. Some balloons allow continuous blood flow during angioplasty to reduce pressure and possible stent migration.

EVAR Technique

A straight, stiff, 260-cm Lunderquist wire is advanced to the descending portion of the thoracic aorta from bilateral common femoral arteries. The end of the wire should be marked and efforts made to ensure that the wire stays in this position while fluoroscopy is directed elsewhere. It is preferable to associate the end of the wire with a physical landmark on the table rather than marking the sterile drape, which can crumple and move.

Serial dilation is then performed to reach the minimum required outer diameter of the sheath for the chosen device. If there is no contraindication for heparin (such as active intracranial hemorrhage or gastrointestinal bleed), systemic heparin should be initiated at this time, with a goal of activated clotting time over 250 seconds.

Initial Angiogram

A 5 French 70-cm Omni flush catheter is advanced into the proximal abdominal aorta from the contralateral femoral artery (*ie*, the side not chosen for main body deployment). The endograft is then advanced over the Lunderquist wire. The Omni flush catheter is connected to a power injector via sterile tubing and a three-way stopcock. Air is flushed from the system. If the patient is intubated, induction of temporary apnea should be requested. Power injection is then used to obtain an initial aortogram, which can identify the configuration of the visceral vessels (Fig. 30.3).

IVUS can be used as an adjunct or replacement for the angiogram. IVUS reduces contrast use by allowing identification of branch vessels and both axial and longitudinal measurements. This is particularly useful in patients with renal insufficiency and a diminished glomerular filtration rate.

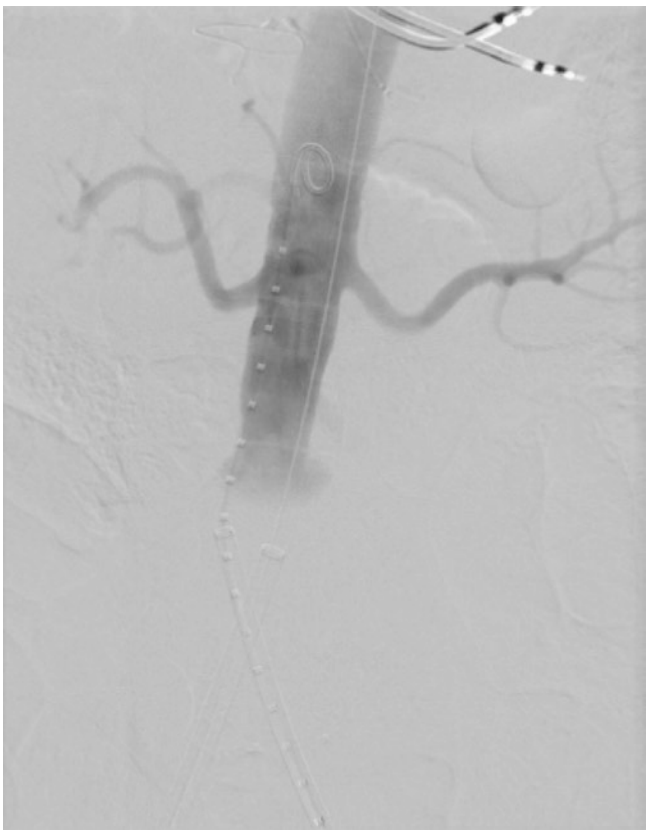

Fig. 30.3 Initial proximal angiogram for repair of an infrarenal abdominal aortic aneurysm. The origin of the renal vessels is clearly visualized

Device Deployment

After a satisfactory angiogram is performed and the boundary vessels are marked, the main body of the graft can be deployed over the Lunderquist wire. To obtain maximal infrarenal seal, the graft is deployed so the fabric edge is just distal to the lowest ostia of the renal arteries. The graft should also be rotated in such a way as to allow optimal cannulation of the contralateral gate. Care should also be taken to orient the image intensifier in such an angle as to best visualize the infrarenal neck and lowest renal artery, to optimize the proximal seal zone. To avoid twisting of the graft while rotating, the graft can be inched up and down vertically during these adjustments.

After the contralateral gate is deployed, the omniflush catheter can be retracted below the contralateral gate and used in combination with a hydrophilic wire (such as a Glidewire®) to cannulate the main body. Verification of gate cannulation can be performed by pushing the catheter up into the main body over the wire, then retracting the wire and spinning the catheter. Other confirmatory techniques include balloon inflation in the gate, IVUS, or a catheter-based angiogram. If cannulation is successful, the pigtail catheter should spin freely within the main body; if the catheter is outside the stent, it is usually constrained against the aortic wall (Fig. 30.4).

The wire can then be exchanged for a Lunderquist wire, and the fixed imaging or C-arm orientation changed to the contralateral anterior oblique view (for example, left anterior oblique for the right iliac bifurcation). Angiography is then performed to identify the hypogastric origin, and the pigtail marker is used to count the distance between the contralateral gate and the hypogastric origin, with allowance for the minimal required stent overlap. A contralateral limb can then be exchanged for the catheter and deployed to just proximal to the origin of the hypogastric artery.

If needed, ipsilateral extension of the main body limb to the hypogastric origin can be performed in similar fashion with a pigtail catheter and a Lunderquist wire; cannulation will not be necessary.

Graft Molding

Balloon molding is performed with compliant balloons, moving from proximal to distal. Typically the proximal aortic seal zone is ballooned, followed by areas of stent overlap, including the region of overlap between the contralateral gate and the contralateral limb, and the proximal zone of all extension pieces. The distal seal zones are then molded.

Final Angiogram and Closure

An aortogram is then performed with the tip of the pigtail catheter superior to the stent graft to assess for appropriate position, device patency, and endoleaks. Once the aortogram is satisfactory, closure is performed (Figs. 30.5 and 30.6).

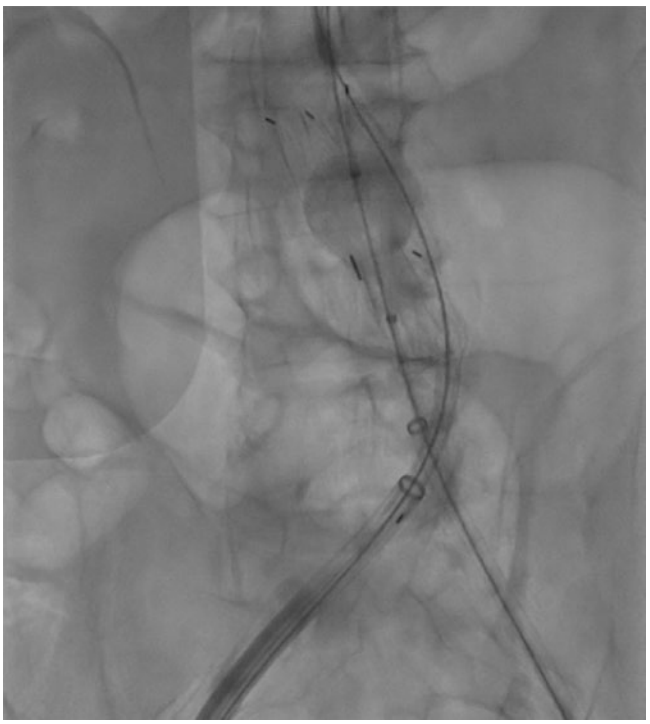

Fig. 30.4 A "mushroom" effect of a balloon inflated partway into the proximal body and the contralateral gate confirms accurate gate cannulation

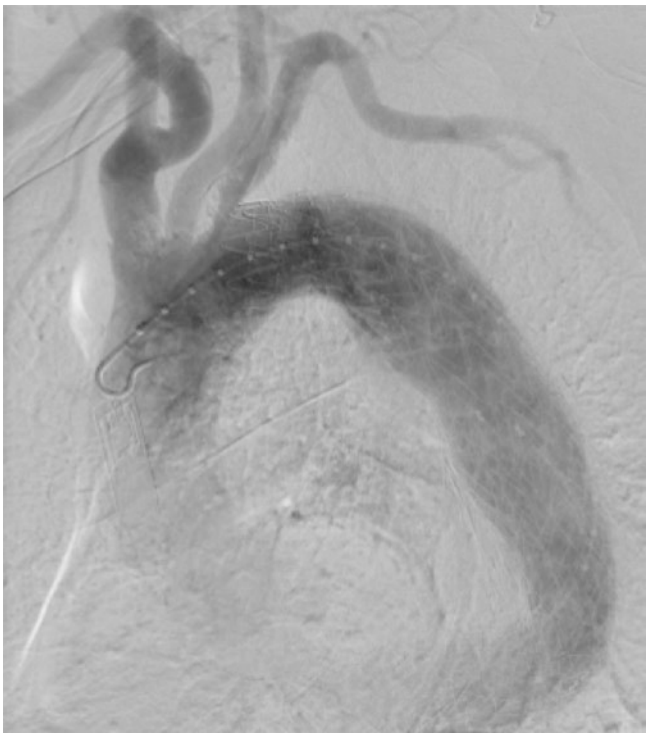

Fig. 30.5 Completion angiogram of TEVAR for descending thoracic aneurysm with proximal graft landing zone just distal to the origin of the left subclavian. There is filling of the left subclavian artery without evidence of endoleak

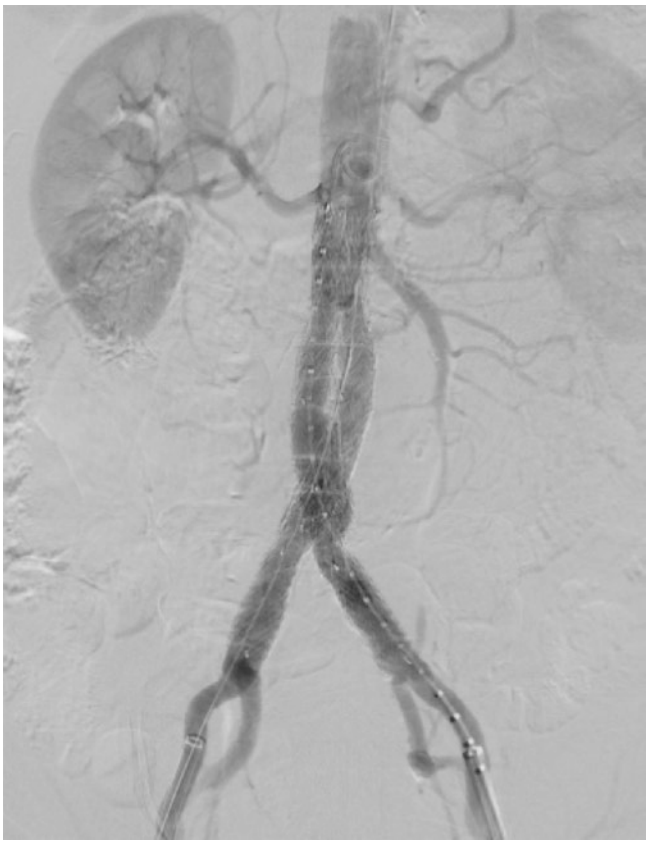

Fig. 30.6 Completion angiogram for EVAR for repair of an infrarenal abdominal aortic aneurysm. There is filling of the renal vessels, superior mesenteric artery, and hypogastric vessels without evidence of endoleak

If access was performed percutaneously, then the previously placed suture-mediated closure devices can be used to close the arteriotomy. The previously placed knots are cinched down and the suture is cut.

If open exposure of the femoral artery was performed, proximal and distal control is obtained, the sheath and wire are removed, and the arteriotomy is closed primarily with polypropylene suture. Prior to complete closure, the clamps are temporarily released to de-air the clamped segment. If a Dacron conduit was sewn to the vessel, it can be ligated to a short stump, either with a vascular stapler or suture. The wound can then be closed in a layered fashion.

Suggested Reading

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Endovascular Therapy for Thoracic Aortic Dissection and Intramural Hematoma

31

Viony M. Belvroy, Ponraj Chinnadurai, and Jean Bismuth

Introduction

Depending on the duration of symptoms at the time of presentation, thoracic aortic dissection can be classified as an acute or chronic disease. Identifying a dissection within less than 15 days of symptom initiation is considered the acute phase; from 15 to 92 days, it is called the subacute phase; after 93 days, it is considered chronic [1]. This classification is based on the morbidity and mortality rates that occur in the different phases.

The anatomical classifications follow the Stanford or DeBakey systems [2]. The Stanford classification describes a dissection involving the ascending aorta as a type A aortic dissection, whereas if the entry tear occurs distal to the left subclavian artery (LSA), it is considered a type B aortic dissection. The DeBakey classification uses the site of entry tear location: type 1 originates in the ascending aorta and propagates to at least the aortic arch; type 2 originates in and is confined to the ascending aorta; and type 3 originates distal to the LSA. A type A dissection occurs twice as frequently as a type B dissection. If type B dissections are uncomplicated, medical management is focused mainly on pain relief, maintaining a low blood pressure, and controlling heart rate [3]. Surgical treatment is generally reserved for complicated dissections. Although surgical management can be handled with either open surgery or endovascular repair, it is clear that endovascular management is favored because of its improved outcomes [4]. This chapter focuses only on the endovascular treatment of aortic dissection.

An aortic intramural hematoma (IMH) is a hemorrhage within the media layer of the aortic wall without an intimal lesion [5]; it can be a precursor for aortic dissection. Data suggest that 8–16% will develop into a dissection [6]. The classification of an IMH is the same as for aortic dissection, with type A occurring in the ascending aorta and type B, in the descending aorta. Type B IMH occurs more often than type A. Medical therapy plays an important role in type B IMH and is the mainstay of therapy. The mortality is lower with medical therapy, with fewer cardiac complications; they less often develop into a type B aortic dissection [7, 8]. The 5-year survival rate is about 85% [9]. For patients with type A IMH, the medical treatment is more controversial, as 27–96% of patients treated medically had severe aortic events requiring aortic replacement during follow-up [7]. Others reported that one third of the medically treated type A IMH cases developed into an aortic dissection, ruptured, and/or eventually needed surgery [8, 10, 11]. If surgery is eventually necessary, patients with type A IMH receive open surgical repair, and patients with type B IMH can undergo thoracic endovascular aortic repair (TEVAR) [12]. Literature suggests medical treatment for uncomplicated type B IMH; the 3-year aortic event–related mortality was 5.4%, as opposed 23.2% with open surgery and 7.1% with endovascular therapy [13]. Patients treated for IMH have a higher risk of developing retrograde aortic dissection (RAD) after TEVAR [14], which should be taken into account when planning for endovascular therapy.

Preoperative and Postoperative Imaging

An aortic dissection can be diagnosed with multiple imaging modalities, most commonly CT angiography (CTA), transesophageal echocardiography (TEE), and in some cases, MR angiography (MRA). In the acute setting, time is of the essence. When the patient is hemodynamically stable, the most commonly used imaging modality remains CTA (63%), or less often TEE (32%) or MRA (4%) [15]. In the hemodynamically unstable patient, availability and local expertise determine the appropriateness of the modality, in most cases CTA [16].

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Imaging of IMH is the cornerstone for diagnosis. CTA has a negative predictive value of 100% [17]. The typical finding on CTA is a crescent-shaped area of uniform hyperattenuation with associated aortic wall thickening (Fig. 31.1). MRA is used less commonly because of slower scan times, but it is able to differentiate between acute and chronic hematomas. On T2-weighted images (in which blood appears white), acute IMHs (<7 days old) are hyperintense (bright white), and chronic IMHs (>7 days) are less intense (*see* Fig. 31.1). A recent study by Schwein et al. suggests MR imaging criteria to confirm IMH, as opposed to aortic dissection [18]. This pilot study confirms not only the pathology of the disease but also lesion volume decrease during follow-up, which should make this a more commonly used imaging modality.

Intraoperative Imaging

Two imaging modalities are most widely used in TEVAR, fluoroscopy and intravascular ultrasound (IVUS). Fluoroscopy is used to assess the anatomy and the placement and deployment of a stent graft. It is mainly used for the arteriography of the aorta and great vessels. It is now not uncommon also to use a combination of preoperative CTA (3D) and fusion with fluoroscopy (2D or 3D). By fusing the images, the surgeon benefits from a continuous visualization of the intraoperative landmarks for improved endograft navigation and placement [19].

IVUS provides real-time data during interventions and is mainly used for accurate graft sizing during the placement of endovascular stent grafts; some prefer it to CTA [20, 21]. It can provide imaging information that can reduce the contrast load in patients with renal dysfunction [22]. In aortic dissection, we believe it is essential to use IVUS to help define the entry and re-entry sites during treatment [23].

Unlike type B dissections, the difficulty with IMH is that there is no intimal disruption. Therefore, the extent of the required endograft coverage of the descending aorta is unclear.

TEE is another imaging modality that can be used intraoperatively. It is mainly employed to reduce the contrast load and radiation exposure, but when contrast TEE (cTEE) is used, it can have additional benefits, such as in the preoperative characterization phase of aortic pathology (identifying the number of entry tears), or intraprocedural or postprocedural identification of slow and/or remaining flow, persistent leaks, or retrograde dissection [24, 25].

Preoperative Planning

As mentioned earlier, two main imaging modalities are used for the planning of TEVAR. MR and CT are widely used to give a clear overview of the aortic side branches (i.e., supra aortic trunks, celiac trunk), the landing zone, the angle of the take-off branch vessels, and the entry- and re-entry tears

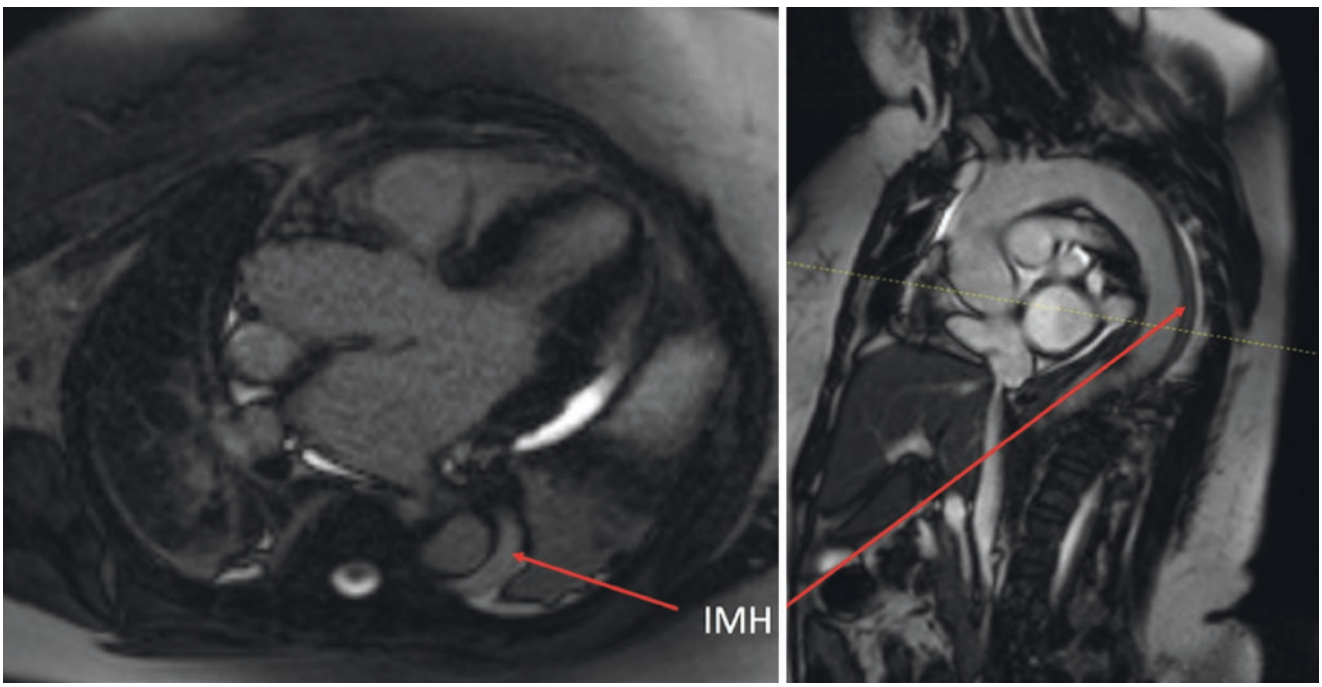

Fig. 31.1 Axial and sagittal MR images of 58-year-old female patient showing chronic type B intramural hematoma (IMH)

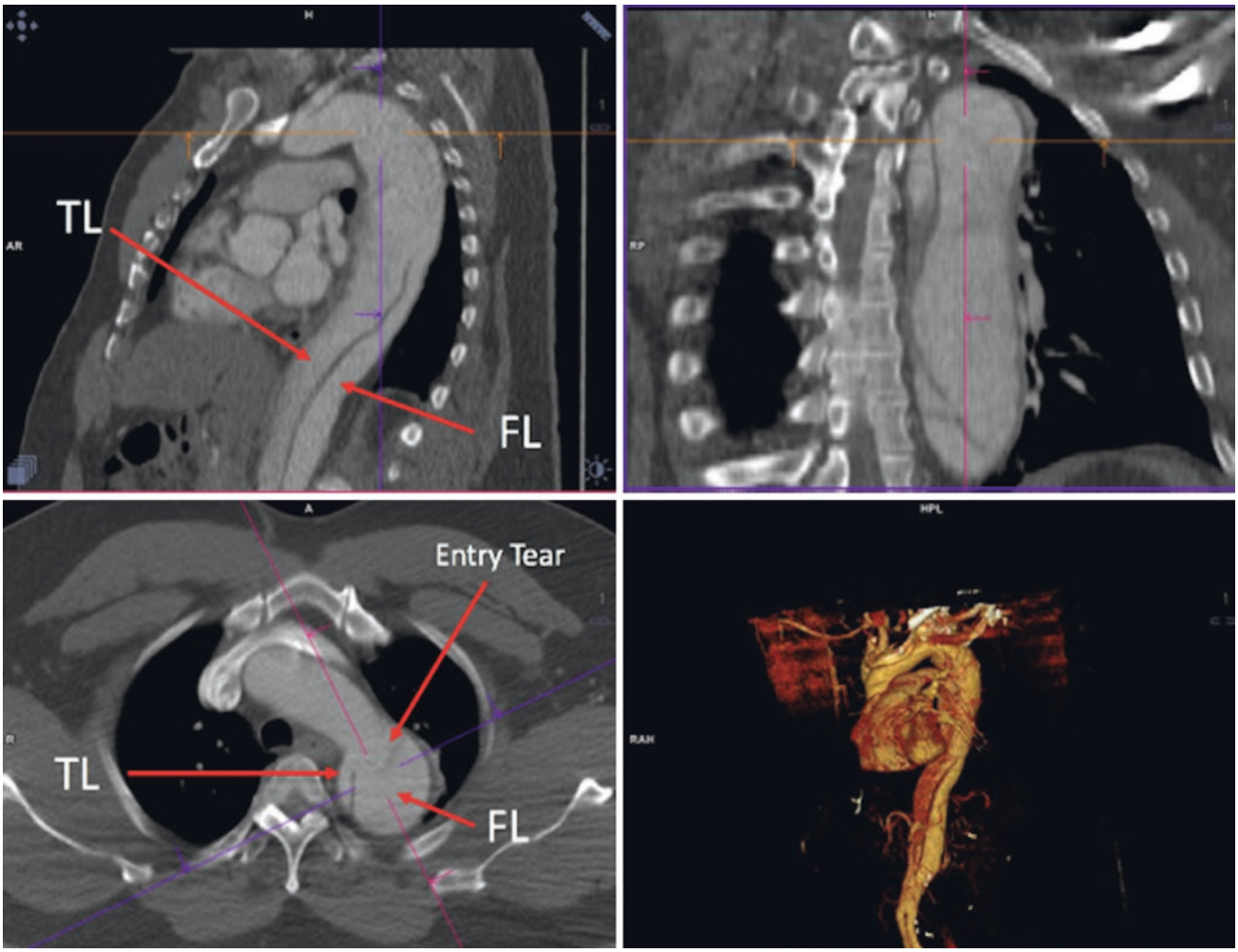

Fig. 31.2 Multiplanar reconstructions of CT angiography (CTA) with sagittal, coronal, and axial views and 3D reconstruction in a 49-year-old male patient, who presented with type B aortic dissection demonstrating the true lumen (TL) and false lumen (FL)

(Figs. 31.2 and 31.3). It is important to observe whether the flow goes retrograde or antegrade into the false lumen.

When planning TEVAR for a type A aortic dissection/IMH, it is critical to pay attention to the innominate artery, and in case of a type B aortic dissection/IMH, to the left subclavian artery (LSA). It is necessary to avoid covering these arteries with the TEVAR, and critical to understand the associated risks if they are covered. If there is a high risk of complications, other surgical options can be considered, such as debranching or some form of investigational device that allows for preservation of the supra-aortic branches.

To get a continuous visualization of the critical landmarks during surgery, fusion imaging is used. The use of this imaging ensures reductions in contrast media, radiation exposure, and procedure time [26, 27]. Fusion imaging uses the preoperative cross-sectional images (CTA and MRA scans) and marks the critical landmarks.

In a 3D-3D registration, the non–contrast-enhanced cone beam CT (nCBCT) is combined with the preoperative CTA to create a 3D model, which is based on normalized mutual information and aligns bony structures and vessel calcifications and vessels [28]. It is clear that the more points of co-registration, the more likely that there is a reliable fusion.

A 2D-3D registration lays the preoperative CTA scan over two projections of 2D fluoroscopic images (anteroposterior and lateral). Both 2D-3D and 3D-3D are good choices for co-registration during TEVAR (Figs. 31.4 and 31.5) [19].

Intravascular ultrasound (IVUS) is a critical part of a TEVAR in the setting of aortic dissection. The distal portion consists of a cylindrical ultrasound transducer and is highly accurate in measuring the luminal diameter or identifying the position of branch vessels, inspecting vessel wall morphology, evaluating the presence of plaques or thrombi, and selecting appropriate landing zones for endografts [29].

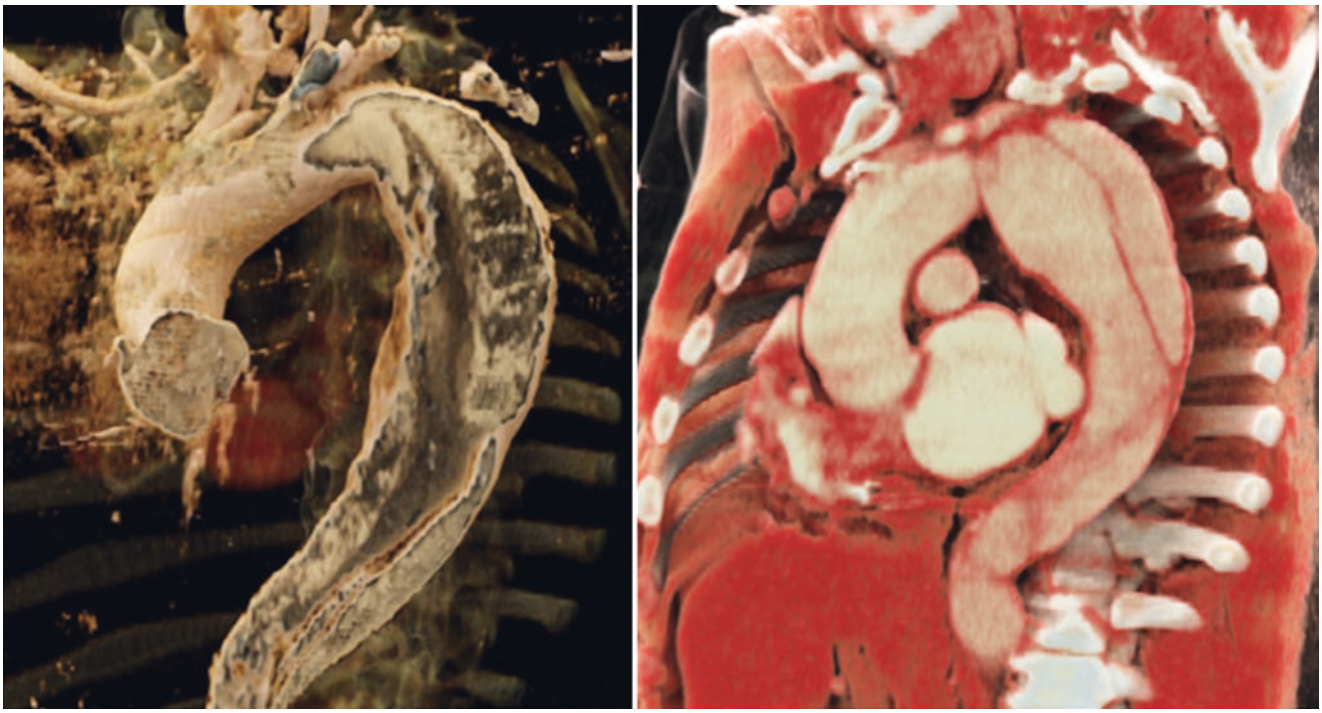

Fig. 31.3 Advanced cinematic rendering of CT images showing type B aortic dissection

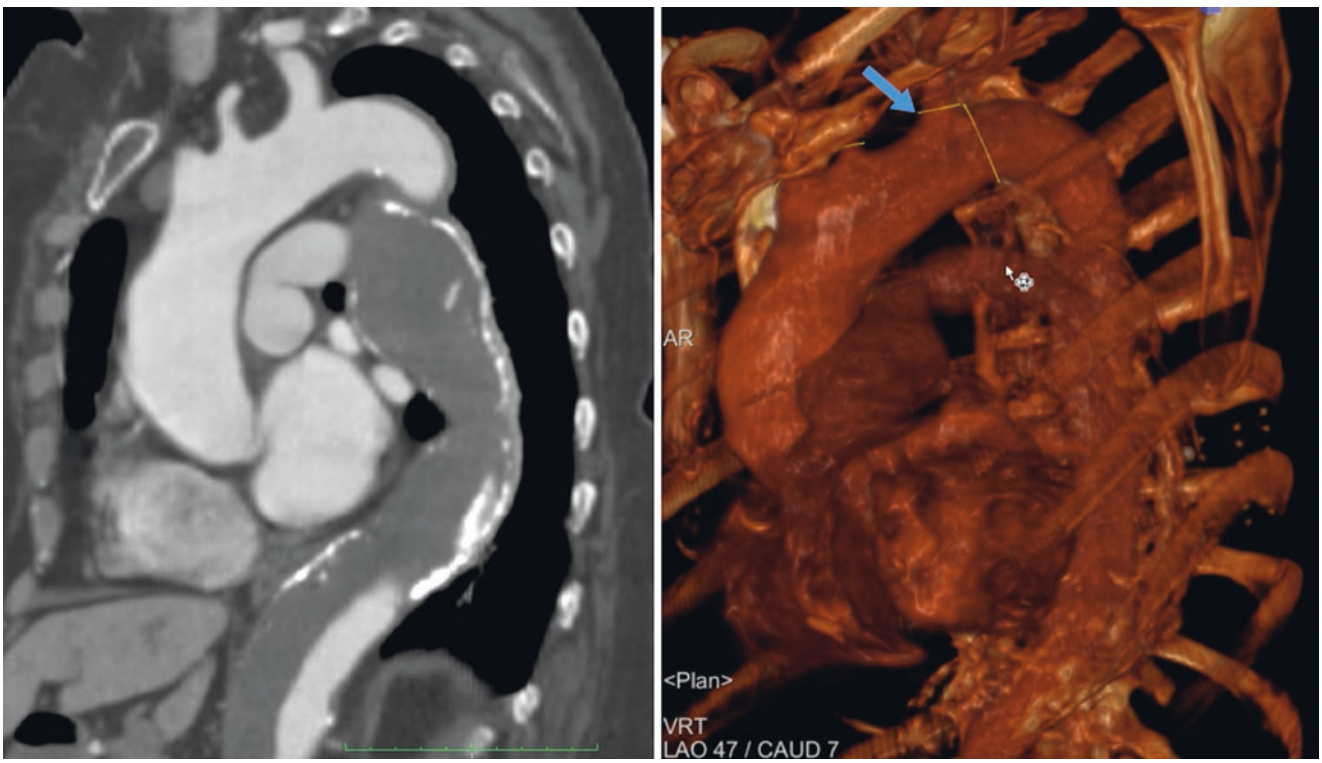

Fig. 31.4 Sagittal (**a**) and volume-rendered (**b**) CTA images demonstrating 3D planning for thoracic endovascular aortic repair (TEVAR) procedure. Origins of left carotid and left subclavian arteries, including the aortic landing zone for TEVAR, were electronically marked in the planning CTA images (*blue arrow*)

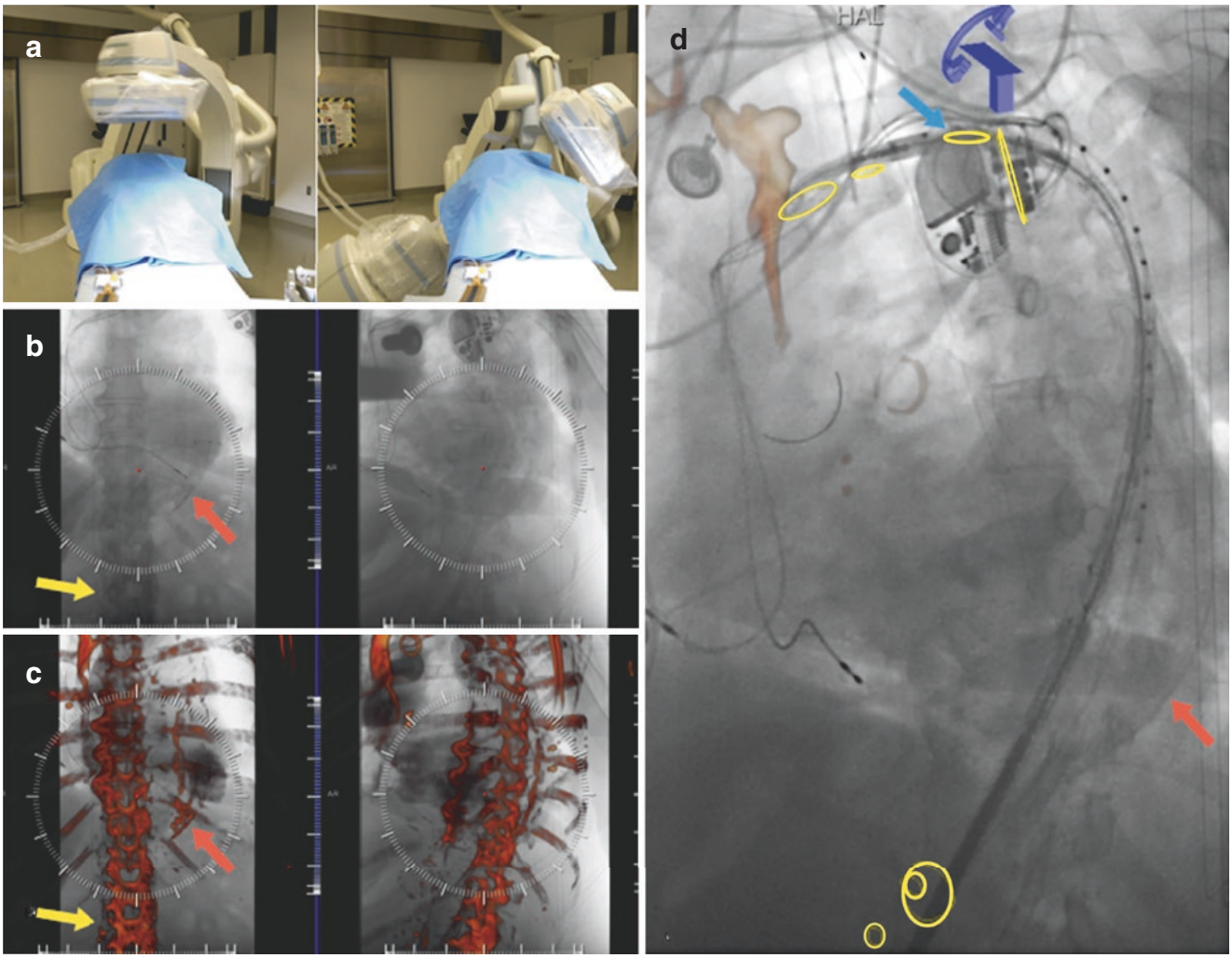

Fig. 31.5 CTA-fluoroscopy 2D-3D image fusion workflow. (**a**, **b**) A robotic C-arm angiography system was used to acquire two fluoroscopic images in anteroposterior (AP) and left anterior oblique (LAO 45) views. (**c**) 3D CT images are overlaid on 2D fluoroscopic images, demonstrating 2D-3D fusion using the spine (*yellow arrow*) and aortic wall calcifications (*red arrow*) as landmarks. (**d**) Overlay of vessel landmarks (*yellow circles*) from CTA on 2D fluoroscopy during stent graft deployment, at the planned landing zone (*blue arrow*)

Equipment for Thoracic Endovascular Aortic Repair

As an interventionalist, it is important to have expertise with the various tools that are commonly used in endovascular practice. TEVAR is no different in this respect, involving not only devices but also occlusion balloons, sheaths, guidewires, and catheters. The tools required for a TEVAR in the context of an aortic dissection or IMH are not very different from those used for a standard TEVAR, although there are some important nuances.

Sheaths are widely used to gain safe access to the vascular system when performing an endovascular procedure. In TEVAR, the devices are generally larger, and this becomes even more of an issue for newer, advanced devices with side branches or other variations. The benefit of sheaths is that they minimize localized-access vessel trauma from the guidewire or catheter repeatedly entering the vessel [30], and more importantly, they provide a safe port of access for tool delivery. Sheaths are made of Teflon (tetrafluoroethylene), an inflexible material that has a low friction coefficient and is very torquable (turning the ex vivo portion results in rotation of the vivo portion). Torquability can vary by sheath, however, and particularly by its apposition to the vessel wall. Therefore, if a sheath fits in a vessel with great difficulty due to size or occlusive disease, torqueing the sheath is not advisable, as the vessel may be injured. Sheaths are sized by their inner diameter, which should be taken into account when estimating the largest-size device that can be inserted through them [29]. To determine the maximum sheath size tolerated by a vessel, one would need to multiply the vessel's actual inner diameter by a factor of 3. Additionally, it is important to assess vessel occlusive disease to further evaluate risk of rupture.

Guidewires help the surgeon navigate through the vascular system without damaging the vessel. The stiff inner wire is tapered and does not extend to the end of the guidewire, so the tip is more flexible and atraumatic to the vessel walls. The different types of wire tip configurations include J-curved, angled, straight, or those that can be formed into the shape preferred by the surgeon, called the "floppy" tip. Of equal importance is the core of the wire, which is generally either Nitinol or stainless steel. A safe standard J-tip or Starter wire (Bentson) is generally used for initial access, although many use a soft Glidewire®. These are generally used to gain access to the ascending aorta in a TEVAR case. These wires usually are exchanged later to stainless steel stiff wires over a support catheter of choice. The wires usually all have a form of antifriction coating, and some even an antithrombogenic coating. For access to a specific vessel or catheterization, the standard length of the guidewire is between 145 and 180 cm. When the guidewire is needed to exchange catheters and devices during an endovascular procedure, the length is usually between 260 to 300 cm [29]; this is always the case in TEVAR. As a rule of thumb, in order to appropriately gauge the length of wire needed, you simply double the shaft length of your catheter or device to calculate the minimum wire length needed. (For example, a device with shaft length of 120 cm needs a wire of at least 240 cm.)

This section is not intended to be an exhaustive discussion of all catheters; it will discuss only those used for the purpose of performing a TEVAR. Catheters serve essentially three primary purposes: (1) an infusion flush catheter, (2) a support catheter, and (3) a directional (selective) catheter. They are essential to performing the intervention safely. A variety of materials are used to make catheters (polyurethane, polyethylene, nylon, and Teflon), each with different characteristics—flexibility (the ability to track the guidewire to the intended position), the coefficient of friction, and the capacity for torqueing—which help in choosing the correct catheter [29].

Many different devices can be used in the treatment of aortic diseases. We recommend referring to the instructions for use (IFU) for each device. As different devices are approved in each country, this chapter simply refers to the device in a general sense, and not to a vendor-specific tool. Selection of device is most commonly based on availability and physician preference.

Thoracic Endovascular Aortic Repair: Step-by-Step Procedure

Accessing the Femoral Artery

The first step is access to the vascular system. This can be done either through a percutaneous access or an open exposure of the access vessel. This choice depends mostly on surgeon preference, unless a conduit is needed. Anecdotally, we prefer an open femoral exposure in cases of aortic dissection, as it is our experience that even the femoral artery can sometimes be a fragile vessel, so we favor a direct arterial repair rather than a percutaneous one. In the case of an aortic dissection, it is crucial to identify the extent of the dissection into the iliac or femoral vessels before accessing the femoral artery. Accessing the false lumen could have undesirable implications for the procedure. When puncturing the femoral artery, it is critical to use ultrasound as guidance, particularly if the femoral artery is dissected. Depending on the device and procedure, groin access may be bilateral or unilateral. We prefer to use a micropuncture set when accessing the vessels.

Insertion of 0.035 Guidewire, Sheath, and Support Catheter

When the access has been created, a guidewire is inserted, followed by a 9 Fr sheath. The 9 Fr sheath is essential in order to be able to perform IVUS. It is better to perform the IVUS over stiff wire, as the anatomy could be altered with a stiff wire, in comparison to a softer wire. With the appropriate support catheter, the guidewire is advanced to the aortic valve. Commonly used guidewires for this purpose are the Bentson wire 260 cm (Cook Medical, Bloomington, IN) or a hydrophilic wire, 260 cm.

Exchange to Stiff Wire

To get the eventual device in the correct position, a stiff guidewire is used. A catheter is therefore initially placed over the floppy guidewire, and the floppy guidewire is removed and exchanged for a stiff guidewire. We prefer a Lunderquist® 300 cm stiff wire (Cook Medical, Bloomington, IN), but a number of other wires with adequate support also can be used.

Intravascular Ultrasound

After placing the stiff wire in position, an IVUS catheter is used to confirm that the wire is in the true lumen throughout the aorta. It is important to understand that the true lumen is generally the smaller of the two lumens and usually appears as a half-moon (Fig. 31.6). Another reason for IVUS is to check for side branches, their locations, and entry and re-entry tears.

Place Device into Position

When IVUS has confirmed the position of the wire in the true lumen, the device is advanced into position over the stiff guidewire.

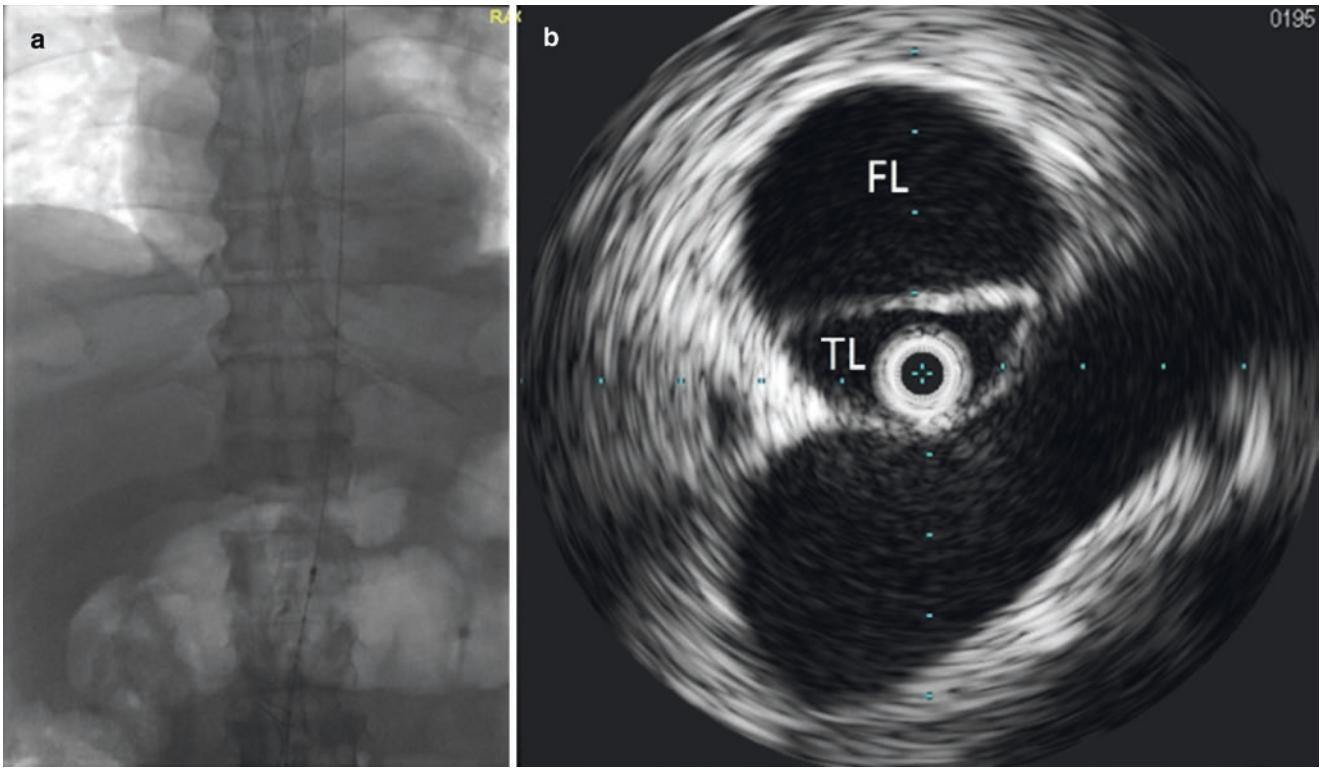

Fig. 31.6 Intravascular ultrasound (IVUS) of patient with type B aortic dissection. (**a**) IVUS catheter pull-back was performed under fluoroscopy. (**b**) IVUS image demonstrating visualization of the true lumen (TL) and false lumen (FL)

Aortogram

The aortogram confirms the device position and is the last step prior to deployment. For a type B dissection, it is important for the aortogram to include the arch; that will not only allow you to see the branch vessels but also will allow you to see the baseline aortic appearance so that you can ensure that there is no retrograde dissection on your completion films. The aortogram is generally done either by getting a second wire through your existing sheath and bringing a pigtail into position or via a second femoral puncture on the contralateral side. It is imperative to perform an arch aortogram in a left anterior oblique (LAO) projection (40–60 degrees). The actual angle can be estimated from the preoperative CTA.

Deploy Stent Graft

When everything is in the correct position, the stent graft will be deployed. Depending on the stent graft, it might be possible to adjust the device a little more before full deployment.

Aortogram to Confirm

After full deployment of the stent graft, an angiogram is performed to confirm the position of the stent graft and to check whether there is flow in the branch vessels and whether there is any evidence of retrograde aortic dissection (Fig. 31.7). If there is any doubt about a retrograde arch dissection, TEE is a useful imaging modality, as is your IVUS.

Extended TEVAR

When the disease involves the ascending aorta and/or the aortic arch, there are different treatment options. Generally, open surgery is the standard for type A dissections and can consist of hemiarch repair or a total arch repair [31, 32].

Debranching the supra-aortic trunks affords options for extending endovascular options. There are three types of aortic debranching, but the most commonly used types are type I and type II. In a type I aortic debranching, the supra-aortic trunks are inserted in the ascending aorta to obtain a Z0 landing zone for TEVAR. Type II aortic debranching consists of reconstruction of the ascending aorta to create a proximal Z0 landing zone [33].

A total arch repair (often in combination with a frozen elephant trunk procedure) is done when the disease extends mainly in the aortic arch. The proximal portion is non-stented and consists of a Dacron sleeve for a conventional surgical approach. The distal part consists of a stent graft [34, 35]. A stent graft currently used for the frozen elephant trunk technique is the E-vita open plus graft (Jotec; Hechingen, Germany).

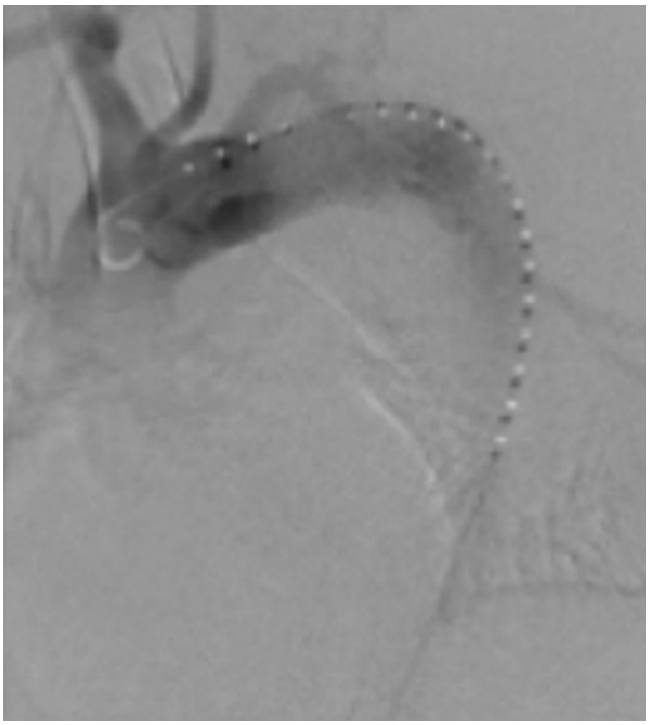

Fig. 31.7 Aortogram after stent graft implantation, with no signs of endoleaks or retrograde dissection, with flow in the branch vessels

Totally endovascular solutions are currently being used, as seen in anecdotal reports, and purpose-built devices are in trials. The overall techniques are essentially no different from that for type B dissection TEVAR, but the precautions differ, based on landmarks such as the coronary arteries and Innominate artery. Additionally, it is important to have experience in crossing the aortic valve with a guidewire, to understand rapid ventricular pacing, and to have TEE surveillance during the procedure. Because of the investigational status of this procedure in the ascending aorta and arch, this chapter will not go into any further details.

Pearls of TEVAR for Aortic Dissection

- Three phases of onset: acute (<15 days), subacute (15–92 days), and chronic (>92 days).
- Medical management for uncomplicated type B aortic dissection, with focus on pain relief, blood pressure and heart rate reduction, and close follow-up.
- Endovascular repair favorable over open surgery.
- Imaging is critical. CTA is most commonly used preoperatively in aortic dissection, to give a clear overview of the aortic side branches, landing zones, angles, and entry and re-entry tears. Intraoperative fluoroscopy and IVUS are essential for consistent and optimal results.
- Steps of TEVAR:
  - Accessing the femoral Artery.
  - Insertion of 0.035 guidewire, sheath, and support catheter.
  - Exchange to stiff wire.
  - IVUS.
  - Place device into position.
  - Aortogram.
  - Deploy stent graft.
  - Aortogram to confirm.

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Fenestrated and Branched Endografts

32

Aleem K. Mirza, Gustavo S. Oderich, and Bernardo C. Mendes

Fenestrated-branched endovascular aortic aneurysm repair is evolving and achieving its maturity in treatment of complex abdominal and thoracoabdominal aortic aneurysms. Excellent early- and long-term results have been reported by multiple institutions. These procedures are complex and require advanced endovascular imaging and technique. The objective of this chapter is to provide a summary of different stent graft designs and general technical principles of implantation.

Introduction

Fenestrated-branched endovascular aortic repair (F-BEVAR) has rapidly developed since the 1990s. The first fenestrated repair was performed in 1996 by Park, using a modified device with a single fenestration to incorporate an accessory renal artery for infrarenal abdominal aortic aneurysm (AAA) [1]. A year later, a research team in Perth, Australia, led by Tom Browne, Michael Lawrence-Browne, and David Hartley, also demonstrated target-vessel preservation in an animal model with a single fenestration. In 1998, Dr. John Anderson performed the first clinical fenestrated repair for a juxtarenal AAA in Adelaide, Australia, without placement of an aligning stent. Anderson later partnered with the research team from Perth, adding a balloon-expandable stent to the technique in order to fix the fenestration to the target-vessel orifice [2]. The technology rapidly spread through Australia, Asia, and Europe, before it was adopted and subsequently popularized in the United States by Roy Greenberg [3]. The technology was first applied to thoracoabdominal aortic aneurysms (TAAA) by Michael Denton, with incorporation of the celiac axis (CA) and superior mesenteric artery (SMA) [1].

Many adjuncts and improvements have been added to the technique, including nitinol rings for reinforcement of the fenestrations, radiopaque markers to facilitate orientation of the main body and identification of the fenestrations, as well as diameter-reducing ties to allow for intracorporeal maneuvering of the device (Fig. 32.1). This led to the development of the Cook Zenith Fenestrated AAA Endovascular stent-graft (Cook Medical Inc., Bloomington, IN), which was commercially approved in the USA by the Food and Drug Administration (FDA) in 2012 [4]. Advances in the technology have continued, with the addition of preloaded catheters/wires, directional branches, inner branches, upper extremity access, and off-the-shelf devices. Application of this technology has also progressed, from juxtarenal AAA to TAAA, chronic post-dissection aneurysms, and more recently, to aortic arch pathologies [1].

Stent-Graft Designs

It is important to note that some of the stent-grafts discussed in this section are still in clinical trials and are not commercially available.

Cook Zenith Fenestrated Stent-Graft

The Cook Zenith Fenestrated was approved by the FDA for use in the United States for aneurysms with short infrarenal necks, measuring >4 and < 15 mm. The components of the device include a proximal fenestrated main body, with a universal bifurcated distal device and contralateral limb extension. The device is constructed of woven polyester, sewn to self-expandable stainless steel Cook Z-stents. The fenestrated component is patient-specific, custom-made for

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J. J. Hoballah, C. F. Bechara (eds.), *Vascular Reconstructions*, https://doi.org/10.1007/978-1-0716-1089-3_32

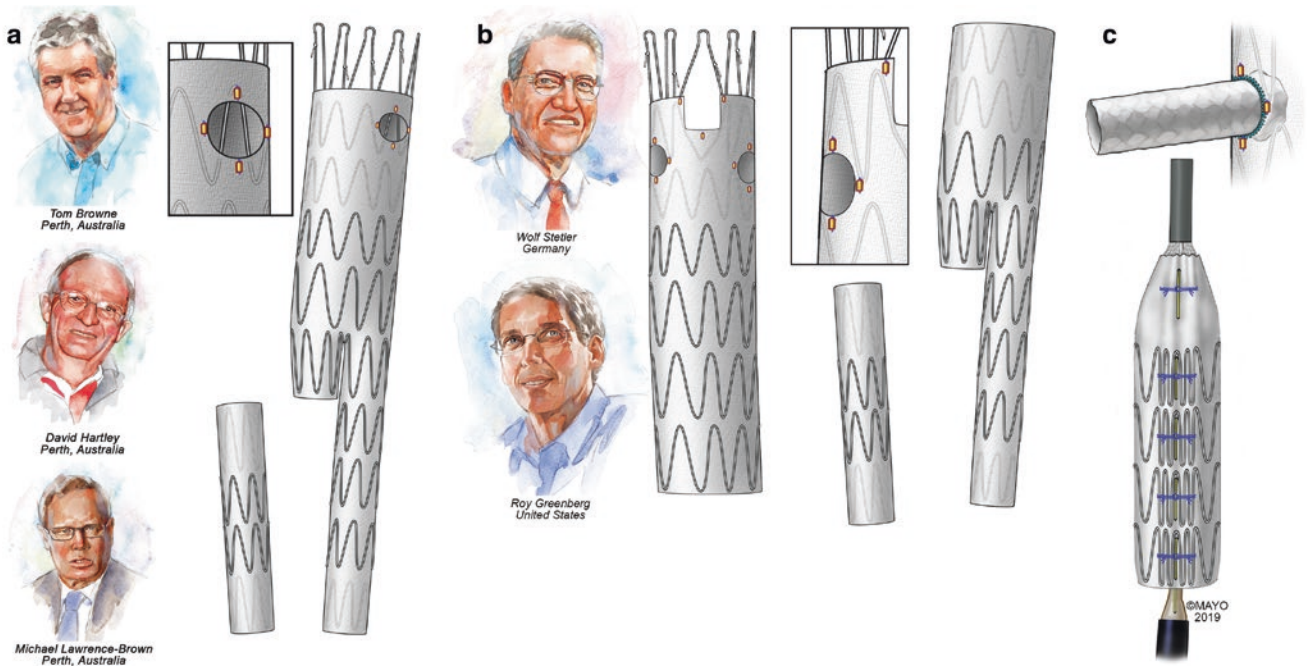


Fig. 32.1 Development of fenestrated endovascular aortic repair. (**a**) The Perth research team of Tom Browne, David Hartley, and Michael Lawrence-Brown based the initial fenestrated graft design on the Zenith Bifurcated Stent with a non-reinforced fenestration and radiopaque markers; struts crossed the fenestration, which was not intended to be stented. (**b**) Wolf Stelter in Germany suggested the concept of a separate tubular component with fenestrations and a distal bifurcated component. Roy Greenberg in the USA is credited with applying the technology to wide clinical use. Note that the fenestrations were not reinforced at this point, but the design evolved to avoid struts across the fenestrations. (**c**) The graft evolved to include a nitinol-reinforced ring and gold radiopaque markers, the use of covered stents to replace bare metal stents for alignment of fenestrations, and diameter-reducing ties. (By permission of Mayo Foundation for Medical Education and Research. All rights reserved. *Adapted from* Roeder et al. [1]; *with permission*)

each patient's anatomy. Designs may include up to three fenestrations, of which two can be of the same type. Options include small fenestrations (6 × 6 mm or 6 × 8 mm) that are reinforced with nitinol, with no stent struts crossing through the fenestration. Large fenestrations (8–12 mm) are not nitinol-reinforced and may have struts crossing through the fenestration, making placement of alignment stents more difficult. Scallops are openings in the cephalad edge of the graft fabric, which measure 10 mm wide by 6–12 mm high (Fig. 32.2) [4].

Cook p-Branch

The Cook p-Branch is an off-the-shelf stent-graft, constructed of polyester with a proximal stainless steel uncovered stent with barbs. Distal to this, it is reinforced with nitinol Z-stents. The modular system measures 26–36 mm in diameter, tapering distal to the renal fenestrations to 24 mm. The design includes a scallop for the CA, one fixed 8-mm strut-free fenestration for the SMA, and two pivot fenestrations for each renal artery, which have outer diameters of 15 mm and inner diameters of 6 mm. There are preloaded wires for both renal pivot fenestrations, and a diameter-reducing constraining wire to allow for intracorporeal manipulation and orientation. Two configurations are available; one option includes renal fenestrations at the same longitudinal level, and the other has the left renal fenestration 4 mm caudal to the right renal. The device is deployed through a 20 Fr delivery system [6].

Cook t-Branch

The Cook t-Branch is an off-the-shelf stent-graft intended for treatment of thoracoabdominal aortic aneurysms. It is constructed of woven polyester sutured to stainless steel Z-stents. Proximally, the diameter is 34 mm, tapering to 18 mm distally. The device length is 202 mm. At the mid portion of the graft, there are four external, caudally directed cuffs that are located 18 mm apart longitudinally. The CA and SMA cuffs are axially located at the 01:00 and 12:00 positions respectively. The two renal cuffs are located at the 10:00 and 03:00 positions. There are no preloaded wires or catheters, and the device is deployed through a 22 Fr system [7].

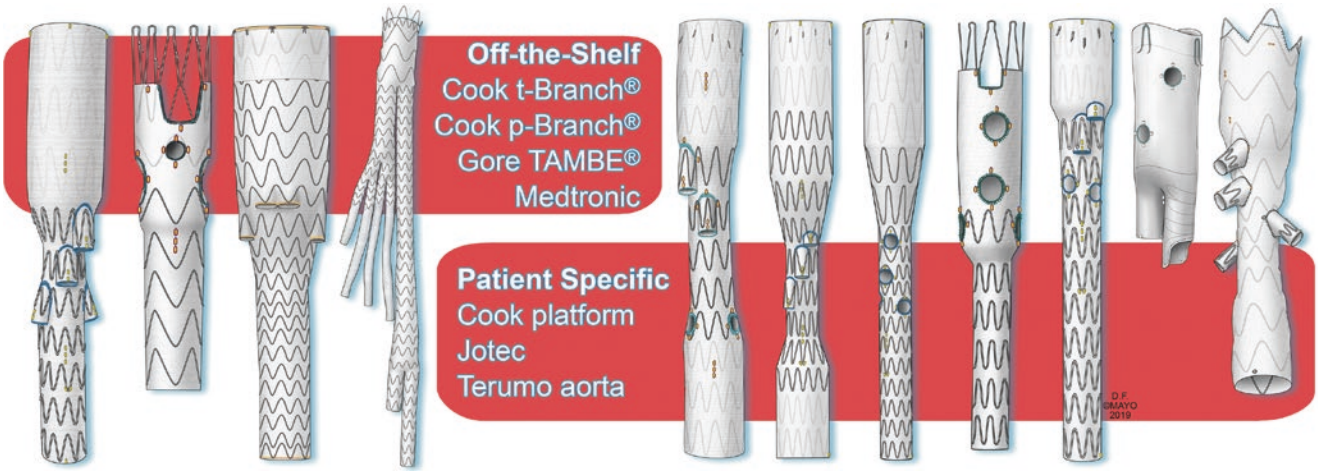


Fig. 32.2 Multiple device designs are in use or are currently under investigation, including off-the-shelf stent-grafts such as the Cook t-Branch, Cook p-Branch, WL Gore Thoracoabdominal Multibranch Endoprosthesis (TAMBE), and the Medtronic platform. Additionally, multiple different configurations can be obtained utilizing a patient-specific platform, with any combination of down-going branches and fenestrations, with or without tapering of the device. (By permission of Mayo Foundation for Medical Education and Research. All rights reserved. *Adapted from* Roeder et al. [5]; *with permission*)

WL Gore Thoracoabdominal Branched Endoprosthesis (TAMBE)

The Gore TAMBE is an off-the-shelf, multicomponent system with a proximal multibranched component, a distal bifurcated piece, and iliac limb extensions. Several configurations are available for visceral vessel incorporation, originally designed with the option of antegrade or retrograde renal artery portals. An upcoming clinical trial will include the design with four antegrade portals, with proximal diameters of 31 or 37 mm, a length of 160 mm, and a distal diameter of 20 mm [8]. The delivery system requires a 22 Fr sheath. The device has pre-cannulated, removable guiding tubes through all portals, which will assist with preloading of guidewires.

Preoperative Planning

The most important aspect of preoperative planning is identification of a healthy proximal and distal sealing zone (Fig. 32.3). Preoperative CT angiography (CTA) should be evaluated with centerline of flow (CLF) imaging. This will provide the greatest amount of information on the extent of disease. Aortic dilatation can be readily identified, compared with adjacent segments, and evaluated for specific vessel involvement. Generally, a minimum of 2 cm of length is preferred for sealing zones, with a segment of parallel aortic walls. Segments with a reverse conic configuration, or those with significant calcium or thrombus, are not suitable necks and should be considered part of the pathology [9].

Supra-celiac sealing zones are preferred whenever feasible. Our practice is to treat pararenal aneurysms with at least three fenestrations and a CA scallop, whereas paravisceral and extent IV TAAAs are typically repaired with four fenestrations. The authors favor a sealing length of 2.5 cm for TAAAs, and if there are no paired intercostal arteries cephalad to this, the sealing zone is extended for 3–4 cm [9].

The method of target vessel incorporation is largely based on anatomy. Fenestrations are selected when the vessels originate from narrower aortic diameters (<30 mm). This is the method most often used for pararenal and extent IV TAAAs. Additionally, fenestrations are preferred for renal artery incorporation if possible, because of their excellent 5-year patency rates. Transversely oriented or up-going vessels—frequently seen in extent I TAAAs—are also well suited for fenestrations. Directional branches are utilized for more extensive aneurysms, in which the inner aortic diameter is >30 mm. They are advantageous particularly for caudally oriented vessels such as the CA and SMA, or when renal arteries are down-going. Directional branches are typically deployed 2 cm cephalad to their intended target, resulting in the need for higher sealing zones.

Repair is usually performed with access via one or both iliofemoral arteries. The CTA should be scrutinized for small-caliber iliac arteries, severe calcification, occlusion, or tortuosity. In these cases, iliofemoral conduits may be required. Upper extremity access is an important adjunct in complex cases that involve directional down-going branches, or when target vessels are caudally oriented. The CA frequently can demonstrate stenosis due to median arcuate ligament compression, and efficient cannulation in these cases is also facilitated by an upper extremity approach. Many

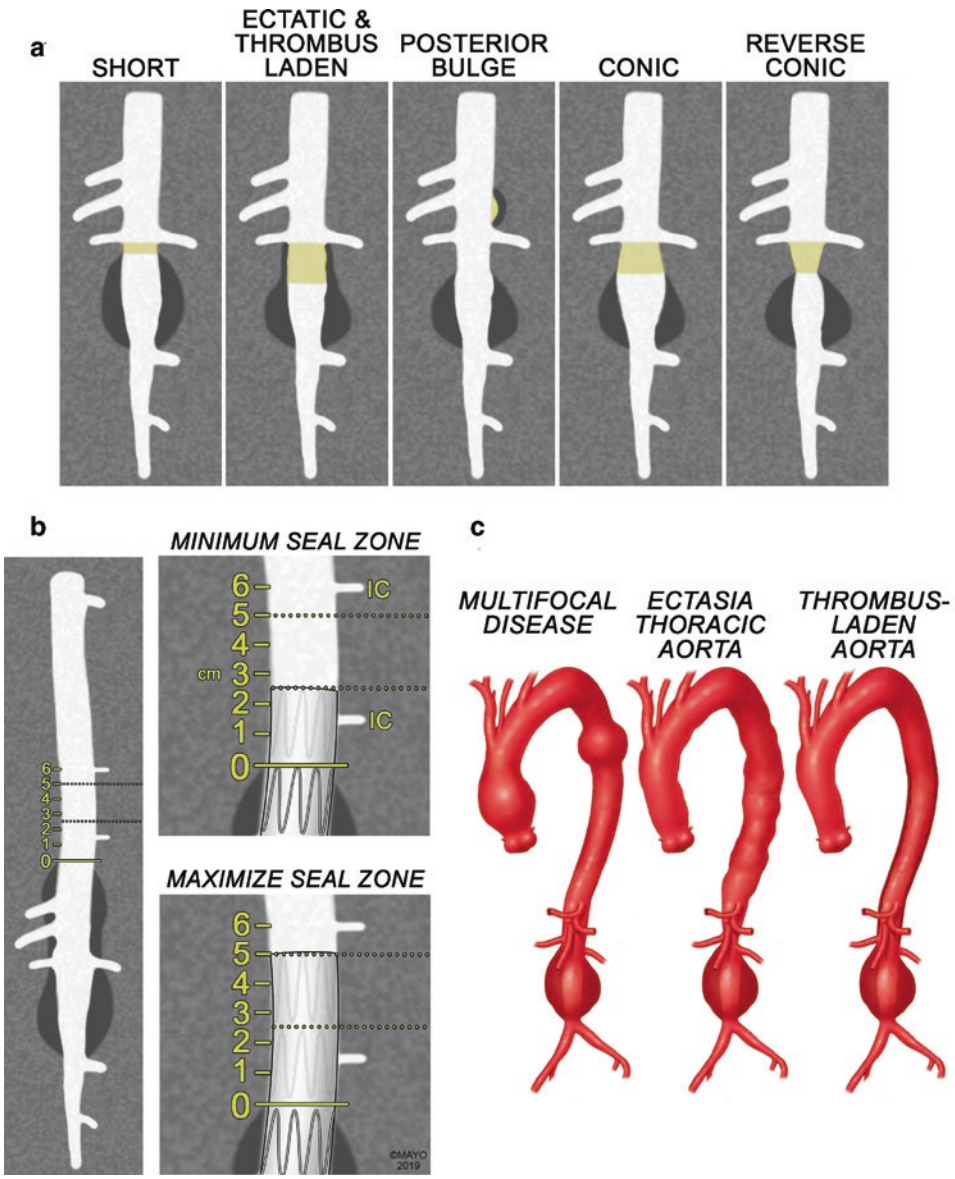


Fig. 32.3 (**a**) Suboptimal necks for endovascular aortic repair and selection of parallel walled aorta for placement of endograft. (**b**) Selection of healthy landing zones. Note the minimum of 2.5–3 cm used by the authors, ideally in the supra-celiac segment, with a minimum of a double scallop for the celiac axis, with maximization of the neck and sealing zone if there are no intercostal artery pairs in the area. (**c**) Longer lengths are needed in tortuous segments, such as in the aortic arch, or in patients with familial history of aortic disease, ectasia, or thrombus-laden aorta. (By permission of Mayo Foundation for Medical Education and Research. All rights reserved. *Adapted from* Oderich and Mendes [9]; *with permission*)

operators prefer left-sided upper extremity access to avoid crossing the aortic arch. The authors' practice has evolved away from selecting the left side whenever feasible, moving to the right side because of evidence of equivalent cerebroembolic complications. In addition, the right arm can be tucked at the patient's side to simulate femoral access, decreasing operator radiation exposure and improving ergonomics and workflow. Aortic arch anatomy should always be assessed, including arch type and thrombus and calcium burden, as well as disease of the supra-aortic trunks. Type III and some type II arches are better suited for left-sided access to prevent undue strain and manipulation of the arch.

Technique

Arterial Access

Whenever feasible, a percutaneous approach is utilized for femoral arterial access (Fig. 32.4). Preoperative CTA and intraoperative ultrasound evaluation is used to assess for heavily calcified arteries, high femoral bifurcations, or anteriorly positioned plaques. Under ultrasound guidance, a micropuncture needle is used to gain access to the anterior aspect of the common femoral artery, 1 cm proximal to the bifurcation. In obese patients, in whom body habitus may be

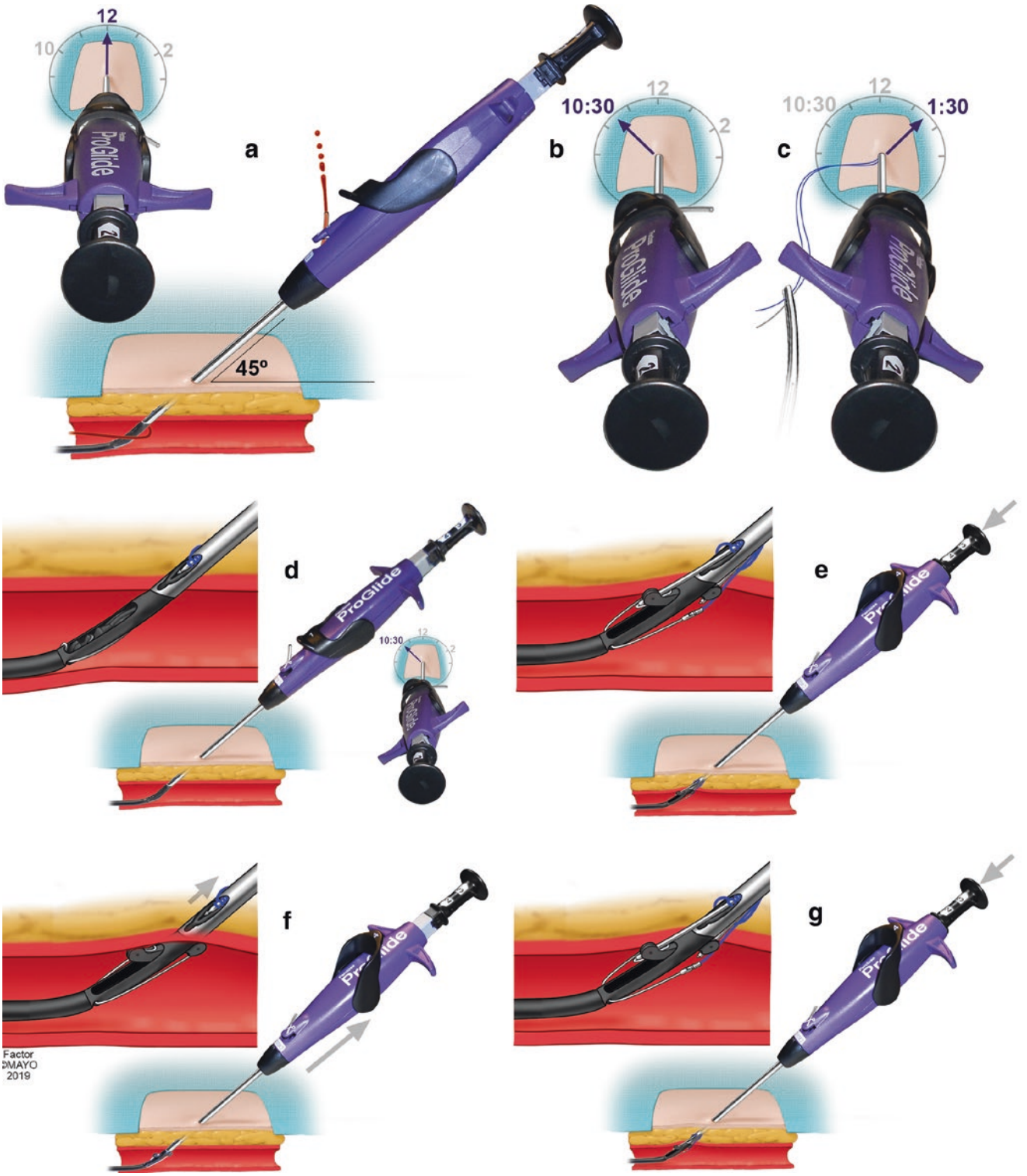
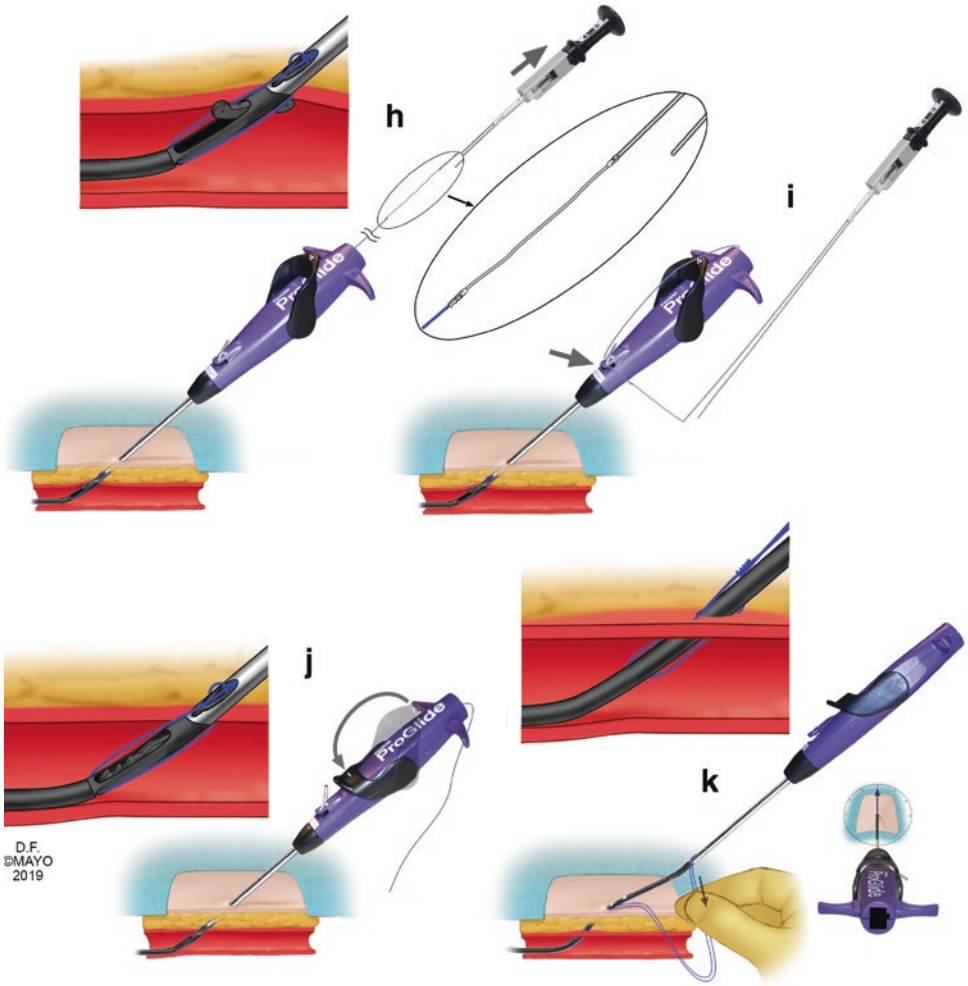


Fig. 32.4 Pre-closure technique is performed using the Perclose Proglide device. The device is introduced with a 45° angle to the skin entrance (**a**) until there is pulsatile bleeding via the side port. The percutaneous stitches are deployed at the 10:30 (**b**) and 1:30 (**c**) clock positions. After the device is introduced (**d**), the lever is pulled up, positioning the spatulas (**e**) parallel to the arterial wall, and using gentle traction (**f**), the stitch is applied (**g**). The suture string is pulled out (**h**), as indicated by #3, and the white portion of the suture is cut (**i**). The lever is lowered, as indicated by #4 (**j**), and both suture strings are secured to the drapes (**k**). (By permission of Mayo Foundation for Medical Education and Research. All rights reserved. *Adapted from* Roeder et al. [12]; *with permission*)

Fig. 32.4 (continued)



relatively prohibitive to common femoral access, large-caliber superficial femoral arteries may be used. An 0.018-inch guide-wire is advanced. A small oblique incision is made over the needle to allow for dilation of the skin and underlying soft tissue, and to facilitate subsequent placement of percutaneous vascular closure devices and large-caliber sheaths. A 4-Fr micro-sheath is used to exchange for a 0.035-inch guide-wire, such as a Bentson, followed by a 6 Fr × 10-cm sheath to dilate the arteriotomy. A set of two Perclose ProGlide closure devices is used at each femoral access site, with deployment at 1:30 and 10:30 clock positions, after which 8-Fr sheaths are advanced under fluoroscopic guidance into the external iliac arteries. The Bentson guide-wires are exchanged for Kumpe catheters and soft-angled glide-wires, which are advanced into the ascending aorta. The glide-wires are then exchanged for stiff, 0.035-inch Lunderquist wires (Cook Medical, Bloomington, IN).

The choice of access site for the main body depends on patient anatomy. If there are no constraints of vessel caliber or disease, the authors' preference is to utilize the right femoral approach for target-vessel catheterization, and introduce the fenestrated and bifurcated components from the left side. If the delivery system utilizes preloaded renal guide-catheters, such as with the Cook p-Branch, the fenestrated component is advanced from the right side. Once the Lunderquist wires are positioned, a large-caliber Check-Flo sheath (Cook Medical Inc., Bloomington, IN) is introduced through the right femoral approach. A 20-Fr sheath is utilized for two fenestrations, and 22-Fr for three fenestrations. The Check-Flo sheath is optimal for visceral cannulation because of the configuration of its valve with four leaflets. Two or three of the leaflets are accessed with a micropuncture needle to facilitate placement of 7-Fr × 10-cm sheaths to work through for visceral cannulation (Fig. 32.5).

In cases that warrant an upper extremity approach (four-vessel fenestrated grafts, directional branches), surgical exposure of the proximal brachial artery is preferred, although percutaneous access has been increasingly utilized [10].

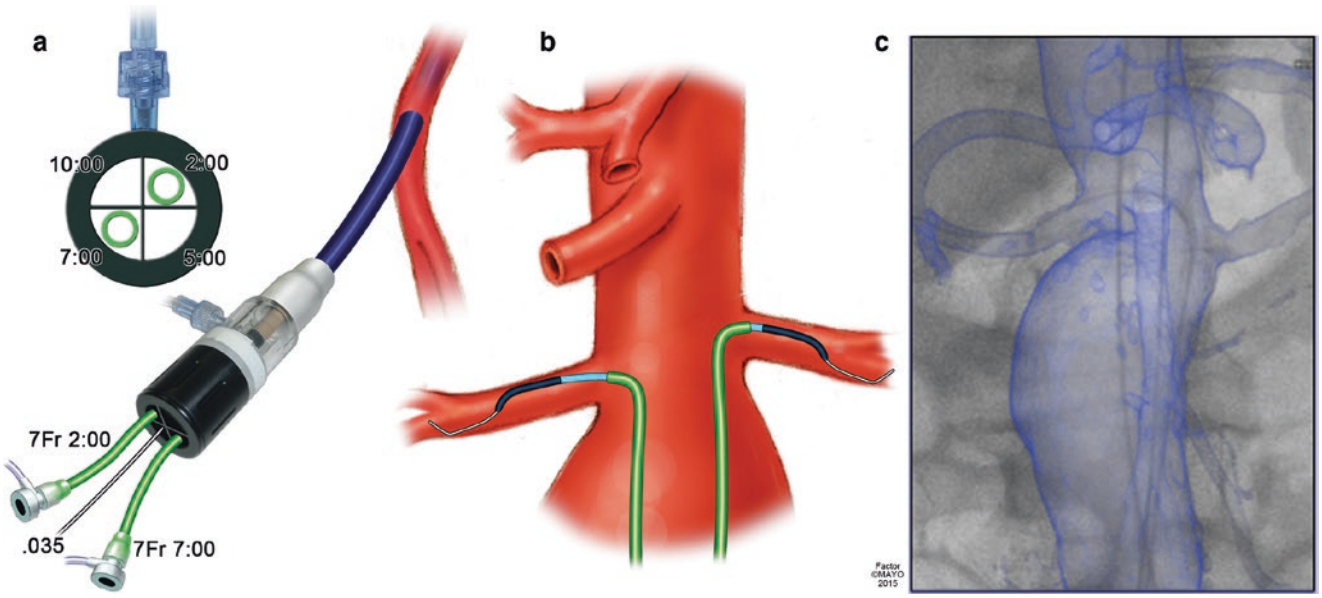


Fig. 32.5 Multi-sheath femoral access is obtained using a Check-Flo sheath, which has four valve leaflets that can be punctured for placement of two 7-Fr sheaths (**a**). Access into one or both renal arteries is obtained using LIMA guide-catheters and catheters (**b**) to calibrate on-lay fusion CT imaging and localize target vessels, minimizing the use of fluoroscopy and contrast (**c**). (By permission of Mayo Foundation for Medical Education and Research. All rights reserved. *Adapted from* Roeder et al. [12]; *with permission*)

Ultrasound evaluation is used to confirm that the artery is 4 mm in diameter. A transverse incision is made in the interval between the biceps and triceps muscles, just distal to the axilla. The median nerve is identified and protected, and the brachial artery is controlled with Silastic vessel loops. Under direct visualization, a micropuncture set is used to access the brachial artery and exchange for a 5-Fr × 10-cm sheath. Before cannulating the descending thoracic aorta, the patient is systemically heparinized for an activated clotting time of 225 seconds. A Cobra C2 catheter (Terumo, Somerset, NJ) and a soft angled glide-wire are used to cannulate the descending thoracic aorta. Over the protection of a stiff Amplatz Guidewire (Boston Scientific, Marlborough, MA), a 12-Fr Gore Dryseal Flex sheath (WL Gore, Flagstaff, AZ) is advanced in a single pass, to the mid descending thoracic aorta. This 12-Fr sheath allows for upper extremity use without repeated manipulation of the arch (Fig. 32.6) [11].

On-Lay Fusion CT

The concept of fusion is to use the preoperative CTA as a template for intraoperative navigation. The CT scan is processed to obtain a transparent volume-rendering reconstruction of the aortic lumen and its branches. This rendering can then be overlaid on the fluoroscopic image during the operation. Preoperative marking can be performed to identify important landmarks such as the proximal and distal landing zones, target-vessel origins, and the aortic bifurcation. This allows for intraoperative identification without repeated angiography and panning of the c-arm without fluoroscopy [13]. In order to calibrate the on-lay fusion CT, pre-catheterization of at least one renal artery is performed. This is accomplished with an 0.035-inch glide-wire and 5-Fr Kumpe catheter, with support from a 7-Fr LIMA guide-catheter. Limited angiography is performed to confirm positioning in the renal artery, and the fusion markers/rings are adjusted accordingly (*see* Fig. 32.5).

Device Deployment

Once the CT fusion has been calibrated, the fenestrated graft is extracorporeally oriented under fluoroscopy. It is then advanced through the left femoral approach and again oriented intracorporeally. The device should be deployed slightly higher than intended, as advancing the device after deployment is difficult. It is useful to deploy the first two to three stents and then confirm device orientation in multiple fluoroscopic planes. Once the fenestrated component has been deployed, each target vessel is catheterized, starting with the vessel furthest from the access site. For four-vessel configurations, we frequently utilize upper extremity access for the CA and SMA, so the device is ordered with preloaded catheters for these two vessels (Fig. 32.7). The preloaded catheters exit via an access scallop at the top of the device. A 480-cm 0.035-inch Metro guide-wire (Cook Medical Inc., Bloomington, IN) is advanced into each of the preloaded catheters from the femoral approach, and snared via the 12-Fr brachial sheath. This allows immediate access to the

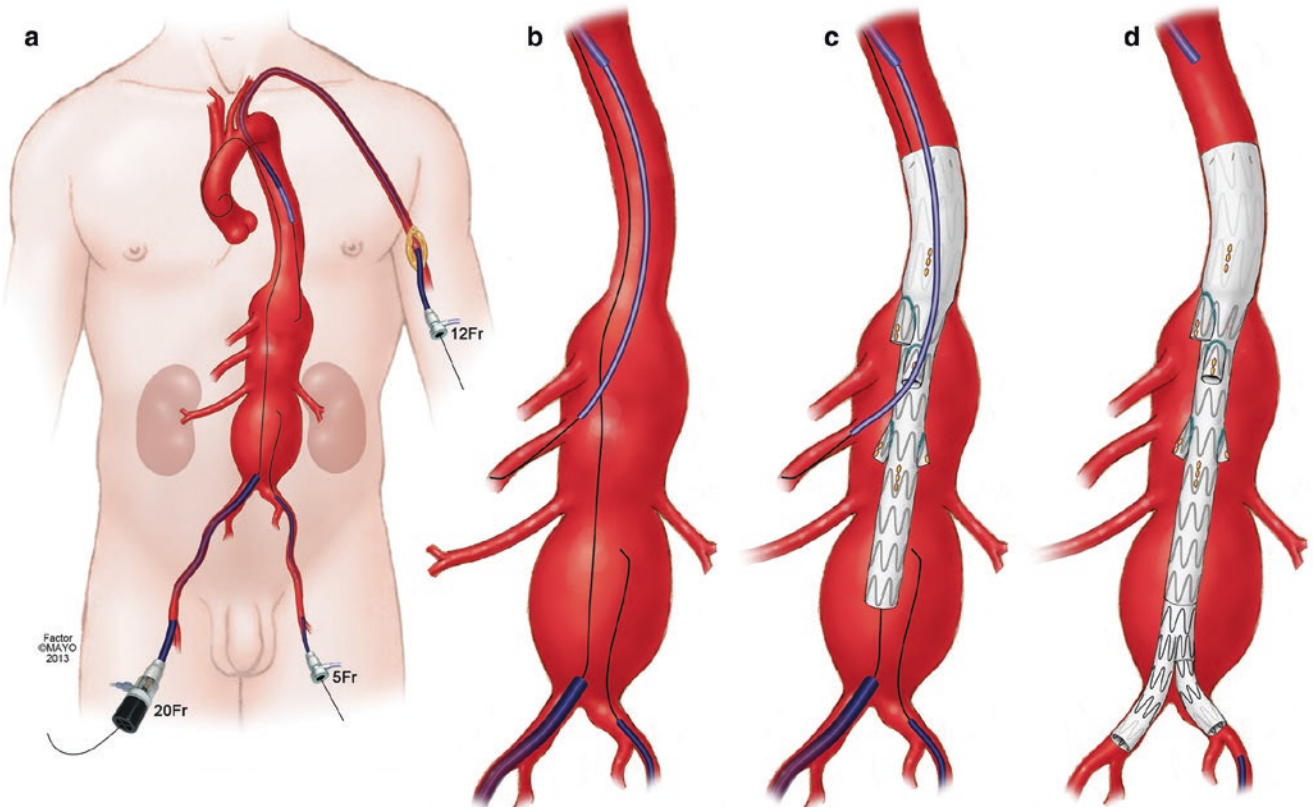


Fig. 32.6 Multibranched stent-grafts are designed with four directional branches for the celiac axis (CA), superior mesenteric artery (SMA), and both renal arteries. The procedure is usually done using bilateral femoral and left brachial access (**a**), although the authors' preference has recently changed to right brachial access. One of the target vessels is catheterized (**b**) to guide deployment of the stent-graft (**c**). The distal bifurcated device and iliac limbs are added and flow is restored to the lower limbs (**d**). (By permission of Mayo Foundation for Medical Education and Research. All rights reserved. *Adapted from* Roeder et al. [12]; *with permission*.)

CA and SMA fenestrations or branches, to facilitate rapid target-vessel cannulation. In these cases, staggered deployment of the device is used, first deploying distal to the CA fenestration, until the CA is catheterized. An 0.035-inch Amplatz wire is left in place, and the device is deployed below the SMA, again leaving behind an Amplatz wire once this vessel is catheterized. A 7-Fr hydrophilic sheath is then advanced into the SMA, and the remainder of the device is deployed.

The renal arteries are catheterized from below, using a soft angled glide-wire, Kumpe catheter, and LIMA guide-catheter. Angiography is performed to confirm positioning in the renal arteries, and then 0.035-inch Rosen wires (Cook Medical Inc., Bloomington, IN) are left in place (Fig. 32.8). The J-shaped tip of the Rosen wire is atraumatic and reduces risk of small-branch perforation, which is why it is favored in the renal arteries. If the renal arteries and SMA are intended to be stented from the femoral approach, 7-Fr Ansel sheaths (Cook Medical Inc., Bloomington, IN) are advanced into each vessel. If the CA and SMA are incorporated from the brachial approach, the renals are stented after the entire device is deployed. If there is any resistance or difficulty advancing the sheaths into the visceral vessels, an undersized balloon can be inflated at the vessel origin, and the sheath can be advanced over the balloon as it is deflated.

Target-Vessel Stenting

The alignment stents are placed under the protection of the 7–Fr sheath, with the tip of the stent just beyond the sheath. This technique prevents trauma to the visceral arteries by the sheath, when balloon angioplasty of the aortic neck is performed. Once all of the target-vessels have been accessed by sheaths, the diameter-reducing ties are removed. When a four-vessel repair is being performed, the access to the CA is maintained with an Amplatz wire, not a sheath. The device is completely deployed by advancing the top cap to release the uncovered fixation stent. The top cap is then retrieved, taking care not to lose target-vessel access. The proximal landing zone is then balloon-dilated with a Coda balloon (Cook Medical Inc., Bloomington, IN).

Target-vessel incorporation usually starts with the vessel furthest from the access site. In the case of three-vessel

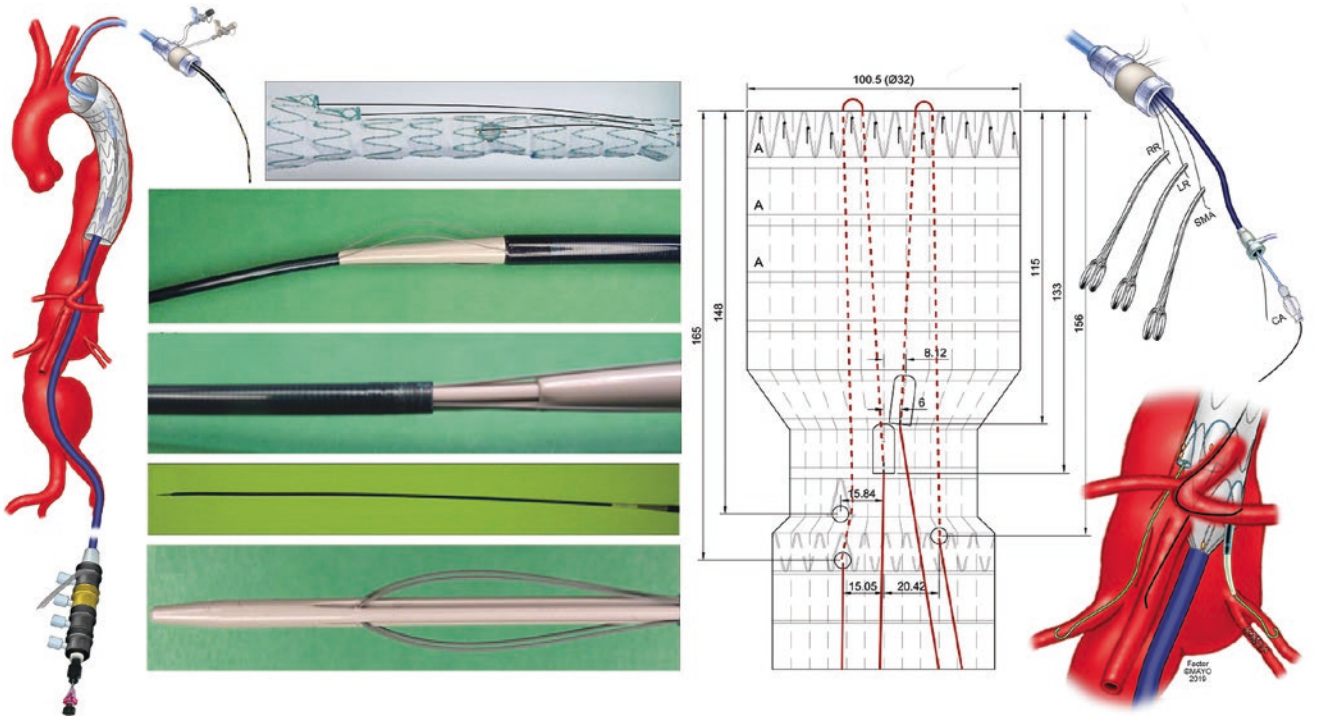


Fig. 32.7 Patient-specific fenestrated-branched stent-graft with preloaded guidewires, which the authors have used routinely with the Transabdominal Preloaded Delivery System (TPDS). The device has a long 8-Fr sleeve, which is exteriorized via the brachial sheath; the sleeve is removed, and the preloaded wires are cut and tagged individually to be utilized to access each branch or fenestration. Staggered deployment of the device is then performed as access is gained into each target vessel. (By permission of Mayo Foundation for Medical Education and Research. All rights reserved. *Adapted from* Oderich and Mendes [9]; *with permission*)

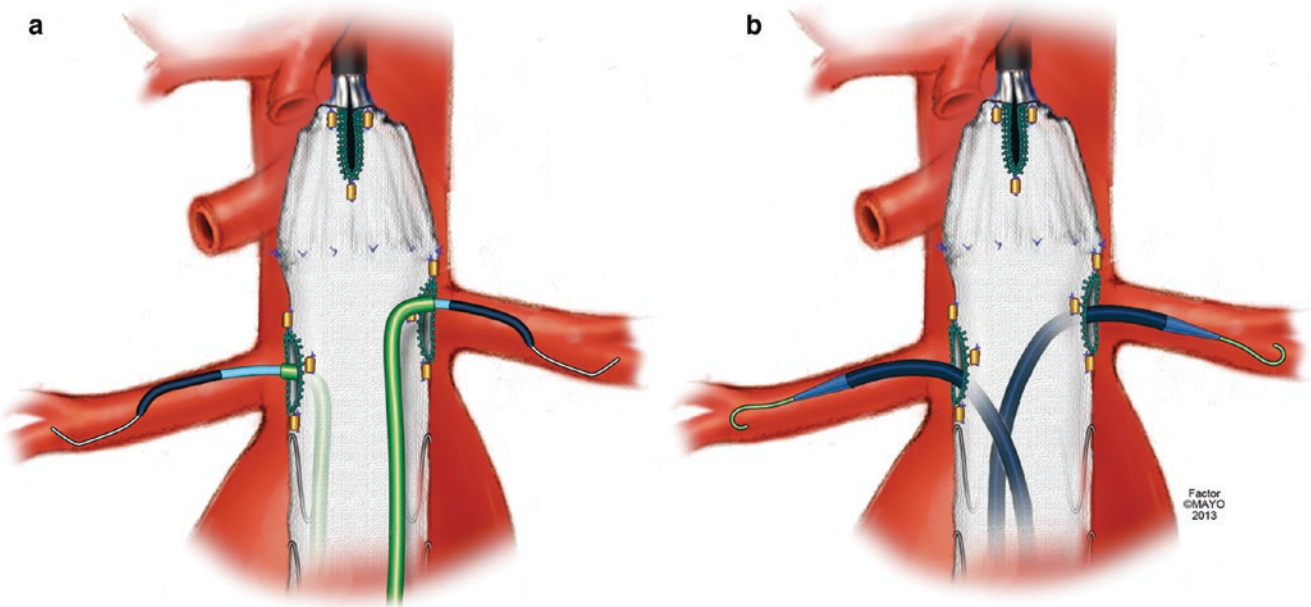


Fig. 32.8 In patients with juxtarenal aneurysms, devices are often designed with three fenestrations for the bilateral renal arteries and the SMA, with a double scallop to the CA, or with two fenestrations for the renal arteries and a scallop for the SMA, similar to the commercially approved Z-Fen device. In these cases, the authors' preference is to use only femoral access whenever possible. (**a**) Note the device is deployed matching the renal catheters or slightly higher. (**b**) Each catheter is sequentially removed from the renal artery and used to regain access into the fenestrations and target vessels, followed by advancement of a hydrophilic sheath over 0.035-inch Rosen guide-wires. (By permission of Mayo Foundation for Medical Education and Research. All rights reserved. *Adapted from* Roeder et al. [12]; *with permission*)

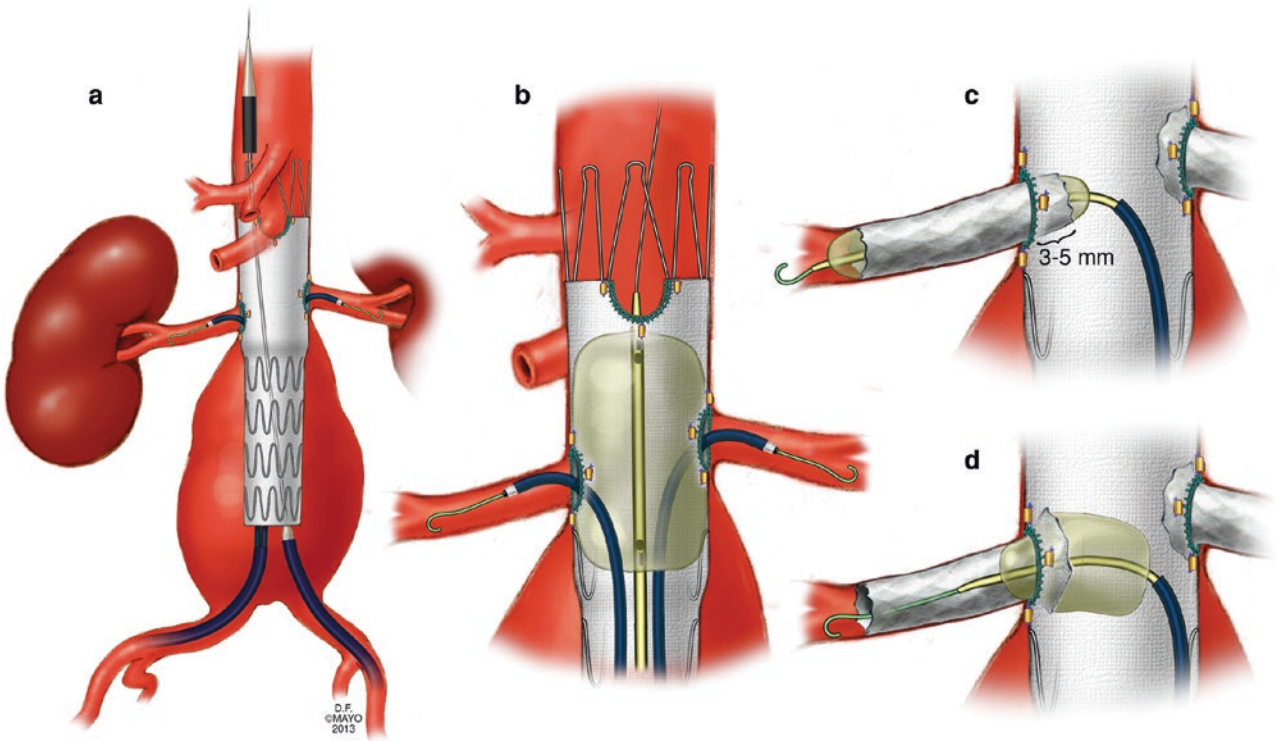


Fig. 32.9 Once the renal sheaths are positioned, the diameter-reducing tie is removed and the top cap is retrieved (**a**). The proximal sealing zone is gently dilated with a Coda balloon (**b**), followed by placement of the alignment stents (**c**). Each of the stents is flared using a 10-mm angioplasty balloon (**d**). (By permission of Mayo Foundation for Medical Education and Research. All rights reserved. *Adapted from* Roeder et al. [12]; *with permission*)

designs, the authors' preference is therefore to start with the SMA, followed by the higher renal artery. For four-vessel designs with preloaded CA and SMA catheters, the renal arteries are stented first, followed by the bifurcated component, and then the SMA and CA. Angiography is used to confirm stent positioning, and then the stent is ideally deployed 3–5 mm into the aorta (Fig. 32.9). The intra-aortic portion of the stent is flared with a 10-mm × 2-cm balloon, and a hand-injected limited angiography is performed to interrogate the repair. If close inspection of a target vessel is desired, digital subtraction angiography (DSA) can be employed, but otherwise, all efforts should be made to limit radiation exposure.

Once alignment stents have been deployed, the bifurcated component is advanced from the contralateral groin for three-vessel repairs. The dilator for the device can encroach on the contralateral renal or SMA stent. In order to protect these stents, it is helpful to leave a 10-mm balloon in these visceral stents to prevent crushing of the stent leaflets. A minimum of two full stents of overlap is required between the fenestrated and bifurcated components, but ideally three or more stents of overlap is recommended. Removal of the bifurcated delivery system should also be performed with care, again to prevent damage to the alignment stents. For four-vessel designs, the bifurcated device and iliac limbs are deployed prior to the SMA and CA alignment stents. This technique not only prevents damage to the SMA stent during placement of the bifurcated device, but also allows earlier restoration of lower extremity and pelvic flow, which is important for spinal cord perfusion in more extensive aneurysms.

The contralateral gate is catheterized with a 5-Fr Kumpe catheter and soft angled glide-wire. The catheter is rotated within the graft to confirm position; a Coda balloon also can be inflated in cases where catheter rotation is equivocal.

Extent I-III Thoracoabdominal Aneurysms

Most patients who undergo more extensive repair, with coverage starting from the left subclavian artery, have a staged repair. The first stage consists of proximal placement of a thoracic stent-graft, with extension to just above the CA. At this time, cervical debranching or iliofemoral conduits are also performed if necessary (Fig. 32.10).

For extent II and III TAAAs, a type 1b endoleak is typically expected at the end of the case. The second stage is focused on completion F-BEVAR, at which time extension

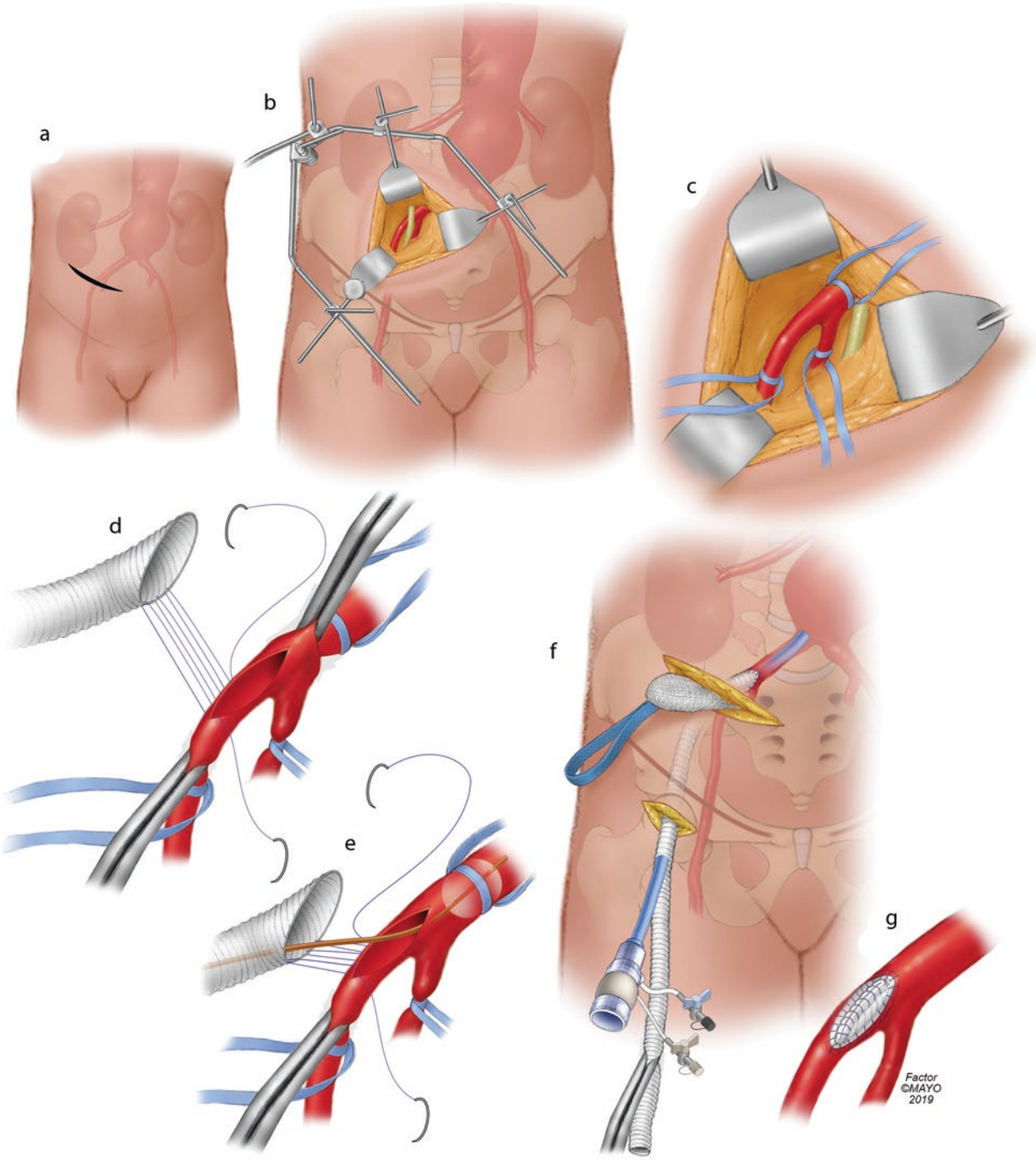


Fig. 32.10 Retroperitoneal exposure for open surgical iliac artery conduits is done using a curvilinear incision (**a**) and self-retaining retractor (**b**) to expose the common, external, and internal iliac arteries (**c**). After proximal and distal control is obtained, a longitudinal arteriotomy is made and 10-mm polyester graft is anastomosed end-to-side using 4–0 Prolene suture (**d**). Occasionally, balloon occlusion is needed for proximal control if the vessel is significantly calcified (**e**). The conduit is exteriorized via a small counter-incision in the groin (**f**). Once the procedure is completed, the graft is excised, leaving a small patch of graft in the iliac arteries (**g**). (By permission of Mayo Foundation for Medical Education and Research. All rights reserved. *Adapted from* Roeder et al. [14]; *with permission*)

of the thoracic stent-graft is performed first, if required. The authors frequently select designs with preloaded catheters for the CA and SMA in these cases. A staggered deployment is performed to just below the SMA branch/fenestration. Once access has been established in the CA and SMA branches/fenestrations, the CA is catheterized and a 0.018 Steelcore guide-wire (Abbott Vascular, Chicago, IL) is used to maintain wire access. Once the SMA is catheterized, a 9-Fr sheath is advanced into the vessel over a 1-cm–tip Amplatz wire. The fenestrated device is then reoriented to achieve perfect alignment of the renal fenestrations with the renal artery origins. The remainder of the device is completely unsheathed, and the renal arteries are accessed with 7-Fr hydrophilic sheaths, as previously described. With all four target-vessels catheterized, the diameter-reducing ties are released. The renal arteries are sequentially stented, followed by deployment of the bifurcated component and iliac limbs. Lower extremity perfusion is re-established, and upper extremity access is used to incorporate the SMA, followed by the CA.

Cone-Beam Computed Tomography

Traditionally, completion DSA is used for final assessment of the endovascular repair. For complex repairs, multiple projections may be necessary to evaluate the aortic, visceral, and iliac components of the reconstruction; these would require multiple contrast injections. Furthermore, CTA is commonly performed before hospital discharge, especially when findings on completion DSA were inconclusive or questionable. If reintervention is required, the patient then must be taken back to the operating room. A completion cone-beam CT (CBCT) overcomes these issues, using only one contrast injection and maintaining wire access during the procedure, which allows for rapid revision, if required. Our practice has evolved, and currently we prefer to perform a CBCT (with and without contrast), with no DSA. This has also replaced the CTA before hospital discharge (Fig. 32.11).

Access Site Closure

At the completion of the procedure, femoral arterial access is maintained with a wire until hemostasis is confirmed, allowing for the deployment of an additional closure device if necessary, or the reintroduction of a large-caliber sheath/balloon in patients (fewer than 5%) who require femoral artery exposure and open repair.

The brachial sheath is withdrawn and control is obtained by vascular clamps. The artery is inspected carefully for the presence of dissection, small intimal flap, or other flow-limiting pathology. Generally, the arteriotomy is closed primarily with 6–0 or 7–0 interrupted Prolene sutures. In our experience, 13% of brachial arteries are closed with bovine patch angioplasty to prevent any postoperative thrombotic or flow-limiting complications (Fig. 32.12) [11].

Summary

Fenestrated-branched endovascular aortic repair has rapidly progressed since its development in the 1990s. Continued advances in technology, operative adjuncts, and implantation techniques have allowed the expansion of its application from juxtarenal AAA to complex post-dissection aneurysms and aortic arch pathology. Careful preoperative planning is of paramount importance; there must be no compromise on identification of healthy sealing zones. Attention to detail and efficiency of operative technique and maneuvers are required for successful implantation.

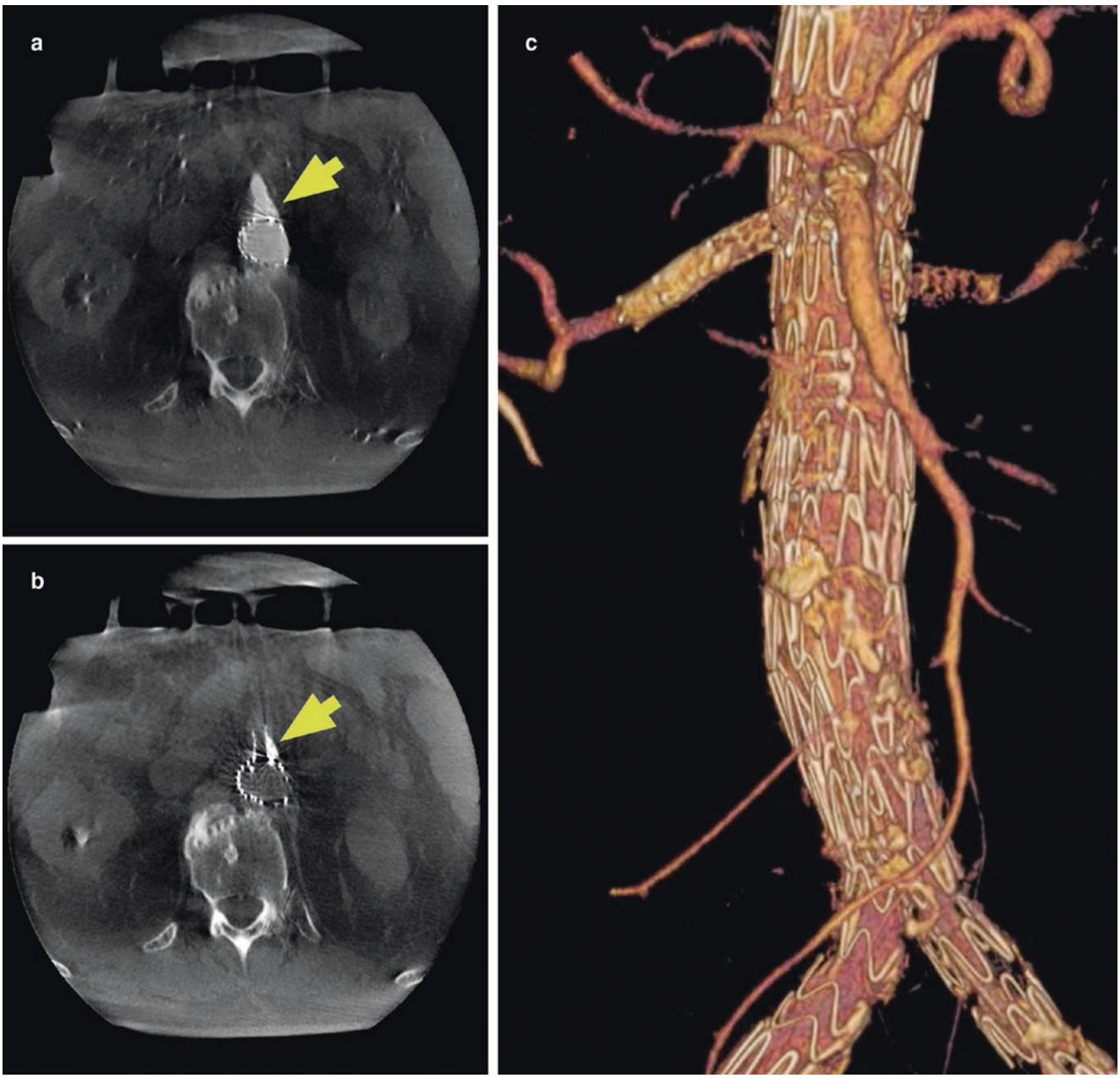


Fig. 32.11 Cone-beam computed tomography (CBCT) images with (**a**) and without (**b**) intra-arterial contrast are performed routinely at completion of the procedure, assisting with immediate intraoperative identification of stent kinks, occlusions, or endoleaks. Note the importance of the series without contrast in identifying a large, calcified plaque (*arrows*) at the origin of the SMA; this plaque resembled an endoleak in the phase with contrast**.** A three-dimensional reconstruction is generated to better delineate the stent morphology and architecture (**c**). (By permission of Mayo Foundation for Medical Education and Research. All rights reserved; *with permission*)

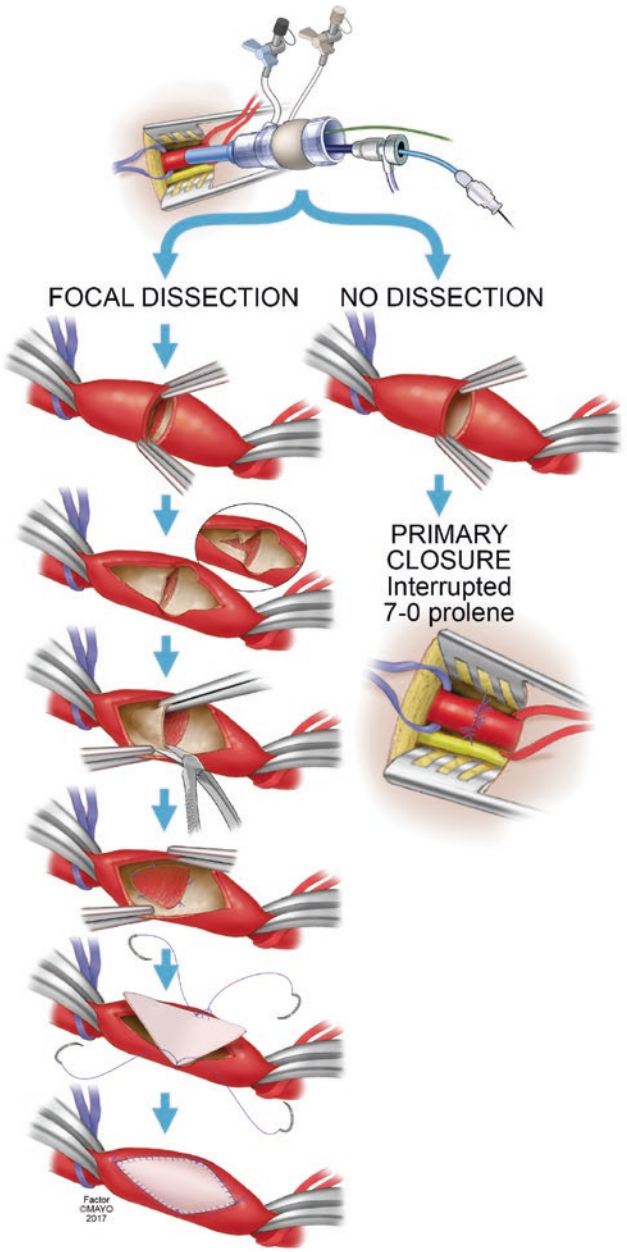


Fig. 32.12 Algorithm for brachial arteriotomy closure after routine inspection and sheath removal. If a focal dissection is identified, the flap is resected and tacked with 7–0 Prolene sutures, and the brachial arteriotomy is closed with a bovine pericardium patch. If no dissection is identified, primary closure with interrupted 7–0 Prolene suture is performed. (By permission of Mayo Foundation for Medical Education and Research. All rights reserved. *Adapted from* Mirza et al. [11]; *with permission*)

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Deep Vein Thrombosis and Pulmonary Embolus Thrombolysis and Endovascular Treatment

33

Patrick Muck

The field of vascular surgery has experienced by far the most dramatic evolution of any specialty in the medicine in the past three decades. New endovascular techniques have revolutionized the care of patients afflicted with vascular pathologies from arterial to venous disease. This chapter examines and focuses on deep vein thrombosis (DVT) and pulmonary embolus (PE). The natural history, existing literature, and available endovascular options for DVT and PE are examined.

Introduction

The United States Surgeon General issued a Call to Action in 2008 recognizing venous thromboembolism (VTE) as a major public health problem [1]. VTE, which encompasses deep vein thrombosis (DVT) and pulmonary embolism (PE), is the third most frequent cardiovascular disease, with an overall annual incidence of 100 to 200 per 100,000 inhabitants [2].

Deep Vein Thrombosis

Natural History

Venous thromboembolism has an annual incidence of 0.1%, a rate that varies from 0.01% in young adulthood to nearly 1.0% in persons 60 years of age or older [8–10]. The pathogenesis of venous thrombosis is mediated by the three components of Virchow's Triad: vessel wall damage, venous stasis, and hypercoagulability. Venous thromboembolism has multiple risk factors that often have a compound effect in combination. Some prominent risk factors include inherited antithrombin and protein C and protein S deficiency, acquired conditions such as major surgery or major trauma, antiphospholipid antibodies, and age greater than 70 years [11, 12].

Approximately 10% of all cases of deep vein thrombosis (DVT) involve the upper extremities, resulting in an annual incidence of 0.4–1 case per 10,000 people [13–15]. These cases have become more common with the increased use of central venous catheters, cardiac pacemakers, and defibrillators. Patients with DVT of the upper extremities tend to be younger, leaner, and more likely to have a diagnosis of cancer than those with DVT of the lower extremities [12].

Complications of DVT include pulmonary embolism (6% for upper extremities [16] vs. 15–32% for lower extremities [4, 12, 17]), recurrence at 12 months (2–5% for upper extremities [18, 19] vs. 10% for lower extremities [20]), and the post-thrombotic syndrome (5% for upper extremities [21] vs. up to 56% for lower extremities [22, 23]). In a prospective outcome study published in 2008 of 512 patients with upper extremity DVT (38% of whom had cancer), the 3-month mortality rate was 11%, with only one death due to PE [15].

Medical Therapy

Once the diagnosis of acute DVT is made, the goals of treatment are the relief of symptoms and the prevention of embolization and recurrence. Therapy is broken up into initial therapy for the acute thrombosis (5–10 days), a maintenance period of 3–6 months, and long-term therapy for secondary prophylaxis [24].

Clinical guides can help physicians decide whether a patient needs long-term anticoagulant therapy or if the medication can be stopped at an earlier point, such as following ≥3 months of anticoagulation [25]. Initial anticoagulant therapy is designed to dissolve the clot, restore blood flow, and prevent PE or recurrent DVT. There is no standard for the medical treatment for DVT. Recommendations should be

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based on clot location, separating patients with iliofemoral DVT (IFDVT) from those with more proximal DVT.

Per the AHA 2011 standard [3], three classes of patients can be identified:

- Patients with a first episode of DVT related to a major reversible risk factor (recent surgery, trauma) can safely stop anticoagulation after 3 months in most cases.
- Patients with recurrent or unprovoked DVT require indefinite duration of anticoagulants, with periodic reassessment of risk and benefit.
- Cancer patients have specific considerations based on their treatment regimens.

The AHA published recommendations for IFDVT [3]:

- In the absence of suspected or proven heparin-induced thrombocytopenia, patients with IFDVT should receive therapeutic anticoagulation with either intravenous UFH (Class I, LOE A); UFH by subcutaneous injection (Class I, LOE B); low molecular weight heparin (LMWH) (Class I, LOE A); or fondaparinux (Class I; LOE A).
- Patients with IFDVT who have suspected or proven heparin-induced thrombocytopenia should receive a direct thrombin inhibitor (Class I; LOE B).

To prevent recurrence, patients are given antithrombotic therapy of heparin and vitamin K antagonists or direct oral anticoagulants (DOAC) for at least 3 months [2].

Anticoagulation with unfractionated heparin is given by continuous intravenous infusion following a loading dose. Laboratory monitoring to assess activated PTT is required, with adjustment of the dose. Hemorrhage occurs in up to 7% of patients during initial treatment; the risk is a function of the dose of heparin, the patient's age, and the concomitant use of antiplatelet and thrombolytic agents [26]. If heparin is used for longer than 1 month, osteoporosis may result [27–29].

Heparin-induced thrombocytopenia is immune-mediated, and 30–50% of cases are associated with venous or arterial thrombosis. Patients who have had previous heparin-induced thrombocytopenia are treated with alternative anticoagulant agents [14, 27].

Meta-analyses suggest that LMWH is just as effective as UFH in preventing recurrent venous thromboembolism, while causing less bleeding [30]. Additionally, LMWH produces a lower incidence of heparin-induced thrombocytopenia than UFH [31, 32], and it causes less osteoporosis [24, 28, 29, 31]. In selected patients, outpatient therapy with LMWH is safe and effective; over 80% of patients can be treated without hospitalization [31, 33, 34].

However, outpatient therapy is unsuitable in the acute phase of this disease in patients with massive thrombosis, serious coexisting illness, or those at a high risk of hemorrhage. Such patients are usually elderly, have undergone recent surgery, or have a history of bleeding or renal or liver disease. After 5 days of overlap with vitamin K antagonists (VKAs) such as warfarin, heparin treatment can be stopped. Nonetheless, VKAs have a narrow therapeutic index due to interactions with other prescription medications and foods.

Recently, direct oral anticoagulants (DOACs) were recommended for acute DVT by the American College of Chest Physicians (ACCP) as the first-line anticoagulant therapy over VKAs (i.e., initial 3 months), although receiving a weak Grade 2B recommendation [6]. This recommendation follows six large phase-3 trials assessing four DOACs (dabigatran, rivaroxaban, apixaban, and edoxaban) that are comparable in efficacy to VKA therapy, but with a lower risk of bleeding and fewer interactions with other medications and/or food [23, 35–38]. Indeed, a meta-analysis established that use of DOACs was associated with a 39% decrease in major bleeding [39]. Though DOACs should be considered as first-line treatments, VKAs are still recommended for use in patients with renal impairment or those in whom these drugs are contraindicated [40].

Based on two recent trials demonstrating that aspirin reduces the risk of venous thromboembolism by about 30%, the ACCP has given a weak Grade 2C recommendation for aspirin in patients with venous thromboembolism for whom extended-duration anticoagulant therapy is contraindicated [41, 42].

Endovascular Therapy

The 2011 statement from the AHA [3] discusses several thrombo-reductive strategies for clot treatment:

Systemic thrombolysis is not recommended for the treatment of acute DVT, owing to the increased risk of major bleeding [43]. Instead, local thrombolysis with CDT is used in patients with severe symptoms and a high risk of bleeding [44, 45]. Thrombolytic agents dissolve fresh clots and restore venous patency more rapidly than do anticoagulants. Selective, interventional, catheter-directed infusion results in a higher local concentration of the lytic agent than systemic administration. Theoretically, selective endovascular administration of the drug should result in higher efficacy, but this hypothesis remains untested. Both routes of administration cause substantially more bleeding than heparin [46].

Catheter-directed therapies (CDTs) allow for the infusion of a thrombolytic agent directly into the blood clot, with a multi-side hole catheter and guidance from imaging [47].

Pharmacomechanical catheter-directed thrombolysis (PCDT) couples the delivery of intra-thrombus thrombolytic agent infusion with mechanical thrombectomy devices [47]. PCDT is faster than CDT in terms of dissolving the clot, and it

improves safety by reducing the drug dose and exposure time [43, 48, 49]. In particular, with AngioJet (a PCDT device) [50].

- 96% of patients had Grade II/III (50–100%) clot reduction
- Significant improvements over baseline in both physician and mental component scores of the SF-12.
- 83% freedom from rethrombosis at 12 months.

Percutaneous mechanical thrombolysis (PMT) refers to a catheter-based device that mechanically contributes fragmentation, maceration, balloon angioplasty, stenting, and/or thrombectomy [47]. PMT typically is used only in patients with persistent or severe DVT who are refractory to thrombolysis. In a case series of 49 patients, venous stents provided a temporary clinical benefit in most patients, but 62% required repeat intervention within 2 years [51]. The use of these devices alone without concomitant thrombolytic administration decreases the need for overnight drug infusion but may be associated with symptomatic PE (Table 33.1).

Percutaneous aspiration thrombectomy (PAT), a type of mechanical thrombectomy, involves aspiration of the throm-

Table 33.1 Recommendations for acute phase treatment of Pulmonary Embolism (PE): European Society of Cardiology (ESC)

Recommendations	Class of Recommendation	Level of Evidence
PE with shock or hypotension (high-risk)		
Initiate intravenous anticoagulation with unfractionated heparin (UFH) without delay	I	C
Thrombolytic therapy	I	B
Perform surgical pulmonary embolectomy for patients in whom thrombolysis is contraindicated or has failed[a]	I	C
Consider percutaneous catheter-directed treatment as an alternative to surgical pulmonary embolectomy for patients in whom full-dose systemic thrombolysis is contraindicated or has failed[a]	IIa	C
PE without shock or hypotension (intermediate or low risk)		
Anticoagulation: Combination of parenteral treatment with vitamin K antagonist (VKA)		
Parenteral anticoagulation without delay is recommended for patients with high or intermediate probability of PE while diagnostic workup is in progress	I	C
LMWH or fondaparinux is the recommended form of acute phase parenteral anticoagulation for most patients	I	A
In parallel to parenteral anticoagulation, treatment with a VKA is recommended, targeting an INR of 2.5 (range 2.0–3.0)	I	B
Anticoagulation: New Oral anticoagulants		
As an alternative to the combination of parenteral anticoagulation with a VKA, anticoagulation with rivaroxaban (15 mg BID for 3 weeks, followed by 20 mg qd) is recommended	I	B
As an alternative to the combination of parenteral anticoagulation with a VKA, anticoagulation with apixaban (10 mg BID for 7 days, followed by 5 mg BID) is recommended	I	B
As an alternative to VKA treatment, administration of dabigatran (150 mg BID or 110 mg BID for patients ≥80 years of age or those under concomitant verapamil treatment) is recommended following acute-phase parenteral anticoagulation	I	B
As an alternative to VKA treatment, administration of edoxaban is recommended following acute-phase parenteral anticoagulation	I	B
New oral anticoagulants (rivaroxaban, apixaban, dabigatran, edoxaban) are not recommended in patients with severe renal impairment.	III	A
Reperfusion treatment		
Routine use of primary systemic thrombolysis is not recommended in patients not suffering from shock or hypotension	III	B
Close monitoring is recommended in patients with intermediate–high risk PE to permit early detection of hemodynamic decompensation and timely initiation of "rescue" reperfusion therapy	I	B
Consider thrombolytic therapy for patients with intermediate–high-risk PE and clinical signs of hemodynamic decompensation	IIa	B
Consider surgical pulmonary embolectomy for intermediate–high-risk patients if the anticipated risk of bleeding under thrombolytic treatment is high	IIb	C
Consider percutaneous catheter-directed treatment for intermediate–high-risk patients if the anticipated risk of bleeding under thrombolytic treatment is high	IIb	B
Early discharge and home treatment		
Patients with acute low-risk PE should be considered for early discharge and continuation of treatment at home if proper outpatient care and anticoagulant treatment can be provided.	IIa	B

Adapted from Konstantinides et al. [5]
LMWH low molecular weight heparin.
[a]If appropriate resources and expertise are available on site

bus using a syringe or other suction source [47]. Preliminary studies related to these devices have shown high rates of recanalization (86%) [52] and favorable safety profiles when compared with alternatives for the treatment of iliofemoral venous thrombosis [53].

Choice of Endovascular Thrombolysis

Acute DVT: Systemic thrombolysis is not recommended for the treatment of acute DVT, because of the increased risk of major bleeding [43]. Instead, local thrombolysis with CDT is used in patients with severe symptoms and a high risk of bleeding [44, 45]. Thrombolytic agents dissolve fresh clots and restore venous patency more rapidly than do anticoagulants. Selective, interventional, catheter-directed infusion results in a higher local concentration of the lytic agent than systemic administration. Theoretically, selective endovascular administration of the drug should result in higher efficacy, though both routes of administration cause substantially more bleeding than heparin [46]. The 250-patient randomized CaVenT trial demonstrated that CDT reduced the incidence of post-thrombotic syndrome in patients with iliofemoral DVT patients, but it was not associated with a corresponding improvement in quality of life [54].

DVT of an upper extremity: Data regarding the outcome of thrombolysis in patients with upper extremity DVT are limited. Among 30 such patients who underwent CDT with recombinant tPA (median total dose, 52 mg), the rate of partial or complete recanalization was 97%, the rate of major bleeding complications was 9%, and the rate of mild post-thrombotic syndrome was 21% [55]. Although the recanalization rate appears to be satisfactory, it remains unclear whether thrombolysis (compared with anticoagulation alone) reduces the risk of recurrent thrombosis, PE, or the post-thrombotic syndrome among patients with DVT of an upper extremity.

Results of Therapy Studies

One of the largest published experiences with selective catheter-directed techniques has been the National Venous Thrombolysis Registry, which reported on 287 patients in whom 1- year follow up was available [56]. Complications included an 11% incidence of major bleeding that required transfusion of blood products, and a 16% incidence of minor bleeding. The risks of intracranial hemorrhage and death were 0.2% and 0.4%, respectively.

In older endovascular therapy studies, major bleeding was reported in 5–12% of patients, but more recent randomized controlled trials report much lower bleeding rates, and fatal PE after CDT is rare [55, 56–59].

The multicenter randomized 692-patient Acute Venous Thrombosis: Thrombus Removal with Adjunctive Catheter-Directed Thrombolysis (ATTRACT) trial, published in the *New England Journal of Medicine* in 2017, compared anticoagulant therapy with and without CDT [60]. In the CDT group, CDT (delivery of <35 mg of recombinant tPA directly into the thrombus) was done in one of three ways. In patients with popliteal vein obstruction or inferior vena cava involvement, "infusion-first" therapy was used, in which a multiside hole catheter was placed across the venous thrombus and the tPA was infused for no longer than 30 hours. For the other patients, physicians could use either the AngioJet Rheolytic Thrombectomy System (Boston Scientific), delivering a pulse-spray of tPA to the thrombus, or the Trellis Peripheral Infusion System (Covidien), with two catheter-mounted balloons that are inflated to isolate the thrombus-bearing venous segment; the tPA is delivered through side holes in the catheter. The tPA was infused for no longer than 24 hours if residual thrombus was present.

After the initial delivery of tPA, other techniques were used to clear residual thrombus and treat obstructive lesions, including balloon maceration, catheter aspiration, thrombectomy (with use of the AngioJet or Trellis system), percutaneous transluminal balloon venoplasty, stent placement (in the iliac or common femoral vein), or combined procedures.

The primary efficacy endpoint of the ATTRACT trial was post-thrombotic syndrome (PTS) as defined by a score of ≥5 on the Villalta PTS scale at any time between 6 months and 24 months after randomization [61]. This trial found that the addition of pharmacomechanical CDT to anticoagulation did not reduce the risk of PTS (48% with anticoagulation alone, compared with 47% in the CDT-added group, $p = 0.56$), but it did result in a higher risk of major bleeding (0.3% with anticoagulation alone, compared with 1.7% in the CDT-added group, $p = 0.049$).

Overall Conclusions Related to Endovascular Therapy

The current use of CDT for the treatment of long infusion times, longer hospital stays, and systemic bleeding. PMT is the treatment of DVT [49]. -PAT is generally accepted as a safe technique for the management of DVT, as mechanical thrombectomy devices are not required, limiting the risk of damage to the vascular walls. Further, thrombolytic agents are not required for PAT treatment, so the risk of systemic bleeding is absent [62].

Endovascular Devices

Inari Medical ClotTriever® Thrombectomy System

The Inari Medical ClotTriever® Thrombectomy System (Inari Medical, Irvine, CA) is the first interventional product designed specifically to treat venous clot by "coring" clot from the vessel wall, without the need for thrombolytic drugs (tPA) and with no capital equipment. The system allows

"single session" treatment of venous clot. The single-use, sterile medical device is designed to remove soft thrombi and emboli from the peripheral vasculature. The ClotTriever® Thrombectomy System consists of the ClotTriever Sheath ("Sheath") and the ClotTriever Catheter ("Catheter"), each packaged separately.

The Sheath (Fig. 33.1) is an introducer sheath with a distal self-expanding funnel, aspiration port, and proximal hub. A dilator is provided to aid insertion and positioning of the Sheath. The Sheath and Dilator tips are radiopaque, and there is a radiopaque marker band at the proximal end of the Sheath funnel.

The ClotTriever Catheter (Figs. 33.2 and 33.3) is a coaxial catheter assembly (inner, intermediate, and outer) with a distal collection bag for collecting thrombus. The proximal handle is used to expand the collapsed collection bag. Two stopcocks are provided for de-airing the ClotTriever catheter shafts.

The ClotTriever® Thrombectomy System is indicated for the nonsurgical removal of soft thrombi and emboli from blood vessels and for the injection, infusion, and/or aspiration of contrast media and other fluids into or from a blood vessel. The system is intended for use in the peripheral vasculature.

Inari Medical FlowTriever® Thrombectomy System

The Inari Medical FlowTriever® Thrombectomy System (Inari Medical, Irvine, CA) is a single-use, sterile medical device comprising two components, the FlowTriever Catheter and the Triever20. The FlowTriever Catheter is used to engage and retrieve emboli and thrombi. It consists of a coaxial catheter assembly with an outer delivery catheter and an inner catheter having a flexible shaft attached to distal self-expanding wire form disks. A "Y" connector with a rotatable hemostatic valve and stopcock is attached to the proximal end of the outer delivery catheter. Radiopaque markers are positioned near the distal tip of the delivery catheter and at the proximal and distal ends of the self-expanding FlowTriever disks to aid with fluoroscopic visualization (Fig. 33.4a).

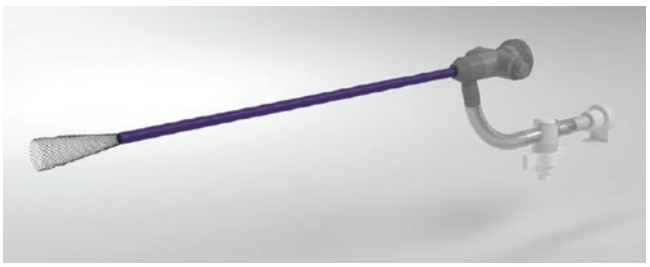

Fig. 33.1 ClotTriever® Sheath with dilator (*Used with permission of* Inari Medical)

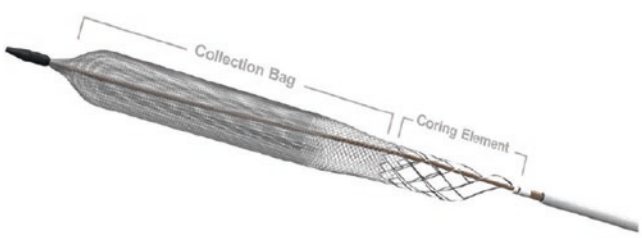

Fig. 33.2 ClotTriever catheter (*Used with permission of* Inari Medical)

Fig. 33.3 Expanded ClotTriever catheter (collection bag deployed) (*Used with permission of* Inari Medical)

The Triever20 provides a conduit for FlowTriever Catheter deployment, aspiration, and clot removal. The Triever20 is a single-lumen catheter with a proximal hemostatic valve and a side port with a stopcock terminating in a large-bore connector. A radiopaque marker is positioned near the distal tip to aid with fluoroscopic visualization. A dilator compatible with a 0.035″ guidewire is provided for the Triever20 (Fig. 33.4b).

The FlowTriever® Thrombectomy System is indicated for the nonsurgical removal of emboli and thrombi from blood vessels, and for injection, infusion, and/or aspiration of contrast media and other fluids into or from a blood vessel. The system is intended for use in the peripheral vasculature and for the treatment of pulmonary embolism.

The FLARE Study

The objectives of the FLARE (FlowTriever Pulmonary Embolectomy) clinical study [7] were to evaluate the safety and effectiveness of percutaneous mechanical thrombectomy using the FlowTriever System in a prospective trial of patients with acute, intermediate-risk PE. Patients were eligible for enrollment if they had symptomatic, CT-documented PE and RV/LV ratio ≥ 0.9, with no recent thrombolytic therapy or contraindication to anticoagulation. The primary effectiveness endpoint was core laboratory-assessed change in RV/LV ratio. The primary safety endpoint comprised device-related death, major bleeding, treatment-related clini-

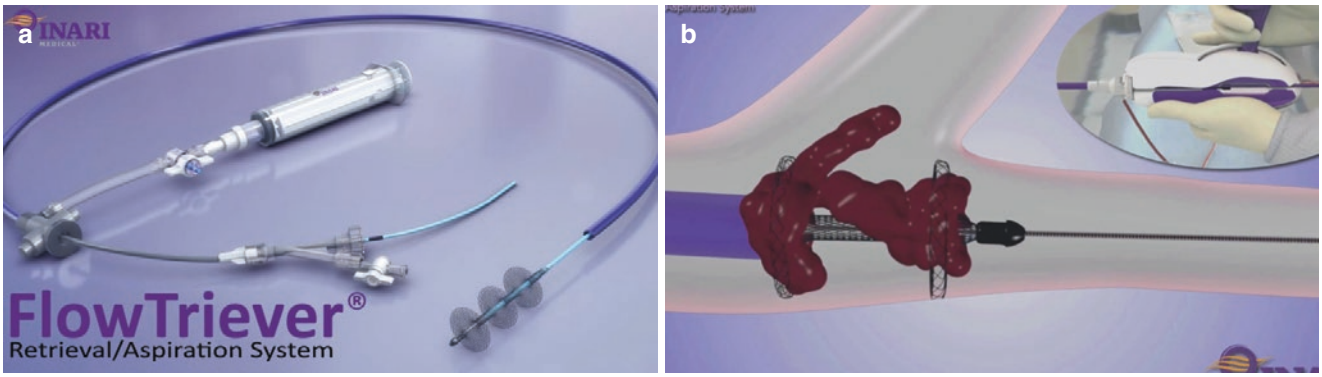

Fig. 33.4 (**a**, **b**) FlowTriever® catheter (*Used with permission of* Inari Medical)

cal deterioration, pulmonary vascular injury, or cardiac injury within 48 hours of thrombectomy.

From April 2016 to October 2017, 106 patients were treated with the FlowTriever System at 18 U.S. sites. Two patients (1.9%) received adjunctive thrombolytics and were analyzed separately. Mean procedural time was 94 minutes; mean ICU stay was 1.5 days; 43 patients (41.3%) did not require any ICU stay. At 48 hours post-procedure, average RV/LV ratio reduction was 0.38 (25.1%; $P < 0.0001$). Four patients (3.8%) experienced six major adverse events; 1 patient experienced major bleeding. One patient (1.0%) died, of undiagnosed breast cancer, through 30-day follow-up.

The conclusion was that percutaneous mechanical thrombectomy with the FlowTriever System is safe and effective in patients with acute intermediate-risk PE, with significant improvement in RV/LV ratio and minimal major bleeding. Potential advantages include immediate thrombus removal, absence of thrombolytic complications, and reduced need for post-procedure critical care.

Indigo® Mechanical Thrombectomy System

The Indigo® Mechanical Thrombectomy System (Penumbra, Inc.; Alameda, CA) utilizes continuous aspiration technology, with a braided noncollapsible catheter connected to a aspiration unit. The Indigo® system is intended to be used for thrombus removal in all vessels. Figures 33.5, 33.6, 33.7, and 33.8 illustrate the catheter extracting thrombus.

JETi® Thrombectomy System

JETi® Thrombectomy System (Walk Vascular, Irvine, CA) utilizes a clot disruptor system with active catheter aspiration (Fig. 33.9).

AngioJet™ Thrombectomy System

The AngioJet™ Thrombectomy System (Boston Scientific, Marlborough, MA) is a rheolytic thrombectomy system, which is indicated for use in the peripheral venous system. It utilizes the Bernoulli principle, with aspiration through the central segment of the catheter (Figs. 33.10, 33.11, and 33.12).

AngioVac® Cannula and Circuit

The AngioVac® Venous Drainage System (AngioDynamics, Latham, NY) (Figs. 33.13 and 33.14) is indicated for use as a venous drainage cannula during extracorporeal bypass and for removal of fresh, soft thrombi or emboli during extracorporeal bypass for up to 6 hours. It is contraindicated if the patient has severe arterial or venous vascular disease, and it should not be used for the removal of chronic firmly adherent intravascular material (e.g., atherosclerotic plaque, chronic pulmonary embolism).

EKOS® Thrombectomy System

The EKOS® technology is called Acoustic Pulse Thrombolysis™ treatment. It uses ultrasound in combination with a thrombolytic drug to quickly, safely, and effectively dissolve thrombus. The ultrasound thins the clot fibrin to allow the drug to penetrate the clot more rapidly and completely. The system (Figs. 33.15, 33.16, and 33.17) automatically monitors and controls the ultrasound delivery. The single-use sterile EkoSonic® Endovascular device consists of an infusion catheter (labeled IDDC) and an ultrasonic core (labeled MSD).The reusable EkoSonic® Control Unit provides power to the device and includes the user interface for operator control.

Fig. 33.7 Penumbra Engine (Aspiration Pump)

Fig. 33.5 Thrombus clearing with XTORQ Indigo® catheter

Fig. 33.6 Indigo System Catheters CAT 3,5, Rx,6,8,D

Fig. 33.8 Penumbra Engine (Original)

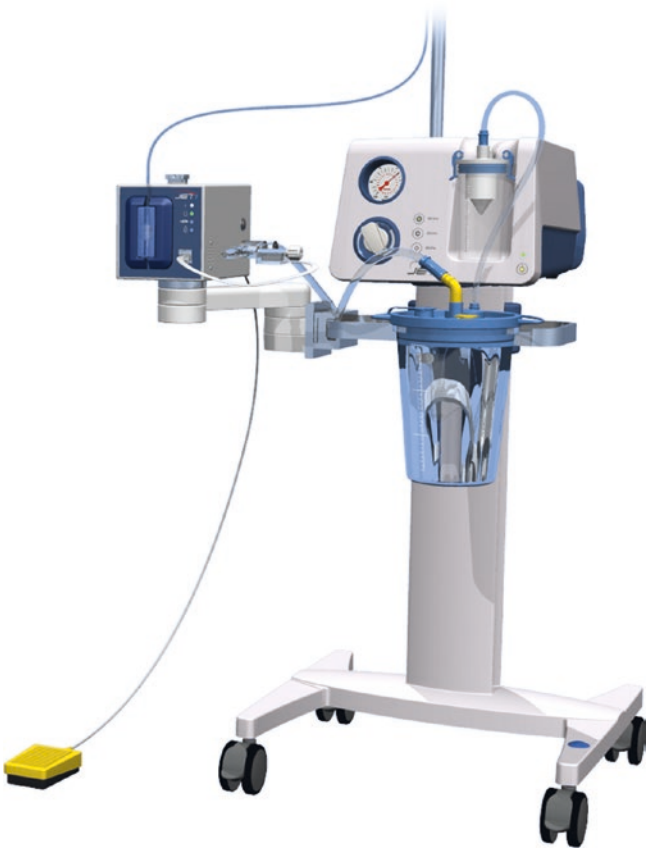

Fig. 33.9 JETi® Thrombectomy System setup with console, catheter, and foot pedal

Fig. 33.10 AngioJet™ console

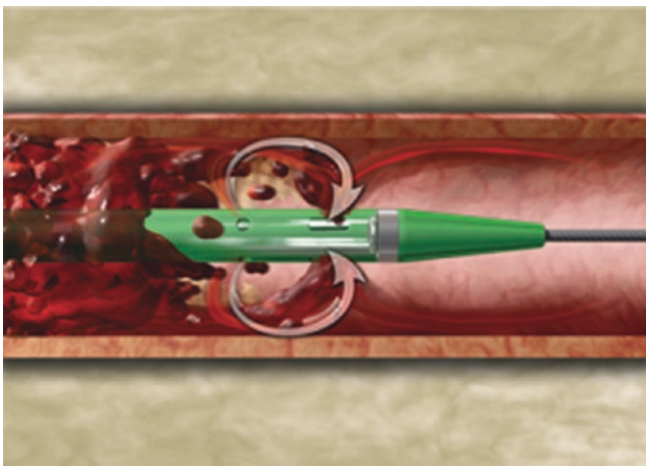

Fig. 33.11 AngioJet™ catheter mechanism of action

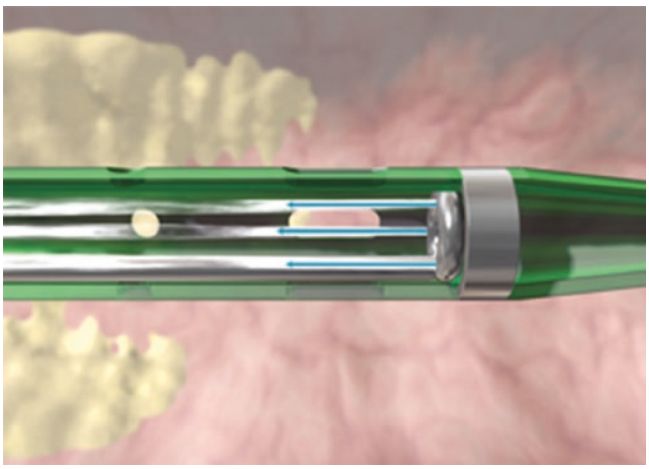

Fig. 33.12 AngioJet™ catheter mechanism of action

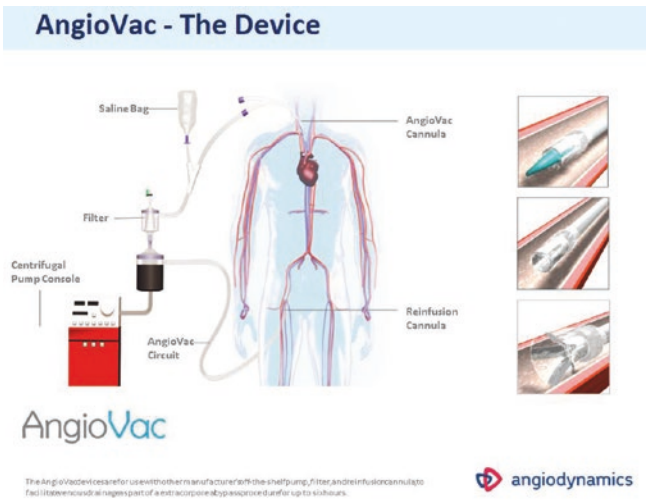

Fig. 33.14 AngioVac® system with centrifugal pump

Fig. 33.13 AngioVac® catheter

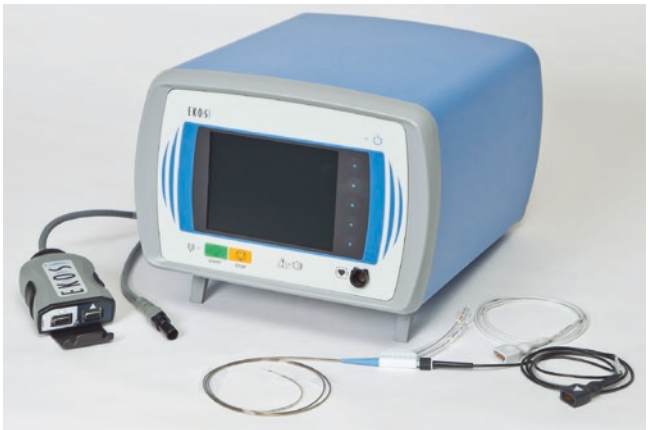

Fig. 33.15 EKOS® console

Fig. 33.16 EKOS® catheter

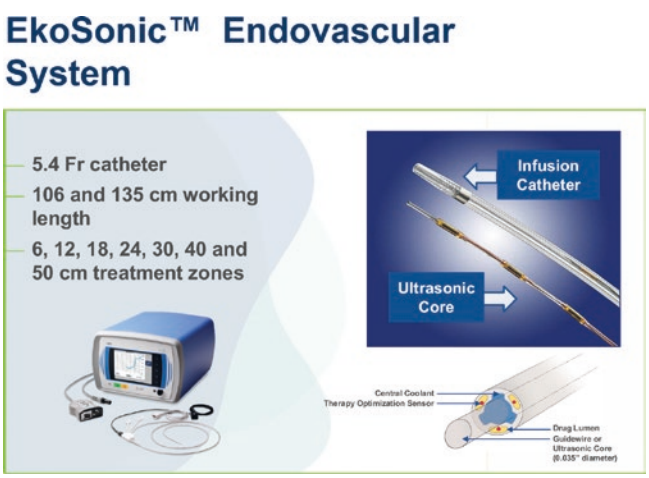

Fig. 33.17 EKOS® system and length of treatment zones

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Great Saphenous Vein Endovenous Treatment

34

Bernadette Aulivola

General Principles

Treatment methods for addressing great saphenous venous insufficiency have evolved over the past several decades. The standard treatment technique for saphenous insufficiency for many years involved surgical ligation at the saphenofemoral junction (SFJ) and stripping of the great saphenous vein (GSV). This approach was noted to be associated with prolonged recovery time and high recurrence rates of 25% at 5 years [1]. Endovenous ablation is now the primary mode of treatment for symptomatic insufficiency of the great saphenous vein; saphenous vein ligation and stripping are rarely performed.

Multiple modalities are available for saphenous ablation. Endovenous techniques have been available since the late 1990s and have undergone multiple improvements since that time. Earlier endovenous ablation techniques included endovenous laser ablation (EVLA) and radiofrequency ablation (RFA), both of which use thermal energy sources to cause venous fibrosis, sclerosis, and thrombosis of the treated vein. EVLA and RFA are equally effective and safe in treating GSV reflux. As compared with GSV stripping, thermal ablation is associated with reduced recovery time and less periprocedural pain, discomfort, and morbidity. Other techniques used for saphenous ablation that avoid the need for tumescent anesthesia are adhesive closure using n-butyl cyanoacrylate (VenaSeal™ closure system, Medtronic, Minneapolis MN) and mechanicochemical ablation (ClariVein®, Merit Medical, South Jordan, UT). Such non-thermal ablation techniques accomplish venous ablation quickly with minimal patient discomfort and quick recovery time. All techniques have certain advantages and indications, with significant overlap in the roles that they play in treatment. Sclerotherapy alone has not been demonstrated to be as efficacious as endothermal ablation for GSV treatment and is not discussed further here.

The method of venous ablation often depends on physician preference, as several techniques have been demonstrated to have acceptable outcomes with respect to technical success and incidence of complications such as deep venous thrombosis [2–4]. Patient-related and anatomic factors may play a role in the recommendation for one ablation technique over another, and insurance coverage is not uniform for all ablation techniques. The practicalities of decision-making on ablation technique should take into consideration many factors. Optimal management of GSV insufficiency requires a comprehensive understanding of the venous anatomy of the lower extremity, appropriate diagnostic evaluation, and proper patient selection.

Evaluation of Venous Insufficiency

Duplex ultrasound of the lower extremities is essential in the evaluation and diagnosis of venous insufficiency and thrombosis. Standard venous reflux imaging protocols include assessment of the deep, superficial, perforating, and tributary venous systems for reflux or obstruction. In the evaluation of the superficial venous system, the presence or absence of reflux is identified in the great saphenous and small saphenous veins, as well as in tributary and accessory veins. Diagnostic criteria for the presence of significant reflux within the superficial venous system of the lower extremities includes reversal of flow for greater than 500 ms (Fig. 34.1). In the deep veins, reversal of flow for greater than 1000 ms is diagnostic of significant reflux. Treatment algorithms for venous insufficiency are tailored to the patient, taking into consideration clinical symptoms and the location of reflux. Typically, the approach involves addressing the most proximal extent of the superficial venous reflux, which often entails treatment of the great saphenous vein.

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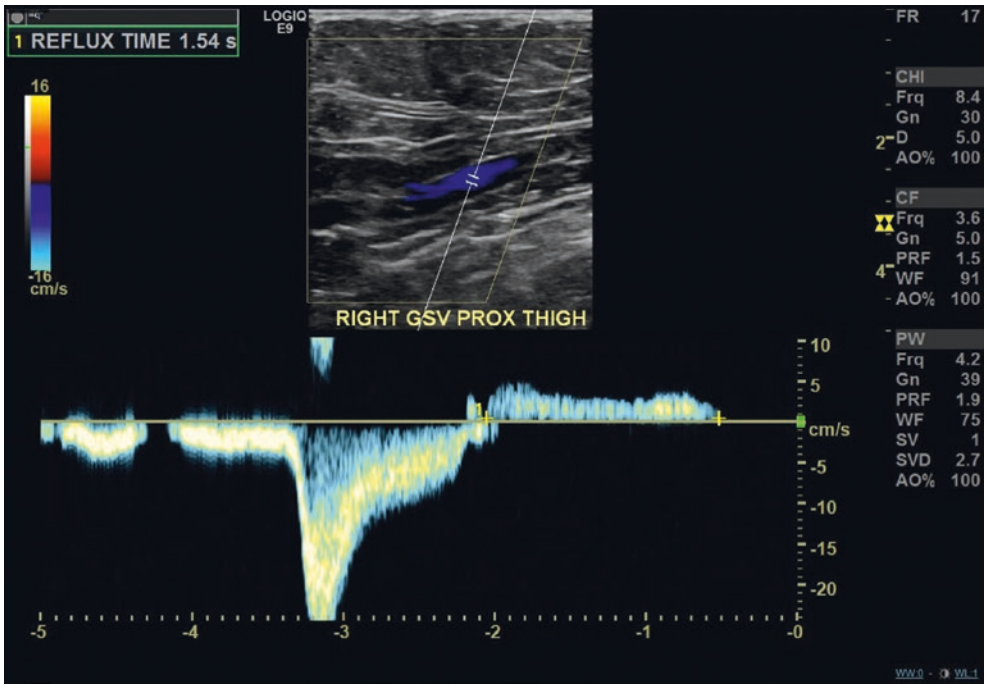

Fig. 34.1 Venous duplex ultrasound demonstrating significant reflux in the great saphenous vein (GSV)

Indications for Endovenous Treatment

It is essential to adopt a standard system for evaluation in the clinical assessment of venous insufficiency. Many use the CEAP classification (clinical, etiologic, anatomic, pathophysiologic). This chapter does not comprehensively cover the indications for saphenous ablation, but rather covers the techniques available to effect saphenous ablation. One should consider the risks and benefits of ablation of the saphenous vein. Known risks of saphenous ablation include deep venous thrombosis, pain and discomfort, saphenous and sural neuropathy, ecchymosis, and symptoms associated with superficial thrombophlebitis.

Relative contraindications to saphenous ablation include the presence of concomitant peripheral artery disease or coronary artery disease, given the destruction of a potential future autogenous vein conduit for bypass. However, it is also helpful to take into consideration in this patient population that tortuous, enlarged saphenous veins may not serve as a suitable conduit for autogenous vein use anyway. A discussion with the patient regarding the risk/benefit ratio is warranted prior to treatment planning. Deep venous reflux is not a contraindication to saphenous ablation, but deep vein obstruction is a relative contraindication.

There exists some controversy as to whether adjunctive treatments such as stab phlebectomy or reticular, spider, or varicose vein sclerotherapy should be performed at the same time as saphenous ablation or in a staged manner. In patients undergoing concomitant saphenous laser ablation and phlebectomy, 94% avoided additional ambulatory phlebectomy procedures [5]. In a study of patients undergoing saphenous RFA first, 75% required additional treatment with ambulatory phlebectomy [6]. A systematic review of the literature on this topic identified three prospective randomized trials, two prospective trials, and three retrospective reviews. Based on these data, Quality of Life scores improved more quickly with a combined approach; 30% to 60% of patients who underwent ablation required subsequent treatment of varicosities. Few complications were seen with either sequential or staged procedures. This review concluded that combined treatment of saphenous reflux and symptomatic varicose veins results in better short-term results and better to equivalent long-term patient outcomes [7].

General Ablation Techniques

Patient Preparation

GSV ablation may be safely and comfortably performed in the office setting. Patient preparation should include assessment for the need for intravenous sedation or an oral anxiolytic medication such as diazepam prior to the procedure. Our practice rarely uses these; our patients tolerate the procedure quite well using local anesthetic only. The application of EMLA cream (lidocaine 2.5%, prilocaine 2.5%) to the skin along the course of the vein to be ablated may help to avoid some of the discomfort related to the injection of tumescent anesthesia required for thermal ablation procedures. If used, EMLA is applied to the anteromedial thigh and calf 1 hour prior to the intervention. The area is covered with an occlusive dressing to allow enough time for it to take effect.

Given the risk of deep venous thrombosis associated with saphenous ablation procedures, individualized thromboembolism prophylaxis is considered. We routinely administer a prophylactic dose of 5000 units of subcutaneous heparin prior to the ablation procedure in any patient with an elevated risk of venous thromboembolism, such as those with a known hypercoagulable state, obesity, recent cancer diagnosis, or history of venous thromboembolic event, if they are not already on therapeutic anticoagulation. It is unnecessary to discontinue antiplatelet agents or anticoagulants for saphenous ablation procedures.

Procedure Room Setup

Venous ablation procedures may be safely and comfortably performed in the clinic or procedure room setting. The typical table setup is shown in Fig. 34.2 for EVLA and Fig. 34.3 for adhesive ablation. Room setup typically includes the following:

- Tilt table.
- Sterile field and drapes.
- Ultrasound machine with sterile probe cover (Fig. 34.4).
- Local anesthetic (1% plain lidocaine) in 10 cc syringe.
- Injectable normal saline.
- Micropuncture access kit.
  - Echogenic-tipped 18-gauge needle, 0.018″ guidewire, 4 or 5 French sheath.
- Long guidewire.
- Ablation sheath and catheter.
- Ablation device.
- Tumescent pump for thermal ablation.
- Laser safety goggles for patient and staff (for laser ablation).
- Sclerosing agent (for mechanicochemical ablation).
- Skin prep sticks.

Additional items that should be available:

- Torque device.
- Angled hydrophilic guidewire.

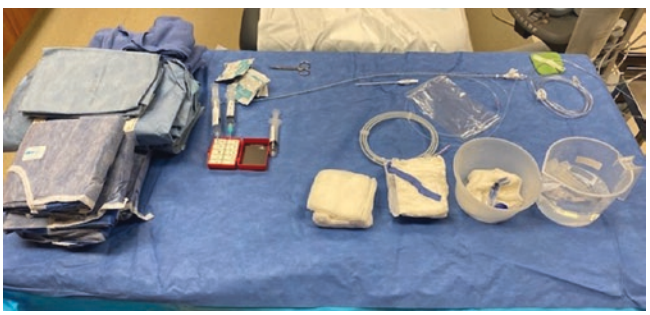

Fig. 34.2 Table setup for endovenous laser ablation (EVLA)

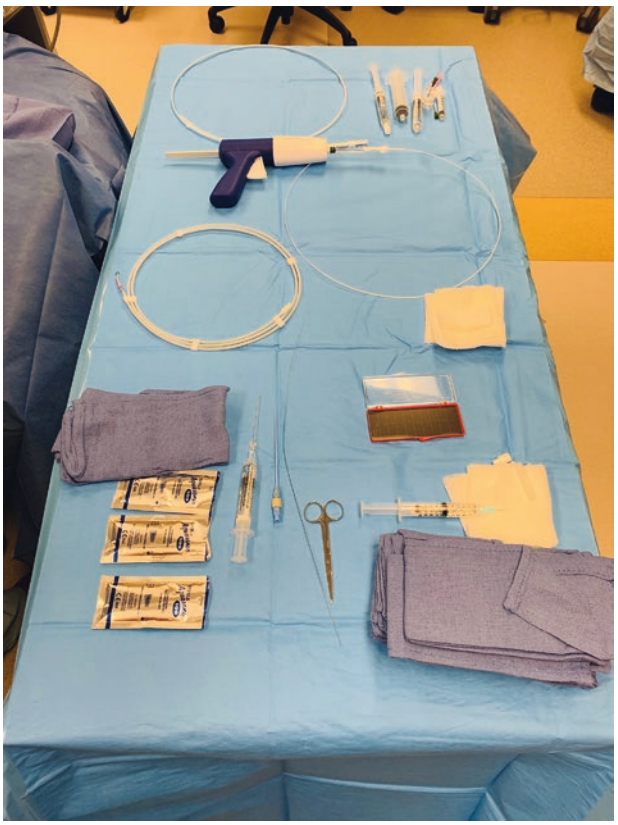

Fig. 34.3 Table setup for adhesive ablation (VenaSeal)

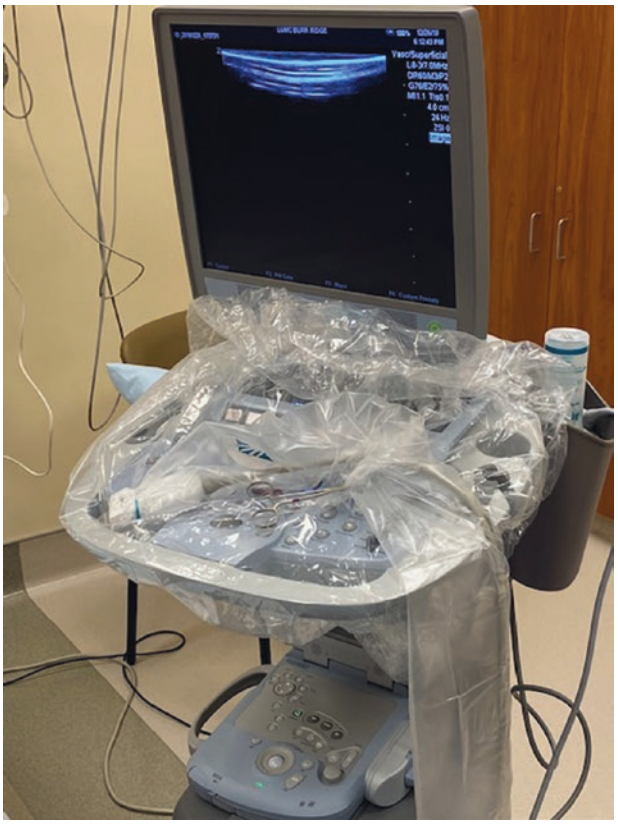

Fig. 34.4 Ultrasound machine setup

Patient Setup and Venous Access

Patients presenting for great saphenous vein ablation typically have undergone a full venous reflux imaging protocol, but real-time imaging from the SFJ distally is essential to clarify the anatomy. The ipsilateral lower extremity is prepped and draped using standard sterile technique. The groin should be included in the prepped area, as imaging of the SFJ at the groin crease is necessary. In patients with venous ulceration, care should be taken to keep wounds remote from the procedural field, assuming that vein access need not involve this area. Placement of a roll of towels under the bent knee and external rotation at the hip facilitates imaging of the great saphenous vein. Great saphenous vein puncture may be facilitated by placing the patient in the reverse Trendelenburg position to dilate the incompetent vein, if a tilt table is available. This is not necessary but is helpful, especially if the diameter of the vein is small. Use of an ultrasound technologist for intraprocedural imaging is an option but is not our routine.

Once the patient is positioned properly, ultrasound imaging is performed starting at the groin crease (Fig. 34.5). The common femoral vein and SFJ are identified first, following the great saphenous vein distally. The great saphenous vein is typically located within the saphenous sheath, but it may be located more superficially if it exits the sheath. Endothermal ablation may be performed even if the saphenous vein exits the sheath, as long as its depth after tumescent solution infiltration is more than 1.0 cm from the surface of the skin. When performing thermal ablation, the decision about access location should consider the risks of heat-induced nerve injury when the vein is treated below the knee. Typically, access of the great saphenous vein is achieved at or just below the knee for this reason when EVLA or RFA is being performed. When adhesive or mechanicochemical ablation is being used, the vein may be accessed at the ankle for treatment of the entire length, without concern about nerve injury.

Once the area to be punctured is identified, local anesthetic is infiltrated at the skin level. Typically 1% plain lidocaine is used. Local anesthetic containing epinephrine should be avoided, given its vasospastic effect. Venous puncture using an echogenic-tipped micropuncture needle is performed under ultrasound guidance. We prefer to perform the puncture with the ultrasound probe in transverse imaging orientation (Fig. 34.6). A micropuncture wire is then inserted and the needle is exchanged for a 4 Fr or 5 Fr micropuncture sheath. The sequence of events differs for thermal versus non-thermal ablation techniques, as described below.

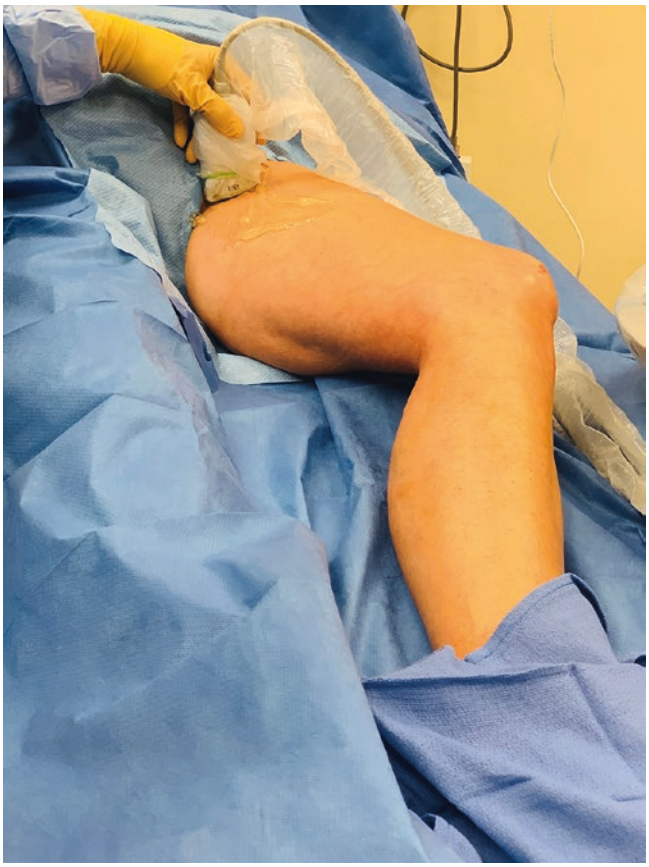

Fig. 34.5 Patient positioning and ultrasound imaging of groin

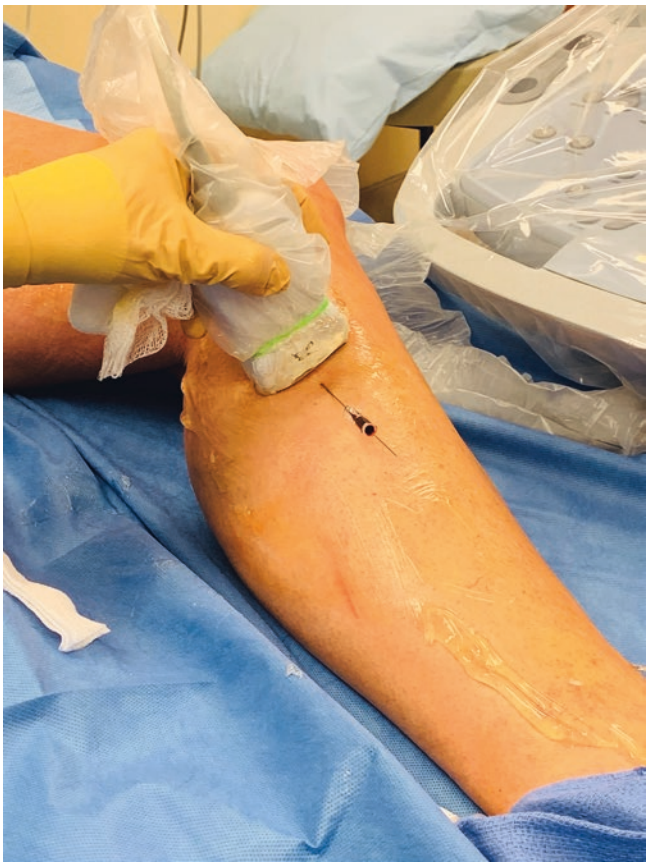

Fig. 34.6 Ultrasound-guided micropuncture access of the great saphenous vein

Thermal Endovenous Ablation Techniques

Endovenous ablation techniques that utilize thermal energy are generally performed with the use of perivenous tumescent local anesthesia. The desired effects of the infiltration of tumescent solution include its anesthetic effects, protection of the skin and surrounding structures (such as nerves) from thermal injury, and induction of vasospasm and compression of the treated vein to facilitate contact with the thermal ablation device. The exact composition of the tumescent solution may vary, but it typically includes a crystalloid fluid, local anesthetic, and epinephrine, as well as bicarbonate to reduce its acidity and thus alleviate patient discomfort related to its injection:

- 450 mL normal saline
- 50 mL 1% lidocaine with 1:200,000 epinephrine
- 5 mL 8.4% sodium bicarbonate.

Endovenous Laser Ablation

It is essential that the patient and all members of the patient care team don laser safety goggles when a laser device is used. Figure 34.7 shows the VenaCure 1470 nm laser (AngioDynamics, Latham, NY). Many institutions require completion of a laser safety training course with annual recredentialing as a prerequisite to using this device. Once saphenous vein micropuncture access is performed, an 0.035″ J-wire is advanced from the puncture site proximally towards the SFJ (Fig. 34.8). It is helpful to follow the tip of the wire throughout its course with ultrasound imaging. The tip of the wire should be advanced until it passes through the SFJ into the common femoral vein. Imaging is most easily performed with the ultrasound probe in the transverse orientation while following the wire as it is advanced proximally, transitioning to a longitudinal view at the SFJ (Fig. 34.9).

There are several situations in which challenges may be encountered in navigation of the guidewire from the punc-

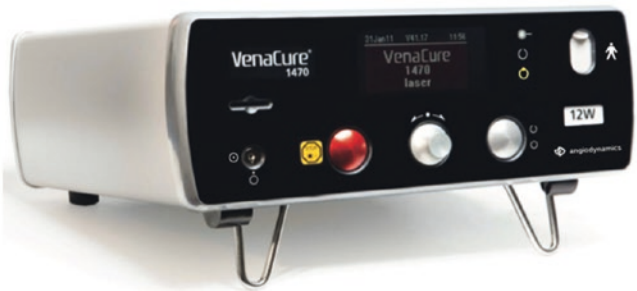

Fig. 34.7 VenaCure 1470 nm laser device (AngioDynamics, Latham, NY)

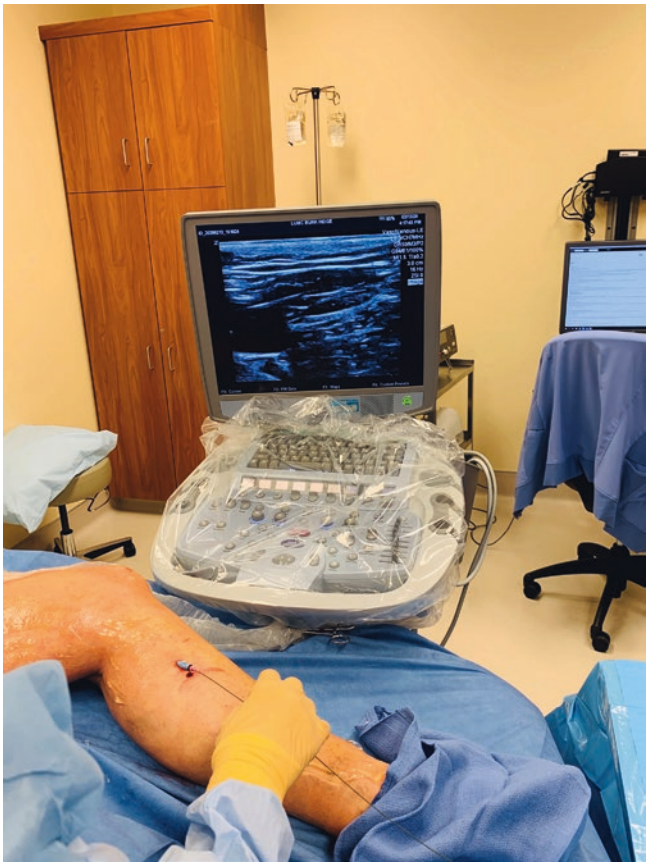

Fig. 34.8 Guidewire placement via micropuncture access

Fig. 34.9 Guidewire positioning across the saphenofemoral junction (SFJ). CFV—common femoral vein

ture site to the SFJ. If the vein is narrow in caliber, the J wire may not advance easily. In this case, the wire may be retracted to straighten the J-shaped tip, or it can be inserted from its back end, which has a straight, floppy tip. If the saphenous vein is tortuous or has large branches, it is helpful to have an angled 0.035″ hydrophilic guidewire and torque device on hand to steer through the region using ultrasound guidance. External manual pressure may also aid in navigation through tortuous veins. More rarely, if the ablation is being performed after a prior failed ablation or in the setting of previous superficial thrombophlebitis and segments of the vein are occluded, it may be necessary to treat separate segments of the vein via multiple access sites.

Once guidewire access is achieved across the SFJ, the micropuncture sheath is exchanged for the long sheath, which is inserted to the common femoral vein (CFV). The sheath tip is much more easily visualized on ultrasound after the wire and dilator are removed. The tip of the sheath is then withdrawn to a location 2 cm distal to the distal aspect of the SFJ. The laser catheter is inserted into the sheath. A white plastic peel-away marker on the laser catheter prevents its insertion past the tip of the sheath. Once the laser is inserted, the plastic peel-away marker is removed and the sheath is withdrawn to join it to the laser fiber, and the two are secured together. This step ensures that the laser catheter is positioned properly with its tip 2 cm away from the SFJ.

Infiltration of tumescent solution from the catheter insertion site to the SFJ is required for any thermal ablation procedure. Though manual injection using a large syringe is an option, the use of an injector pump facilitates this step of the procedure (Fig. 34.10). The echogenic-tipped 18-gauge needle is connected to a 500 cc bag of tumescent solution via the injector pump tubing. The tubing is threaded through the injector pump. Ultrasound-guided puncture of the saphenous sheath is performed at the laser insertion site. The pump is typically set with the dial at 5, but a slower injection rate can be used if the patient reports significant discomfort. Ultrasound imaging is performed, scanning in the cranial direction, to follow the most proximal extent of the tumescent solution infiltration. Tumescent solution is injected within the saphenous sheath but outside of the saphenous vein. One can observe external compression of the great saphenous vein, in addition to its increasing distance from the skin, as the tumescent solution is injected. When using the pump, typically three or four punctures are required to allow tumescent solution to track along the length of the vein. The pump is activated by a foot pedal. Depending upon the length of vein to be ablated, between 250 cc and 500 cc of solution may be required. Tumescent solution infiltration can be imaged in the longitudinal or transverse orientation.

Fig. 34.10 Tumescent solution injection pump (AngioDynamics)

The 1470 nm wavelength diode laser targets water as a chromophore to absorb laser energy. Given that the vein contains water, laser energy is transmitted to the vein wall, causing sclerosis and fibrosis. The laser device is typically set at 5–10 watts; the maximum setting is 12 watts. Effective vein ablation occurs with the targeted energy of 30–50 joules per centimeter at a setting of 5–7 watts. The laser may be set at a higher wattage, which allows for increased speed of catheter withdrawal. A foot pedal is used to activate the laser, and then the laser catheter is withdrawn at a steady rate. At 8 watts, the catheter is withdrawn 1 cm every 5 seconds. The laser can be set to have a notification beep sound at 5-second intervals to help pace the catheter withdrawal.

Caution must be exercised in laser treatment of the great saphenous vein in the calf, given the proximity of the saphenous nerve, the small saphenous vein, and the sural nerve, as heat-induced nerve injury can occur.

Radiofrequency Ablation

Radiofrequency ablation (RFA) (Venefit™ procedure; ClosureFast catheter) requires a radiofrequency generator (Fig. 34.11). Once venous access is achieved as detailed above, a short 7 Fr sheath is inserted and the RFA catheter is advanced using ultrasound guidance to a location 2 cm distal to the SFJ. In most cases, the catheter can be advanced on its own to the region of the SFJ, but if the vein is tortuous, it can be advanced over an angled 0.025″ hydrophilic guidewire. Tumescent solution is infiltrated around the vein as described above. The RFA catheter treats the saphenous vein in a segmental fashion, typically treating a 7 cm segment of the vein over a 20-second interval. Successful RFA ablation depends on vein wall contact with the catheter, so ultrasound-guided compression is performed over the segment being treated, to enhance contact between the catheter and the vein wall. Positioning the patient in Trendelenburg position is also helpful in decompressing the vein to facilitate its contact with the RFA catheter. The catheter delivers uniform heat to the vein, which denatures collagen and smooth muscle in the vein wall, causing fibrosis and thrombosis of the treated vein segment. The most proximal segment of the vein is treated twice before withdrawing the catheter 7 cm. Activation of the radiofrequency device is triggered by depressing a button on the catheter itself. After each segment is treated, the catheter is withdrawn 7 cm at a time, using markers on the catheter to guide the withdrawal distance. The RFA catheter is also available with a tip 3 cm long, for treatment of shorter refluxing vein segments.

Fig. 34.11 Radiofrequency ablation system (Covidien ClosureFast™)

As with EVLA, caution should be exercised in treatment of the great saphenous vein at calf level or the small saphenous vein, given the risk of heat-induced nerve injury.

Mechanicochemical Ablation

Mechanicochemical ablation utilizes a 3 Fr infusion catheter with a rotating wire tip for dispersion of a physician-selected sclerosing agent to the targeted treatment area. This device is fully disposable. Given that this is a non-thermal ablation technique, there is no need for infiltration of tumescent solution around the targeted treatment vein. The device includes an infusion catheter with a motor drive unit that is operated by a low-voltage, self-contained power system. Multiple speed settings allow for rotation of the wire tip between 2000 and 3500 revolutions per minute. The device also includes a syringe and stopcock for delivery of the sclerosing agent (Fig. 34.12).

Micropuncture access is achieved as described above. The ClariVein catheter is advanced through the micropuncture sheath to the region of the SFJ. Its device tip is angled and allows for some steering of the device as it advances into the vein. Once the catheter is in place, its distal end is attached to the motor drive unit and clicked into place. When the catheter is clicked fully into the handle, the treatment wire protrudes from the end of the catheter. Confirmation of device positioning 2 cm distal to the SFJ is performed with ultrasound prior to starting treatment. The wire rotation is activated by squeezing the trigger with the index finger while injecting a sclerosing agent (such as sodium tetradecyl sulfate) with the thumb on the plunger of the attached syringe. The pullback rate is approximately 1.5 mm per second, or 1 cm per 6–7 seconds. A total of 20–30 cc of sclerosing agent is typically used for treatment of the thigh segment of the great saphenous vein, so the attached 5 cc syringe must be refilled several times during the treatment. There is a marker

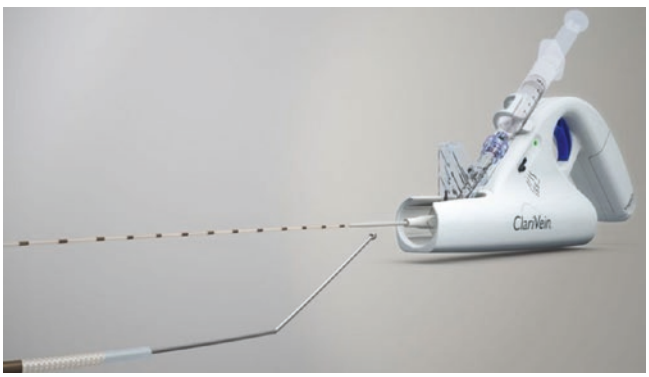

Fig. 34.12 Mechanicochemical ablation device (ClariVein®, Vascular Insights LLC)

on the distal aspect of the catheter past which an additional 2 cm may be withdrawn prior to ceasing treatment. The wire should be resheathed prior to removal. Compression of the vein is not required during treatment with the mechanico-chemical ablation device.

Adhesive Ablation

Adhesive ablation (VenaSeal™ closure system, Medtronic) is a non-thermal form of ablation that may be used throughout the saphenous system without concern for thermal injury to surrounding structures. Tumescent solution is not required. This system is completely disposable and involves a catheter-based injection of a small volume of medical adhesive, cyanoacrylate. Once micropuncture access of the saphenous vein is achieved (Fig. 34.13), a 0.035″ 180-cm J-wire is inserted though the sheath vein proximally to the SFJ (Fig. 34.14). The sheath is exchanged for the 7 Fr blue introducer/dilator. Once inserted to the SFJ, the wire and dilator are removed. The blue introducer is then flushed with normal saline and pulled back under ultrasound guidance so that its tip is positioned 5 cm distal to the SFJ (Fig. 34.15). The adhesive is drawn up using the 3 cc syringe, taking care to remove air bubbles from the syringe. The adhesive syringe is attached to the 5 Fr adhesive delivery catheter. The adhesive syringe is then inserted into the dispenser gun and rotated clockwise to lock it in place. The delivery catheter is primed by pulling the trigger to advance adhesive to the distal marker, located 3 cm from the catheter tip. The primed delivery catheter is then advanced into the blue introducer until the laser mark on the proximal aspect of the catheter reaches the hub of the blue introducer (Fig. 34.16). The blue introducer is then pulled back at the skin an additional 5 cm, and the adhesive catheter is inserted the remainder of the way, locking it in place. Prior to treatment, the tip of the adhesive delivery catheter should be confirmed at 5 cm distal to the SFJ.

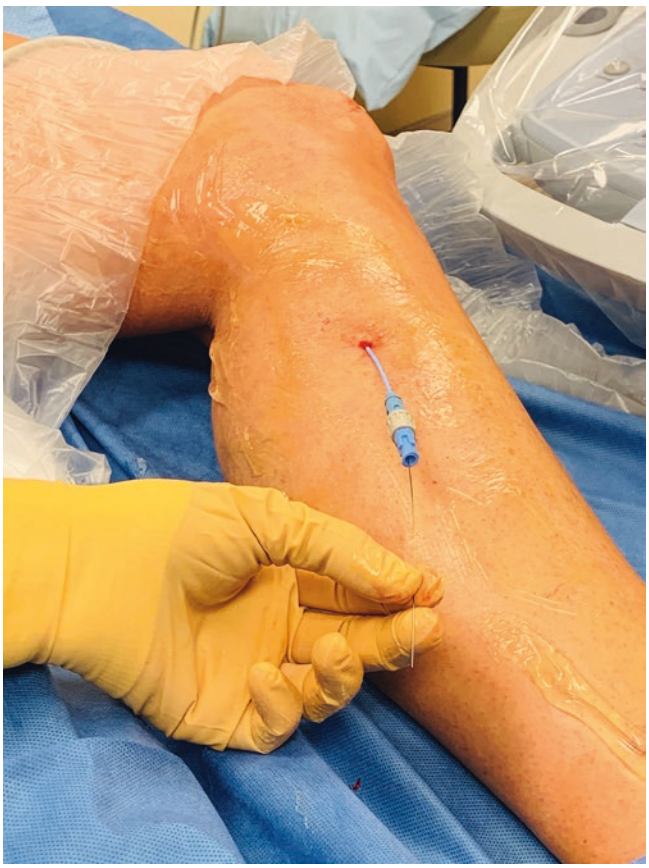

Fig. 34.13 Micropuncture access for adhesive ablation

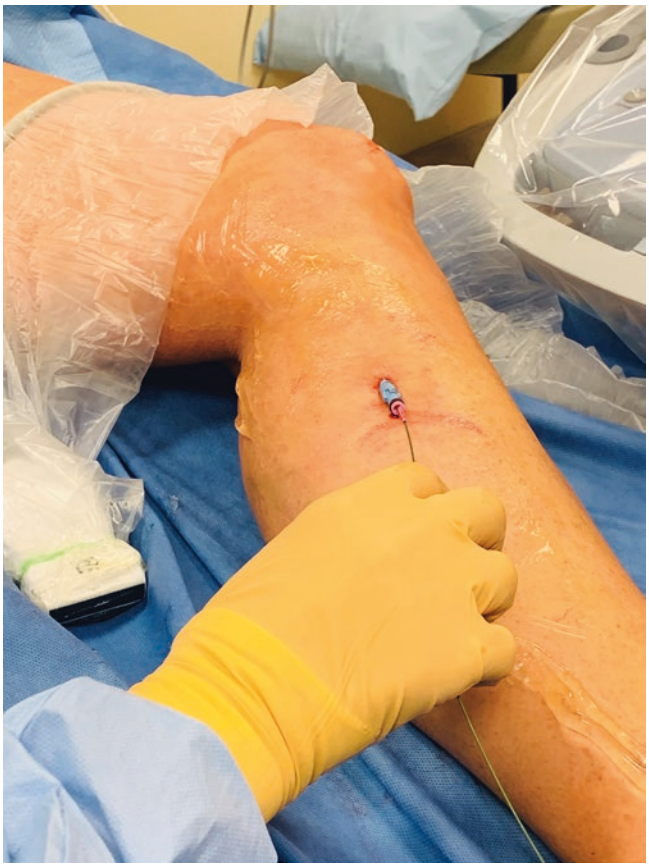

Fig. 34.14 J-wire insertion via micropuncture access for adhesive ablation

Ultrasound imaging of the great saphenous vein is performed to identify the proximal tip of the catheter. The ultrasound probe should be oriented in transverse position and the great saphenous vein should be compressed just proximal to the catheter tip prior to injection. Adhesive injection is then performed by pulling the trigger on the dispenser gun. The catheter is pulled back by 1 cm, and a second injection is performed. The catheter is pulled back 3 cm, and the region distal to the ultrasound probe is manually compressed for

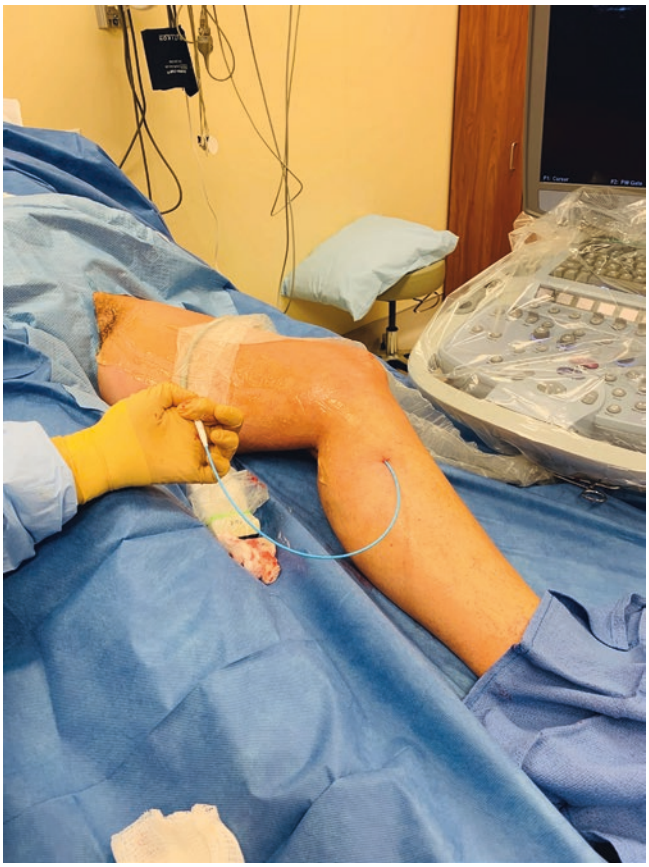

Fig. 34.15 Adhesive ablation introducer

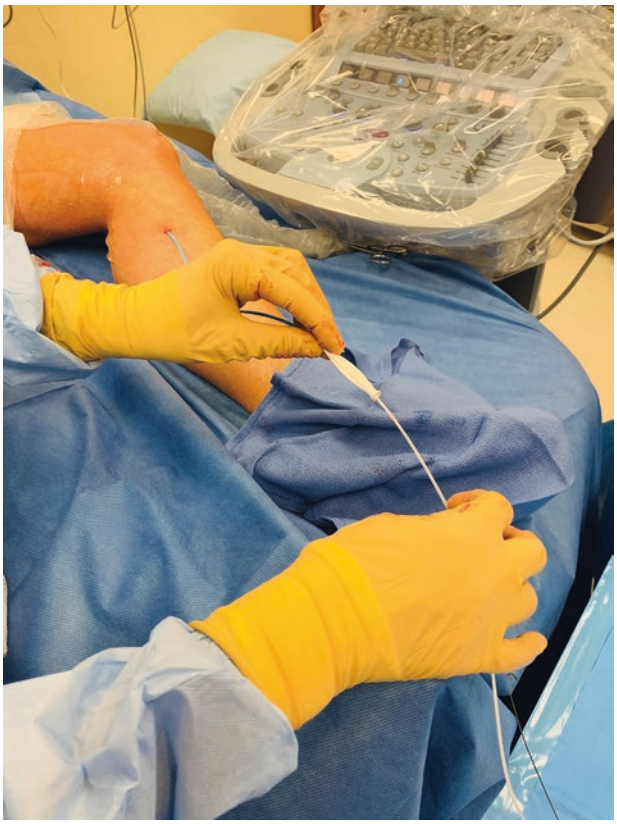

Fig. 34.16 Adhesive ablation delivery catheter insertion

3 minutes (Fig. 34.17). Subsequently, treatment of the remainder of the vein is performed with the following sequence: Compress vein just proximal to catheter tip, inject, pull catheter back 3 cm, inject, pull catheter back 3 cm, then compress the 6 cm treated segment for 30 seconds. This sequence is repeated for the length of the treatment zone. Once the treatment is completed, the catheter should be pulled back into the introducer, then both are removed as a unit.

Adhesive ablation has been demonstrated to have a 95% closure rate at 5 years [4, 8].

Subsequent Care

On completion of ablation, ultrasound imaging at the SFJ should document a patent segment of the proximal great saphenous vein. This region should be compressible, with color-flow documented. It is quite rare to see extension of thrombus to the SFJ following ablation.

Regardless of the method of ablation, a single bandage at the catheter insertion site is placed on completion of the procedure (Fig. 34.18). Medical-grade compression stockings are advised following the procedure, with various protocols for compression therapy following the ablation. Patients undergoing thermal ablation procedures may expe-

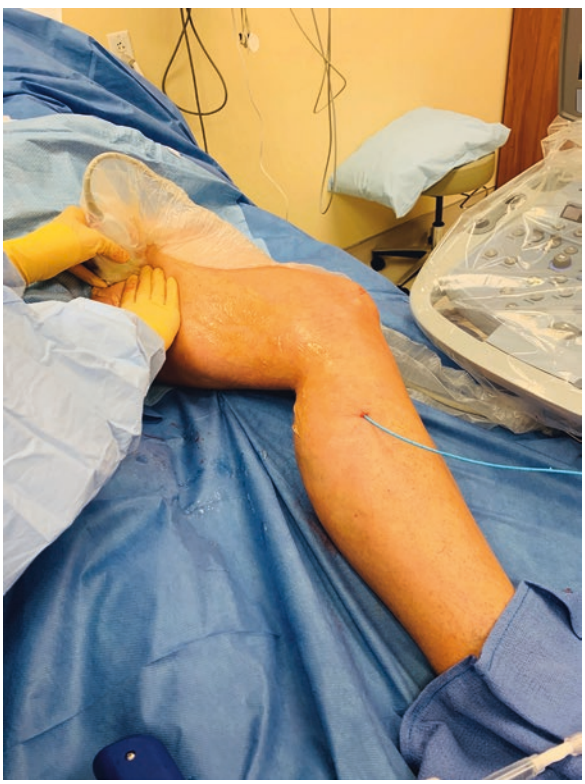

Fig. 34.17 Manual and ultrasound compression after adhesive injection

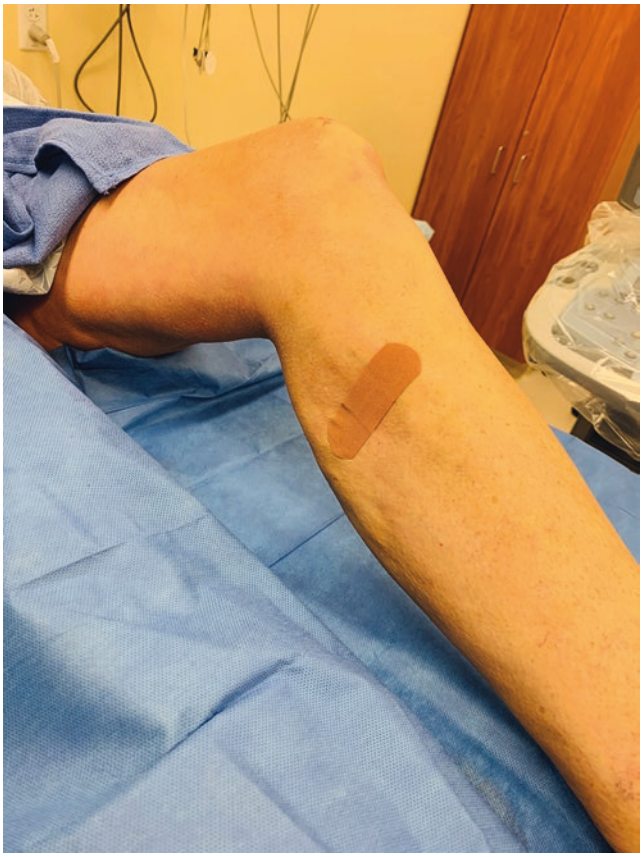

Fig. 34.18 Bandage placement after saphenous ablation

rience inflammatory changes and discomfort following the ablation. These symptoms are generally mild and may be alleviated with nonsteroidal anti-inflammatory medication (such as ibuprofen 600 mg PO q 8 hours), which may be taken around the clock for 24 to 28 hours to minimize soreness.

Following ablation, patients are instructed to resume normal activity. We do not limit patient activity following the procedure. Patients return for duplex imaging of the ipsilateral lower extremity within 5–7 days in order to document successful ablation and to rule out deep venous thrombosis. The follow-up duplex imaging protocol does not assess for reflux.

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IVC Filter Placement and Removal

35

Bradley J. Bowles and Matthew R. Smeds

The number of inferior vena cava (IVC) filters placed to prevent pulmonary embolism has dramatically increased since their inception. This chapter covers the general principles for IVC filter placement and removal including a discussion on standard approaches, imaging, and supplies needed. Advanced techniques to use in cases of complex removal, including balloon repositioning, wire loops, and the use of forceps or laser extractors are outlined.

Introduction

Inferior vena cava (IVC) filters have been used since the 1970s to prevent catastrophic pulmonary embolism in patients with venous thromboembolism for whom anticoagulation cannot be used or has failed [1]. The filters initially used were permanent, but subsequent modifications have resulted in retrievable filters that can be placed percutaneously from either femoral or jugular access [2]. There are many different filter designs, but most depend on laminar flow within the IVC and assume that large embolic debris will be travelling in the center of this flow. These filters are often conical in design, with large spaces in the periphery to allow continued blood flow and a central apical portion that captures the clot. A hook, usually on the cranial portion of the filter, is present to allow retrieval (Fig. 35.1). The target location for delivery is optimally in an infrarenal vein, with the tip extending just caudal to the renal veins in the central portion of the vein (without tilting). This ensures unobstructed flow from the renal veins, avoiding the devastating complication of renal vein thrombosis and simplifying retrieval if needed. This chapter discusses standard techniques for placement and retrieval of IVC filters and of adjuncts that may be used for complicated cases.

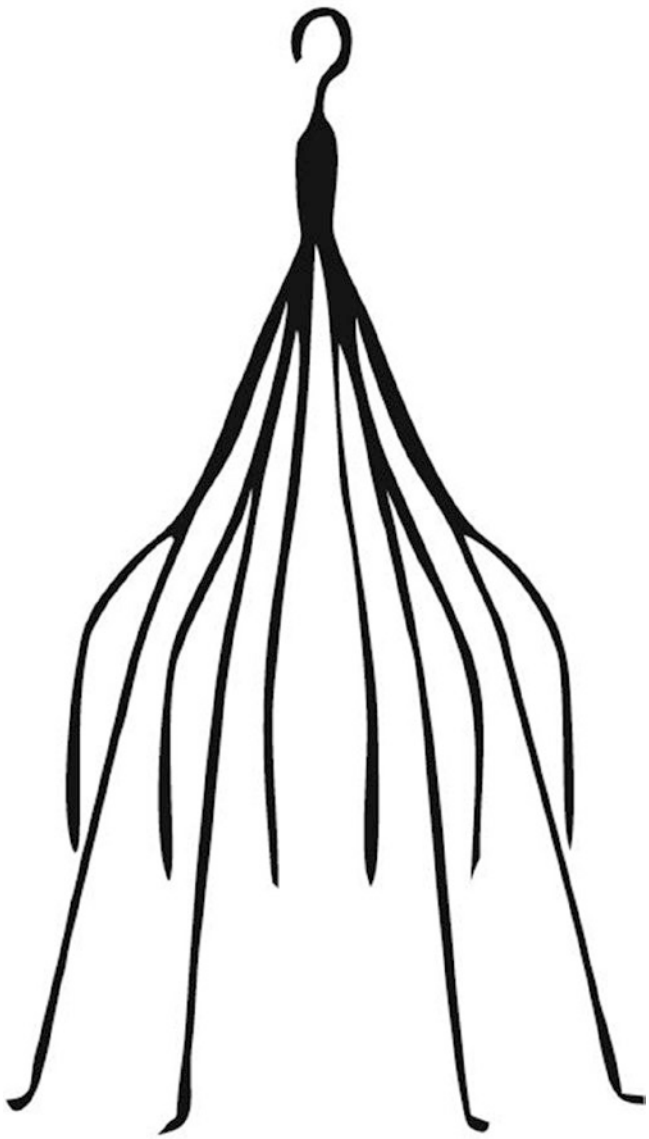

Fig. 35.1 A representative illustration of an inferior vena cava (IVC) filter shows its conical nature and central hook

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IVC Filter Placement

General Principles

Preoperative imaging of the planned access vessels, most commonly with venous ultrasound, is necessary to ensure patency, lack of thrombus, and ease of sheath placement in the presence of external factors such as a cervical collar or extremity external fixators. Computed tomographic (CT) venography is not commonly done, but it can identify evidence of IVC or iliac vein thrombus and can delineate the size of these vessels and the location of renal veins, as well as the presence of any anatomical variants such as a duplicated IVC.

The recommended supply list is similar regardless of the planned approach:

- Jugular or femoral-oriented filter delivery kit (includes filter, sheath, dilators, delivery catheter).
- Ultrasound with probe cover.
- Local anesthetic (with needles, syringe).
- Micropuncture set (needle, wire, 4- or 5-French sheath).
- #11 scalpel
- Short (80 cm), 0.035″ medium stiff wire with a floppy tip (*eg*, Bentson wire).
- Contrast and heparinized saline.
- Dressings (*eg*, gauze and tape).

The patient is placed supine on the interventional table. If femoral access is used, most operators will stand to the patient's right side with the C-arm located to the patient's left side and will place the entry sheath in the right common femoral vein. In this case, both groins are prepped to the belly button and draped into the field to allow access to either leg as needed. If jugular access is entertained, the operator stands to the patient's head or to the right side of the head, with entry planned in the right jugular vein. The patient's head is turned to the left for the procedure, and the neck is prepped from jaw to clavicle and draped as appropriate.

Transfemoral Approach

The femoral pulse is palpated, and ultrasound guidance is used to locate the femoral vein medial to the artery at the level of the femoral head. Patency is confirmed with gentle compression. The optimal puncture location is caudal to the entry of the greater saphenous vein, below the inguinal ligament and before the femoral vein dives beneath the femoral artery to become the iliac vein. Local anesthetic is injected subcutaneously. Using a micropuncture access needle under ultrasound guidance, the femoral vein is punctured in preparation of the Seldinger technique to gain access. A micropuncture wire is advanced into the iliac vein, a small skin incision is made directly next to the needle with a #11 scalpel to allow easy passage of the sheath, and the needle is removed over the wire, with gentle pressure held on the groin. A 4- or 5-French micropuncture sheath is then advanced into the femoral vein over the wire (Fig. 35.2).

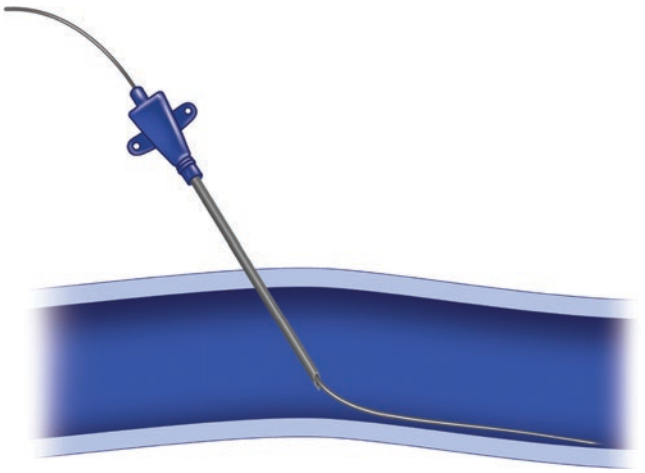

Fig. 35.2 Seldinger access technique for placement of a micropuncture catheter. A microneedle is used to access the vein. A micropuncture wire is advanced through this needle. After removal of the microneedle, a micropuncture catheter is advanced over the wire into the vein

The micropuncture wire and dilator are removed, and a venogram is performed through the micropuncture sheath to confirm patency of the iliac vein and IVC, usually with an injection by hand of 4–5 cc of contrast and 4 cc of heparinized saline in a 10-cc syringe. A medium-stiff wire with a floppy tip (*eg*, a Bentson wire) is placed in the micropuncture sheath and gently advanced into the IVC under fluoroscopic guidance. The micropuncture catheter is removed, and the access site is sequentially dilated with the included dilators placed over the Bentson wire to the size of the device sheath used. The filter delivery sheath is then advanced over the Bentson wire under fluoroscopic guidance to below the location of the renal veins. (The tip of the sheath would be at approximately L2 to L3.) A venogram of the IVC is performed to identify the location of the renal veins, which are then marked on the imaging screen. Given the direction of blood flow, the renal veins may not completely enhance; in fact, voids of flow may be seen as indentations in the IVC where the renal veins enter the IVC. Maneuvers can be done to identify the renal vein origins by asking the patient to hold his or her breath and bear down during the venogram.

The sheath is positioned at the level of the renal veins or slightly above them, and the Bentson wire is removed. The IVC filter is advanced to the end of the sheath, and the apex is fluoroscopically confirmed to be just above the lowest renal vein. Proper positioning of the apex is in the middle of the vessel lumen, not tilted toward one wall or the other.

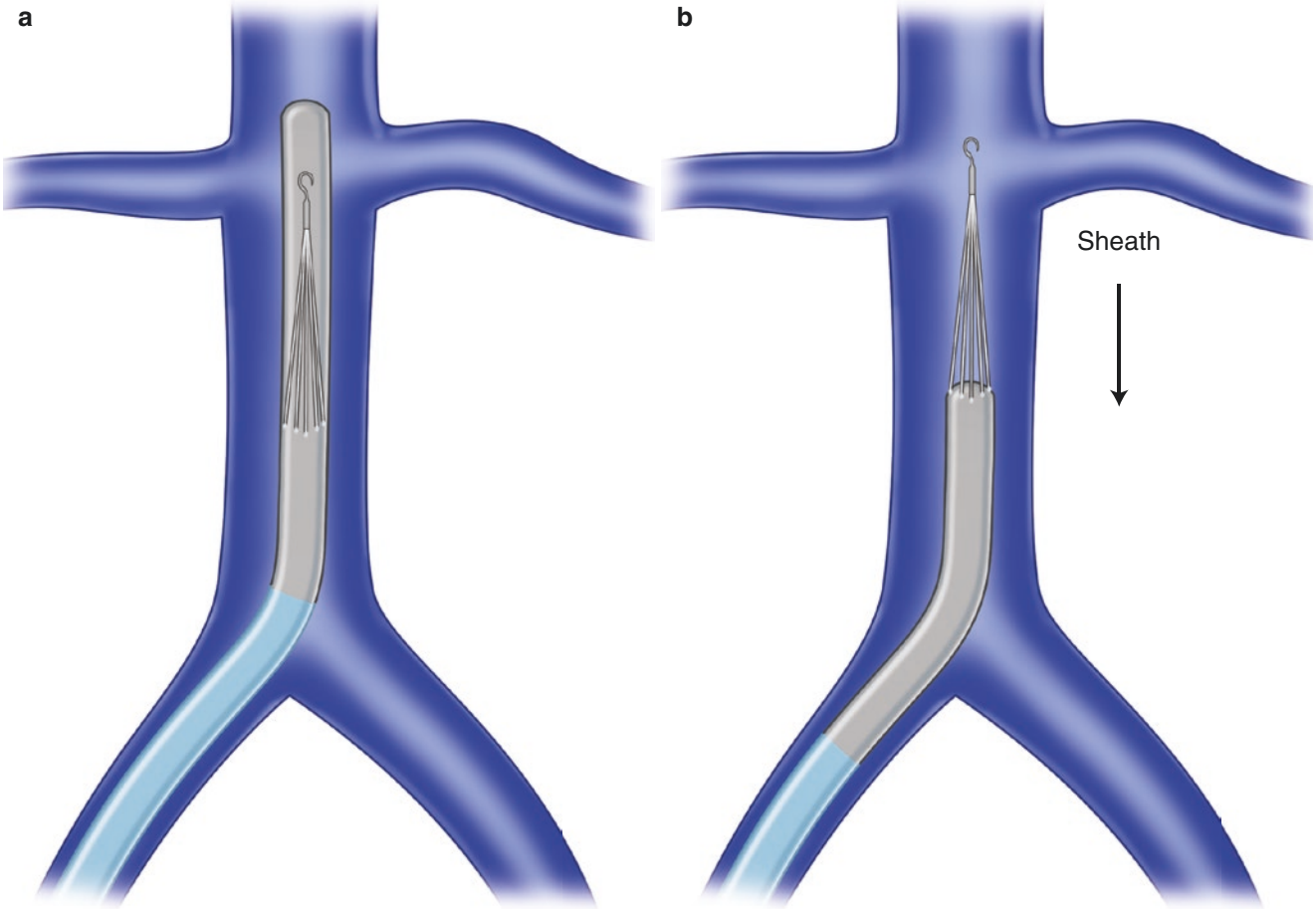

Fig. 35.3 Deployment of an IVC filter: most devices use a "pin and pull" method to deploy the filter. (**a**) The sheath is positioned just above the lowest renal vein identified by venogram or via bony landmarks at around spinal level L2. (**b**) The sheath is pulled back to expose the filter. Some filters require additional steps to fully deploy

Most devices use a "pin and pull" method to deliver the filter, in which the back end of the filter delivery device is held in place ("pinned") while the sheath is "pulled" back to unsheath the filter (Fig. 35.3).

Some devices require an additional step to release the filter from the device after appropriate positioning is confirmed and the filter has been unsheathed. The delivery system is then removed from the sheath. At the discretion of the operator, a completion venogram is sometimes performed through the sheath to confirm IVC patency and filter placement below the renal veins, with the apex just caudal to the lowest vein. This position allows for a lower incidence of IVC filter thrombosis due to flow from both renal veins. The sheath is removed, and pressure is held gently to the access site to ensure hemostasis prior to placement of a sterile dressing over the puncture site.

Transjugular Approach

Most IVC filters come in either transfemoral or transjugular orientation. The steps for deployment are very similar. Under ultrasound guidance, the jugular vein is accessed at the lower portion of the neck above the clavicle, and the micropuncture sheath is placed as outlined above. Through this micropuncture sheath, a medium-stiff wire with a floppy tip (*eg*, a Bentson wire) is advanced through the internal jugular vein into the brachiocephalic vein and superior vena cava (SVC), and into the IVC under fluoroscopic guidance. The right jugular vein is more of a "straight shot" to the IVC, but either side may be used. Deviation of the wire toward the left side is seen when the wire is passing into the right ventricle. If ectopic beats are seen on EKG monitoring, the wire should be pulled back into the SVC and redirected. The wire should advance directly caudal in a straight line toward the abdomen. Deviation of the wire to the right side may indicate positioning in the hepatic vein. Once the wire is in the IVC, the sheath is advanced to the level of the renal veins and a venogram is performed as above to confirm the location at approximately L2. The sheath is positioned below the renal veins, which are marked on the screen, and the filter is deployed via the same mechanism as outlined above.

IVC Filter Retrieval

Despite an increase in placement of retrievable IVC filters, many are not removed, with the most common reason being loss of the patient to follow-up [3]. Many interventionalists place IVC filters, but adequate follow-up and evaluation for continued filter need is often lacking. Other reasons for continued filter usage include contraindications to anticoagulation and a continued need for embolic protection, or failed retrieval. The risks and benefits of IVC filter retrieval should be discussed with the patient, and most filters should be removed as soon as possible [4].

The traditional approach for IVC filter removal is from access in the internal jugular vein, most commonly on the patient's right side. Most filters are conical in design with a retrieval hook placed in cranial orientation, but there are exceptions with filter placement in the SVC or dual-apex designs such as the Cordis OPTEASE® (Cordis, Santa Clara, CA), for which the hook can be at either end of the device.

Standard Retrieval Technique

Retrieval kits are available from some manufacturers; it is beyond the scope of this chapter to describe each kit. They most commonly include venous dilators, a large access sheath, and a snare system to capture the cranial device hook. A standard technique using off-the-shelf components requires a large sheath (typically 9 to 11 French) and a single or tri-lobed snare with associated catheter. The patient's internal jugular vein is accessed using Seldinger technique with a micropuncture kit, as described previously. Once access is obtained and a medium-stiff wire with a floppy tip is placed in the IVC, the jugular vein is dilated with prepackaged dilators to the appropriate size, followed by advancement of the sheath into the IVC just above the level of the filter, which is seen on fluoroscopy. A venacavogram is obtained through the sheath to verify patency of the filter, without a filling defect to suggest retained clot. Evidence of thrombus within the filter is a contraindication for retrieval because collapse of the filter into the retrieval sheath can shower thrombus cranially. The snare catheter is advanced into the IVC via the sheath, and the snare is opened by extending it beyond the snare catheter (Fig. 35.4). It is vitally important to keep the loop(s) of the snare above the levels of the filter prongs to prevent inadvertent capture of the filter limbs below the cranial hook; doing so would cause the filter to tilt. Coordinated manipulation of the sheath, catheter, and snare is used to direct a single loop over the apex of the filter. Simultaneous withdrawal of the snare on the hook and advancement of the snare catheter captures the hook of the filter. Sometimes you capture the apex but not the hook; do not attempt to resheath the filter if the hook has not been snared. As you pull back, the tip might not be in the sheath and you could shear the cava wall instead. At this point, while keeping the hook captured by the snare and catheter, the sheath is advanced over the filter, with subsequent collapse of the filter struts and complete encasement by the sheath. The operator should take caution not to pull the filter into the sheath, as doing so can cause the filter prongs to shear the caval wall. It helps to push the sheath forward as you collapse the filter to push the struts off the wall. Once the filter is completely in the sheath, it can be removed simultaneously with the sheath. A completion venacavogram may not be required if the filter hooks were easily disengaged from the IVC wall, but it is recommended to verify caval integrity. This can be achieved by initially placing a 9-French sheath within a larger sheath and withdrawing the filter via the smaller sheath, leaving the larger sheath in the IVC to perform a venogram. Once all sheaths are removed, direct pressure should be placed over the venous access site for hemostasis. The timeframe depends on the coagulation status of the patient; it should be at least 5 minutes. An occlusive dressing is placed, and the site should be monitored in the recovery area for bleeding or hematoma formation.

Advanced Retrieval Techniques

Advanced retrieval techniques are approaches outside the commercially available retrieval kits or simple snare retrieval. These are typically employed for filters with significant tilt against the caval wall, an apical fibrin cap over the hook, or filter fragmentation [5, 6]. Prolonged filter time is a risk factor for failure of standard retrieval techniques [7].

Balloon Repositioning

A guidewire can be placed between the hook or the neck of the filter and the caval wall, over which a balloon can be advanced (Fig. 35.5). Ballooning this area may disrupt the intimal hyperplasia enough to allow access to the hook via a snare loop as described above. Additionally, once the hook has disengaged from the caval wall, the balloon can be removed and a snare can be loaded onto the back end of the guidewire, which can help guide the snare over the filter retrieval hook [8, 9].

Wire Loop Technique

After exchange for a 14F sheath, a reverse-curve catheter is advanced with an angled floppy glidewire and guided between the filter and caval wall, directed cranially. A snare is placed in tandem with the catheter and is used to capture the free floppy end of the wire. The wire is pulled through the

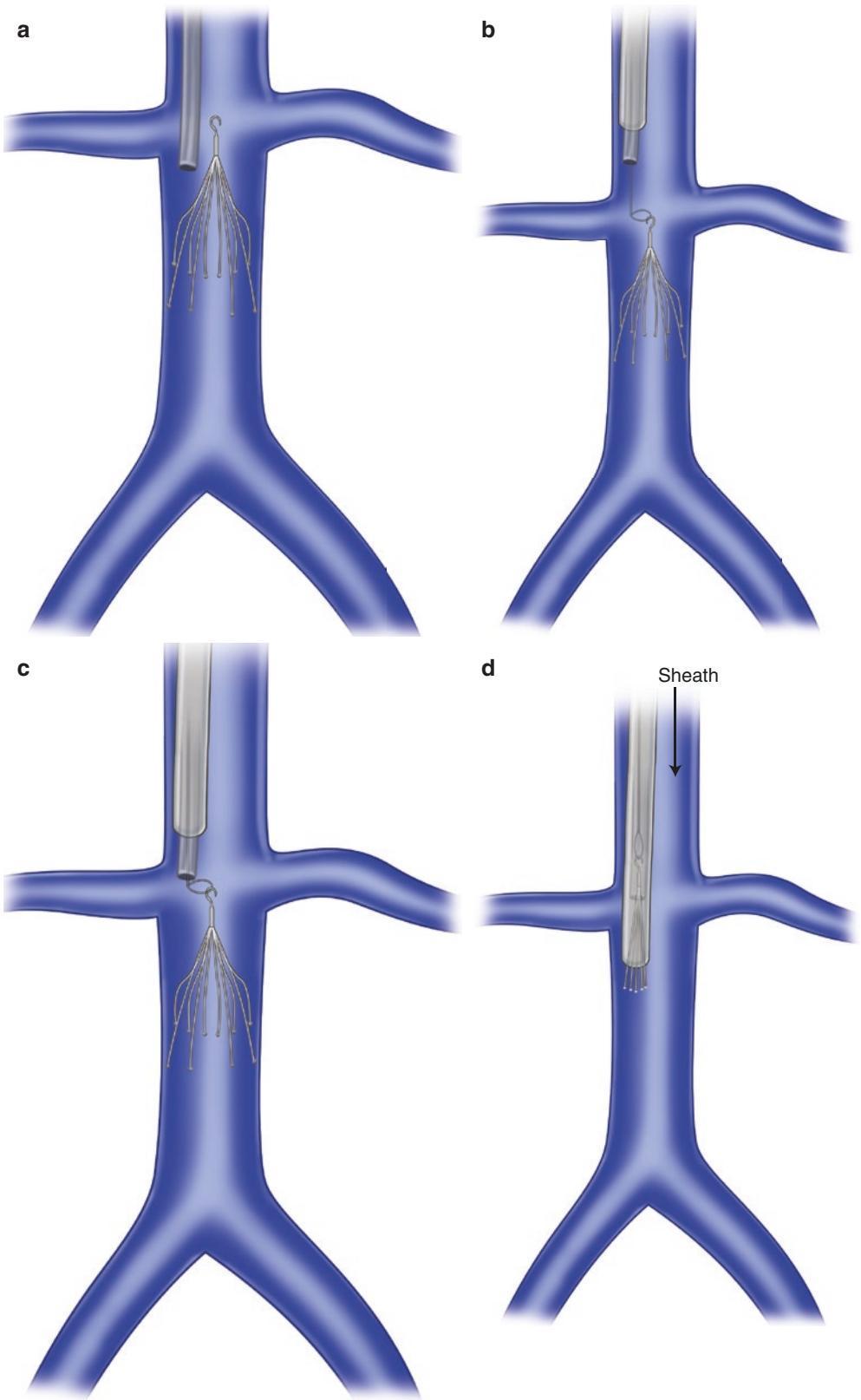

Fig. 35.4 Retrieval of an IVC filter occurring from an internal jugular access. (**a**) The sheath should be positioned just above the filter. (**b**) A snare should be inserted via a snare catheter placed through the sheath. (**c**) The snare is used to capture the cranial hook of the IVC filter. (**d**) The sheath is advanced over the captured hook, collapsing and completely containing it. The sheath is subsequently removed

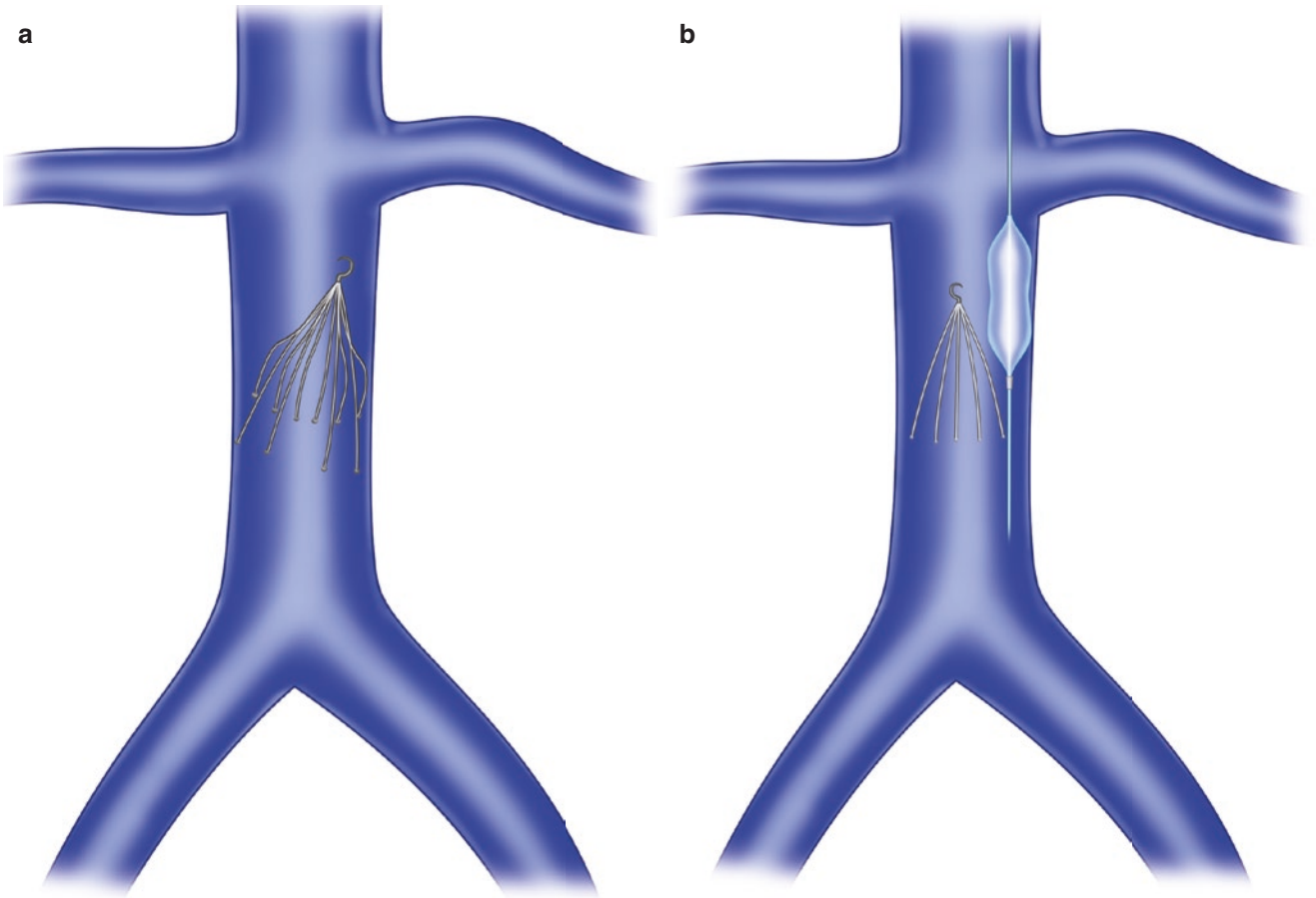

Fig. 35.5 (**a**) The hook of a tilted IVC filter may be embedded in the caval wall and a fibrin cap. (**b**) A balloon technique may be used to center the filter away from the caval wall. This can disrupt the fibrin cap and allow capture by a snare placed through the sheath

sheath, forming a loop that may catch the hook, disrupt the fibrin cap, or draw the apex more centrally into the lumen of the IVC. In the first case, the sheath can be advanced over the looped wire and the filter is captured. This method can be used to remove a permanent filter by directing the wire between struts at the neck prior to snaring. Another technique is to back-load the snare loop over both ends of the guidewire, which will guide the snare over the filter. The latter two scenarios may expose the hook or reposition the filter enough for successful retrieval with standard snare techniques [9–15].

Rigid Endobronchial Forceps

Rigid endobronchial forceps can be used to directly retrieve the filter or fragments, or for disruption of intimal hyperplastic tissue. The forceps are malleable for steerability and are inserted through a minimum sheath size of 12F. Significant injury to the caval wall can occur with use of forceps, so they are not recommended as a first-line advanced technique. The use of a bioptome in a similar fashion has also been described [16–18]. This method can also be used to remove permanent filters without a retrieval hook.

Two-Sheath Dissection

Occasionally the filter struts become embedded in intimal hyperplastic tissue of the wall and do not release despite capture of the hook. This adherent tissue can be dissected using a two-sheath technique, as long as control of the filter hook is first obtained via an inner small sheath (9 or 10 French) within an outer, larger (14F) sheath. The snare is introduced with its catheter through the smaller sheath, the apex is engaged and the sheath is advanced over the filter as described above to capture as much of the filter struts as possible. The 14F sheath is then advanced in a twisting fashion over the smaller sheath to disrupt the fibrous tissue and dissect the adherent struts off the caval wall. Small advancements with alternating movements of the outer and inner sheath while twisting can release the struts [6].

Lead Extractor Laser Technique

This technique employs a 14F sheath with a 12F pacemaker lead extraction laser sheath (*eg*, CVX-300 Excimer laser system, Philips, Andover, MA) in an off-label fashion. Similar to the two-sheath dissection described above, the double catheters are advanced in alternating movements. The laser

can be activated for short periods of time (3–5 seconds) to help dissect the tissue off the struts. Major vessel perforation has been observed in less than 5% of cases from pacemaker lead extraction series [18–20].

Additional Retrieval Considerations

It is recommended to meticulously inspect the retrieved IVC filter immediately for evidence of fracture or missing pieces. Angiography can then be used to identify any embolization of these fragments, which may need to be addressed at the time of the procedure [21, 22]. Multiple approaches can be used for fragment retrieval, including snare or forceps. A larger sheath (*eg*, 14F) may be needed to capture the fragments and reduce the risk of embolization during retrieval.

Permanent filters can be removed by grasping the apex with rigid endobronchial forceps or by using the wire loop technique between the filter struts.

Completion venacavogram should be performed after advanced retrieval techniques, as the risk for caval injury is not insignificant [23]. If the cava looks abnormal, with some residual stenosis or a filling defect, consider keeping the patient on anticoagulation for few months and repeating the venogram. If contrast extravasation consistent with rupture is seen, it can typically be managed by a large, compliant balloon (*eg*, Coda®, Cook Medical, Bloomington, IN). The balloon is insufflated across the area of injury under low pressure and maintained in place for 15 minutes, repeated as necessary. Hemostasis is verified by repeat venacavogram.

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Miscellaneous Helpful Techniques

36

Carlos F. Bechara, Fady Haddad, and Jamal J. Hoballah

This chapter discusses some techniques and tricks that are helpful for all vascular surgeons and interventionalists.

Snaring

Snaring is effective in removing retained and foreign objects from the vascular system. Occasionally snaring a wire is needed to achieve through-and-through wire "body floss" for stability and support. Snares and microsnares come in a variety of shapes, lengths, and diameters. They can be angled, and the loop snare can consist of one loop or multiple loops. The diameter of the loop also can vary: Removing a retained object from the tibial artery, for example, requires a microsnare (Fig. 36.1), but a bigger loop is needed to snare a retained wire in a large vessel. Successful snaring requires two individuals who are familiar with the technique and the device. For example, assume a wire is being snared to allow going up and over the aortic bifurcation. First, advance the snare and its catheter into the optimal spot where the wire can be advanced to be captured (Fig. 36.2). Then open the snare and the leaflets. (Often the snare must be rotated to free the leaflets and ensure that they are wide open and not trapped by the vessel wall.) Then advance the wire to be snared through the snare loop. Keeping the wire in its place, pull back on the snare while advancing the catheter to tighten the snare. See if the wire is captured. If not, then redo the steps. An oblique image might be helpful to make sure that the snare loop and the wire are in the correct position. Once the wire is captured, tighten the snare on its catheter by tightening the torque device. Then pull the snare, catheter, and wire as one system, making sure that the individual handling the wire is no longer holding onto the wire; otherwise the wire will slip out of the loop.

If a foreign body is being removed, the best approach is to get close to the foreign body by placing a sheath or catheter

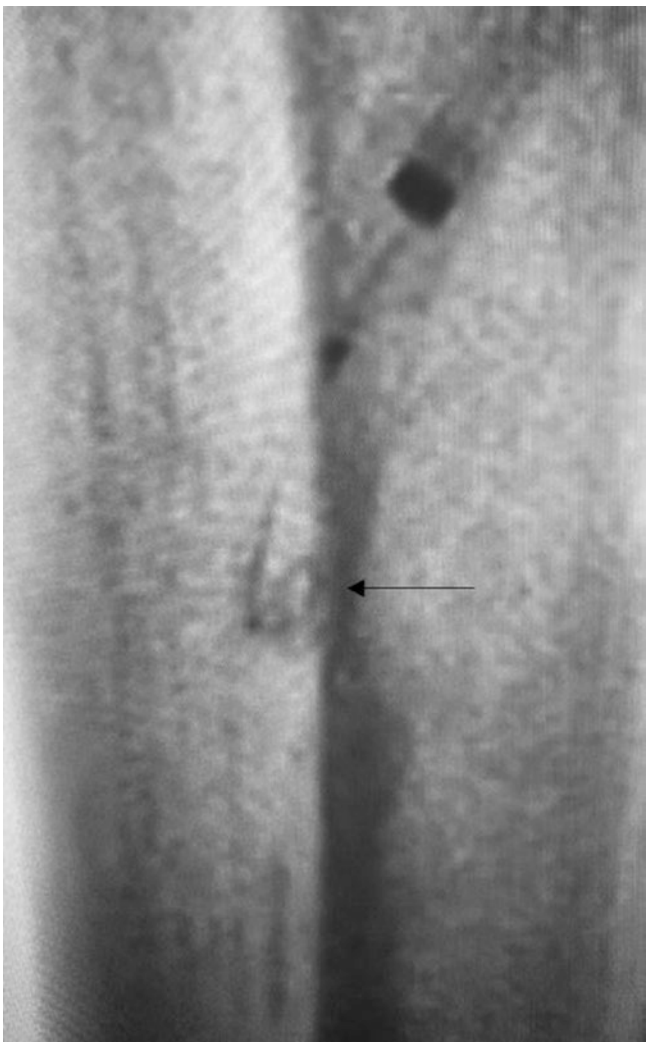

Fig. 36.1 Microsnare passed to retrieve a retained piece of microcatheter in an anterior tibial artery. *Arrow* indicates the microsnare loop

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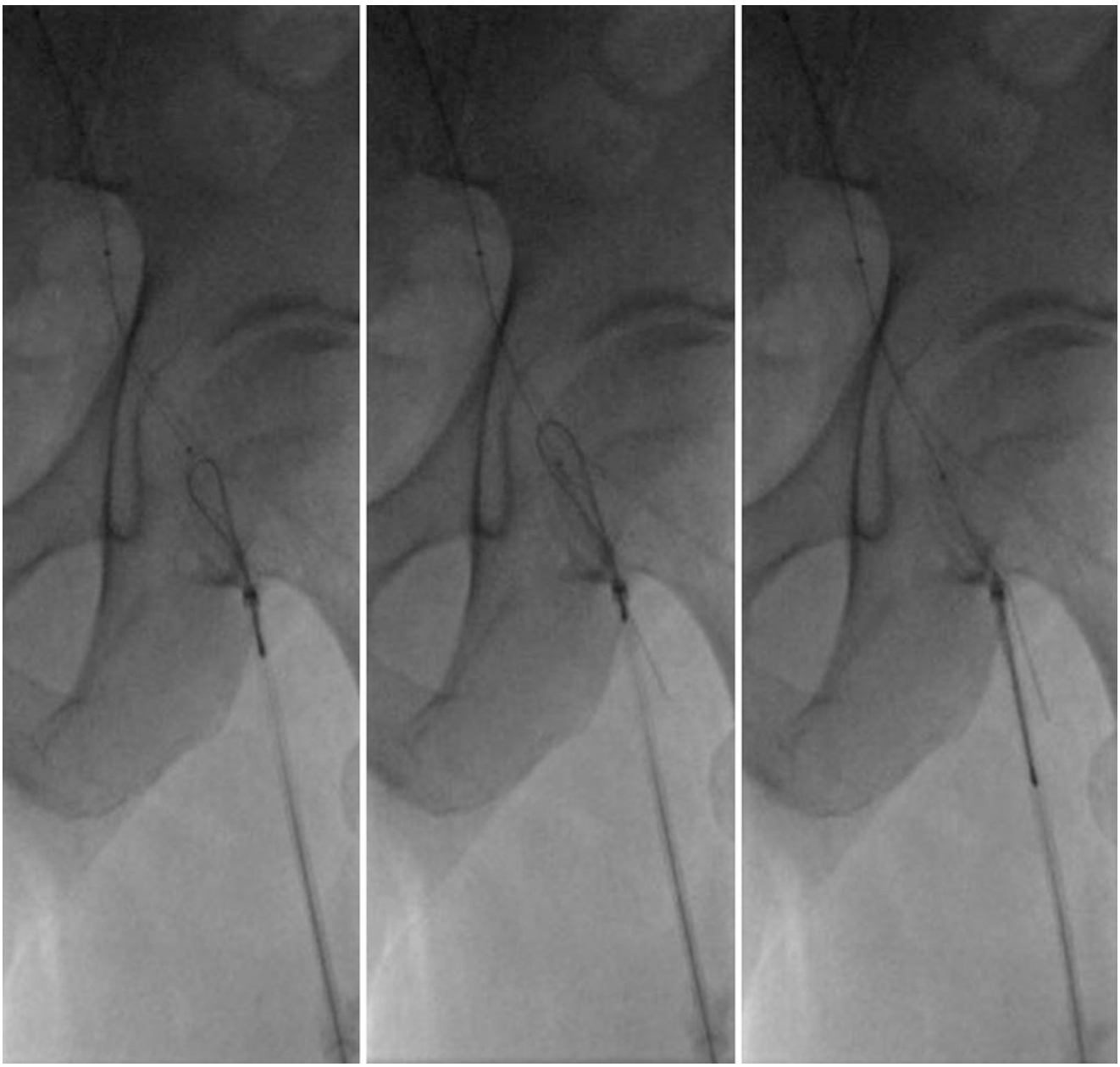


Fig. 36.2 How to snare a wire using a multiloop snare

with the snare close to the foreign body. Open and rotate the snare loop(s) to catch a part of the foreign body. Then pull on the snare and catheter to lock it and retrieve the foreign body if is captured (Fig. 36.3). If the attempt is not successful, repeat the same steps but change the angle of the C arm or use a different type of snare (one-loop vs. multiple, straight vs. angled, smaller or larger loop).

Use of Touhy-Borst Adapter

The advantage of the Touhy-Borst (TB) adapter is that it allows the interventionalist to take an angiogram or inject medication like nitroglycerin while maintaining wire access through the lesion without a long sheath. To do that, you need a lower-profile wire than the size of the catheter. For

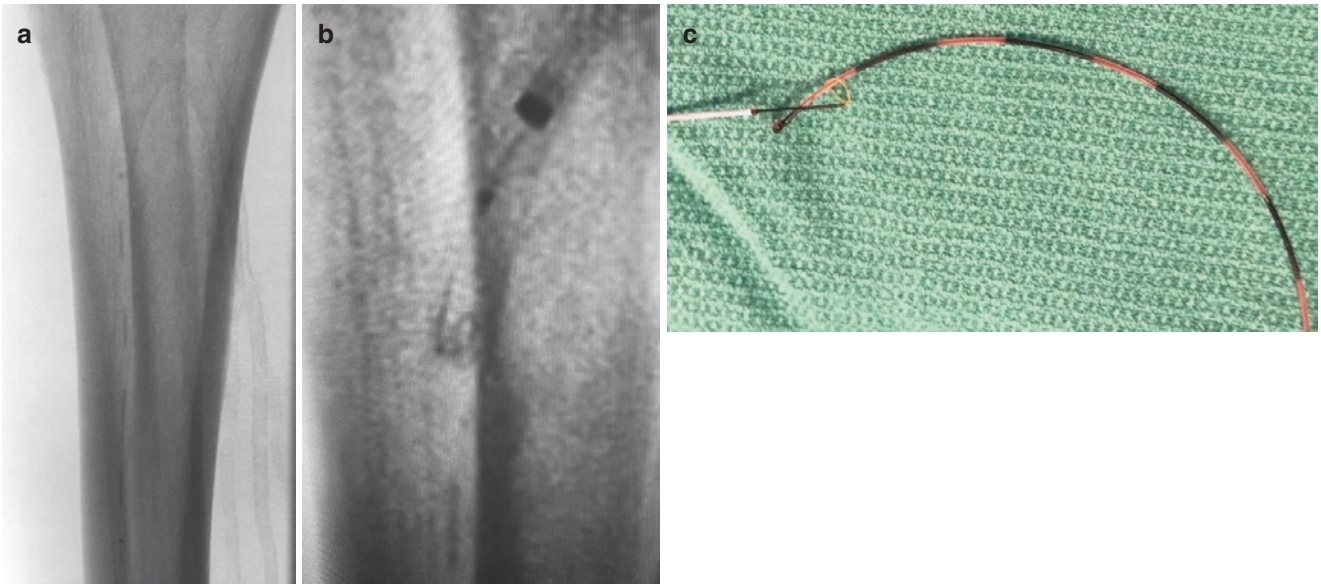


Fig. 36.3 Use of a single-loop microsnare to remove a retained catheter tip from the tibial artery. (**a**) Retained microcatheter in the anterior tibial artery. (**b**) Microsnare retrieving the microcatheter. (**c**) The retained catheter once outside the body

example, assume you have an 0.035″ wire through a high-grade focal popliteal artery stenosis, but the sheath is in the contralateral femoral artery. You pass a balloon and perform angioplasty of that lesion. Then remove the balloon and advance the 0.035″ catheter distal to the lesion, remove the 0.035″ wire and replace it with 0.014″. Then pull the catheter back proximal to the lesion and perform an angiogram using the TB to assess the angioplasty result. If you keep the 0.035″, the same profile wire as the catheter, you will not be able to inject through the TB. If the procedure is more complex, then it is best is to place a long sheath.

Brachial Access

With improvements in radial access, the need to access the brachial artery is expected to dwindle, but when it is used, brachial access hematomas and thrombosis can be minimized by using the technique described here. (For details on upper extremity access, please refer to Chap. 2). Starting with a proper access technique is essential. Access the brachial artery at or above the elbow, just above the humerus bone, to allow for proper compression against the bone. Assuming a long (6 Fr × 90 cm) sheath was introduced in the brachial artery, once the procedure is concluded, the sheath is replaced with a shorter (6 Fr × 11 cm) sheath. The heparin is reversed with protamine. To avoid thrombus formation around the sheath and brachial artery, nonheparinized saline is injected through the sheath every few minutes until the heparin is fully reversed. Place your left index finger on the radial artery (should be prepped in the field); then place one finger above and one below the sheath near the puncture site. Let the nurse or assistant pull out the sheath. Gently compress the brachial artery with your two fingers for 10–20 minutes, until you feel a faint radial pulse with your left index finger. This allows for proper hemostasis while maintaining blood flow to avoid brachial artery thrombosis.

Palmaz Stent

Because of better technology in endovascular aortic aneurysm repairs and better patient selection, the Palmaz stent is rarely used to treat a type IA endoleak after exhausting other techniques. The Palmaz stent is a balloon-expandable stent that comes in 10-mm diameter and variable lengths (30, 40, or 50 mm). This stent will foreshorten when deployed in large vessels like the aorta. It needs to be hand mounted on a balloon such as the Z-MED™ valvuloplasty balloon (Braun). It can be molded with compliant or semicompliant balloons. Mounting the stent on the balloon is a very crucial step. The balloon must be longer than the stent to avoid the watermelon effect when it is deployed. A large sheath is placed at the desired location and the stent is advanced through the sheath under fluoroscopy, to ensure that it does not come off the bal-

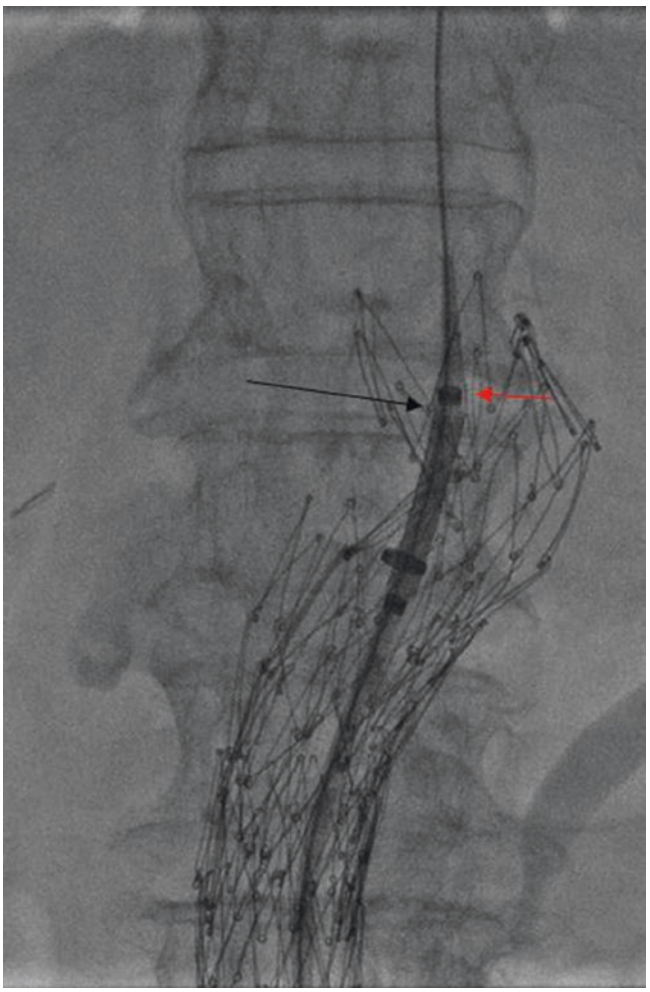


Fig. 36.4 Positioning a Palmaz stent in a patient with type IA endoleak. The sheath and mounted Palmaz stent are positioned in the aortic neck, with the shoulders of the balloon (*red arrow*) extending outside the edge of the Palmaz stent (*black arrow*)

loon (Fig. 36.4). Some deploy the stent within the sheath, allowing the proximal balloon to expand the proximal shoulder to prevent it from being displaced. Then the sheath is pulled back for full stent deployment.

Evaluating Proximal Dialysis Access

When intervening on failing or failed hemodialysis access, the sheath is typically inserted towards the venous anastomotic side, which is the most common site for failure, but it is also important to assess the entire access, including the proximal anastomosis. To visualize the proximal access as well as the arterial anastomosis, dye is injected in the sheath and the access is compressed, forcing the dye to fill the proximal graft and anastomosis retrogradely. The access can be compressed manually, but manual compression results in high radiation exposure to the hand, particularly if digital subtraction is performed. An alternative method is to compress the access using a sterile, large Penrose drain tourniquet around the upper arm, tied and supported by a clamp. A third approach is to perform a retrograde angiogram while performing balloon angioplasty of the access or the venous anastomosis by injecting through the sheath during the balloon insufflation. The balloon will replace the hand in occluding the access (Fig. 36.5), avoiding radiation exposure to the hand. It is important to ensure that the sheath size is one French size larger than needed for the balloon, to make it easier to inject the contrast. For instance, if the balloon will go through a 5 Fr sheath, make sure to use at least a 6 Fr sheath to allow injection of contrast around the balloon.

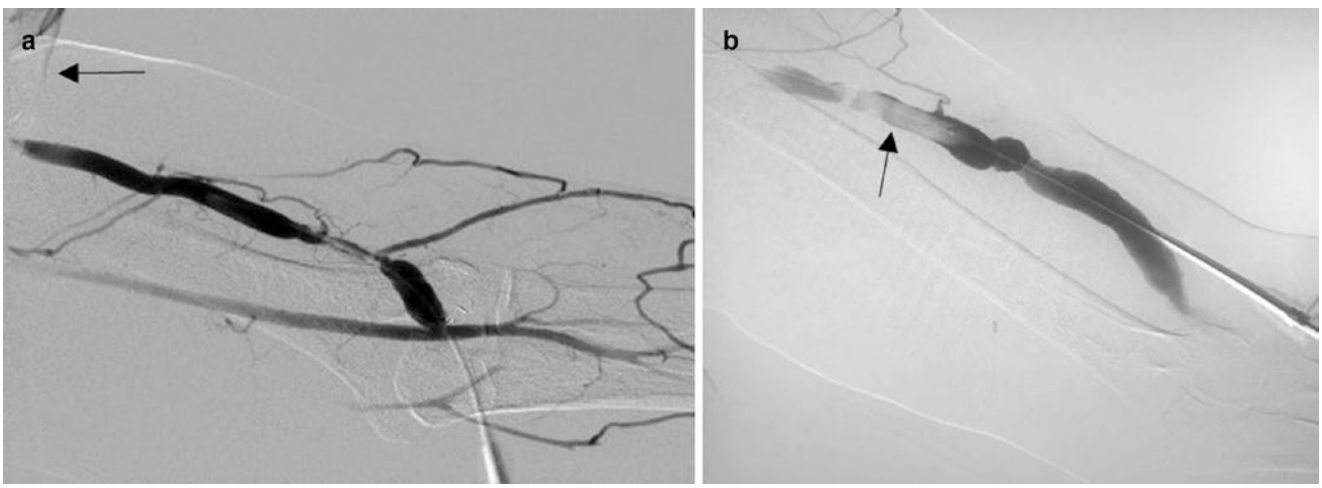


Fig. 36.5 Evaluation of proximal dialysis access. (**a**) Index finger (*arrow*) compressing the arteriovenous fistula (AVF) to allow for retrograde visualization of the access. (**b**) Using the balloon instead of the finger to avoid direct radiation

Appendix: Vascular Anastomosis Workshop

Purpose

The purpose of this workshop is to expose the participant to commonly used basic vascular reconstructions. The participant is expected to learn new skills during the workshop and be able to review and practice what was learned at a later convenient date. It is hoped that this workshop will improve the surgical residents' performance in the operating room when rotating on the vascular surgery service.

Description

The workshop will have a structured format with flexible applications. The participant will be asked to perform a series of technical exercises of increasing complexity. Participants can skip the exercises that may be too simple for their level of training.

At the completion of the workshop, the participant should be familiar with

1. Primary closure of an arteriotomy using an interrupted or continuous suture technique.
2. Patch angioplasty closure of an arteriotomy using an "anchor" or "parachute" technique.
3. End-to-side anastomosis using an "anchor" or "parachute" technique.
4. End-to-end anastomosis in a straight or beveled fashion.
5. End-to-end anastomosis between two grafts of different diameters.

Workshop Tools

Each participant will be provided with.

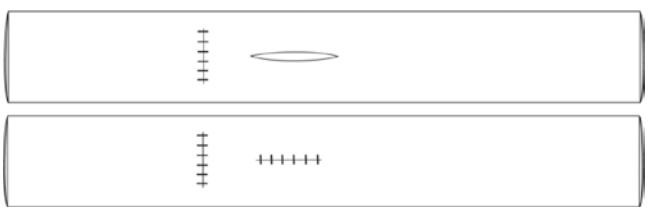
- 1 suture board
- 1 needle holder
- 1 forceps
- 1 scissors
- (2) 8-mm grafts
- (2) 6-mm grafts
- Vascular sutures
- Workshop manual (Part II)

Part II will provide guidance through detailed illustrations on the various techniques used to perform the required exercises. The workshop supervisor can add his/her suggestions and recommendations to the instructions provided in Part II. Even with minimal supervision, the participant should be able to benefit from the workshop and identify any shortcomings in understanding the technical aspects of the reconstruction. A workshop video demonstrating the exercises to be performed can also be supplemented for review before or after the workshop.

Exercises to Be Performed in the Workshop

For the purpose of this workshop, assume that the 8-mm graft is an artery. The 6-mm graft will serve as a conduit to be used for creating a bypass.

Create a transverse arteriotomy.
Close the arteriotomy with interrupted sutures.



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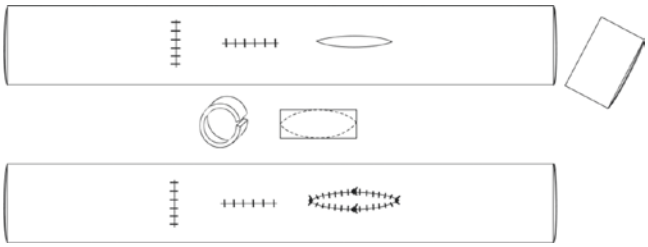
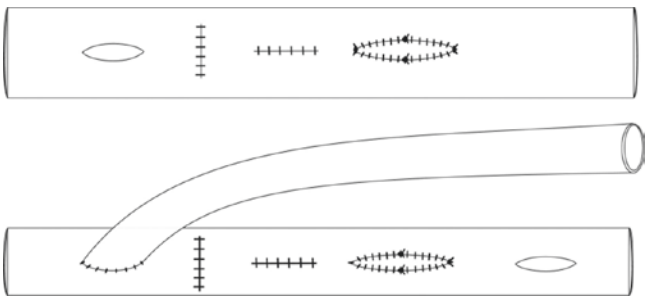
Create a longitudinal arteriotomy.
Close the arteriotomy with a running suture.

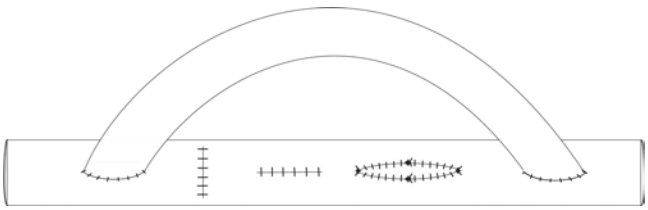


Create a longitudinal arteriotomy. Transect a 2-cm segment of the distal part of the 6-mm graft. Create a patch from that segment. Use that patch to close the arteriotomy.

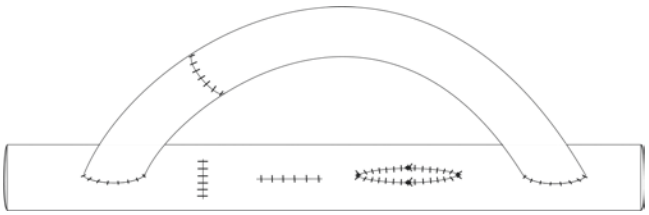


Create a 1-cm longitudinal arteriotomy in the 8-mm graft near the left end. Construct an end-to-side anastomosis with one end of the 6-mm graft using an anchor technique.

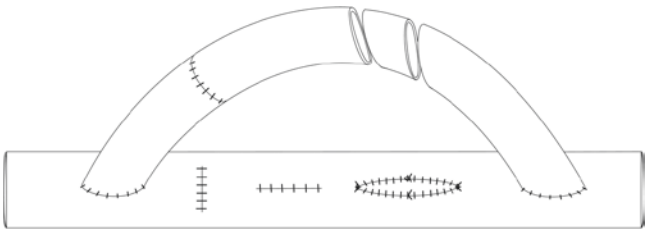
Exercises to Be Performed in the Workshop

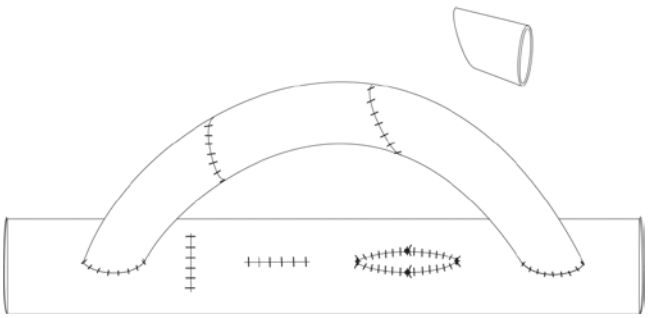


Create a 1-cm longitudinal arteriotomy in the 8-mm graft close to its right end. Construct an end-to-side anastomosis with the free end of the 6-mm graft using a parachute technique.

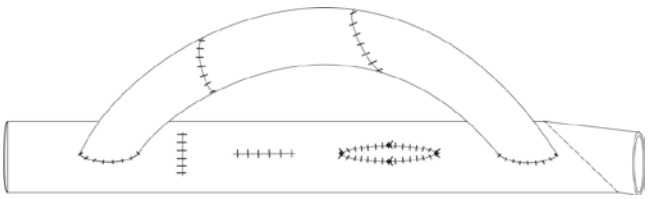


Transect the 6-mm graft and suture it back together in a straight fashion.





Excise a 4-cm segment of the 6-mm graft and suture the ends back together in a beveled fashion.



Construct an end-to-end anastomosis between the 6-mm graft segment and the 8-mm graft.

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