An arterial aneurysm is defined as a permanent localized enlargement of an artery to a diameter more than 1.5 times its expected diameter. Aneurysms are classified according to morphology, etiology, and anatomic site. The most common morphology is a fusiform, symmetrical, circumferential enlargement that involves all layers of the arterial wall. A saccular morphology is also seen, in which aneurysmal degeneration affects only part of the arterial circumference.

The most common cause of an arterial aneurysm is atherosclerotic degeneration of the arterial wall. The pathogenesis is a multifactorial process involving genetic predisposition, aging, atherosclerosis, inflammation, and localized activation of proteolytic enzymes. Most aneurysms occur in elderly persons, and the prevalence rises with increasing age. Aneurysms also occur in genetically susceptible individuals with Ehlers-Danlos syndrome or Marfan syndrome. Other causes include tertiary syphilis and localized infection resulting in a mycotic aneurysm. Aneurysms of the infrarenal aorta are by far the most common arterial aneurysms encountered in clinical practice today: they are three to seven times more common than thoracic aneurysms and affect four times as many men as women. Abdominal aortic aneurysms (AAAs) have a tendency to enlarge and rupture, causing death. In the United States, AAAs result in approximately 15,000 deaths each year and are thus the 13th leading cause of death. The only way to reduce the death rate is to identify and treat aortic aneurysms before they rupture [see 6:3 Pulsatile Abdominal Mass].

The relationship between aneurysm size and risk of rupture is well known. The annual risk of rupture is 1% to 2% for aneurysms less than 5 cm in diameter, 10% for aneurysms 5 to 6 cm in diameter, and 25% or higher for aneurysms larger than 6 cm. Although large aneurysms are much more likely to rupture than small aneurysms, small aneurysms can and do rupture on occasion.

The exact size at which an asymptomatic small AAA should be treated remains unsettled. This issue was the subject of two prospective, randomized clinical trials: the United Kingdom Small Aneurysm Trial. Small aneurysms can and do rupture on occasion. With respect to the primary end point—overall survival—the two trials came to similar conclusions: there was no difference in overall survival between the surgery group and the surveillance group. There was, however, a late survival benefit in the surgery group in the U.K. Small Aneurysm Trial.

Aneurysm rupture rates were low (1%) in both trials, leading many clinicians to conclude that aneurysms smaller than 5.5 cm need not be treated, because the risk of rupture is so low. Closer examination of the data, however, reveals that more than 60% of the patients in the surveillance groups underwent open surgical repair during the two trials: 81% of patients with 5.0 to 5.4 cm aneurysms in the ADAM trial underwent surgery, and almost all patients in the U.K. trial ultimately required surgical management. Thus, it is likely that the reason for the low rupture risk in these trials was that surgical treatment of the aneurysm was provided when clinically indicated. This conclusion is supported by data from a prospective study of patients from the VA hospitals involved in the ADAM trial who were not eligible for randomization and did not undergo operative repair. In these patients, the 1-year risk of rupture for slightly larger (5.5 to 5.9 cm) aneurysms was 9.4%. Furthermore, very close surveillance with ultrasound examinations every 3 to 6 months did not prevent aneurysm rupture in 1% of patients. Thus, the decision whether to treat an aneurysm is based on assessment of the risk of aneurysm rupture relative to the risk associated with treatment rather than on an absolute size criterion or a surveillance protocol.

Open Repair

PREOPERATIVE EVALUATION

Identification of Risk Factors

For successful surgical reconstruction of AAAs, any significant comorbidities that would increase the risk of operative repair must be identified and managed at an early stage. Patients undergoing the procedure usually are elderly and often have coexisting cardiac, pulmonary, cerebrovascular, renal, or peripheral vascular disease. The major anesthetic risk factors for elective resection of AAAs are similar to those for other major intra-abdominal operations; in particular, they include inadequate cardiopulmonary and renal function. Patients with unstable angina or angina at rest, a cardiac ejection fraction of less than 25%, a serum creatinine concentration higher than 3 mg/dl, or pulmonary disease (manifested by arterial oxygen tension < 50 mm Hg, elevated arterial carbon dioxide tension, or both on room air) are considered to be at high risk.

Myocardial ischemia is the most common cause of perioperative morbidity and mortality after arterial reconstruction of the aorta. Optimization of preoperative medical management, perioperative invasive monitoring, and long-term risk-factor modification are all facilitated by an accurate preoperative cardiac evaluation. Such evaluation may include transthoracic echocardiography, exercise stress testing, myocardial scintigraphy, stress echocardiography, and coronary angiography; each test has its own merits and limitations with regard to clinical risk assessment.

There has been considerable controversy over the potential benefit of preoperative coronary revascularization in this setting. This issue was addressed by a clinical trial in which patients requiring AAA or peripheral vascular surgery who had high-risk cardiac disease were randomly assigned to undergo either vascular surgery without preoperative coronary revascularization or coronary revascularization followed by vascular surgery. There was no differ-
ence between the two groups with respect to the incidence of postoperative MI or overall mortality. The investigators concluded that patients with stable coronary disease do not benefit from preoperative coronary revascularization. Patients with unstable severe coronary disease may benefit from invasive cardiac evaluation and preliminary coronary intervention.

To reduce the mortality associated with resection of AAAs, it is necessary not only to identify high-risk groups but also to institute appropriate preoperative, intraoperative, and postoperative alterations in patient care. With intensive perioperative monitoring and support in place, resection of AAAs has been successfully performed even in high-risk patients, with operative mortalities of less than 6%.12-14

**Confirmation of Diagnosis and Determination of Aneurysm Size**

Physical examination suffices for detection of most large aneurysms. To determine the exact size of the aneurysm and to identify smaller aneurysms, however, more objective methods are available and should be used. Determination of the size of the aneurysm is extremely important because size is the most important determinant of the likelihood of rupture and plays a crucial role in subsequent management decisions. Imaging modalities commonly employed to diagnose and measure aneurysms include duplex ultrasonography (DUS), aortography, computed tomography, and magnetic resonance imaging.

The main advantages of DUS are its ready availability in both inpatient and outpatient settings, its low cost, its safety, and its good performance; many studies have documented the ability of DUS to establish the diagnosis and accurately determine the size of AAAs [see Figure 1].15-17 The primary limitations of DUS are that imaging of the thoracic and suprarenal aorta is poor, that the quality of the images is considerably lower in the presence of obesity or large amounts of intestinal gas, and that it must be performed by a skilled imaging technician.

Aortography yields excellent images of the contours of the aortic lumen, but it is not a reliable method for determining the diameter of an aneurysm or even for establishing its presence, because the mural thrombus within the aneurysm tends to reduce the lumen to near-normal size. Nonetheless, aortography can be helpful in determining the extent of an aneurysm (especially when there is iliac or suprarenal involvement), defining associated arterial lesions involving the renal and visceral arteries, and detecting lower-extremity occlusive disease. There are risks associated with aortography that place some restrictions on its use. Among these risks are the potential renal toxicity resulting from the use of contrast agents. In addition, manipulation of catheters through the laminated mural thrombus increases the risk of distal embolization. Finally, local arterial complications may arise at the arterial puncture site.

CT provides reliable information about the size of the entire aorta, thereby allowing accurate determination of both the size and the extent of the AAA [see Figure 2]. Spiral CT scanning permits identification of the visceral and renal arteries and their relationship to the aneurysm. The administration of I.V. contrast material allows assessment of the aortic lumen, the amount and location of mural thrombus, and the presence or absence of retroperitoneal hematoma [see Figure 3]. Overall, spiral CT is currently the most useful imaging method for evaluation of the abdominal aorta.

MRI is also useful in the preoperative evaluation of aortic aneurysms.18,19 It employs radiofrequency energy and a magnetic field to produce images in longitudinal, transverse, and coronal planes. The advantages of MRI over CT are that no ionizing radiation is administered, multiplane images can be obtained, and no nephrotoxic contrast agents are used.

**Classification of Patients for Elective or Urgent Repair**

Patients may usefully be classified into three categories according to how they present for repair: (1) elective patients, (2) symptomatic patients, and (3) patients with ruptured aneurysms.

**Figure 1** Duplex ultrasonography may be used as a screening test and to determine the actual size of the aneurysm.

**Figure 2** Shown is a CT angiogram providing a three-dimensional reconstruction of an infrarenal AAA after endovascular repair. Of particular interest is the relation of the graft to the renal arteries and the hypogastric arteries distally.
Elective aneurysm repair is recommended for asymptomatic patients who have aneurysms 5.0 cm in diameter or larger, who have an acceptable level of operative risk, and who have a life expectancy of 1 year or more. Furthermore, elective operation should be considered for patients with aneurysms smaller than 5.0 cm who are not at high operative risk if they are hypertensive or live in a remote area where proper medical care is not readily available. Repair is also appropriate for aneurysms that are between 4.0 and 5.0 cm in diameter and have shown growth of more than 0.5 cm on serial images in less than 6 to 12 months. Peripheral embolization originating from the aneurysm is an indication for repair, regardless of the size of the aneurysm.

Urgent operation is indicated for patients with symptomatic aneurysms, regardless of the size of the aneurysm. Such patients typically present with abdominal or back pain. Sometimes, the back pain radiates to the groin, much as in ureteral colic; this pain may be elicited by palpating the aneurysm. In most cases, DUS, CT, and MRI will reliably detect the presence of periaortic blood; however, the absence of this finding should not delay operation, because actual rupture of the aneurysm can occur at any time.

Emergency operation is indicated for almost all patients with known or suspected rupture of an aneurysm.

OPERATIVE PLANNING

Preoperative planning is essential for a successful outcome after repair of an infrarenal AAA. Like the choice between elective and urgent or emergency repair, operative planning is governed by the presentation of the patient. In patients with ruptured aneurysms, diagnosis is immediately followed by operative repair. In patients with symptomatic aneurysms, the amount of preoperative imaging done is balanced against the risk of impending rupture. In patients presenting for elective repair, it is generally possible to perform extensive imaging to determine whether the repair is best done via an endovascular approach [see Endovascular Repair, below] or a standard open approach. Current preoperative imaging methods utilizing CT angiography (CTA) obviate several common pitfalls. The availability of endovascular techniques for excluding an aneurysm should not alter the patient selection criteria for aneurysm repair. Consideration of endovascular aneurysm repair (EVAR) does introduce certain morphologic criteria into the process of patient selection, in that stent grafting is appropriate only for patients in whom the infrarenal neck and the iliac arteries are suitable.

Given that the long-term outcome of endovascular grafting is currently unknown, younger patients who are at low operative risk and are expected to survive into the long term are typically better served with open surgical repair. In addition, patients who require additional abdominal or pelvic revascularization procedures, who have small or diseased access vessels, or who have short (< 10 mm) or tortuous infrarenal necks are not candidates for endovascular grafting and should undergo open surgical repair instead.

Preoperative preparation to optimize cardiopulmonary function, administration of preoperative antibiotics, and intraoperative hemodynamic monitoring with appropriate fluid management can significantly reduce the risks associated with AAA repair. Before aortic cross-clamping, appropriate volume loading, combined with vasodilatation, is carried out to help prevent declamping hypotension.

OPERATIVE TECHNIQUE

Step 1: Initial Incision and Choice of Approach

Open surgical repair of infrarenal AAAs is performed through a transperitoneal or retroperitoneal exposure of the aorta with the patient under general endotracheal anesthesia. The aneurysm may be exposed through either a long midline incision (for the transperitoneal approach) or an oblique flank incision (for the retroperitoneal approach) [see Figure 4a]. An upper abdominal transverse incision may also be used for either retroperitoneal or transperitoneal exposure. The results with the two exposures are equivalent. The transperitoneal approach is preferred when exposure of the right renal artery is required and when access to the distal right iliac system or to intra-abdominal organs is necessary. The retroperitoneal exposure offers advantages when extensive peri- toneal adhesions, an intestinal stoma, or severe pulmonary disease is present and when there is a need for suprarenal exposure. Use of the retroperitoneal approach has been associated with a shorter
duration of postoperative ileus, a lower incidence of pulmonary complications, and a reduction in length of stay in the ICU.

Step 2 (Transperitoneal Approach): Exposure and Control of Aorta and Iliac Arteries

When the transperitoneal approach is taken, the small bowel (including the duodenum) is retracted to the right, and the retroperitoneum overlying the aneurysm is divided to the left of the midline [see Figure 4b]. The duodenum is completely mobilized, and the left renal vein is identified and exposed. The normal infrarenal neck, which is just below the left renal vein, is then exposed and encircled for proximal control. Both common iliac arteries are mobilized and controlled, with care taken to avoid the underlying iliac veins and ureters that cross over at the iliac bifurcation [see Figure 5]. If the common iliac arteries are aneurysmal, then both the internal and the external iliac arteries are controlled. The inferior mesenteric artery is then dissected out and controlled for possible reimplantation into the graft after the aneurysm has been repaired.

Step 2 (Retroperitoneal Approach): Exposure and Control of Aorta and Iliac Arteries

When the retroperitoneal approach is taken, a transverse left abdominal or flank incision is made, and the peritoneum is reflectoned anteriorly. The left kidney usually is left in place but may be mobilized anteriorly to expose the posterolateral aorta. Exposure of the right iliac system can be achieved by dividing the inferior mesenteric artery early in the course of dissection. The aorta and the iliac arteries are controlled in essentially the same fashion regardless of the type of incision used.

Step 3: Opening of Aneurysm and Creation of Proximal Anastomosis

Systemic anticoagulation with I.V. heparin is then performed. After sufficient time (3 to 5 minutes) has elapsed to permit adequate circulation, the infrarenal neck and the iliac arteries are clamped. To prevent distal embolization, the distal clamps should be applied before the proximal aortic clamp. The aneurysm is then

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**Figure 4** Open repair of infrarenal AAAs. (a) For the transabdominal approach to the abdominal aorta, a midline or transverse incision is appropriate. For the retroperitoneal approach, an oblique flank incision may be used. (b) The small intestine (including the duodenum) is retracted laterally after the ligament of Treitz is mobilized, and the retroperitoneum is incised in the midline. The left renal vein is the landmark for the infrarenal neck.
opened longitudinally, the mural thrombus is removed, and backbleeding lumbar arteries are oversewn. Depending on its degree of backflow and on the patency of the hypogastric arteries, the inferior mesenteric artery may be either ligated or clamped and left with a rim of aortic wall for subsequent reimplantation [see Troubleshooting, below].

The aortic neck is then partially or completely transected, and an appropriately sized tubular or bifurcated graft is sutured to the aorta with a continuous nonabsorbable monofilament suture [see Figure 6]. When the proximal aortic neck is very short, suprarenal aortic clamping may be required for performance of the proximal anastomosis. If suprarenal clamping is necessary, the security of the proximal anastomosis should be verified, and the clamp should then be moved onto the graft below the renal arteries as soon as possible to minimize renal ischemia. If the aorta is especially weak or friable, the anastomosis may be supported with Teflon-felt pledgets.

**Step 4: Creation of Distal Anastomosis**

When the aneurysm is confined to the aorta, the distal anastomosis is performed by suturing a straight tube graft to the aortic

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**Figure 5**  Open repair of infrarenal AAAs.  
(a) Once the aneurysm is exposed, proximal control is obtained by encircling the proximal neck with an umbilical tape or heavy Silastic. The inferior mesenteric artery is identified and then either clamped or ligated for possible reimplantation at the end of the procedure.  
(b) The iliac arteries are dissected free, systemic heparin anticoagulation is instituted, and distal control is obtained, followed by proximal control to prevent distal embolization. The aneurysm sac is then opened longitudinally.  
(c) All mural thrombus is removed, and the proximal and distal necks of the aorta are incised.
bifurcation [see Figure 7]; straight tube graft reconstructions are used about 30% of the time. Distally, the dissection should avoid the fibroareolar tissue overlying the left common iliac artery because this tissue contains branches of the inferior mesenteric artery and the autonomic nerves that control sexual function in men.

When the aneurysm extends into the common iliac arteries, the distal anastomosis is accomplished by suturing a bifurcated graft to the distal common iliac arteries or, in the case of significant occlusive disease, to the common femoral arteries. In these situations, control of the iliac arteries is best achieved by mobilizing the external and internal arteries and clamping them individually [see Figure 8]. It is sometimes easier to control iliac artery back-bleeding by using intraluminal balloon catheters and oversewing the common iliac arteries from within the opened aortic or iliac aneurysms. Care must be taken not to injure the accompanying venous structures or the ureters, which cross anterior to the iliac bifurcation. Every effort should be made to ensure perfusion of at least one hypogastric artery to help minimize the risk of postoperative left colon ischemia.

Declamping hypotension may occur after reperfusion of the lower extremities. It is essential to maintain communication with the anesthesiologist so that blood and fluid replacement can be adjusted in anticipation of lower-extremity reperfusion. Even though the graft and vessels are flushed and back-bleed before distal flow is reestablished, it is preferable first to establish flow into one of the hypogastric arteries so as to minimize the chances of distal embolization to the legs.

Before the abdomen is closed, adequate perfusion of the lower extremities and the left colon should be ensured via either direct inspection or noninvasive monitoring. The open aneurysm sac is then sutured closed over the aortic graft to separate the graft from the duodenum and the viscera [see Figure 9]. This step reduces the risk of aortoenteric fistula.
Troubleshooting

If the inferior mesenteric artery is small and back-bleeding is adequate, it may be ligated [see Figure 10a]; however, if the vessel is large or back-bleeding is meager, it should be reimplemented. Reimplantation of the inferior mesenteric artery can be accomplished with relative ease by using the Carrel patch technique. After the graft has been completely sewn to the aorta, a partial occluding clamp is placed on the main body of the graft or on one of the limbs. An opening in the graft is then created, and an end-to-side anastomosis [see Figure 10b]—with an interposition graft added if necessary [see Figure 10c]—is used to reconstruct the inferior mesenteric artery. This anastomosis is created with a continuous monofilament suture.

SPECIAL CONSIDERATIONS

Concurrent Disease Processes

At times, a concurrent disease process complicates repair of an AAA. The most common problems encountered are hepatobiliary, pancreatic, gastrointestinal, gynecologic, and genitourinary disorders. Careful evaluation of the situation is necessary to determine whether to treat the two disease entities concurrently. As a rule, the more life-threatening disorder is treated first.

There are three key points that should be remembered in the management of patients with AAAs and concurrent diseases. First, a careful preoperative diagnostic workup usually detects any concomitant disease processes. Second, in emergency situations such as ruptured or symptomatic aneurysms, the aneurysm always takes priority unless the other condition is life-threatening and the aneurysm clearly is not the cause of the critical symptoms. Finally, many concomitant intra-abdominal problems can be avoided by taking an endovascular approach.
incidence is quite low. Left renal vein variants, such as retroaortic left renal veins and circumaortic venous rings, are the most commonly seen venous anomalies. Azygous continuation of the inferior vena cava and bilateral inferior vena cava have also been noted. Unnecessary bleeding can be prevented by means of careful dissection and meticulous technique.

**Inflammatory Aneurysm**

Approximately 5% of infrarenal AAAs are inflammatory. These AAAs have a dense fibroinflammatory rind that typically adheres to the fourth portion of the duodenum; they may also involve the inferior vena cava, the left renal vein, or the ureters. Patients with inflammatory AAAs typically experience abdominal or flank pain and may present with weight loss. The erythrocyte sedimentation rate is usually elevated as well. Inflammatory aneurysms rarely rupture, because most are symptomatic and consequently are treated before rupture can occur. Repair of inflammatory aneurysms poses technical problems because of the involvement of adjacent structures. A retroperitoneal approach is usually advocated for these aneurysms.

**Ruptured Aneurysm**

Infrarenal AAAs can rupture freely into the peritoneal cavity or into the retroperitoneum. Free rupture into the peritoneal cavity is usually anterior and is typically accompanied by immediate hemodynamic collapse and a very high mortality. Retroperitoneal ruptures are usually posterior and may be contained by the psoas muscle and adjacent periaortic and perivertebral tissue. This type of rupture may occur without significant blood loss initially, and the patient may be hemodynamically stable.

When an aortic aneurysm ruptures, immediate surgical repair is indicated. If the patient is unstable and either an abdominal aortic aneurysm was previously diagnosed or a palpable abdominal mass is present, no further evaluation is necessary and the patient should be taken directly to the OR. If the patient is stable and the diagnosis is questionable, CT scanning may be performed to confirm the presence of an aneurysm and determine its extent, the site of the rupture, and the degree of iliac involvement. Bedside ultrasonography may also be used for quick confirmation of the presence of an AAA.

Surgical repair of ruptured aneurysms is performed via a transperitoneal approach. In cases of contained rupture, supraceliac control should be achieved before infrarenal dissection; once the neck of the aneurysm has been dissected free, the aortic clamp may be moved to the infrarenal level. In cases of free rupture, efforts to obtain vascular control may include compression of the aorta at the hiatus and infrarenal control with a clamp or an intraluminal balloon. Once proximal and distal control have been achieved, the operation is conducted in much the same way as an elective repair.

**OUTCOME EVALUATION**

The mortality associated with repair of AAAs has been greatly reduced by improvements in preoperative evaluation and perioperative care: leading centers currently report death rates ranging from 0% to 5%. Mortality after repair of inflammatory aneurysms and after emergency repair of symptomatic nonruptured aneurysms continues to be somewhat higher (5% to 10%), primarily as a consequence of less thorough preoperative evaluation.

Overall morbidity after elective aneurysm repair ranges from 10% to 30%. The most common complication is myocardial ischemia, and MI is the most common cause of postoperative death. Mild renal insufficiency is the second most frequent com-
plication, occurring after 6% of elective aneurysm repairs; however, severe renal failure necessitating dialysis is rare in this setting. The third most common complication is pulmonary disease; the incidence of postoperative pneumonia is approximately 5%.

Postoperative bleeding may occur as well. Common sources of such bleeding include the anastomotic suture lines, inadequately recognized venous injuries, and coagulopathies resulting from intraoperative hypothermia or excessive blood loss. Any evidence of ongoing bleeding is an indication for early exploration.

Lower-extremity ischemia may occur as a result of either emboli or thrombosis of the graft and may necessitate reoperation and thrombectomy. So-called trash foot may also develop when diffuse microemboli are carried into the distal circulation.

Colon ischemia develops after 1% of elective aneurysm repairs. Patients usually present with bloody diarrhea, abdominal pain, a distended abdomen, and leukocytosis. The diagnosis is confirmed by sigmoidoscopy, which reveals mucosal sloughing. In cases of transmural colonic necrosis, colon resection and exteriorization of stomas are warranted.

Paraplegia is rare after repair of infrarenal AAAs: the incidence is only 0.2%. Most instances of paraplegia occur after repair of a ruptured aneurysm or when the pelvis has been devascularized. The majority of patients recover at least some degree of neurologic function.

Late complications (e.g., pseudoaneurysms at the suture lines, graft or graft limb thrombosis, and graft infection) may occur but are extremely rare. Graft infection may be associated with graft-enteric fistula and is notoriously difficult to diagnose and treat.

Long-term survival in patients who have undergone successful AAA repair is reduced in comparison with that in the general population. The 5-year survival rate after AAA repair is 67% (range, 49% to 84%), compared with 80% to 85% in age-matched control subjects, and the mean duration of survival after AAA repair is 7.4 years. Part of the difference in survival can be attributed to associated coronary disease in patients with aneurysms. Late deaths result primarily from cardiac causes.

**Endovascular Repair**

Endovascular repair was introduced during the 1990s as a less invasive approach to treating infrarenal AAAs. In this approach, a stent-graft is placed endoluminally via bilateral groin incisions; thus, there is no need for a major abdominal incision and aortic clamping. The results to date have been promising: blood loss is decreased, hospital stay is shortened, and earlier return to function is achieved. Not all patients are candidates for endovascular repair, however. In September 1999, the Food and Drug Administration approved two stent-graft devices for use in surgical management of AAAs: the Ancure device (Guidant, Indianapolis, Indiana), which is a balloon-expandable one-piece bifurcated stent-graft, and the
AneuRx device (Medtronic AVE, Santa Rosa, California), which is a self-expanding bifurcated modular device that is fully supported externally by a nitinol stent. Subsequently, the FDA approved three more devices for endovascular repair of AAAs: the Excluder Bifurcated Endoprosthesis (W. L. Gore and Associates, Flagstaff, Arizona), in November 2002, the Zenith AAA Endovascular Graft (Cook Incorporated, Bloomington, Indiana), in May 2003, and the Endologix Powerlink System (Endologix Incorporated, Irvine, California), in November 2004. The Ancure device is no longer available.

**PREOPERATIVE PREPARATION**

Precise preoperative evaluation that yields accurate measurements will result in proper planning and effective prevention of
problems. Both CTA and contrast biplane angiography are used for this purpose. Of the two, spiral CTA is currently preferred. This imaging modality is capable of obtaining high-quality images of the vascular anatomy and reconfiguring them into detailed three-dimensional images. For optimal evaluation, images should be obtained at 1.5 to 3 mm intervals from the celiac artery to the femoral arteries. Spiral CTA accurately defines the proximal and distal characteristics of the AAA, as well as detects any significant renal, visceral, or iliac occlusive disease. It is particularly helpful in defining the infrarenal neck between the renal arteries and the proximal portion of the aneurysm.

Angiography is employed as a complement to spiral CTA in this setting. An arteriogram is useful in that it helps define renal, mesenteric, and distal arterial anatomy; helps characterize tortuosity, calcification, and stenoses in access arteries; and helps determine the angles between the aorta, the proximal neck, and the aneurysm.

Intravascular ultrasonography (IVUS) is a useful intraoperative imaging adjunct in the process of sizing and selecting endograft components. It can be used to measure vessel diameters and landing zone lengths, as well as to determine the amount of mural thrombus in the aneurysm neck. In patients with severe renal insufficiency, IVUS is used primarily to identify the renal and hypogastric arteries, allowing the endograft to be deployed with minimal or no resort to angiography.

Proper patient selection is mandatory for successful outcome. The common femoral arteries must be large enough to accept a delivery system larger than 21 French. The proximal infrarenal aortic neck must be suitable for device implantation—that is, its diameter must be between 16 and 28 mm, and its length should be at least 15 mm. The common iliac artery implantation should be carried out as close to the iliac bifurcation as possible to increase the columnar strength of the implanted device. The iliac artery diameter must be between 8 and 20 mm. In patients with iliac artery aneurysms, it is possible to land the end of the stent in the external iliac artery and thereby exclude one internal iliac artery. Exclusion of both internal iliac arteries should be avoided so as to prevent ischemic sequelae (e.g., buttock claudication, colon ischemia, and erectile dysfunction). Coil embolization may be performed in conjunction with EVAR to treat internal iliac aneurysms. However, a waiting period of several weeks between coil embolization of a hypogastric artery on one side and the same procedure on the other side should be considered to allow recruitment of collateral vessels and reduce the incidence of pelvic ischemia.

TECHNIQUE

The methods and technical principles we briefly describe here derive from the personal experience of two surgeons (F.R.A and C.K.Z) with more than 1,000 modular implants. The ensuing technical description is not intended to be exhaustive, nor is it derived from the personal experience of two surgeons (F.R.A and C.K.Z) with more than 1,000 modular implants. The ensuing technical description is not intended to be exhaustive, nor is it necessarily a substitute for the instructions provided by any of the manufacturers.

The patient is placed under epidural or general anesthesia. Bilateral femoral artery cutdowns are performed through transverse groin incisions to allow exposure of the common femoral artery from the inguinal ligament to the femoral bifurcation. Proximal control of the femoral arteries is obtained with umbilical tapes. Systemic anticoagulation with I.V. heparin is instituted to prolong the activated clotting time (ACT) to greater than 250 seconds. The ACT is monitored and maintained at this level throughout the procedure, and additional heparin is given as needed.

The femoral arteries are cannulated with an 18-gauge needle, and 0.035-in. guide wires are placed bilaterally under fluoroscopic guidance; 10 French sheaths are then placed over the two guide wires and advanced into the aneurysm under fluoroscopic guidance. A superstiff 0.035-in. guide wire 260 cm in length is inserted into the thoracic aorta, usually from the right limb. In the contralateral iliac artery, a pigtail catheter is placed just above the level of the renal arteries, and an initial roadmapping aortogram is obtained. The 10 French sheath in the right femoral artery is then exchanged for the device, which is placed over the superstiff guide wire and carefully advanced into the proximal infrarenal aorta under fluoroscopic guidance, then into the perirenal aorta [see Figure 11a]. A second aortogram is performed to verify the position of the renal arteries. Under fluoroscopic guidance, the stent graft is then gradually deployed by retracting the outer sheath and allowing the graft to expand, and it is positioned directly below the level of the renal arteries [see Figure 11b].

Once the main bifurcation module has been deployed, the 10 French sheath in the contralateral iliac artery is pulled back, and a 0.035-in. angled hydrophilic wire and a guide catheter are inserted into the contralateral limb of the bifurcation module. The hydrophilic wire is then exchanged for a superstiff guide wire, over which the contralateral limb is then advanced through the sheath into the contralateral vessel and deployed [see Figure 11c]. A final aortogram is then performed to confirm that a satisfactory technical result has been achieved [see Figure 11d]. Proximal and distal extender cuffs may be placed if necessary. The femoral arteriotomies are repaired, and lower-extremity perfusion is reestablished.

OUTCOME EVALUATION

EVAR is significantly less invasive than open surgical repair and consequently is associated with a significant reduction in major procedure-related morbidity. Prospective clinical trials comparing open AAA repair with EVAR have consistently found that patients undergoing the latter experience less intraoperative blood loss, need less postoperative ICU care, have shorter lengths of stay, and regain normal function earlier.25,26 Procedure-related mortality after EVAR is 1% to 2%, which is essentially equivalent to that reported after open repair in prospective clinical trials but lower than the 5% mortality reported after open repair in most multicenter studies.27,28

In the past few years, two randomized, controlled trials comparing EVAR with open AAA repair have been published. The Dutch Randomized Endovascular Aneurysm Management (DREAM) trial found EVAR to have a significant advantage in the first 30 days, with reduced mortality and a lower incidence of severe complications.29 This survival advantage was not sustained, however, and at 1 year, there was no difference between EVAR and open AAA repair. The EVAR 1 trial, carried out in the United Kingdom, found EVAR to yield a similar reduction in 30-day mortality.30 Again, this survival advantage was not sustained, and at 4 years, there was no difference between EVAR and open repair in terms of overall mortality or health-related quality of life. EVAR did, however, have a significant advantage over open AAA repair with regard to 4-year aneurysm-related mortality. The impact of this advantage will continue to be assessed as this trial’s follow-up period lengths.

On occasion, EVAR fails to exclude blood flow from the aneurysm sac completely. This condition, known as endoleak, may arise from an incomplete seal at the site where the endograft is affixed to the aortic neck or the iliac arteries (type I endoleak), from retrograde flow into the aneurysm from the inferior mesenteric artery or the lumbar arteries (type II endoleak), or from the graft or modular junction site (type III endoleak). Type I and type
III endoleaks call for secondary treatment to prevent possible aneurysm rupture. The significance of type II endoleaks is less certain. There is no clear evidence that type II endoleaks lead to aneurysm rupture; however, most such endoleaks are treated if they are associated with aneurysm enlargement. Although numerous studies have shown that endovascular AAA repair results in less morbidity and perioperative mortality than open repair, reports describing endograft migration over time, aneurysm enlargement, and occasional aneurysm rupture have raised questions about the long-term durability of the procedure. These adverse events, though uncommon, serve as reminders that EVAR is still a new technology, one whose long-term outcome is unknown. Accordingly, close patient monitoring and follow-up surveillance are warranted, and secondary treatments may be required (e.g., additional endovascular procedures or, possibly, open surgical repair). New endovascular devices are currently being designed and evaluated in clinical trials, and endovascular treatment strategies continue to evolve and improve. Clinical follow-up of patients treated during the initial prospective clinical trials now extends to more than 7 years, and EVAR continues to show favorable results. The largest multicenter endovascular clinical trial to date, involving 1,193 patients who were followed for as long as 6 years, found that prevention of aneurysm rupture (the primary objective) was achieved in 99% of patients, whereas procedure-, aneurysm-, or graft-related death was avoided in 97%. These results are consistent with the favorable overall outcomes reported from a European registry of EVAR using a variety of endovascular devices. Thus, the midterm results of EVAR are favorable and support the consideration of this approach for most patients who are candidates for the procedure.

References


Acknowledgment

Figures 4 through 11 Susan Brust, C.M.I.