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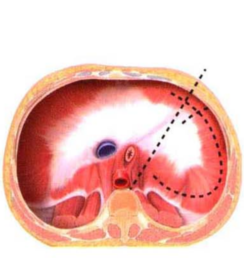
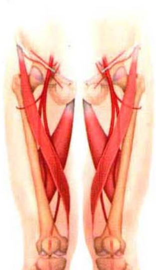
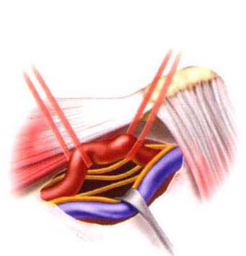
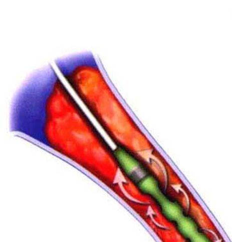
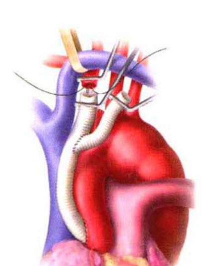
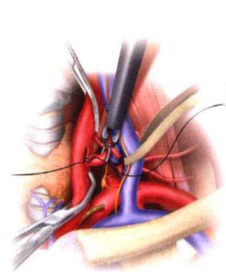
OPERATIVE TECHNIQUES IN VASCULAR SURGERY

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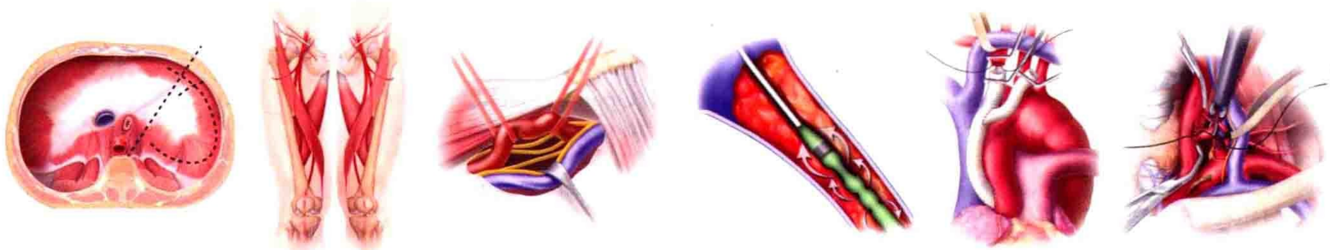
Operative Techniques in Vascular Surgery



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Dedication

The love and support of my wife, Jocelyn J. Dunn MD, continues to enable all my professional accomplishments.

—Ronald L. Dalman

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Series Preface

Operative therapy is complex, technically demanding, and rapidly evolving. Although there are a number of standard textbooks that cover aspects of general, thoracic, vascular, or transplant surgery, *Operative Techniques in Surgery* is unique in offering a comprehensive treatment of contemporary procedures. Open operations, laparoscopic procedures, and newly described robotic approaches are all included. Where alternative or complementary approaches exist, all are provided. The scope and ambition of the project is one of a kind.

The series is organized anatomically in sections covering thoracic surgery, upper gastrointestinal surgery, hepato-pancreatico-biliary surgery, and colorectal surgery. Breast surgery, endocrine surgery, and topics related to surgical oncology are included in a separate volume. Modern approaches to vascular surgery and transplantation surgery are also covered in separate volumes.

The series editors are renowned surgeons with expertise in their respective fields. Each is a leader in the discipline of surgery, each recognized for superb surgical judgment and outstanding operative skill. Breast surgery, endocrine procedures, and surgical oncology topics were edited by Dr. Michael Sabel of the University of Michigan. Thoracic and upper gastrointestinal surgery topics were edited by Dr. Mary Hawn of the University of Alabama at Birmingham, with Dr. Steven Hughes of the University of Florida directing the volume on hepato-pancreatico-biliary surgery. Dr. Daniel Albo of Baylor College of Medicine directed the volume dedicated to colorectal surgery. Dr. Ronald Dalman of Stanford University edited topics related to vascular surgery, including both open and endovascular approaches. The discipline of transplantation surgery is represented by Dr. Michael Englesbe of the University of Michigan. In turn, the editors have recruited contributors that are world-renowned; the resulting volumes have a distinctly international flavor.

Surgery is a visual discipline. *Operative Techniques in Surgery* is lavishly illustrated with a compelling combination of line art and intraoperative photography. The illustrated material was all executed by a single source, Body Scientific International, to provide a uniform style emphasizing clarity and strong, clean lines. Intraoperative photographs are taken from the perspective of the operating surgeon so that operations might be visualized as they would be performed. The result is visually striking, often beautiful. The accompanying text is intentionally spare, with a focus on crucial operative details and important aspects of postoperative management.

The series is designed for surgeons at all levels of practice, from surgical residents to advanced practice fellows to surgeons of wide experience. The incredible pace at which surgical technique evolves means that the volumes will offer new insights and novel approaches to all surgeons.

Operative Techniques in Surgery would be possible only at Wolters Kluwer Health, an organization of unique vision, organization, and talent. Brian Brown, executive editor, Keith Donnellan, acquisitions editor, and Brendan Huffman, product development editor, deserve special recognition for vision and perseverance.

Michael W. Mulholland, MD, PhD

Preface

The pace of innovation in vascular surgery continues to accelerate. Driven by surgeons and industry alike, catheter-based, image-guided intervention, coupled with minimally invasive or "hybrid" exposures, are both revolutionizing care of the vascular patient. The surgeon-authors featured herein represent the vanguard of this movement—leveraging all the advantages inherent in new technology while maintaining fidelity with the fundamental principles of open surgery.

As part of the series *Operative Techniques in Surgery*, this atlas was created to provide a comprehensive reference for practicing surgeons looking to incorporate new skills in vascular disease management as well as trainees at all levels looking for expert guidance. Familiarity of the reader with endovascular skills as well as a representative range of device options for arterial and venous intervention are assumed—those interested in more background should consult a fundamental reference first.

Successful completion of this project was enabled by the steady and encouraging guidance of the series editor, Dr. Michael W. Mulholland, and the professional editorial and project management staff at Wolters Kluwer Health, especially Brendan Huffman and Keith Donnellan. Dr. Jason Lee provided invaluable structural guidance and contributor recommendations. On behalf of everyone involved on this project, it is our shared hope that the thousands of hours of operative insights condensed in this edition will inspire the next generation of vascular specialists.

Ronald L. Dalman, MD

Contents

Chapter 1

Arch and Great Vessel Reconstruction with Debranching Techniques

W. Anthony Lee   Alexander Kulik

DEFINITION

- An aortic arch aneurysm is defined as dilation of the aortic arch to greater than 5 cm in diameter. Rarely occurring in isolation, aneurysms of the aortic arch are often extensions of aneurysms present in the ascending or descending aorta. Causes of aortic arch aneurysms included atherosclerotic degeneration, cystic medial degeneration, aortic dissection, congenital aortopathy (i.e., bicuspid aortic valve), penetrating aortic ulcer, previous traumatic transection (chronic pseudoaneurysm), and previously repaired aortic coarctation (postsurgical pseudoaneurysm). Aortic arch aneurysms have traditionally been repaired with graft replacement of the aorta, with or without an elephant trunk, using cardiopulmonary bypass and deep hypothermic circulatory arrest. With the advent of thoracic endovascular aortic repair (TEVAR), debranching of the brachiocephalic vessels is a recently developed technique that takes advantage of the reduced surgical trauma associated with stent grafting.[1] Debranching functionally extends the proximal landing zone by repositioning the inflow of the brachiocephalic arteries toward the proximal ascending aorta. This facilitates endovascular stent graft repair of the aortic aneurysm by allowing stent coverage across the ostia of the arch vessels, producing a stable and fixed proximal landing zone in the ascending aorta.

PATIENT HISTORY AND PHYSICAL FINDINGS

- Aortic arch aneurysms are usually diagnosed as incidental findings noted on imaging studies, such as a chest x-ray or computed tomography (CT) scan, to evaluate other concurrent medical conditions.
- Most patients have no symptoms from their aneurysms. Symptoms, if they exist, may include chest or back pain from aneurysmal growth or those associated with compression of adjacent structures (i.e., trachea, esophagus). Hoarseness may develop from stretching of the left recurrent laryngeal nerve (Ortner's syndrome). Acute chest or back pain, with or without signs of shock, should raise the suspicion of impending aortic rupture and/or acute aortic dissection. Additional details regarding a patient's past medical history should be gathered, including a history of previous coronary intervention, previous cardiac surgery, known valvular heart disease, previous aneurysm surgery, or a family history of aortopathy.
- The physical examination is often unremarkable. However, attention should be directed to the presence of aortic valve insufficiency (diastolic murmur, widened pulse pressure), previous surgical incisions, and the presence of concomitant peripheral vascular disease.

IMAGING AND OTHER DIAGNOSTIC STUDIES

- Although a routine chest x-ray may be the first imaging test to note an aortic arch abnormality, further imaging is necessary, including a CT scan of the aorta (**FIG 1**) and an echocardiogram.
- An arterial phase CT angiogram should evaluate the entire length of the aorta, from the level of the skull base proximally to the femoral heads distally, to ensure visualization of the vertebral and iliofemoral arteries, respectively. The CT images are then processed using 3D imaging software for case planning and device selection. A magnetic resonance imaging (MRI) or a noncontrast CT scan will not suffice.
- A transthoracic (2D) echocardiogram should be performed to assess left and right ventricular function and to exclude the presence of significant valvular heart disease.
- Strong consideration should be given to evaluating the anatomy of the coronary arteries in the preoperative period. A CT coronary angiogram may be an option for younger patients or those with complex proximal aortic dissection. However, if there is a strong suspicion of coronary disease, then a preoperative conventional coronary angiogram should be performed, including those patients older than 40 years of age and those with a history of smoking.

SURGICAL MANAGEMENT

Preoperative Planning

- Indications for repair of an aortic arch aneurysm include large aneurysmal size (>5.5 cm), rapid growth (>0.5 cm per year), the presence of chest pain or back pain unexplained by other causes, and compression of adjacent organs (esophagus, trachea, or left main bronchus).[2]
- More aggressive size criteria may be applied for patients with Marfan's syndrome (repair at 4.5 to 5 cm). However, stent graft outcomes appear less favorable in patients with

FIG 1 • Preoperative computed tomography (CT) angiogram of an aortic arch aneurysm.

connective tissue disease, and therefore, alternative surgical techniques (such as conventional aortic replacement surgery) should be considered.[2]

- The presence of significant concurrent cardiac disease may alter the surgical approach. Should significant coronary artery or valvular heart disease be identified in the preoperative period, consideration may be given to performing concomitant coronary artery bypass grafting (CABG) or valve replacement at the time of the aortic debranching procedure.
- During the second stage of the arch repair, stent graft deployment in the distal ascending aorta may require the placement of a guidewire across the aortic valve into the left ventricular cavity. The presence of a mechanical aortic prosthetic valve, through which a guidewire and the delivery system cannot safely be placed, may require a single-stage approach with deployment of the stent graft at the time of debranching (see endovascular second stage). A bioprosthetic valve in the aortic position may allow for careful transvalvular introduction of devices, with preference to bovine pericardial valves over porcine valves.
- Selection of the ideal treatment strategy for repair of an aortic arch aneurysm remains controversial and is dictated by surgical experience and local area expertise. Aortic arch debranching and stent graft completion is an appealing repair option that avoids a thoracotomy incision and may avert the use of cardiopulmonary bypass and circulatory arrest. These types of hybrid procedures may be performed either as single- or two-stage repairs. However, conventional open replacement of the entire aortic arch,[3,4] or replacement of the ascending aorta and proximal arch with the creation of an elephant trunk followed by stent graft completion,[1,5] should be considered as clinically indicated.
- Debranching of the aortic arch off the ascending aorta may not be applicable for a patient with an aortic arch aneurysm who has previously undergone cardiac surgery and who is too high-risk for consideration of redo sternotomy. In this case, an alternative option would include extra-anatomic debranching of the aortic arch (carotid–carotid, carotid–subclavian) followed by stent graft repair of the arch, with or without innominate artery chimney (snorkel) stenting.[6]
- The preoperative CT scan requires careful review before undertaking an aortic arch debranching operation. Arch branch anatomy and appropriate landing zones need to be identified proximal and distal to the arch aneurysm, with criteria similar to those that apply for stent graft repair of a descending thoracic aortic aneurysm. Anatomic variations of the aortic arch anatomy may require modification of the debranching procedure. These include a bovine aortic arch (common trunk of the innominate and left common carotid), arch origin of left vertebral artery, and an aberrant right subclavian artery.
- The ascending aorta is typically 6 to 7 cm in length from the sinotubular junction to the innominate artery. Placement of the proximal inflow anastomosis as low as possible on the ascending aorta (just distal to the sinotubular junction) will result in an optimal 3- to 4-cm proximal landing zone for the stent graft repair. The largest currently available thoracic stent grafts are 42 to 46 mm in diameter. To provide a safe and durable proximal landing zone and avoid a proximal type I endoleak, we recommend replacement of an ascending aorta that is extremely short or if its diameter is 36 mm or larger. Open replacement of the ascending aorta would be performed at the time of the arch debranching procedure, with implantation of an aortic graft 34 mm or smaller.
- The size of the iliofemoral arteries is worth noting on the preoperative CT study. The external iliac arteries need to be larger than 7 mm in diameter to provide adequate vascular access to deliver the stent graft devices during the second stage. An iliac artery conduit may be needed if the iliofemoral arteries are extremely small or in the presence of severe calcification and occlusive disease. Alternatively, a single-stage antegrade introduction of the stent graft from the ascending aorta may be performed (see endovascular second stage) to avoid access problems from a retrograde iliofemoral approach.
- The diameters of the brachiocephalic arteries are measured on the preoperative CT scan to determine the interposition graft sizes for the debranching procedure. Most frequently, the size of the graft chosen for the innominate artery branch is 10 to 14 mm, with 6- to 8-mm grafts usually used for the left carotid and left subclavian arteries.
- Cerebral oximetry monitoring may be helpful for the aortic debranching procedure to monitor brain perfusion before and after clamping of the brachiocephalic arteries. For the second-stage endovascular procedure, cerebrospinal fluid (CSF) drains are placed preoperatively to reduce the risk of spinal cord ischemia if a significant length of the descending thoracic aorta is to be covered.

Positioning

- For the arch debranching procedure, patients are positioned supine just as they are during standard cardiac surgical operations. Prepping is performed from the neck to the knees, with draping higher than usual to strategically provide access to the lower neck. The head may be turned slightly to the right to facilitate extension of the sternotomy incision proximally along the left sternocleidomastoid muscle.

AORTIC ARCH DEBRANCHING

- Although some advocate the use of a right thoracotomy incision or upper hemisternotomy, we prefer to expose the ascending aorta through a conventional sternotomy incision. This provides optimal visualization and control. The pericardium is incised and retracted.
- The ascending aorta is carefully mobilized to facilitate later placement of a proximally positioned side-biting clamp. The space between the left side of the aorta and the pulmonary artery is dissected, with small vessels cauterized or clipped and divided. The ascending aorta is mobilized proximally down to the level of the aortic root (sinotubular junction) to enable identification (and avoid injury) to the right coronary artery.
- The brachiocephalic arteries are circumferentially exposed. The innominate vein is mobilized and retracted

with an umbilical tape to facilitate exposure of the arch vessels (**FIG 2**). Uncommonly, the innominate vein requires ligation and division to aid in arch exposure. The left subclavian artery is often more posterior than expected, and exposure of this artery may be difficult. In these circumstances, the sternotomy incision may be extended superiorly and leftward along the sternocleidomastoid muscle. Alternatively, innominate and left carotid debranching may be combined with a left carotid-subclavian bypass/transposition procedure, through a standard supraclavicular approach, obviating the need to expose the left subclavian artery through the sternotomy.

- Although a preformed bifurcated or multilimb graft may be used, these occupy a large footprint and reduce the length available for the ascending aortic landing zone. Instead, we prefer to construct a Y-graft by sewing a beveled smaller Dacron graft end-to-side to larger Dacron graft (**FIG 3**). The graft sizes are selected based on the measured diameters from the preoperative CT scan. Typically, a 10- or 12-mm graft is used for the innominate artery, and a 6- or 8-mm graft is used for the left carotid artery.
- Heparin is administered to achieve an activated clotting time (ACT) of 200 seconds. The blood pressure is lowered to 90 mmHg systolic, and an aortic side-biting clamp is placed on the right anterolateral side (convexity) of the ascending aorta, as low as possible, with care not to compromise the right coronary artery. A retraction suture in the right atrial appendage may be needed to facilitate proximal aortic exposure. Consideration may be given to performing this and subsequent steps in the operation with cardiopulmonary bypass to provide optimal hemodynamic control during clamp application and removal and to improve brain protection with systemic cooling in the range of 32°C to 34°C.
- The proximal end of the larger (10 or 12 mm) graft is cut to the appropriate length so the Y-graft easily reaches the arch vessels. The graft is beveled and sewn end-to-side to the ascending aorta with a running 3-0 or 4-0 polypropylene suture (**FIG 4**). BioGlue may be applied to further support the anastomosis. The aortic clamp is gently released. A large clip may be placed across the heel of the anastomosis. This will help visualize the origin of the debranching graft from the ascending aorta and precisely define the proximal landing zone without the need for contrast during the second-stage endovascular procedure.
- The innominate artery is transected, and the proximal end is oversewn with two layers of 4-0 polypropylene. The distal large end of the Y-graft is then tunneled underneath the innominate vein and sewn end-to-end to the innominate artery with running 5-0 polypropylene (**FIG 5**).
- Next, the left common carotid artery is transected, and the proximal end of the carotid artery is oversewn with 4-0 polypropylene. The distal smaller end of the Y-graft is tunneled underneath the innominate vein and sewn

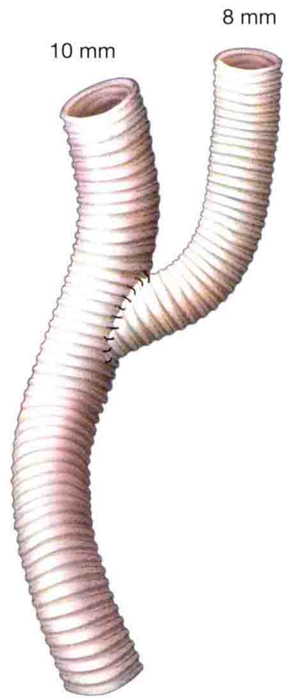

FIG 3 • A Y-graft is constructed by sewing a beveled smaller Dacron graft (6 to 8 mm) end-to-side to larger Dacron graft (10 to 12 mm).

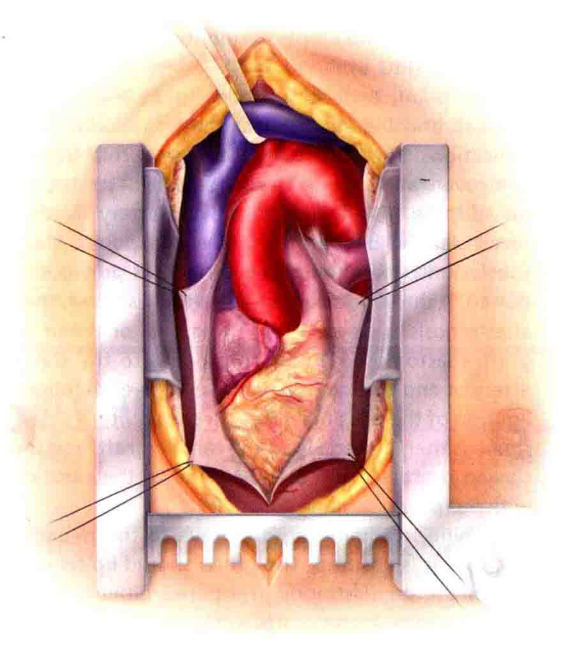

FIG 2 • After sternotomy, the pericardium is incised and retracted. The ascending aorta is mobilized, and the brachiocephalic arteries are circumferentially exposed. The innominate vein is mobilized and retracted with an umbilical tape to facilitate exposure of the arch vessels.

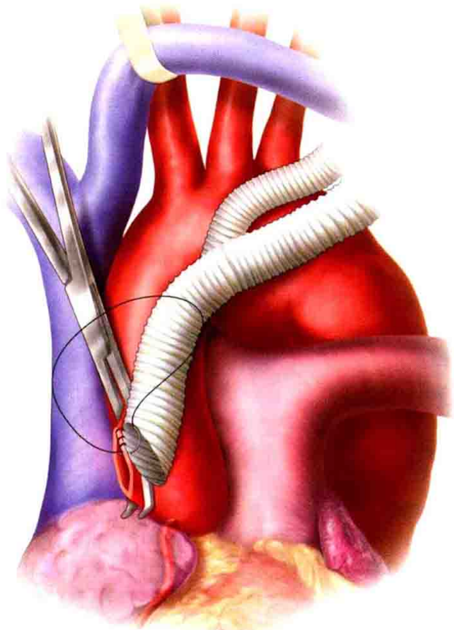

FIG 4 • An aortic side-biting clamp is placed on the right anterolateral side (convexity) of the ascending aorta, as low as possible. The proximal end of the larger (10 or 12 mm) graft is beveled and sewn end-to-side to the ascending aorta with a running 3-0 or 4-0 polypropylene suture.

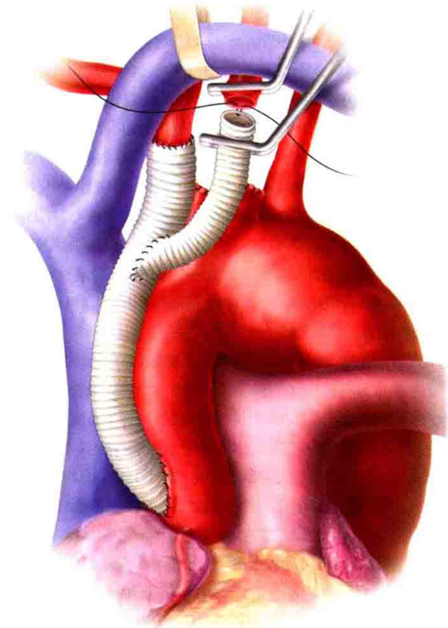

FIG 6 • The left common carotid artery is transected, and the proximal end of the carotid artery is oversewn with 4-0 polypropylene. The distal smaller end of the Y-graft is tunneled underneath the innominate vein and sewn end-to-end to the carotid artery with running 5-0 polypropylene.

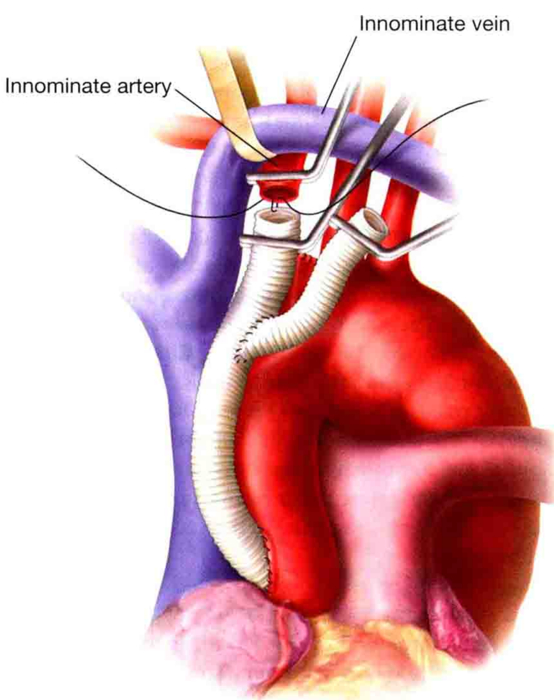

FIG 5 • The innominate artery is transected, and the proximal end is oversewn 4-0 polypropylene. The distal large end of the Y-graft is then tunneled underneath the innominate vein and sewn end-to-end to the innominate artery with running 5-0 polypropylene.

end-to-end to the carotid artery with running 5-0 polypropylene (FIG 6).

- At this point, a decision needs to be made regarding the debranching strategy for the left subclavian artery. Indications for left subclavian revascularization are controversial. Routine versus selective strategies may be adopted.[7] If the left subclavian artery needs to be revascularized but cannot safely be exposed, a carotid–subclavian bypass can be performed as previously mentioned. If the subclavian artery can be exposed, the distal anastomosis is created first using a 6- or 8-mm Dacron graft anastomosed either end-to-end to the transected artery or end-to-side (functional end-to-end) followed by ligation of the proximal artery in continuity. A side-biting clamp is then placed along the carotid graft, and the subclavian graft is sutured end-to-side to the carotid graft with 5-0 polypropylene suture (FIG 7).
- Protamine is administered to reverse the heparin, and hemostasis is ensured. The grafts should lie tension free within the mediastinum. The pericardium may be partially closed over the grafts, with care to avoid compression of the graft branches. Chest tubes are positioned, and the sternum is closed routinely. After the sternum is closed, the blood pressure should be assessed in each arm and cerebral oximetry monitored to confirm adequate perfusion through the graft branches and the absence of graft compression.

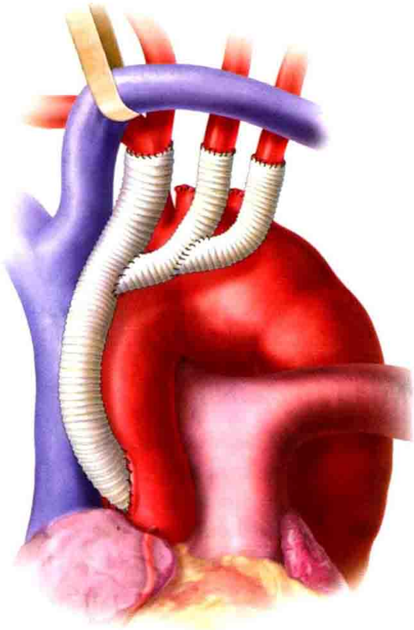

FIG 7 • If the subclavian artery can be exposed, the distal anastomosis is created first using a 6- or 8-mm Dacron graft anastomosed end-to-end to the transected artery. The subclavian graft is then sutured end-to-side to the carotid graft with 5-0 polypropylene suture.

ENDOVASCULAR SECOND STAGE

- The endovascular second stage of the arch repair is conducted in a fairly similar manner to that of stent graft repair of a descending thoracic aortic aneurysm, as described in Chapter 13 (Thoracic Endografting).
- The timing of the endovascular repair as a single versus staged approach remains controversial. We prefer to delay the second stage depending on the clinical scenario. It can range from a few days (same hospitalization) to several weeks (separate admission) to allow the patient to recover from the first procedure. This reduces the overall physiologic stress on the patient.
- Although we favor delivery of the stent graft in a retrograde manner from the iliofemoral arteries, in cases of a mechanical aortic valve or severe iliofemoral occlusive disease, single-stage antegrade deployment should be considered. The technical variations for these less common situations are beyond the scope of the present chapter.
- The site of insertion of the endovascular graft delivery system is decided based on the size and quality of the access vessels. In general, the grafts are delivered through the common femoral artery, whereas an iliac conduit may be required for very small or diseased iliofemoral arteries.
- The delivery guidewire is placed in the left ventricle during the endovascular procedure to provide sufficient proximal rail support for the endovascular graft.
- The proximal stent graft is deployed in the ascending aorta just distal to the origin of the debranching graft. During deployment, it is useful to lower the blood pressure using one of a variety of pharmacologic, ventricular pacing or atrial inflow occlusion techniques.[8]

PEARLS AND PITFALLS

Indications	■ The preoperative CT angiogram should be reviewed in detail to ensure the patient is a suitable candidate for aortic arch repair with debranching and stent grafting, including appropriate landing zones proximally and distally and adequate vascular access.
Proximal type I endoleak	■ To optimize the length of the proximal landing zone and prevent a type I endoleak, the debranching graft should be placed as low as possible on the ascending aorta. Preemptive replacement of the ascending aorta should be performed if it is extremely short or its diameter is >34 mm.
Mechanical aortic prosthesis	■ After aortic debranching, the endovascular graft delivery system may have to cross the aortic valve. Although transvalvular placement of a large sheath is relatively safe for native and bioprosthetic valves, it is contraindicated for a mechanical aortic valve. Antegrade stent graft deployment at the time of debranching should be considered in the presence of a mechanical prosthesis.
Injury to right coronary artery	■ Care should be taken when applying the side-biting clamp low on the ascending aorta to avoid occlusion or injury to the right coronary artery.

Ascending aortic dissection	■ The systolic blood pressure should be lowered to <90 mmHg when applying the side-biting clamp on the ascending aorta to prevent injury and dissection of an already fragile and diseased aorta.
Left subclavian artery	■ If the left subclavian artery is not easily accessible via the sternotomy incision (large rotated aortic arch aneurysm), then debranching of this artery can be performed via carotid–subclavian bypass.
Compression and kinking of debranching grafts	■ Ideally, the main debranching graft should lie along the right side of the ascending aorta to avoid compression by the sternum after chest closure. The graft branches should lie tension free, with care taken to avoid kinking at the time of pericardial and chest wall closure.

POSTOPERATIVE CARE

- Following the debranching procedure, patients are monitored in a cardiovascular surgical intensive care unit for 48 hours, with a focus on neurologic status, applying standard postoperative cardiac surgery protocols.
- Chest tubes are typically removed 2 days after the debranching operation.
- If a patient is recovering well after debranching without complication and has stable renal function, then the stent graft completion can be performed 3 to 5 days postoperatively. In the event of a major complication requiring extended recovery, the patient may be discharged to a rehabilitation center. The stent graft procedure can be delayed for a few weeks. However, up to 25% of patients may not return for their second stage.
- Following the second-stage stent graft procedure, the blood pressure is augmented with fluid and vasopressor support to achieve a target systolic blood pressure of 140 to 160 mmHg for 48 hours to optimize spinal cord perfusion.
- CSF drains are left open for 24 hours following stent grafting. Drainage is limited to less than 15 mL per hour or less than 350 mL per day to avoid the potential risk of subdural hemorrhage. In the absence of spinal cord injury, CSF drains are then clamped for 12 hours and subsequently removed.
- Follow-up CT angiograms of the aorta are performed at 1 and 6 months after the stent graft procedure, and then yearly thereafter.

OUTCOMES

- In the authors' experience of 37 aortic arch debranching procedures,[1] rates of spinal cord injury, stroke, and 30-day mortality were 0%, 10.8%, and 16.2%, respectively. The incidence of proximal type I endoleak was 3.7% at 1 and 12 months. Survival at 1 and 12 months was 86.5±5.6% and 71.6±8.5%, respectively. Freedom from undergoing any secondary surgical procedure after stent graft completion at 1 and 12 months was 71.0±7.8% and 52.8±10%, respectively.
- A recent systematic review of aortic arch debranching summarized the clinical outcomes of 27 published studies including a total of 642 patients.[9] Reporting results similar to those of the authors' experience[1]; the review noted rates of spinal cord injury, stroke, and 30-day mortality of 4.3%, 7.3%, and 11.9%, respectively. In this review, a trend existed between higher surgical volume and lower neurologic complications, with stroke rates of 9.6% and 6.5% in low-volume and high-volume case series, respectively.[9]
- In another review article that included 18 studies and data from 195 patients, the technical success rate following aortic arch debranching and stent graft repair was reported at 86%. The most common reason for technical failure was endoleak (9%).[10]

COMPLICATIONS

- Reopening for bleeding
- Stroke or transient ischemic attack (TIA)
- Spinal cord ischemic injury
- Ascending aortic dissection
- Endoleak
- Iliofemoral artery injury
- Mortality

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