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1. Which of the following is a serum marker of chronic inflammation in patients with an abdominal aortic aneurysm?
   a) Hypercholesterolemia
   b) Elevated platelet count
   c) Elevated high-sensitivity C-reactive protein
   d) Elevated hemoglobin A1c
   e) Elevated levels of tumor necrosis factor alpha

2. What percentage of annual aneurysm-related deaths occur in women?
   a) 10%
   b) 3%
   c) 79%
   d) 44%
   e) 33%

3. What percentage of aneurysm-related deaths occurs in nonsmokers?
   a) 78%
   b) 2.5%
   c) 22.5%
   d) 10%
   e) 34%

4. Population-based studies have identified which of the following as an independent risk factor for abdominal aortic aneurysms?
   a) Female gender
   b) Hypertension
   c) Diabetes
   d) Family history of aneurysms
   e) Ischemic heart disease

5. Cigarette smoking increases the risk of aneurysm growth. Serum levels of cotinine are associated with this risk. Increased serum levels of which of the following are associated with the destruction of connective tissue elements in the aortic wall and growth of the aneurysm?
   a) Elastase
   b) Tumor necrosis factor alpha
   c) Interleukin 8
   d) Cholesterol
   e) Hemoglobin A1c

6. Disorders of the matrix metalloproteinase enzyme system have been confirmed in the aortic wall of experimental animals with aneurysms. Which of the following is associated with large aneurysms?
   a) MMP 2
   b) MMP 3
   c) MMP 1
   d) MMP 4
   e) MMP 9

7. Which of the following is a serum marker of continued smoking?
   a) Serum mercury levels
   b) Serum creatinine level
   c) Serum elastin level
   d) Serum cotinine level
   e) Serum collagenase level
8. Altered matrix metalloproteinase enzymes are produced in aneurysms by which of the following cell types?
   a) Leucocytes
   b) Macrophages
   c) Endothelial cells
   d) Fibroblasts
   e) Stellate cells

9. Which of the following drugs stabilizes the MMP enzyme system in aneurysms?
   a) Penicillin
   b) Erythromycin
   c) Aspirin
   d) Doxycycline
   e) Hydrochlorothiazide

10. Endovascular repair of small aneurysms discovered on ultrasound screening is not recommended for which of the following reasons?
    a) Long-term risk of aneurysm-related death and aneurysm rupture is equivalent in patients undergoing endovascular repair and patients observed without intervention
    b) Endovascular repair is too costly
    c) Endovascular repair is associated with complications in 10% of patients
    d) Mortality of endovascular repair is 1%
    e) Endovascular repair is not feasible for small aneurysms

11. In order to obtain complete data for determining quality of care for patients with abdominal aortic aneurysms according to the Donabedian principles, information in each of the following areas would be necessary except which one?
    a) Structure
    b) Process
    c) Outcomes
    d) Composite measures
    e) Geographic location of facilities

12. The first successful operation for an abdominal aortic aneurysm with aortic replacement was reported in the American literature in 1952 by which of the following surgeons?
    a) DeBakey
    b) Cooley
    c) Blalock
    d) DuBost
    e) Parodi

13. The reported mortality rate for elective open abdominal aortic aneurysm repair is in which of the following ranges?
    a) 0.5%–1%
    b) 1.5%–2%
    c) 8%–10%
    d) 11%–15%
    e) 3%–8%

14. Multicenter retrospective data suggest which of the following surveillance approaches in patients who have undergone endovascular abdominal aortic aneurysm repair?
    a) If no endoleak is discovered at six months postrepair by CT imaging, annual ultrasound imaging thereafter
    b) CT imaging at six month intervals
    c) Magnetic resonance imaging at three and six months postrepair, with CT imaging annually thereafter
    d) Annual CT imaging
    e) Annual magnetic resonance imaging

15. The risk of delayed aneurysm rupture in patients without endoleak after endovascular abdominal aortic aneurysm repair is which of the following?
    a) 3.7%
    b) 5%
    c) 1%
    d) 0.25%
    e) 7.5%
16. Each of the following is useful for imaging diagnosis of thoracic aortic aneurysms except which one?
   a) Transthoracic echocardiography
   b) Contrast-enhanced multislice CT scanning
   c) Magnetic resonance imaging
   d) Transesophageal echocardiography
   e) Positron emission tomography

17. Each of the following is an important symptom of an acute complication of thoracic aortic aneurysms except which one?
   a) Back pain
   b) Lower extremity numbness
   c) Lower extremity weakness
   d) Headache
   e) Hypotension

18. Each of the following is useful for prevention of paraplegia in patients undergoing operation for thoracic aortic aneurysms except which one?
   a) Spinal fluid drainage
   b) Electrical stimulation
   c) Mild hypothermia
   d) Sequential aortic clamping
   e) Reattachment of intercostal arteries

19. Popliteal artery aneurysm thrombosis with distal embolization can produce all of the following symptoms except which one?
   a) Blue-toe syndrome
   b) Intermittent claudication
   c) Rest pain
   d) Foot drop
   e) Acute limb ischemia

20. Etiologies of superior mesenteric artery aneurysms include all of the following except which one?
   a) Atherosclerosis
   b) Arterial degeneration
   c) Polyarteritis nodosa
   d) Infection
   e) Turner syndrome

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Welcome to *Selected Readings in General Surgery (SRGS)*: Vascular Surgery, Part I. This issue begins a three-part series that focuses on the knowledge and techniques general surgeons need in order to provide effective and safe care to patients with vascular disease.

This issue will open with aneurysm disease: we will review the genetic, molecular, and inflammatory processes that cause it. The types of aneurysms that are encountered most often by general surgeons include aneurysms of the abdominal aorta, popliteal artery, the femoral arterial system, and visceral arteries—Vascular Surgery, Part I will focus on this group of aneurysms. Traumatic false aneurysms and mycotic aneurysms of various arteries will be discussed in Part III of our Vascular Surgery series.

Aortic aneurysms, in particular, are a major health problem for elderly patients, especially male smokers. This disease is a progressive one that leads to increasing dilatation of the aorta and eventual rupture. Traditionally, surgeons have been taught that the process of dilation and rupture of the aortic aneurysm is mechanical—in keeping with the Law of Laplace—with expansion and rupture occurring as increasing wall tension produces thinning, and eventually, the dissolution of the aortic wall. However, there is now good evidence that the process of aneurysm formation, expansion, and rupture is not solely mechanical—occurring simultaneously is a progressive destruction of the integrity of the aortic wall that is driven by multiple cellular and metabolic processes involving proteolytic enzymes, oxidative stress, inflammation, and the coagulation mechanism.

Accordingly, this issue will also highlight the differences between aneurysm disease and atherosclerotic arterial disease—although aneurysms of the thoracic and abdominal aorta are often called “atherosclerotic aneurysms,” and while aneurysm disease and atherosclerosis of the aorta frequently coexist, there is convincing evidence that aneurysm disease is a discrete entity that is not entirely a complication of atherosclerotic vascular disease. Clinical and pathological evidence of atherosclerotic vascular disease is observed at arterial bifurcations, and complications of atherosclerotic arterial disease arise from these lesions. Aneurysms, on the other hand, involve the straight segments of arteries above and below bifurcation areas. Again, these interesting areas of knowledge will be explored in this issue.

I am grateful to Girma Tefera, MD, FACS, who provided editorial assistance for this three-part Vascular Surgery series.
Abdominal Aortic Aneurysms

Abdominal aortic aneurysms are a significant cause of mortality and morbidity, especially in older men and women. A useful review of abdominal aortic aneurysms was presented in an article by Takayama and Yamanouchi in *Surgical Clinics of North America*, 2013. Data cited in the review show that abdominal aortic aneurysm ruptures carry a mortality risk exceeding 80%. Because most abdominal aortic aneurysms are asymptomatic, screening strategies have been implemented for patients who are at an increased risk for abdominal aortic aneurysms. Clinical practice guidelines cited in the review article recommend physical examination and ultrasound screening for patients over age 65 that are smokers or have a family history of aneurysms.

Miller and coauthors described the health burden and general clinical features of abdominal aortic aneurysms in the *Journal of the American College of Radiology*, 2008. These authors began by stressing the adverse health impact of abdominal aortic aneurysms: 1.3% of the deaths occurring annually in American men between the ages 65 and 85 are due to abdominal aneurysm-related complications. This equals 15,000 deaths in the United States each year, and the vast majority of these deaths occur because of aneurysm rupture. Miller and coauthors noted that the prevalence of aneurysm disease increases with age: 1.5% in men over 45 years of age and 12.5% in men older than 75 years; the corresponding prevalence figures for women are 0% and 5.2%, respectively. By contrast, the prevalence of thoracic aneurysms is 0.1%, and there is no gender difference. Miller and associates explained that the presence of aneurysms in the abdominal aorta is defined by aortic diameter. Data cited in the review article by Takayama and Yamanouchi showed that the normal diameter of the abdominal aorta is 10–20 mm and that an aneurysm is defined as a 50% or greater increase in aortic diameter. Thus, an aneurysm is present when the diameter of the aorta exceeds 3 cm. Miller and coauthors acknowledged that most abdominal aortic aneurysms are asymptomatic and are diagnosed either as a result of routine physical examination or imaging studies done to investigate symptoms not thought to be due to abdominal aortic aneurysms. Aneurysms that are symptomatic can cause abdominal pain, back pain, and symptoms caused by the compression of adjacent structures, such as the inferior vena cava and duodenum. Rarely, catastrophic complications other than frank rupture of the aneurysm can occur (e.g., aortoenteric fistula and aortocaval fistula).

Most guidelines for aneurysm repair do not recommend operation until the aneurysm diameter reaches 5 cm. This means it is important to determine which patients should be screened for aneurysms and which patients should undergo periodic surveillance to detect the rate of aneurysm growth, so that an intervention can be effectively timed. Miller and coauthors confirmed these recommendations:

Regular aneurysm screenings should be performed for:

- Men between 65 and 75 who have ever smoked
- Women over 65 with risk factors for cardiovascular disease
- Men or women aged over 50 years with a family history of aneurysmal disease

Once aneurysm presence has been documented, and aneurysm diameter is ≥4.5 cm, operative intervention is recommended for good-risk patients who are anticipated to have a normal or near-normal life expectancy. Patients with abdominal aneurysms of 3 cm, but less than 5 cm, can derive benefit from aneurysm surveillance via periodic ultrasound examinations to determine aneurysm growth rate. Miller and associates noted that surveillance intervals are recommended based on initial aneurysm diameter.

Screening and surveillance programs come not only with a financial cost but also the expenditure of a patient’s time, energy, and discomfort. Thus, screening programs must be efficacious in avoiding additional morbidity and should help prevent disease-associated mortality and morbidity. In addition, screening costs should be justified.

In *Archives of Internal Medicine*, 2000, Ledele and coauthors presented data that identified the patient groups in which screening was likely beneficial. The authors analyzed data from nearly 53,000 patients in the Veterans Administration (VA) Health System. Ultrasound imaging detected aneurysms in 1.2% of patients. The data analysis revealed that aneurysm screening significantly benefited women, patients with a family history of aneurysms, and smokers.
A consensus statement about screening for abdominal aortic aneurysms with abdominal ultrasound was presented by Kent and coauthors in the Journal of Vascular Surgery, 2004. This article is supplied as a full-text reprint accompanying some formats of SRGS. The authors noted that the overall risk of aneurysms >3 cm in diameter in men aged 60 years and older is 4%–8%. The risk is 1.5% for women in the same age group. The authors emphasized that the presence of risk factors such as smoking and evidence of atherosclerotic disease increases this risk. For women and men, a family history of aneurysm disease and a diagnosis of an aneurysm in another location also significantly increase the risk. One-time ultrasound screening for men 65 years and older and women 70 years and older is probably cost-effective. A normal aortic diameter does not require further screening unless risk factors are present. The importance of follow-up screening for patients with risk factors is justified by data cited by the authors, confirming that open or endovascular repair of an abdominal aortic aneurysm discovered on screening carries a low mortality risk (less than 2%). The authors further noted that although open or endovascular repair is expensive, the cost increases greatly if emergency repair is needed. They concluded the consensus statement with recommendations that men between 60 and 85 years old be screened once, with further imaging conducted if an aneurysm is discovered. Women should be screened if risk factors are present. If family history is present, screening should begin at age 50. Annual screening is indicated if aortic diameter is 3 cm or greater. If the diameter of the aorta is >3.5 cm, screening is recommended at six-month intervals. Intervention is recommended for any aneurysm >4.5 cm in diameter.

Because the risk of aneurysm development and complications is significantly higher in patients with risk factors, the question of restricting screening to high-risk patients has been examined. Data were presented in an article by Lindholt and coauthors in the European Journal of Vascular and Endovascular Surgery, 2007. These authors analyzed data from nearly 13,000 patients who had undergone screening. Examining data from patients with risk factors, compared with patients with no risk factors, disclosed that restricting screening to high-risk patients would have prevented fewer than half of the aneurysm-related deaths. The authors concluded that for men 65 to 80 years old, screening is beneficial regardless of whether or not they have risk factors.

Several articles have examined the cost-effectiveness of screening in several different countries. These studies have confirmed the cost-effectiveness and mortality reduction associated with the discovery of an abdominal aortic aneurysm prior to rupture or other symptoms. These benefits have been consistently observed in studies with both low and high attendance. Most importantly, the benefits have persisted at follow-up intervals of up to 15 years.

Available aneurysm screening data have confirmed attendance rates of less than 50% in some trials. A reliable serum marker that would predict aneurysm growth would offer the potential of surveillance within a primary care practice—possibly without the need for surveillance ultrasound. DeHaro and coauthors focused on this topic in the Journal of Vascular Surgery, 2012. These authors evaluated the variation rate of serum levels of high-sensitivity C-reactive protein in a group of patients who had their aneurysm diameters determined by CT scanning. The data disclosed that the highest rate of expansion occurred in patients with a variation >1.4 mg/L per year. Patients in this group had aneurysm growth that was almost 1 mm per year greater than patients with lower C-reactive protein variability. The authors concluded that this laboratory test has potential for predicting aneurysm growth.

Aneurysm Risk Factors

Wanhainen and coauthors opened their report in the Journal of Vascular Surgery, 2005, by citing data from population-based studies that have confirmed male gender, age, cigarette smoking, and a family history of aneurysms as independent risk factors for abdominal aortic aneurysms. They went on to note that the available data have not consistently shown a strong association between aortic aneurysms and the confirmed risk factors for atherosclerosis (diabetes, hypertension, dyslipidemia). These observations suggest that the mechanisms leading to ab-
Aneurysm Risk Factors | VASCULAR SURGERY, PART I

dominal aortic aneurysms are complex and, in some ways, different from those associated with atherosclerosis. The authors conducted a case-control study in a single community in Sweden. Residents of the community were asked to complete a health questionnaire and donate a blood sample at age 60. When these same residents reached the age range of 65–75, they were invited to participate in an abdominal aortic aneurysm screening study; in this second study, ultrasound screening was done and additional health information was obtained. Nearly all of the eligible residents of the community participated in the two studies. Thirty-five patients who were found to have an abdominal aortic aneurysm on ultrasound screening were compared with 140 patients who did not have an aneurysm discovered. The authors found that smoking, a family history of aneurysms, and a history of atherosclerosis were independent risk factors for abdominal aortic aneurysms. High-sensitivity C-reactive protein, which is a marker of chronic inflammation, was not identified as a risk factor, but patients with aneurysms showed a progressive increase in serum levels of this marker over time. This observation suggests that chronic inflammation plays a role in aneurysms progression. Some variables associated with atherosclerosis were found to be risk factors for aneurysms, while others were not. Dyslipidemia was a risk factor, but diabetes and hypertension were not.

Kent and coauthors analyzed a large group of patients who volunteered for and paid for ultrasound screenings for abdominal aortic aneurysms; this article appeared in the Journal of Vascular Surgery, 2010, and provided data on 3.1 million patients. The authors noted the need for stronger data on risk factors to support potential revisions in the recommendations for ultrasound screening. They also emphasized that current criteria for screening recommend an ultrasound examination for men 65 years and older. Patients who smoke are encouraged to undergo a screening examination, as are patients with a family history of aneurysms. The authors noted that 33% of hospital admissions are for aneurysm ruptures and 44% of annual aneurysm deaths are in women. Twenty-two percent of aneurysm deaths occur in nonsmokers. Using this large patient group, the authors sought to develop an accurate aneurysm prediction scoring system, so that recommendations for screening could be refined. Participating patients completed a health questionnaire that included family history, smoking history, height, weight, prior treatment for atherosclerotic disease, diet history, exercise history, and current drug use (e.g., antiplatelet agents, antihypertensives, other cardiovascular medications). Blood pressure was measured directly; if the measurement indicated confirmed systolic pressure above 140 mm Hg, hypertension was termed “uncontrolled.” Analysis of the data disclosed a strong association of abdominal aortic aneurysms with male gender and smoking. Smoking cessation reduced aneurysm risk and this risk continued to lower as long as smoking cessation continued as well. The data also showed that women’s aneurysm risk was only 20% of the risk observed in males—but the risk of aneurysm rupture appeared to be greater in women than in men. The authors proposed a scoring system that would accurately identify abdominal aortic aneurysm risk. This scoring system recognized that women have a longer life expectancy; given the risk of aneurysm rupture in elderly women, screening in this population is probably justified. Readers are encouraged to review the scoring system presented in a table in the article by Kent and coauthors.

Larsson and coauthors reported data from more than 1,000 patients known to have abdominal aortic aneurysms in Annals of Surgery, 2011. In their study, 354 patients who were followed in a university hospital outpatient clinic had undergone simultaneous thoracic and abdominal CT scanning. A concomitant thoracic aneurysm was discovered in 28% of patients. Of interest was that simultaneous thoracic aneurysms were discovered in 48% of women. The estimated risk of a concomitant thoracic aneurysm was almost three times higher in females than in males. The authors stressed the importance of searching for associated aneurysm diseases, especially in older women who are found to have either a thoracic or abdominal aneurysm on screening examination.
Aneurysm Formation & Growth Factors

Takayama and Yamanouchi\(^1\) reviewed causative factors that contribute to the development of abdominal aortic aneurysms. The most common cause of abdominal aneurysms is the degeneration of the aortic wall; degeneration causes more than 90% of abdominal aneurysms. Data cited in the review article confirmed that degeneration is an important component of the atherosclerotic process. Atherosclerosis contributes to the increased fragility of the aortic wall, which leads to dilation. Additional factors that rarely contribute to abdominal aneurysm development include inflammation, infection, and congenital diseases such as Marfan syndrome (MFS) and Ehlers-Danlos syndrome (EDS). Complex interactions of risk factors, genetic factors, and molecular abnormalities contribute to abdominal aortic aneurysm development and growth. In this section, we will examine cellular and molecular changes influenced by one risk factor—cigarette smoking—on aneurysm development and growth. Data on the actions of matrix metalloproteinases (MMPs) will also be discussed. The final part of this section will review data supporting the role of chronic inflammation in the development and growth of aneurysms.

Cigarette Smoking & Aneurysms

Population-based studies of risk factors for abdominal aortic aneurysms have identified an association between cigarette smoking and abdominal aneurysms. This association was identified in two classic papers from the 1990s: The first of these was by MacSweeney and coauthors\(^{16}\) in \textit{Lancet}, 1994. These authors performed serial ultrasound examinations on patients with small (<3 cm diameter) abdominal aneurysms. They examined growth rates of the aneurysms in a median follow-up interval of two years. The analysis disclosed that aneurysm growth averaged 0.13 cm per year in the entire group. In the patients who were current smokers, the aneurysm growth rate was 0.16 cm per year vs. 0.09 cm per year in patients who did not smoke. The authors confirmed that growth rates increased linearly with the serum concentration of cotinine, a byproduct of cigarette smoke.

The second article was by Wilmink and coauthors\(^{17}\) in the \textit{Journal of Vascular Surgery}, 1999. These authors conducted a nested case-control study, in which 212 smokers were compared with 237 control patients. The data disclosed that smoking significantly increased the risk of small aneurysms. No relationship was noted between large aneurysms and smoking, and the authors’ opinion of this nonrelationship was that factors other than smoking contributed to aneurysm growth once the dilation process started. They also emphasized that many patients stop smoking after an aneurysm is diagnosed; the authors noted a slow decline in aneurysm growth risks after smoking cessation, and they confirmed that the effect of smoking on aneurysm risk is much larger than the effect of smoking on coronary artery disease or peripheral artery atherosclerosis.

Smoking causes pulmonary damage, in part, by increasing the activity of elastase. Whether aortic aneurysm growth is related to the degree of pulmonary damage and the levels of elastase are factors that were examined in an article by Lindholt and coauthors\(^{18}\) in the \textit{European Journal of Vascular and Endovascular Surgery}, 2006. The authors evaluated the extent of pulmonary damage in 79 male patients with small abdominal aortic aneurysms using the ratio of forced expiratory volume in one second (FEV1) to expected FEV1. They measured serum elastase levels. The rate of aneurysm growth was documented with serial ultrasound examinations. Analysis of the data disclosed that the extent of pulmonary damage was not related to aneurysm growth. Serum elastase levels and plasma cotinine levels were correlated with current smoking history and aneurysm growth. The authors concluded that destruction of elastin by elastase causes pulmonary damage and contributes to aneurysm growth, but that other factors simultaneously influence aneurysm growth.

Two articles described studies on the cellular effects of cigarette smoking: The first was by Nordskog and coauthors\(^{19}\) in \textit{Cardiovascular Toxicology}, 2003. These authors exposed aortic endothelial cells to cigarette smoke concentrate; they found that exposing the cells to this concentrate resulted in upregulation of the matrix metalloproteinase system and produced a changed pattern of cellular metabolism that demonstrated a typical proinflammatory pattern. The authors noted that other published data have confirmed that these changes produce
an environment favorable to the destruction of collagen. Nordskog and coauthors concluded that these changes may explain, at least in part, the observed contribution of cigarette smoking to the development of abdominal aortic aneurysms. They also noted that the proinflammatory pattern would facilitate the recruitment of other cells such as neutrophils and macrophages that would, if activated by the proinflammatory response, contribute to ongoing inflammation and aneurysm growth.

Zhang and Ramos used a standard experimental preparation in which mice were infused with a sub-pressor dose of angiotensin II; their study results were reported in Vascular Health Risk Management, 2008. One group of mice was exposed to benzopyrene, a constituent of cigarette smoke, and a second group was exposed to both angiotensin II and benzopyrene. The authors noted that exposure to benzopyrene alone damaged the media of the aorta, but that aneurysm formation did not occur; however, exposure to both agents produced large aneurysms in the mice. Examination of the aortic walls disclosed a significant inflammatory process and reductions of collagen levels. The authors concluded that constituent chemicals in cigarette smoke act on the aortas of vulnerable animals to produce aneurysms and influence aneurysm growth.

Matrix Metalloproteinases & Aneurysms

MMPs are important to the regulation of the extracellular matrix. Data cited by Takayama and Yamanouchi showed that the matrix metalloproteinase system elastases are abundant in the abdominal aortic wall and that these substances can increase the fragility of the wall and contribute to an environment that favors dilation. Abnormalities of the MMP system have been identified in the process of aneurysm development and growth. Additional data on this topic were presented in an article by Lim and coauthors in Current Vascular Pharmacology, 2010. The authors opened their discussion by noting that the MMP system plays a central role in the stability of the extracellular matrix and that abnormalities of this enzyme system cause altered dynamics of the extracellular matrix that contribute to the disruption of the matrix observed in several disease processes, including aneurysmal disease. The authors identified the principal MMP components that have been confirmed to play a role in aneurysm development and growth: MMP2, MMP3, and MMP9. MMP2 is the principal enzyme found in the walls of small aneurysms, while MMP9 is primarily located in larger aneurysms. Of interest was the observation that MMP9 levels decrease in the walls of very large aneurysms, leading to the impression that mechanical factors are more important to the growth of large aneurysms than are the processes of aortic wall breakdown. The level of MMP activity varies within the aortic aneurysm wall, giving rise to the hypothesis that localized increases in MMP activity may play a role in aneurysm rupture. The cell of origin of the altered MMPs is the macrophage; activation of macrophages by the proinflammatory environment of the aneurysm wall is thought to drive macrophage dysfunction that leads to abnormal MMP activity. The authors noted that MMP inhibition is mediated, under normal circumstances, by plasma macroglobulin and by the tissue inhibitors of metalloproteinases (TIMP).

The authors cited experimental animal data that have confirmed the central role of MMPs in the development and growth of aneurysms. Inhibition of MMP activity has reduced the growth rate of aneurysms in murine and rodent models. Because of the interconnected roles of inflammation and MMP activity, attention has focused on drugs that reduce inflammation and simultaneously reduce MMP activity. Two such agents are statin drugs and the tetracycline family of antibiotics; these drugs accumulate in the aortic wall at sufficient levels to attenuate MMP activity and inflammation.

Mata and coauthors described a murine experimental study that sought to confirm the role of the MMP system and inflammation in aneurysm formation in the International Journal of Experimental Pathology, 2011. Animals subjected to a simultaneous aortic wall injury and stenosis developed aortic aneurysms over a 72-hour interval, with final aortic diameters increased by 300%. Analysis of the walls of the aneurysms confirmed a distinct proinflammatory environment and intense activation of the MMP2 and MMP9 systems. The authors concluded that the interaction of inflammation and the MMP systems damages the extracellular matrix, leading to aneurysm formation.
Pharmacologic Modulation of MMPs & Inflammation

As the understanding of the fundamental genetic, cellular, and metabolic aspects of the dynamic processes that lead to aortic wall weakening have improved, avenues for new therapies have emerged. Three examples of this progress will be discussed in this section.

Chapple and coauthors,23 in Annals of Vascular Surgery, 2007, cited anecdotal evidence that anti-inflammatory drugs may exert beneficial effects in patients with aneurysms by decreasing the rate of the aneurysm’s progression. This observation led to the hypothesis that expression of the cyclooxygenase-2 (COX-2) receptor might be increased in aortic aneurysm tissue. These authors studied tissue explants from aortic aneurysms that were unruptured and had been treated surgically; thus, the tissue represented end-stage aneurysm disease. The data demonstrated that expression of the COX-2 receptor was increased in the aortic aneurysm tissue and the intensity of the expression varied directly with the intensity of the aortic wall inflammatory infiltrate. The cell of origin of the COX-2 activity was the macrophage population within the aortic wall. The authors also observed that COX-2 expression was closely related to the process of angiogenesis within the aortic wall. Chapple and coauthors concluded that COX-2 expression within the walls of aneurysms is related to neo-revascularization and that efforts to control angiogenesis stimulated by the aortic wall inflammatory infiltrate might be a fruitful avenue for developing alternative therapies for aortic aneurysms.

Isenburg and coauthors24 noted in Circulation, 2007, that the increasing detection of small abdominal aortic aneurysms because of ultrasound screening programs has identified a group of patients who undergo sequential surveillance ultrasound examinations—these patients are candidates for medical therapy for their aneurysms. Because open and endovascular repairs of aneurysms are treatments reserved for large or progressively enlarging aneurysms, a successful therapy that prolonged the duration of small aneurysm size would be of benefit in this group of patients. Isenburg and coauthors indicated that elastin breakdown is an important feature of aortic aneurysm progression, and they hypothesized that the stabilization of elastin would forestall the progression of experimental aneurysms. These authors used the elastin-stabilizing agent pentagalloyl glucose (PGG). They conducted cytotoxicity studies to ensure that the drug dosage was not toxic to aortic tissue. In one group of animals, the authors pretreated the aorta with periadventitial PGG prior to the application of calcium chloride (an aneurysm-producing agent). This pretreatment prevented aneurysm formation in the experimental group of animals. A second group of animals was treated with calcium chloride and, after 28 days, most of the animals had developed aortic aneurysms. The aneurysms were treated with periadventitial PGG, and it was subsequently noted that aneurysm progression slowed significantly. This salutary effect was noted without any change in the inflammatory infiltrate within the aortic wall. Histologic analysis showed that the PGG was bound to aortic elastin. Isenburg and coauthors concluded that PGG is safe and that it controls aneurysm formation and progression by binding to elastin. They suggested this avenue as a potentially fruitful means of treating small aortic aneurysms nonoperatively.

The effect of statin drugs on inflammation and aneurysm growth was the focus of an article by Schouten and coauthors25 in the European Journal of Vascular and Endovascular Surgery, 2006. The authors cited data showing that statins have a significant anti-inflammatory effect. Interleukin-6 levels and rates of release were reduced by administering statin drugs. Data cited by Schouten and colleagues confirmed that statins also stabilized the function of MMPs. The authors assessed aneurysm growth rates using serial ultrasound examinations. They found that aneurysm growth was significantly slower in patients taking statins, and that this reduction was sustained after adjustment for other factors such as additional anti-inflammatory drugs, initial aneurysm size, gender, and smoking.

Another group of drugs that have anti-inflammatory properties and also stabilize the MMP system is the tetracycline group of antibiotics. Two articles provided perspective on the potential value of this group of drugs for preventing aneurysm growth and complications. Baxter and coauthors26 cited data in Circulation, 2008, indicating that prolonged use of doxycycline (100 mg orally each day) was associated with an acceptable safety profile; this article is supplied as a full-text reprint accompanying some formats of SRGS. Side effects that are common,
such as tooth discoloration, are reasonably well tolerated by the elderly patients that comprise the population with aneurysm disease. Available data suggested, but did not prove, an association between prolonged doxycycline use and a reduction in aneurysm growth rate. Further data are needed.

According to data reported by Hackmann and coauthors\footnote{27} in the Journal of Vascular Surgery, 2008, continued aortic expansion after endovascular repair of abdominal aortic aneurysm may be related to abnormal function of the MMP system. They noted that some data have suggested that this enzyme system may also be associated with an increased risk of endoleak after endovascular treatment. The authors conducted a randomized, prospective, placebo-controlled trial of doxycycline 100 mg per day to determine possible benefits associated with this treatment approach. Doxycycline therapy was effective in reducing the abnormal function of the MMP system. In patients without endoleak, doxycycline treatment was associated with a significant reduction in aortic diameter growth. The authors concluded that doxycycline therapy is a potentially valuable avenue for future studies of the pharmacologic treatment of abdominal aortic aneurysms.

Diagnosing Abdominal Aortic Aneurysms

Updated practice guidelines for diagnosing and managing abdominal aortic aneurysms are found in an article by Rooke and coauthors\footnote{28} in the Journal of the American College of Cardiology, 2011. The free guidelines document is available at: \url{http://circ.ahajournals.org/content/124/18/2020}

Clinical Diagnosis

Abdominal aortic aneurysms are usually asymptomatic until a major complication occurs; these include rupture of the aneurysm and erosion into adjacent structures such as the duodenum or vena cava. As noted previously, most aneurysms are diagnosed on imaging studies performed for symptoms unrelated to the aneurysm or on routine physical examination.

The 2005 American Heart Association (AHA) practice guidelines for the diagnosis and management of peripheral arterial disease were presented in an article by Hirsch and coauthors\footnote{29} in Circulation, 2006. This free article is available at the AHA website at: \url{http://circ.ahajournals.org/content/113/11/e463}

Hirsch and colleagues noted that aneurysms may become symptomatic before rupture or erosion, especially in younger patients. Pain is the most common symptom, and is most often located in the hypogastrium and back; patients may relate that the pain is lessened by lying down with the knees flexed. The practice guidelines emphasized the importance of seeking other aneurysms and obtaining a focused cardiovascular history to determine the presence and severity of associated coronary artery disease and peripheral artery obstructive disease. The practice guidelines document also cited data indicating that diagnosing abdominal aortic aneurysms by palpation is related to the size of the aneurysm—accuracy increases with increasing aortic diameter. According to additional data, more than 80% of abdominal aortic aneurysms are diagnosed by either physical examination or imaging (incidental diagnosis). The guidelines stressed the importance of seeking physical examination findings that would confirm coexisting peripheral vascular disease.

Imaging Diagnosis

Miller and coauthors\footnote{2} noted that findings seen on plain radiographs can suggest the diagnosis of a thoracic aneurysm if there is a widening of the mediastinal shadow. Calcifications of the aortic wall are required in order to detect abdominal aortic aneurysmal dilatation on plain radiographs. Plain radiograph detection of aneurysms is usually the result of diagnostic testing for other types of diseases, while ultrasound is the most cost-effective imaging method to confirm abdominal aortic aneurysms and to quantify their diameter. That said, evaluating abdominal aortic aneurysms via ultrasound can be hampered by overlying bowel gas and body habitus. Sensitivity of ultrasound is reported to be 92%, with a specificity of 100%.
The precise measurement of the dimensions of thoracic aneurysms requires noncontrast computerized tomography (CT). Three-dimensional contrast-enhanced CT (CECT) scans or magnetic resonance angiography (MRA) permits the precise documentation of the anatomy of thoracic and abdominal aortic aneurysms. These images facilitate the planning of open and endovascular interventions for aneurysms by documenting the size and orientation of the aneurysm orifice, the length of the normal diameter artery above and below the sac, the presence of important collaterals to the spinal cord (in the case of thoracic aneurysms), and the anatomy of renal, iliac, and visceral vessels (in the case of complicated abdominal aneurysms). In addition, intraluminal thrombus can be detected.

**Intervention Indications**

Open or endovascular repair is recommended when an abdominal aneurysm reaches a diameter of more than 4.5 cm, abdominal aneurysm growth is more than 5 mm per year, or when a thoracic aneurysm reaches a diameter of more than 6 cm. Aneurysms discovered through ultrasound screening are frequently below the diameter where intervention is recommended. Watchful waiting with ultrasound surveillance has been shown to be effective, but there is evidence that this potentially life-threatening disease, for which no immediate treatment is offered, lowers patients’ quality of life. This fact has stimulated the search for alternative treatments that might reduce the rate of aneurysm growth, prevent aneurysm rupture, and help improve quality of life. When evaluating potential therapies, it is helpful to use standard assessments of the levels of evidence available; these evidence levels are reviewed in the practice guidelines article by Rooke and coauthors.²⁸

Available data about the open repair of small aneurysms do not support this approach as a means of reducing overall mortality, primarily because of the low, but significant, mortality risk associated with an open operation. The most important data source that evaluated open operation for small abdominal aortic aneurysms is the UK small aneurysm trial; this trial was reported in an article in *Lancet*, 1998.³⁰

Although the suggestion has been offered that the safety of endovascular repair might justify a reduction in the diameter at which aneurysm repair is recommended, data to firmly support such a recommendation have not yet emerged. Long-term outcomes data for patients enrolled in the UK small aneurysm trial were reported in an article published in the *New England Journal of Medicine* in 2002.³¹ This trial enrolled more than 1,000 patients who were randomized to receive early surgical repair vs. ultrasound surveillance of aneurysms that averaged 5.5 cm in diameter at the time of randomization. The data analysis showed no long-term survival benefit associated with early surgical repair of small aneurysms. There was a reduced rate of death after abdominal aneurysm diagnosis that was attributed to a reduction in smoking rates following enrollment in the trial.

Ouriel and coauthors³² reported a randomized trial of endovascular repair vs. continued surveillance in patients with small aneurysms in the *Journal of Vascular Surgery*, 2010. Although endovascular repair was safe, aneurysm rupture, aneurysm-related death, and overall mortality risk were similar in both patient groups. In another randomized trial by Cao and coauthors³³ in the *European Journal of Vascular and Endovascular Surgery*, 2011, mortality and aneurysm-related complications did not differ significantly in the groups that were compared. The cost of endovascular repair was significantly higher than for other treatments and, as noted, offered no significant benefit.

**Assessment of Abdominal Aneurysm Repair Outcomes**

The elective repair of abdominal aortic aneurysms has been shown to confer significant patient benefit once the diameter of the aorta reaches 4.5 cm or rapid growth of the aneurysm occurs. While a ruptured aortic aneurysm is an emergency clinical problem that each practicing general surgeon should be prepared to manage, success with elective abdominal aortic aneurysm repair is most likely to occur when the repair is completed in institutions with the appropriate support structure that includes, in addition to surgeon expertise, capability in imaging, interventional radiology, anesthesiology, and critical care.
In such institutions, successful repair using open or endovascular techniques will most likely occur. Solid, risk-adjusted outcomes evidence is needed to identify hospitals and surgeons with excellent results.

An article reviewing assessment of outcomes was by Dimick and Upchurch in Circulation, 2008. These authors began by emphasizing the need for surgeons, other health care professionals, and administrators to understand the methods for establishing quality standards and the measurement tools that can be used to document quality performance. The authors noted that patients, payers, and government have all signaled that recognition and reimbursement is going to be tied to proven quality of care excellence. They then briefly described the three elements of the Donabedian quality measurement and performance paradigm. The classical elements of the Donabedian model are structure, process, and outcomes: Structure is an accurate description of the environment in which an activity occurs. The characteristics of structure for the care of patients with aortic aneurysms would include the characteristics of the health care system available to a patient (i.e., availability of medical specialists, screening programs, hospitals, nursing, and rehabilitation services). Process refers to the sequential actions that comprise patient care. Process is best described on the basis of a review of the available medical records pertinent to the care of a group of patients. The data contained within the individual patient’s medical record can be supplemented with data from administrative databases. Once the structure and the process necessary to produce excellent clinical results are determined, outcomes can be measured in terms of the presence or absence of the features of structure and process that produce excellent results. In this way, suboptimal outcomes can be understood and changes can be imposed to improve outcomes. Dimick and Upchurch suggested that these measurements are time tested and useful in industry, but may be difficult to determine for patient care activities. They added that a fourth assessment be considered and composed of composite variables containing elements of structure and process, multiple structural characteristics, and/or multiple-process characteristics.

Dimick and Upchurch next discussed the most often-used structure measures in research studies dealing with the quality of aortic aneurysm surgery: surgeon and hospital volume. These measures are easy to obtain, and there is abundant data confirming an inverse relationship between surgeon volume, hospital volume, and mortality for both open and endovascular repair of abdominal aortic aneurysms. This relationship also holds for the management of ruptured aneurysms. These authors cited several studies completed using varied data sets that have supported the general consensus that hospital volume in excess of 30–40 abdominal aneurysm repairs annually is associated with an identifiable mortality benefit.

Dimick and Upchurch noted that surgeon training is also an accepted structural characteristic that has been evaluated—postresidency training in vascular surgery is associated with a clear mortality advantage for abdominal aortic aneurysm repair using open and endovascular approaches for both elective and ruptured aneurysms.

The authors continued with the caution that the volume/outcomes relationship is potentially useful as a means of identifying institutions that have good results and institutions with poor results, but an assessment of individual surgeons within each institution is not possible using administrative databases. The authors also noted that the volume/outcomes relationship and the impact of surgeon training on outcomes have both been criticized because the effects of these factors on mortality have been documented by reviews of administrative databases. There are data shortcomings in these sources that prevent an accurate assessment of individual surgeon performance. There are also recognized problems with these data sources due to errors in patient registration and because there is no means of determining whether compared patient groups have the same clinical characteristics. That said, Dimick and Upchurch acknowledged that the volume/outcomes relationship is unlikely to disappear, even with additional and more refined methods of risk stratification. To support this statement, they cited evidence from the VA National Surgical Quality Improvement (NSQIP) program, which documented that in the VA system, a volume/outcomes relationship cannot be shown. When this phenomenon is examined closely, it is evident that the overwhelming
The majority of surgeons providing aortic aneurysm care in the VA system work concurrently in the VA system and in nearby high-volume hospitals.

The process measures commonly used for evaluation of surgical care are measures applicable to all surgical procedures. These include timely and appropriate preoperative systemic antibiotics and the appropriate use of thromboembolism prophylaxis. Process measures applicable to specific surgical procedures are scarce. Dimick and Upchurch noted that the use of perioperative β-blocker therapy has been one process measure put forward as a means of assessing the quality of abdominal aortic aneurysm care. This process measure has one distinct disadvantage: there is significant uncertainty about which patient group is likely to benefit from this intervention. The support for perioperative β-blockade is drawn from studies on patients undergoing coronary artery bypass operations. The patients most likely to benefit from β-blocker therapy are patients with myocardial ischemic disease (which is the case with patients undergoing coronary artery bypass), and abdominal aortic aneurysm patients who do not necessarily have myocardial ischemia at the time of their repair operation.

Another suggested process measure is a comparison of the open vs. endovascular repair approach. Dimick and Upchurch stressed that determining an appropriate measurement methodology has been problematic in this area. Although it is recognized that endovascular repair of abdominal aortic aneurysms is associated with short-term mortality benefit, the long-term outcomes of this approach are not clearly defined. The need for reintervention because of endoleak or device migration and the need for periodic imaging of the endograft add burdens (financial cost and quality of life) not encountered with open repairs. Open repairs are also durable and associated with very low rates of long-term complications.

Dimick and Upchurch stressed that process measures should be continuously sought and refined because they are actionable. This means that modifications in clinician and institutional behavior can be easily instituted to determine if outcomes improvement occurs. In addition, process measures represent care that was actually provided to patients and are, therefore, measures that payers view as “fair” when determining quality measures that are reliable for the determination of “pay-for-performance” measures. The main disadvantage of process measures is that it is not yet known which of the available measures actually results in better outcomes. This is particularly true for specific procedures such as abdominal aortic aneurysm repair.

Dimick and Upchurch next discussed commonly used outcome measures. For surgical procedures, these measures are usually risk-adjusted mortality and morbidity rates. They noted that while these outcomes are, in general, easy to measure, it is not entirely certain that mortality and morbidity (even when risk adjusted) occur because of a problem of poor quality. Outcomes of a surgical procedure are also influenced by hospital factors, surgeon and other caregiver factors, patient factors, and random chance. Determining which mortality and morbidity rates represent departures from acceptable rates has usually been done using the mortality and morbidity rates derived from the prospectively gathered registries of various surgical procedures. Logistic regression analysis allows for the calculation of 95% confidence intervals (CI) for mortality and morbidity. Such intervals can be calculated for a given hospital; if the 95% CI overlaps the intervals defined by the registry, the individual hospital’s mortality and morbidity rates are determined to be “acceptable.”

Dimick and Upchurch argued that this approach does not completely exclude the results that can occur from the types of variation that happen due to the small sample sizes drawn from individual institutions. Deaths and complications occurring in high-volume hospitals may be due to patient factors or factors resulting from “institutional stress.” Institutional stress is a largely uninvestigated, but potentially important, factor. Absence of deaths in low-volume hospitals is much more likely to occur because of chance variation than any institutional quality characteristic. Dimick and Upchurch cited their own completed research looking at sample sizes that would be necessary to satisfactorily account for random variations in results at individual hospitals. They assessed seven surgical procedures using the national impatient sample and determined that coronary artery bypass is the only operation for which sample sizes are large enough to detect a twofold difference in mortality that is not due to random variation. Obviously, additional refinement in the methodologies used to define acceptable outcomes must continue.
The article continued with a discussion of composite measures. These measures have the advantage of permitting quality assessors to gather a single institution sample size that is large enough to support statistically valid conclusions. The authors noted that there are two currently used methods for applying composite measures to the assessment of outcomes for surgical procedures. These methods consist of combining surgical procedures to produce an aggregate performance measure and combining all measures pertinent to a single surgical procedure. The first method is currently used by American College of Surgeons (ACS) NSQIP. The main drawback of this method is that it is not possible to trace the source of a quality problem to its root cause. For example, if a hospital is labeled an outlier because of a higher than expected overall mortality, it is not possible to know whether there are easily remedied problems that can be addressed to correct the problem. Similarly, high overall survivals for some operations can elevate the aggregate overall survival so that weaknesses are masked. The method that aggregates multiple measures pertinent to a single procedure is in use in two formats. One simply sums adverse outcomes and process compliance variables for a single procedure in an “all or none” score; this method is currently used in some pay-for-performance programs. An alternative approach groups adverse outcomes and process adherence scores into separate domains and weights these according to the influence each has on overall outcomes for the procedure in question. This method is under study by a quality improvement group convened by the Society for Thoracic Surgeons. It is also under evaluation by the Agency for Healthcare Research & Quality.

In the next section of their paper, Dimick and Upham discussed avenues for improving quality of care. They noted that there are basically two options: selective referral and local institution quality improvement. The first methodology is appealing because of general acceptance that high-volume hospitals and surgeons are likely to have the best results. This knowledge can be made available to patients so that they can make informed decisions about where to receive care. Payers can participate by creating incentives for patients to seek care at high-volume institutions. Problems arise because there are large areas of the U.S. where there are no high-volume hospitals.

The authors also noted that patient behavior contributes influences that may work to limit the success of selective referral. They cited Medicare data that demonstrate that patients often choose to have high-risk procedures at low-volume hospitals, even though a high-volume hospital is available nearby. Institutional behavior may play a role as well. The high-volume hospital may attempt to increase caseload and unnecessary operations may result. The second approach is to create effective quality improvement programs in groups of hospitals in regions. This has been effectively done in some regions in the field of cardiac surgery. Success of individual institutions’ quality improvement depends on there being identifiable and measurable avenues to improved outcomes. In the VA system, observed outcomes for each institution are made available and expressed relative to expected outcomes. Since this practice started, there has been progressive improvement in outcomes of surgical procedures within the VA system; what is not known is why the improvement occurred. The authors concluded by noting that individual institution quality improvement will likely not occur dependably until evidence is available to support the concept that measurable and statistically valid structure and process variables can be identified and used reliably to improve quality.

Open vs. Endovascular Aneurysm Repair

A successful operation for an abdominal aortic aneurysm, with reconstruction of the aorta, was first reported in the American literature by DuBost and coauthors in 1952. Since that initial step, substantial progress has been made in the development of vascular instruments, suturing and stapling devices, and prosthetic vascular grafts. The most recent innovation is the introduction of endovascular approaches that can be employed for patients in the elective and emergency settings. In this section, we will review available surgical options for treating abdominal aortic aneurysms.
Open Operation for Abdominal Aneurysms

Open operations for abdominal aortic aneurysms have been conducted using standard transperitoneal or retroperitoneal aneurysm exposure with proximal and distal control, systemic heparinization, opening of the aneurysm, control of lumbar vessels, and replacement of the infrarenal aorta with a prosthetic graft covered by suturing the aneurysm wall closed over the implanted graft. The retroperitoneal approach is a useful alternative that can be used for patients who have had previous intraperitoneal operations.

An occluded inferior mesenteric artery is not reimplemented, but an open inferior mesenteric artery with poor backflow is usually reimplemented using the button reanastomosis technique. The distal graft anastomosis may be done above the bifurcation of the aorta, at the level of the iliac arteries, or more distally; the location of the distal anastomoses is usually dictated by the pattern of disease in the distal vessels.

The steps followed in this operation are found in the standard textbooks of surgery. A particularly clear textual description can be found in Mulholland’s revision of the Greenfield Textbook of Surgery. Clear illustrations of anatomic exposure for the open repair of abdominal aortic aneurysms are presented in the textbook by Valentine and Wind. Readers are encouraged to review this material.

The standard open operation for abdominal aortic aneurysm is safe, with high-volume centers achieving mortality rates of less than 3%; other centers report mortality rates in the 5%–8% range. Quality of life for surviving patients is essentially normal. Despite these excellent results, the prospect of further reductions in mortality and shorter periods of disability have led to challenges to the open operation from endovascular techniques. This phenomenon has, in turn, stimulated surgeons to develop less invasive open operations that ideally would offer lower mortality and less down time for the patient, while retaining the excellent long-term results of the standard open operation. The techniques available for accomplishing these goals are the mini-laparotomy open approach to abdominal aneurysm repair and the retroperitoneal approach to the aorta.

The mini-laparotomy approach to abdominal aortic aneurysm repair was described in a case series and a technical report by Turnipseed and coauthors. With the case series, a group of 32 patients underwent mini-laparotomy repair of abdominal aortic aneurysms. These were compared with historical control patients who underwent repair via a standard, long midline incision. For details, the reader is referred to the original manuscript. The main steps in the operation include a midline incision that begins periumbilically and extends for 6–8 cm cephalad. The small intestine is displaced to the patient’s right and gently retracted with the assistance of a rubber “fish” retractor. A small table-mounted retractor with deep blades is positioned to provide exposure of the retroperitoneum. The author emphasized that long instruments and an extended electrocautery facilitate dissection of the aneurysm. Conventional techniques are used to dissect the aneurysm and control the distal vessels. Systemic heparinization is employed. After clamping the proximal and distal vessels, the aneurysm is opened and lumbar vessels are oversewn using a long Castro-Viejo needle holder. The authors emphasized that this instrumentation allows superior suturing control for the lumbar vessels and for the anastomoses. Incision closure is completed in standard fashion. Compared with the historical control group, the authors observed shorter hospital stays and earlier returns to normal diet in the mini-laparotomy group. The authors also found that pararenal aneurysm and aneurysm diameter of 10 cm or greater are contraindications to this approach.

A comparison of the clinical courses of mini-laparotomy patients with endovascular repair patients has been published from this group; the comparison data disclosed similar outcomes for the endovascular and mini-laparotomy patients. The authors recommended the mini-laparotomy approach as a means of lessening time to recovery while retaining the long-term benefits of the open operation.

Shepard and coauthors provided helpful illustrations of the retroperitoneal approach to the repair of abdominal aortic aneurysms in Archives of Surgery, 1986. Readers are encouraged to review the illustrations in this article.

Outcomes of the retroperitoneal approach were discussed in an article by Sicard and coauthors in the Journal of Vascular Surgery, 1995. This report presented data
from a randomized prospective clinical trial involving 145 patients. Seventy-five patients were randomized to be operated on via a transabdominal approach and 70 were operated on via a retroperitoneal approach. About half of the patients in each group were operated on for abdominal aortic aneurysm disease. The operation is performed either through a slightly angled incision placed at the lateral border of the left rectus sheath or, more commonly, through a transverse incision placed in line with the tip of the 11th rib. Muscle layers are separated parallel to the course of the muscle fibers and the peritoneal membrane is reflected medially until the aorta is exposed. There is occasional difficulty in exposing the right iliac vessel, but for aneurysms less than 10 cm diameter, the exposure is satisfactory. In the randomized prospective study done by Sicard and associates, there was a shorter ICU stay and fewer complications overall in the retroperitoneal group. Pulmonary complications were seen in a similar proportion of each group. The retroperitoneal group had lower hospital costs compared with the transperitoneal group. During a follow-up of nearly two years, there was more pain experienced by patients who had the retroperitoneal incision, but the frequency of wound problems and hernias was the same in both groups. The authors concluded that the retroperitoneal approach is associated with fewer complications overall, leading to an economic benefit for this approach.

Teixeira and coauthors compared rates of postoperative complications in patients who had transperitoneal vs. retroperitoneal repairs of abdominal aortic aneurysms in the *Journal of Vascular Surgery*, 2016. This article is supplied as a full-text reprint accompanying some formats of *SRGS*. The authors obtained data from a national vascular surgery database that included more than 3,500 patients. The open transperitoneal approach was used in 74% of the sample and the retroperitoneal approach was used in the remainder. The data analysis showed that the patients in the retroperitoneal exposure group had lower frequencies of iliac artery aneurysms, but had, overall, higher rates of comorbid conditions compared with the transperitoneal exposure group. The retroperitoneal exposure group had a higher frequency of suprarenal aortic clamping. Cardiac complications and frequencies of renal injury were significantly lower in the retroperitoneal exposure group. Overall mortality and risk for pulmonary complications were equivalent in the two groups. The authors hypothesized that the lower rate of use of the retroperitoneal approach might be related to the learning curve necessary to become familiar with this technique. They also acknowledged that their observations of lower frequencies of cardiac and renal complications were not confirmed in a recent systematic review of the literature cited in the report. Observing the limitation imposed by the retrospective nature of their study, the authors recommended that future research include prospective evaluations of these techniques.

**Concomitant Abdominal Disease Management**

Prusa and coauthors discussed approaches to managing concomitant diseases that require surgical treatment at the time of abdominal aneurysm repair in an article in *Archives of Surgery*, 2005. These authors stated that there are abundant data documenting that concomitant colon malignancy, cholelithiasis, hernias, and gastroduodenal diseases can be successfully dealt with at the time of aneurysm repair with little or no increased risk of complications. For other diseases, such as renal malignancy, bladder malignancy, and retroperitoneal sarcoma (where extensive retroperitoneal dissection may be necessary and reconstruction of the urinary tract with intestinal conduits may be required), there is debate about possible increased overall complications for simultaneous treatment of these conditions and abdominal aortic aneurysms.

Prusa and coauthors authors hypothesized that endovascular aneurysm repair, followed later by definitive treatment of the associated disease, could result in lowered complication rates. The authors compared 33 patients undergoing simultaneous open repair of abdominal aneurysms with 49 patients undergoing staged procedures with endovascular aneurysm repair, followed by definitive treatment of the concomitant disease. A clear lowered mortality rate for patients undergoing the staged approach was observed (13.6% vs. 0%). The authors concluded that the staged approach is feasible for patients with concomitant disease and favorable aortic anatomy, offering the possibility of lowered overall mortality. The mortality advantage, it should be noted, was observed in patients with ASA class 3 and 4. This study did not undertake
long-term follow-up; it is therefore not known whether this mortality advantage is durable over the long term. The authors acknowledged that this approach deals only with patients who are known to have concomitant diseases preoperatively and does not examine the optimum strategy for patients who are found to have a concomitant condition at the time of planned open aortic aneurysm repair.

**Durability of Open Abdominal Aneurysm Repair**

Data relevant to the durability of open operation for abdominal aortic aneurysms were presented in an article by Tsai and coauthors in the *Journal of Vascular Surgery*, 2012. These authors reported data from a retrospective, single-center case series involving 199 patients seen over a six-year interval. All patients had infrarenal aneurysms that were close to the renal arteries. Operative mortality was 2.5% for elective open aneurysm repair. Over long-term follow-up, additional aneurysms were discovered in 29% of patients; most of these were thoracic aneurysms. There was one graft infection noted, but no other complications of the aneurysm repairs were noted. Actuarial five-year survival was 74%. The authors concluded that long-term outcomes for open abdominal aneurysm repair in acceptable-risk patients are excellent.

**Endovascular Repair of Abdominal Aneurysms**

Endovascular aneurysm repair techniques are being refined at a rapid rate, and these are now increasingly chosen for elective repair of abdominal aortic aneurysm and, in selected patients, for the management of ruptured aneurysms. The abiding controversy about the use of endovascular approaches is centered on long-term outcomes. While the durability of open repair of abdominal aortic aneurysm has been confirmed repeatedly, the appeal of endovascular repair is its minimally invasive nature and the hope that this will translate into lower mortality and morbidity rates.

Prinssen and coauthors reported results from the Dutch Randomized Endovascular Aneurysm Management (DREAM) trial, a randomized, prospective trial comparing open and endovascular repair of abdominal aortic aneurysms in the *New England Journal of Medicine*, 2004. In this article, the authors reported 30-day outcomes in 345 randomized patients. Data disclosed a significant reduction in mortality and in the combined outcomes of mortality risk and severe perioperative complications.

Updated results from the DREAM trial were presented in an article by Blankensteijn and coauthors in the *New England Journal of Medicine*, 2005. This article is supplied as a full-text reprint accompanying some formats of SRGS. In this article, the authors confirmed, with two-year follow-up data, that the improved mortality results reported in the initial trial were not sustained after the first year. At two-year follow-up, overall and aneurysm-related mortality was equivalent when the two groups were compared.

Similar results have been reported in a randomized, prospective trial conducted in the VA health system. These data were presented in an article by Lederle and coauthors in *JAMA*, 2009. This article is available for free at the JAMA Network: www.jamanetwork.com. This trial involved 881 patients from 42 VA hospitals. The data analysis disclosed a reduced early mortality in the endovascular repair group compared with open operative repair, but long-term overall and aneurysm-related mortality was not reduced.

Additional data have been reported from the EVAR trial conducted in the United Kingdom: these data were reported in an article by Greenhalgh and coauthors in the *New England Journal of Medicine*, 2010. These authors reported data from more than 1,200 patients in this randomized trial. Their data confirm the results reported previously. In addition, the authors noted that the long-term costs of surveillance and reinterventions raise concerns about the cost-effectiveness of the endovascular approach.

A cost-effectiveness analysis of endovascular repair of abdominal aortic aneurysm was presented in an article by Prinssen and coauthors in the *Journal of Vascular Surgery*, 2007. The data in this article were drawn from the DREAM trial. The authors concluded that endovascular repair of abdominal aortic aneurysm is not cost-effective for patients who are acceptable risks for open operation.
What is the potential benefit of endovascular repair for patients whose age and comorbidity profile make them unacceptable risks for open aneurysm repair? Sicard and coauthors focused on this topic in the *Journal of Vascular Surgery*, 2006. This article reported data from 565 patients who were unfit for open aneurysm repair and underwent endovascular repair. The procedure-related mortality for the endovascular repair patients was 2.9%, which compares favorably with aggregate data that demonstrate a mortality risk for open repair of slightly more than 5% in similar patients.

Contrasting data were presented in results of the EVAR-2 randomized trial conducted in the UK. In this trial, nearly 200 patients who were deemed unfit for open operation underwent endovascular repair. A group of similar size had no intervention. Overall and aneurysm-related mortality over a two-year follow-up interval was equivalent in the two groups. Thirty-day procedure-related mortality was 9%. There were significant additional costs incurred in patients who underwent endovascular repair. The authors concluded that there is no demonstrable advantage to endovascular repair in patients unfit for open operation.

**Surveillance after Endovascular Aneurysm Repair**

Because of the risks of endoleaks, delayed expansion, displacement of the endograft, and delayed aortic rupture, ongoing surveillance is necessary in patients who undergo endovascular abdominal aneurysm repair. The updated practice guidelines document found in the article by Rooke and coauthors recommended CT or magnetic resonance imaging (MRI) at one, six, and 12 months after endovascular repair, and yearly surveillance after that interval if endoleaks and/or aneurysm expansion have not occurred. Because this approach is costly, investigators have analyzed the potential benefits of modified surveillance schedules and the use of ultrasound for surveillance.

Sternbergh and coauthors described an alternative approach to surveillance in the *Journal of Vascular Surgery*, 2008. The authors reported data from a multicenter trial of endovascular abdominal aneurysm repair in 739 patients. The authors found that patients who had not developed an endoleak at the six-month surveillance interval remained at a very low risk for aneurysm-related mortality. On the basis of these data, the authors confirmed the safety of a protocol that eliminates the one-year imaging surveillance of patients who are free of endoleaks at the time of six-month surveillance. They further recommended that long-term surveillance be conducted with ultrasound rather than CT or MRI. Data confirming the safety and reliability of ultrasound surveillance in patients with stable aneurysm diameter and stable endoleaks after endovascular repair have been reported. No prospective randomized trial data are yet available, but data that are available suggest that ultrasound surveillance of stable aneurysms after endovascular repair is safe and effective.

**Complications of Endovascular Repair**

The objective of surveillance following the endovascular repair of abdominal aortic aneurysm is to detect endoleaks and device migration. Early detection of these complications is thought to protect against delayed aneurysm rupture.

An article dealing with risk factors for delayed aneurysm rupture was by van Marrewijck and coauthors in the *Journal of Vascular Surgery*, 2002. These authors reported experience from the EUROSTAR endovascular aneurysm repair trial. When patients were categorized into groups according to the presence of type II endoleaks, types I and III endoleaks, and no endoleaks, the authors found that patients with type I and III endoleaks had a risk of delayed rupture of 3.7%. In patients with no endoleaks, the risk of delayed rupture was 0.25%. The authors found that the risk of type I and III endoleaks was higher in centers with less endovascular experience. van Marrewijck and coauthors concluded that surveillance and potential reintervention should be considered in patients with high-risk endoleaks.

An interesting approach to determining the risk of aneurysm expansion and rupture in patients with endoleaks was presented in an article by Dias and coauthors in the *Journal of Vascular Surgery*, 2004. These authors directly measured pressure within the aneurysm sac using a percutaneous approach and calculated a pressure index according to the ratio of aneurysm sac pressure to intraaortic pressure, expressed as a percentage. They reported results from 46 assessments of sac pressure. A
pressure index under 30% was associated with a stable or shrinking aneurysm. Expanding aneurysms had pressure indices in excess of 59%. The authors concluded that direct sac pressure measurements may have value for predicting aneurysm expansion in patients with endoleaks.

**Abdominal Aortic Aneurysm Rupture**

Keys to successfully managing ruptured abdominal aortic aneurysms include applying the principles of early resuscitation and diagnosis, followed by prompt surgical intervention. The principles of trauma resuscitation promulgated in the Advanced Trauma Life Support Course (ATLS) of the Committee on Trauma of the ACS are applicable to the early management of patients with a suspected rupture of an abdominal aneurysm. After establishing a dependable airway and obtaining large bore intravenous access, resuscitation of hypovolemic shock is begun. Trauma surgeons have learned that successful resuscitation is only achieved when efforts to control the site of bleeding go hand in hand with efforts to restore lost blood volume. Volume restoration is begun using balanced electrolyte solution followed, as soon as feasible, with packed red cell transfusion and clotting factor replacement. It is safer for the patient if the surgeon adjusts resuscitation so that the blood pressure endpoint is at a level that will assure adequate perfusion of vital organs, but is not at normal or supranormal levels (hypotensive resuscitation). Mean arterial pressures of 50–70 mm Hg are sought initially. Because many patients with aortic aneurysms are hypertensive, careful monitoring of blood pressure and signs of adequate perfusion, such as mental status and urine output, are necessary because the blood pressure end points may need to be adjusted upwards to maintain adequate perfusion in previously hypertensive patients.

The concept of hypotensive resuscitation for ruptured abdominal aneurysm was described in an article by Roberts and coauthors in the *European Journal of Vascular and Endovascular Surgery*, 2006. These authors performed a meta-analysis of available experimental and clinical studies that analyzed the effects of delayed or hypotensive resuscitation in animals and patients with hemorrhagic shock. Roberts and associates noted that a number of animal studies of uncontrolled intraabdominal hemorrhage and hypovolemic hypotension have shown that the rapid infusion of large volumes of fluid (80 mL/kg) was associated with the return of blood pressure toward normal, followed by the resumption of hemorrhage, recurrent shock, and death. Human research in trauma patients has shown trends toward better survival and fewer complications in patients with penetrating abdominal injuries and shock who are treated with either delayed resuscitation (delayed until arrival in the operating room) or hypotensive resuscitation. Roberts and coauthors stressed that the evidence for rapid surgical intervention combined with delayed or hypotensive resuscitation in patients with ruptured aneurysms is scarce and largely anecdotal. They also cited evidence from older studies suggesting that hypotensive resuscitation was one factor leading to improved operative mortality.

One cited study compared a group of patients who were resuscitated to mean blood pressures of 50–70 mm Hg with a group of patients who were aggressively resuscitated. The mortality of hemodynamically unstable patients in the hypotensive resuscitation group was 42% compared with a mortality of 70% in the aggressively resuscitated patients. Recent data from studies of patients selected for endovascular management of ruptured aneurysms have suggested resuscitation to mean arterial pressures of 50–70 mm Hg until an aortic occluding balloon can be positioned. Success of these approaches is possible only if resources are available for rapid intervention. Surgeons should be fully aware of the capabilities of the institution where the patient is seen as well as the capabilities of nearby institutions that may be able to accept patients in transfer, if transfer can be accomplished safely.

Suspicion of a ruptured abdominal aneurysm diagnosis is critical to achieving optimum management. The practice guidelines document by Hirsch and colleagues contains valuable information regarding this. These authors noted that the classic clinical triad of abdominal pain, hypotension, and a pulsatile abdominal mass is present in less than half of the patients who present with an aneurysm rupture. The symptoms of aneurysm rupture include the sudden onset of abdominal and/or back pain. Flank pain can also be present. The pain may radiate to the buttock, inner thigh, or genitalia. The pain may be an acute worsening of pain that has been present, to a lesser degree, for varying periods of time. These facts explain
why the misdiagnosis of ruptured abdominal aneurysms is frequent—this same symptom pattern is encountered in patients with renal colic and colon diverticulitis. The diagnosis can be considered more strongly if there is obliteration of the psoas shadow on plain abdominal radiographs or if the typical pattern of aortic wall calcification is observed.

Noncontrast-enhanced CT (NECT) scanning is a rapid way to confirm a ruptured aneurysm diagnosis. This topic is discussed in an article by Federle and coauthors in the *American Journal of Radiology*, 2007. In this article, Federle and colleagues provided evidence that CT findings of aneurysms of the abdominal aorta of 5 cm diameter or greater, combined with signs of blood that is contiguous with the aortic shadow, permits the diagnosis of a ruptured abdominal aneurysm. They recommended that patients in whom the diagnosis of ruptured aneurysm is being considered be expeditiously evaluated with a NECT scan. The authors also noted that several signs, such as the aortic crescent and the draped aorta, have been identified on CECT scans as indicative of contained or impending aortic rupture. Patients who show signs of major and/or ongoing blood loss are candidates for immediate operation. Patients with ruptured aneurysms will have significant retroperitoneal hematoma and/or bleeding into the peritoneal cavity. A critical early maneuver is compression of the supraceliac aorta at the esophageal hiatus. The preferred technique is to position and prepare the patient so that full abdominal and thoracic access can be obtained. Initial exploration is performed via a long midline incision extending from xiphoid to pubis. A table-mounted abdominal retractor is useful. The aorta is exposed at the esophageal hiatus by first taking down the attachments of the left lobe of the liver. In patients with ongoing bleeding, it may not be possible to invest the time to take down the liver before compressing the infradiaphragmatic aorta. The esophagus is identified and retracted to the left. Caution is required to avoid the phrenic arteries and inferior phrenic vein, as well as the left hepatic vein. The left lobe of the liver is retracted to the right and the retroperitoneum is exposed via an incision into the lesser omental space. Readers are encouraged to review the relationships of the esophagus to the aorta in illustrations found in the textbook by Valentine and Wind. The aorta can be compressed with digital compression (although this occupies one of the surgeon’s hands and slows the progress of the operation), by using an aortic compressor, or by using a medium-sized Richardson retractor with the retractor blade positioned so that the long axis of the retractor blade is parallel to the long axis of the aorta. Definitive control at the esophageal hiatus is obtained with an aortic clamp. Obtaining definitive control requires dissection of the median arcuate ligament and occasionally requires division of this structure as well as the right crus of the diaphragm using electrocautery. Division of the right crus of the diaphragm will permit additional exposure of the aorta in the lower mediastinum. Occasionally, additional exposure of the proximal abdominal aorta below the esophageal hiatus may be needed. In this situation, the medial visceral rotation maneuver may be helpful: the spleen, splenic flexure of the colon, descending colon, greater omentum, and greater curvature of the stomach are freed and rotated medially, usually in a plane ventral to Gerota’s fascia. The kidney and adrenal gland can also be rotated, if necessary, to gain additional visualization of the left side of the proximal abdominal aorta. Exposure of the infrarenal aorta and control of the neck of the aneurysm below the renal arteries can be accomplished after definitive control and clamping of the aorta at the esophageal hiatus. Once occlusion of the aorta is accomplished, resuscitation of blood loss can occur. It is useful for the surgeon to pause and allow anesthesia personnel to restore volume once ongoing blood loss has been controlled. Systemic anticoagulation with heparin can be accomplished once ongoing bleeding is controlled. Since, in many instances, it is not possible to know the full proximal extent of the aneurysm, suprarenal control of the aorta may be necessary. Elevation and possible division of the left renal vein may be necessary to obtain adequate exposure. Distal control is usually possible just above the aortic bifurcation. Lumbar vessel control and graft replacement of the aneurysm with a straight tube graft is preferable. These steps are identical to those used in elective operations for abdominal aortic aneurysms. The final step in the intraabdominal portion of the operation for ruptured aneurysm is the coverage of the implanted graft with the wall of the aneurysm. Because of the friability of the aneurysm wall, especially...
in the area of the proximal graft to aorta anastomosis, coverage of the proximal suture line may be problematic. Nonetheless, achieving coverage of the proximal suture line is important as a means of preventing the graft from eroding into the adjacent duodenum.

There have been extensive attempts to clarify the risk factors that might define a patient who is a prohibitive operative risk and who should not receive the traditional open operation for a ruptured abdominal aortic aneurysm. Factors such as preoperative cardiac arrest, advanced age, elevated creatinine, hypotension, history of syncope, and anemia have been statistically associated with operative mortality and have been included in scoring systems that have sought to predict accurately operative mortality in this patient group. These scoring systems, which include the Hardman index, the Glasgow aneurysm score, and the Chen score, were described in three articles.\textsuperscript{50-62} Although the ability to accurately predict patients who will certainly die in the perioperative period following repair of a ruptured abdominal aortic aneurysm would be a valuable asset for surgeons caring for these patients, none of the available systems provide the necessary accuracy to fill this need and, therefore, cannot reliably predict outcomes of individual patients. All of the articles cited refer to patients with numerous risk factors who survived operation and recovered, as well as patients with favorable risk scores who succumbed.

The value of hypotensive resuscitation and a protocol-driven approach to hemodynamically unstable patients with suspected abdominal aneurysm rupture was discussed in a somewhat acerbic editorial by Crawford.\textsuperscript{63} The author describes his personal experience with this approach and cited data confirming both its applicability and its value for reducing mortality in a variety of patient care environments.

Open vs. Endovascular Repair of Ruptured Abdominal Aortic Aneurysms

There is an increasing interest in using endovascular techniques to treat ruptured aortic aneurysms. All ruptured aneurysms will not be candidates for endovascular repair because of the size and orientation of the aneurysm neck or because vessels needed to access the aneurysm will be unavailable due to disease or anatomic distortion. It should also be noted that the information necessary to determine suitability for endovascular aneurysm repair requires multislice CECT scanning or MRA; the time necessary to mobilize these resources and obtain the images may preclude their use in unstable patients.

The topic of endovascular repair of ruptured abdominal aneurysms was discussed in a 2007 Cochrane Library report by Dillon and coauthors.\textsuperscript{64} These authors noted that operative mortality for ruptured abdominal aortic aneurysms ranges from 35% to 70% and that these types of ruptures account for almost 7,000 deaths annually in the UK. This significant health problem, which clusters in elderly men with significant comorbid disease, has been an area of focus for health care professionals seeking a less invasive and, hopefully, less morbid means of treating these patients. Dillon and coauthors noted that patients who survive an open repair of a ruptured abdominal aortic aneurysm obtain a quality of life that is equivalent to age-matched and disease-matched patients who have not been operated on. They also noted that studies of endovascular abdominal aortic aneurysm repairs in very high-risk patients have not resulted in a decreased all-cause mortality for these patients.

The above two observations raise questions about the ultimate usefulness of the endovascular repair of ruptured aneurysms. Dillon and coauthors also noted that concerns regarding the time necessary to obtain imaging studies in order to determine suitability for endovascular repair is a matter of continuing discussion. They did mention, however, that it is unusual for a ruptured aneurysm patient who reaches the hospital alive to die within the first two hours of hospitalization; theoretically, then, there should be at least enough time to obtain the necessary images if the facilities exist at the initial treatment facility. Also, the availability of endovascular balloon occluders permit the effective control of ongoing bleeding. Most endografts placed in patients with ruptured aneurysms have been single-branch grafts; this means that the patient must undergo femoral-femoral bypass to establish perfusion to the lower extremity that is not perfused. The authors concluded that it is clear that endovascular approaches to ruptured aneurysms are feasible, but at the time of the
publication of this review, there were no high-quality data to permit a decision on the superiority of endovascular approaches over the standard open operation.

As techniques for endovascular repair of abdominal aneurysm have improved, protocols for managing ruptured aneurysms have been developed. A protocol-driven approach that emphasizes careful resuscitation, rapid imaging, and endovascular repair in an operating room equipped for both open and endovascular techniques has been associated with improved outcomes. An example of such improvement was described in an article by Mayer and coauthors in *Annals of Surgery,* 2009. This article is supplied as a full-text reprint accompanying some formats of SRGS. The article reported a single-center case series involving 102 patients seen over a 10-year interval. Hemorrhagic hypotension was diagnosed in 44% of patients and admission systolic blood pressure was <50 mm Hg in 14 patients in this group. The authors used an aortic occlusion balloon inserted by the transfemoral route to achieve control of inflow. Technical success was achieved in 99% of patients. Early operative mortality was 13%. Abdominal compartment syndrome developed in 20% of patients and all were treated with an open abdomen technique.

An article confirming the applicability of a similar protocol in a community hospital was by Anain and coauthors in the *Journal of Vascular Surgery,* 2007. These authors reported results of treatment of 40 patients with ruptured abdominal aortic aneurysm. Thirty patients were treated with the endovascular approach. Technical success was achieved in 93% of patients who underwent endovascular repair, and the perioperative mortality was 16.6% in this patient group. The authors concluded that a protocol-driven approach to endovascular repair of abdominal aneurysms is appropriate for implementation in a community hospital.

**Thoracic & Thoracoabdominal Aneurysms**

Thoracic aortic aneurysms may be caused by aortic wall degeneration, inherited diseases and syndromes, and by infectious and noninfectious forms of aortitis. The most common reasons for considering operative intervention in patients with thoracic aortic aneurysms is the expansion of the aneurysm or the development of a complication such as dissection or rupture. In this section, we will discuss the diagnosis and management of thoracic aortic aneurysms.

**Diagnosing Thoracic & Thoracoabdominal Aneurysms**

Practice guidelines for diagnosing and managing thoracic aortic aneurysms were promulgated by the American Heart Association with participation by leading surgical organizations. These guidelines appear in an article by Hiratzka and coauthors in *Circulation,* 2010. The free guidelines document is available from the AHA website: [http://circ.ahajournals.org/content/circulationaha/121/13/e266.full.pdf](http://circ.ahajournals.org/content/circulationaha/121/13/e266.full.pdf)

In the introduction to the clinical area of the guidelines document, the authors noted that, in a five-year interval ending in 2005, thoracic and thoracoabdominal aneurysm disease accounted for approximately one-third of the aneurysm admissions at one large group of hospitals (the University Hospital Consortium). The authors listed several critical issues pertinent to managing patients with thoracic aortic aneurysms, and added that most thoracic aneurysms are asymptomatic. Common clinical presentations are associated with the life-threatening complications of thoracic aneurysms, including dissection and rupture. The authors emphasized that it is important to identify large aneurysms, or increases in aneurysm size, because these situations are most likely to be associated with complications. Patients who are at an increased risk for complications of thoracic aneurysm disease are hypertensive patients with documented genetic disorders leading to aneurysm formation and growth, patients with
a family history of thoracic aneurysm disease, and patients with poorly controlled hypertension. The cellular and molecular events leading to degeneration of the connective tissue in the wall of the thoracic aorta, with loss of elastin and vascular smooth muscle fibers, are mediated, as with abdominal aneurysms, by the MMP enzyme system and chronic inflammation. The most accurate means of determining the diameter of the various parts of the thoracic and thoracoabdominal aorta is with multislice CECT scanning. Other imaging modalities, such as MRI with contrast, transthoracic echocardiography (TTE), and transesophageal echocardiography (TEE), are useful, but have inferior overall accuracy. Screening with multislice CECT scanning is associated with an increased risk of radiation exposure and/or contrast toxicity. According to the authors, symptoms suggestive of thoracic aortic aneurysm complications are subtle and nonspecific: chest, back, and abdominal pain are common, but may not be severe until a life-threatening complication has occurred, and some patients with aortic dissection present without pain. The initial symptoms in this group of patients can be hypotension, lower extremity numbness, and lower extremity weakness caused by malperfusion of the lower extremities and the associated nervous structures.

The guidelines document noted that the thoracic aorta is divided into four segments. The aortic root (normal diameter 3.5 cm–3.9 cm) includes the aortic valve components and the sinuses of Valsalva. The ascending aorta extends from the junction of the sinuses of Valsalva, with the tubular portion of the aorta to the origin of the brachiocephalic artery. The normal diameter of this segment is 2.86 cm. The aortic arch (normal diameter 2.8 cm–3 cm) extends from the origin of the brachiocephalic artery to the aortic isthmus—just distal to the origin of the left subclavian artery and proximal to the ligamentum teres. The descending aorta extends from this area to the diaphragm and has a normal diameter range of 2.45 cm–2.98 cm. The authors indicated that thoracic aortic aneurysms and aneurysm complications are usually diagnosed by CT scan (occasionally combined with echocardiography, especially if the delineation of cardiac disease is desired). Diameter is usually adjusted for gender and body surface area. Dilation outside normal ranges suggests a thoracic aortic aneurysm.

Booher and Eagle\textsuperscript{68} also discussed the previously mentioned practice guidelines document in the American Heart Journal, 2011. These guidelines emphasize the importance of a focused history and physical examination: questions to discover a family history of thoracic aneurysm disease are important. The authors also stressed the importance of identifying high-risk symptoms: chest, abdomen, and/or back pain that are sudden in onset, severe in intensity, and ripping, stabbing, or tearing in nature are examples of these high-risk symptoms. The physical examination should include evidence of pulse deficits; a blood pressure difference of more than 20 mm Hg between the two arms is a high-risk finding, as is any neurological deficit. The guidelines document noted that several serum markers of aortic dissection have been suggested. These include plasma smooth-muscle myosin heavy-chain protein, C-reactive protein, and D-Dimer. Prospective data documenting acceptable levels of accuracy are not currently available to support a recommendation of these assays.

According to the authors, patients suspected of having a thoracic aortic aneurysm complication should have an electrocardiogram performed; this is because acute coronary occlusion is a frequently associated abnormality in patients with thoracic aneurysm rupture or dissection. Imaging of the thoracic aorta with multislice CECT scanning, combined with transesophageal echocardiography, is recommended for the acute workup. Urgent surgical consultation is also recommended.

**Imaging Diagnosis of Thoracic Aortic Aneurysms**

Booher and Eagle\textsuperscript{68} provided an informative discussion of imaging for the diagnosis of thoracic aortic aneurysms and their associated complications. Per these authors, CT imaging is the most commonly used imaging modality, and the main advantage of CT imaging is the ability to visualize the entire aorta. Variability in CT scan techniques may lead to incomplete diagnosis. The authors emphasized that images should be of sufficient quality to provide measurements of transverse aortic diameters perpendicular to the axis of flow in each individual seg-
ment of the aorta. Hiratzka and coauthors\(^7\) included criteria, in the practice guidelines document referred to previously, for adequate imaging of the thoracic aorta. According to their criteria, imaging should provide precise diameter measurements, document the presence of complications such as intramural hematoma and dissection, and provide imaging of sufficient quality to document size and anatomic detail of the aortic valve. Extension of aortic disease into branch vessels should also be documented.

Booher and Eagle\(^68\) noted that MRI of the aorta has the advantage of avoiding ionizing radiation. This imaging modality, combined with adjunctive “black blood” imaging, can provide acceptable detail, including some information about the function of the aortic valve. In stable patients receiving acute imaging, and in patients who require ongoing imaging surveillance for diseases that increase the risk of thoracic aortic aneurysm formation, MRI provides a useful alternative. Transthoracic and transesophageal echocardiography is a complementary tool useful for providing information about cardiac function and valvular abnormalities. The authors provided a table that summarizes the strengths and weaknesses of the various imaging modalities (Figure 1).
Inherited Diseases Leading to Thoracic Aortic Dilation

Booher and Eagle\textsuperscript{68} indicated that the common genetically determined diseases that are associated with thoracic aortic aneurysm development include Marfan syndrome (MFS), Ehlers-Danlos syndrome (EDS), and the syndromes associated with the bicuspid aortic valve (Turner syndrome). A final group of genetic abnormalities associated with aneurysm formation include the familial nonsyndromic thoracic aneurysm diseases.

Marfan Syndrome

MFS is caused by a genetic abnormality of the \textit{FBN1} gene. This abnormality results in the typical musculoskeletal, cardiovascular, and ocular manifestations of the syndrome. Documentation of the association of \textit{FBN1} abnormalities and MFS was the focus of an article by Loey and coauthors\textsuperscript{69} in the \textit{Archives of Internal Medicine}, 2001. The authors reported that MFS is diagnosed clinically using the Ghent nosology. They provided a summary table of the major and minor criteria for diagnosis (Figure 2). The authors conducted genetic testing on a group of 171 patients. Ninety-four patients fulfilled clinical diagnostic criteria for MFS and an \textit{FBN1} abnormality was documented in 66\% of this group. Only 12\% of patients not fulfilling clinical criteria had an abnormal genetic test. The authors concluded that \textit{FBN1} testing is useful in patients fulfilling clinical criteria for MFS.

| Diagnostic Criteria According to the Ghent Nosology\textsuperscript{69} |
|---------------------------------|-----------------|-----------------|
| **Skeletal system** | **Major** | **Minor** |
| Manifestations | Pectus carinatum or pectus excavatum requiring surgery, arm span to height ratio >1.05 or reduced US/LS <0.85 (adults), positive wrist and thumb sign, scoliosis >20\% or spondylolisthesis, limited elbow extension (<170\%), plexus planus, proptosis acustaebull (radiography) | Facial appearance, joint hypermobility, pectus excavatum of moderate severity, highly-arched palate |
| Involvement | 4 of 7 major present | 2 of 7 major present or 1 of 7 major and 2 of 4 minor present |
| **Ocular system** | **Major** | **Minor** |
| Manifestations | Ectopia lentis | Myopia, flat cornea, iris or ciliary muscle hypoplasia |
| Involvement | Ectopia lentis present | 2 of 3 minor present |
| **Cardiovascular system** | **Major** | **Minor** |
| Manifestations | Aortic ascendens dilatation with or without aortic regurgitation and involving the sinuses of Valsalva, aorta ascendens dissection | Mitral valve prolaps, annulus mitralis calcification (age of onset, <40 y), pulmonary artery dilatation, aorta descendens or aorta abdominals dilatation or dissection (age of onset, <50 y) |
| Involvement | 1 of 2 major present | 1 of 4 minor present |
| **Pulmonary system** | **Major** | **Minor** |
| Manifestations | None indicated | Pneumothorax, apical blebs (chest radiography) |
| Involvement | None indicated | 1 of 2 minor present |
| **Skin** | **Major** | **Minor** |
| Manifestations | None indicated | Striae atrophicae (not associated with weight changes or pregnancy), recurrent or incisional herniae |
| Involvement | None indicated | 1 of 2 minor present |
| **Dura** | **Major** | **Minor** |
| Manifestations | Lumboascal dural ectasia by CT or MRI | None indicated |
| Involvement | Dural ectasia present | None indicated |
| **Family** | **Major** | **Minor** |
| Involvement | First degree family member independently fulfilling diagnostic criteria, mutation in \textit{FBN1} known to cause MFS | None indicated |

\textsuperscript{68}US/LS indicates the ratio of the upper segment (in meters) to the lower segment (in meters); CT, computed tomography; MRI, magnetic resonance imaging; and MFS, Marfan syndrome.
A second genetic abnormality associated with MFS involves \textit{TGFBR1} and \textit{TGFBR2} genes. This abnormality was discussed in another article by Loeys and coauthors\textsuperscript{70} in \textit{Nature Genetics}, 2005. Loeys-Deitz syndrome is also caused by genetic abnormalities of this gene group. Patients with Loeys-Deitz syndrome do not have the ocular lens dislocation (ectopia lentis) present in patients with MFS. Patients with Loeys-Deitz syndrome are also at an increased risk for developing tortuous arteries, aneurysms, and dissections in all parts of the circulation. Surveillance of patients with this syndrome should include the cerebral vessels and the thoracic and abdominal arteries, and imaging of patients with MFS is recommended on an annual basis. If aneurysm growth occurs, or when aneurysm diameter exceeds 4.5 cm, more frequent imaging is indicated. Women with MFS are at risk for rapid aortic dilation during pregnancy. If the aortic root diameter is >4 cm, operative intervention with replacement of the dilated aortic root may be indicated in women with MFS who are contemplating pregnancy.

**Ehlers-Danlos Syndrome**

Ehlers-Danlos syndrome (EDS) type IV is associated with vascular abnormalities, including an increased risk of thoracic aortic aneurysms. An article that described the clinical and genetic features of this syndrome was by Pepin and coauthors\textsuperscript{71} in the \textit{New England Journal of Medicine}, 2000. The authors found that the clinical features of EDS include easy bruising, thin skin with visible veins, characteristic facial features, and rupture of the arteries, intestines (mostly sigmoid colon), and uterus; the vascular, intestinal, and uterine ruptures occur because of abnormalities in the gene that governs the production of procollagen. The median life expectancy of patients with this syndrome, according to the authors, is less than 50 years. Most experience a complication after childhood, but before age 30; essentially, all deaths are from a complication, mainly arterial and intestinal ruptures. The authors reported data on 220 patients with EDS confirmed by clinical and genetic examinations. They found that survival was uniformly reduced in these patients and that 75% of the deaths were from arterial rupture. The remaining deaths were caused by intestinal complications. Pregnancy complication risks increased in female patients, and included uterine rupture and a high risk of EDS in offspring. The authors suggested the value of genetic counseling in women contemplating pregnancy. The authors also emphasized that the rarity of EDS has impeded an understanding of its natural history and the risk factors for complications. They further stressed that operative repair of arterial rupture is challenging because of the friability of tissues. Pepin and coauthors referred to clinical data suggesting that contained arterial rupture in stable patients might be treated without operation. At the time of this article’s publication, no dependable medical therapies were available to reduce the risk of complications.

Booher and Eagle\textsuperscript{68} confirmed that imaging surveillance and family counseling is indicated for patients with nonsyndromic familial aortic aneurysms and for patients with bicuspid aortic valve and Turner syndrome. Documentation of aneurysm growth suggests the need for more frequent imaging or operative intervention.

**Medical Therapy for Thoracic Aortic Aneurysms**

Booher and Eagle listed some of the medical therapies designed to slow the rate of thoracic aneurysm growth in patients with known risk factors: \(\beta\)-blocker drugs, statins, angiotensin receptors, and angiotensin receptor blockades. The strongest evidence supports strict control of blood pressure and \(\beta\)-blocker therapy. Statin therapy may be useful in patients with atherosclerosis and dyslipidemia. These drugs may also have anti-inflammatory properties, as noted in the discussion of abdominal aortic aneurysms. The practice guidelines reported in the article by Hiratzka and coauthors\textsuperscript{67} support the use of these measures and also recommend efforts to eliminate smoking.

**Indications for Operative & Perioperative Planning**

Booher and Eagle\textsuperscript{68} provided a useful summary table of indications for the operative intervention of various types of thoracic aortic aneurysms (Figure 3). Elective operation is recommended based on aneurysm size and the risk of
aneurysm-related complications. Open repair of thoracic aortic aneurysms, with replacement of the aortic segment using a prosthetic graft, is a commonly recommended procedure. Aortic valve replacement may be necessary in aneurysms of the proximal aorta. The authors noted that endovascular repair of thoracic aneurysms is increasing in frequency. As with other aneurysm diseases, endovascular techniques may result in lower short-term mortality risk, but endovascular repair will necessitate long-term surveillance. Endoleaks occur in up to 20% of thoracic aortic endovascular repairs, but most can be managed nonoperatively.

**Thoracic Aortic Dissection**

Thoracic aortic dissection is a specific type of complication observed in this patient group, and Hiratzka and coauthors provided a useful review of this topic. A thoracic aortic dissection is defined as a rupture of the intimal layer of the aorta, with bleeding into the media. Bleeding creates a false lumen that may reenter the aortic lumen distally, thrombose, or continue to expand until rupture occurs. Per the authors, the classification systems for aortic dissection most commonly used are the DeBakey and the physystems: DeBakey type 1 aneurysms involve the entire aorta; type 2 aneurysms involve the ascending aorta; and type 3 dissections involve the descending aorta. In the Stanford classification system, a type A dissection involves the ascending aorta and type B dissections involve any other part of the aorta. DeBakey types 1 and 2 are combined to form Stanford type A aneurysms because of ascending aortic involvement.

Therapy for aortic dissections is determined by the location of the dissection. Type A dissections represent a surgical emergency, with mortality rates increasing 1%–2% per hour after hospital admission. The principle danger of a type A dissection is rupture of the false lumen into the pericardium, producing pericardial tamponade. Type B dissections are often managed medically with beta-blockade using esmolol to lower blood pressure to a systolic of 110 mm Hg or the lowest level that is tolerated by the patient without signs of hypoperfusion. If blood pressure cannot be maintained at the desired level without reducing the heart rate to a rate <60 beats per minute, the addition of sodium nitroprusside can facilitate reaching the goal blood pressure. Adequate pain control is also an essential component of management. Medical therapy as described above is also used for patients with type A dissections in preparation for operation. These authors indicated that operative mortality rates for type A dissections are in the 20%–25% range.
An expert consensus document that provided recommendations for managing type B aortic aneurysm dissections was by Fattori and coauthors in the *Journal of the American College of Cardiology*, 2013. The consensus panel asserted that strong evidence was not available to support the recommendations provided—mainly because of the heterogeneity of the available studies in the literature. They emphasized that the recommendations in the article should be interpreted with caution. The panel recommended that the definition of a “complicated” type B aortic dissection be based on clinical evidence of organ malperfusion with or without imaging evidence of increases in size of a periaortic hematoma or the presence of a pleural effusion that is confirmed as pleural hemorrhage. The consensus panel recommended medical therapy for uncomplicated type B aortic dissections. For complicated dissections, endovascular therapy was recommended as the first-line treatment. After successful endovascular management, sequential imaging surveillance was recommended to detect complications. The authors provided an algorithm for managing acute type B dissections (Figure 4).

Outcomes of the medical management of type B dissections were presented in an article by Tefera and coauthors in the *Journal of Vascular Surgery*, 2007. The authors presented data from a retrospective review of clinical experience in a single center. In the absence of complications, medical therapy was effective, with an overall mortality rate of 1.6%. When urgent surgical intervention was required, mortality increased to 31.5%. Risk factors for complications necessitating surgery were older age and smoking, with leg pain as one of the presenting symptoms. Patients being treated with β-blocking drugs prior to presentation had better outcomes in all treatment groups. The authors concluded that medical therapy is useful for uncomplicated type B aortic dissections, and they recommended using endovascular techniques as opposed to open surgery for patients who failed medical therapy.

Confirmation of the effectiveness of endovascular therapy for type B aortic dissections was provided in an analysis of long-term results of endovascular repair compared to open surgery using data from a randomized prospective trial. The data were reported by Neinaber and coauthors in *Circulation and Cardiovascular Interventions*, 2013; this article is supplied as a full-text reprint accompanying some formats of SRGS. This study enrolled 140 patients who were randomized to receive optimum medical therapy or medical therapy plus endovascular repair of the dissection. The data analysis showed significantly better long-term outcomes (in terms of overall and aorta-related mortality) for patients treated with endovascular repair compared with long-term medical therapy for type B aortic dissections.

A surgical perspective on the management of thoracic aortic dissections was presented in an article by Wong and coauthors in the *American Surgeon*, 2008. The authors began by pointing out that there are several overlapping terminologies that may confuse readers seeking to learn more about the surgical management of thoracic aortic dissections; these terms include intramural hematoma (IHA) and penetrating aortic ulcer (PAU). In addition, there

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**Figure 4**

Algorithm for management of type B thoraco-abdominal aortic dissection. Reproduced from Fattori and coauthors with permission.
is an “umbrella” term for aortic dissection used mostly in nonsurgical articles: “acute aortic syndrome.” Wong and colleagues stressed that these terms are not currently pertinent to the issue of determining the best treatment for patients with thoracic aortic dissections. They added that the initiating event in an aortic dissection is a tear in the intimal lining of the vessel that permits the formation of a false lumen. This false lumen extends for variable distances proximally and distally. The lumen may thrombose or, because of the spontaneous occurrence of single or multiple fenestrations, flow within the false lumen may persist. If the adventitia is breached by the expansion of the false lumen, contained or free rupture may occur. Aortic dissections are termed acute if they present with a history less than 14 days. From 14–60 days, the aneurysms are termed subacute. Chronic aneurysm dissections are those with a history of more than 60 days. The authors noted that the aorta distal to the clinical extent of the dissection may be diseased and a significant proportion of the distal vessels continue to dilate after surgical therapy. They indicated that a meaningful description of the dissection can usually be drawn from findings on imaging studies and should include, at a minimum, the location of the dissection, a determination of chronicity, a description of complications such as contained rupture, and a comment on the status of branch vessels. The authors provided detailed discussions of preoperative evaluation: they used transesophageal echocardiography, multislice CT scans, and MRI selectively, according to patient status and the information being sought. Wong and coauthors also stressed the importance of critical care and aggressive blood pressure control. Surgical repair is indicated for essentially all type A dissections, with the exception of patients who have suffered severe cerebral damage from a stroke or a terminal illness from a malignancy or other chronic process. In addition, it was revealed, that paraparesis, or paraplegia, is not a contraindication to operation because this condition may improve postoperatively.

Wong and colleagues also provided detailed descriptions of the various open and endovascular repair approaches available for these lesions. The review of data from clinical series indicated that the open repair of acute dissections is associated with an in-hospital mortality risk approaching 30%.76 For both acute and elective repair of dissections, most available data indicate that short- and medium-term results for open and endovascular repair of thoracic aortic aneurysms are equivalent.77,78 Questions remain about long-term complications of endovascular repair, such as endoleaks, aneurysmal dilatation, and possible late rupture and paraplegia risk in patients who have aneurysms of the descending aorta.

Methods of preventing spinal cord ischemia have been developed for open repairs of thoracic aneurysms; these are detailed in a report by Coselli and LeMaire29 in Seminars in Vascular Surgery, 2008. These authors described a number of technical approaches that will reduce overall complication rates for these operations. Specific maneuvers to prevent spinal cord ischemia include sequential aortic clamping, mild hypothermia, spinal fluid drainage, and the reattachment of segmental intercostal arteries.

During the postoperative period, maintenance of mean arterial pressure above a minimum level of 90 mm Hg permits uninterrupted perfusion of the spinal cord and minimizes, insofar as possible, spinal cord ischemia. Wong and coauthors25 noted that permanent paraplegia is currently observed in less than 7% of patients when these precautions are used. The temporary paraparesis rate may approach 10%, but in many of these patients, lower extremity weakness resolves during the postoperative recovery. The authors stressed that while late-appearing paraplegia remains a complication that occurs in few patients, it is nevertheless a very frustrating development for the few patients afflicted with this devastating problem.

The question of measures that should be taken to reduce the risk of spinal cord ischemia in patients who undergo endovascular repair of descending thoracic aortic aneurysms was the topic of a report by Sullivan and Sundt80 in a supplement to the Journal of Vascular Surgery, 2006. These authors noted that permanent paraplegia rates are now reported from one center as 2.4% when spinal fluid drainage was used as an adjunct to endovascular repair of thoracic aneurysms. Sullivan and Sundt indicated that spinal fluid drainage is also useful as a means of rescue therapy in patients who develop paraparesis after an endovascular repair where a drain had not been placed; they currently leave the drain in place for 24 hours after the endovascular repair. Sullivan and Sundt also confirmed that spinal fluid drainage should
be strongly considered when the T9–T12 segments of the thoracic aorta will be covered by the endograft, as well as when the risk of absence of adequate spinal cord collateral circulation is present (as might occur in patients who have had previous abdominal aortic surgery).

One final and interesting question concerns the relative contribution of reattached segmental intercostal vessels in the prevention of paraplegia after thoracic aortic aneurysm repair. This topic was the subject of a report by Acher and coauthors in the *Annals of Surgery*, 2008. These authors used spinal fluid drainage, naloxone, and a strict blood pressure maintenance protocol and noted that paraplegia risk was reduced by 80%. They also developed a detailed paraplegia risk score and identified intercostal arteries that supplied radicular vessels to the spinal cord using preoperative MRI. These vessels were identified intraoperatively and reimplanted using the button technique. The authors documented an additional reduction in paraplegia risk after the practice of intercostal reimplantation was instituted. They concluded from their data that intercostal reimplantation accounted for 20% of the risk reduction for paraplegia.

Peripheral Artery Aneurysms

Hall and coauthors focused on the clinical characteristics and management of peripheral artery aneurysms in *Surgical Clinics of North America*, 2013. The authors emphasized two important clinical features of peripheral artery aneurysms: the presence of one aneurysm thought to be caused by the degenerative changes that accompany atherosclerosis should prompt a search for additional aneurysms in other arterial sites; and peripheral artery aneurysms are frequently asymptomatic. The authors further noted that repair of peripheral artery aneurysms should be considered when the aneurysm is symptomatic or when the aneurysm is one and one-half to two times the normal diameter of the native artery.

Femoral artery aneurysms are divided into two types: type 1 aneurysms involve the common femoral artery proximal to the bifurcation; and type 2 aneurysms extend into the superficial and/or profunda femoris vessels. The majority of femoral artery aneurysms are type 1. According to data cited in their review, the authors recommended conservative management of small femoral artery aneurysms unless the lesions are symptomatic. Larger lesions or aneurysms that increase in size should be considered for resection and interposition grafting. The anatomy and outflow characteristics of the aneurysm can be defined with ultrasound, CT imaging, or MRI.

Hall and colleagues do not recommend using endovascular approaches to manage femoral artery aneurysms because of the anatomic features of the artery and its relationships to surrounding structures such as the hip joint and the inguinal ligament. They concluded by confirming that femoral artery pseudoaneurysms are increasing in frequency because of the increasing number of interventional radiology procedures that are being performed for various clinical problems. They also emphasized that most of these lesions can be managed conservatively; most pseudoaneurysms that are less than 2.5 cm in diameter will thrombose spontaneously unless the patient is chronically anticoagulated. Small aneurysms that do not thrombose spontaneously can be managed with ultrasound-guided compression or ultrasound-guided thrombin injection. Larger aneurysms and those that increase in size should be considered for operative intervention.

Popliteal Artery Aneurysms

Hall and coauthors noted that popliteal artery aneurysms are the most common form of aneurysm disease, after aneurysmal disease, in the aorta and iliac arterial systems, and account for more than two-thirds of lower extremity aneurysms. They are frequently bilateral and afflict mainly elderly males. The patients who have popliteal aneurysms are at risk for coexisting atherosclerotic cardiovascular disease, hypertension, chronic obstructive pulmonary disease, and simultaneous aneurysms of the aortoiliac arterial system. While the most severe complications of aortoiliac aneurysms are rupture, erosion into adjacent visceral and vascular structures, and compression of adjacent struc-
tures, popliteal aneurysms become symptomatic because of thrombosis within the aneurysm. The thrombus releases small emboli into the distal circulation. This causes distal ischemic symptoms such as claudication, rest pain, and blue-toe syndrome. Acute limb- and life-threatening ischemia can occur if there is total aneurysm thrombosis, which carries a significant risk of patient mortality and limb loss because thrombosis occurs in association with prior distal embolization of mural thrombus (which often has progressively occluded distal outflow arteries of the lower limb).

**Diagnosis & Clinical Characteristics of Popliteal Aneurysms**

The diagnosis of popliteal aneurysms was discussed in the peripheral vascular disease guidelines article by Hirsch and coauthors in *Circulation*, 2006. The authors noted that popliteal artery aneurysms account for 70% of all lower-extremity aneurysmal disease. These aneurysms are commonly encountered in patients with aneurysms of other arteries, such as the abdominal aorta. For this reason, a careful history should be obtained from a patient with an abdominal aortic aneurysm to document the presence of lower-extremity ischemic symptoms. These symptoms may occur because of emboli from the aortic aneurysm or emboli from a peripheral aneurysm of the popliteal or other lower extremity system. Practice guidelines state that any patient with palpable enlargement of the popliteal artery should be evaluated with imaging; the most convenient imaging modality for the initial examination is ultrasonography. The authors emphasized that the presence of intraaneurysmal thrombus can reduce the size of the popliteal artery seen on ultrasound images—this could lead to a false negative examination. The guidelines recommended aneurysm repair for symptomatic patients and for any acceptable-risk patient with an aneurysm 2 cm in diameter or larger. Popliteal artery aneurysms are frequently bilateral; bilateral ultrasound imaging is indicated whenever one artery is thought to be abnormal.

Pittathankal and coauthors focused on growth rates of ectatic popliteal arteries in the *European Journal of Vascular and Endovascular Surgery*, 2004. These authors identified 21 patients with unilateral or bilateral popliteal artery aneurysms. Fifteen patients were symptomatic at the time of original diagnosis and all underwent aneurysm repair. In follow-up with ultrasound imaging (annual examinations for more than three years), aneurysm growth rates ranged from 1.5 mm per year to 3.5 mm per year. Growth rates were related to the size of the aneurysm at original diagnosis; more rapid growth was observed in larger aneurysms.

Additional data on aneurysm expansion rates were presented in an article by Magee and coauthors in the *European Journal of Vascular and Endovascular Surgery*, 2010. The authors emphasized that patients treated electively for popliteal aneurysms >2 cm in diameter have better outcomes in terms of limb salvage and mortality compared with patients treated after the aneurysm becomes symptomatic. Because of this observation, imaging surveillance is recommended for patients with ectatic popliteal arteries and for patients who have been treated for aneurysms of other arteries. These authors followed a group of 67 patients for a median interval of more than three years. They observed growth of more than 2 cm in diameter in seven patients. Mean growth rate was 1.5 mm per year. In patients with arteries that expanded to a diameter >2 cm during observation, growth was more rapid. Rapid growth was noted also in patients who had previously undergone treatment for an aneurysm of another artery. The authors noted an increased frequency in the diagnosis of abdominal aortic aneurysms in their patients.

The risk for developing aneurysms of other arteries in patients treated for popliteal artery aneurysms was the focus of an article by Ravn and coauthors in the *British Journal of Surgery*, 2008. A full-text reprint of this article is included with some formats of SRGS. In this study, 571 patients treated for popliteal artery aneurysm were identified from the Swedish Vascular Registry. At the time of treatment of the index popliteal artery aneurysm, 36% of patients had an additional aneurysm identified. Most of the additional aneurysms were located in the aortoiliac system. During the follow-up interval (median seven years), an additional 32% of patients developed aneurysm disease. The authors concluded that patients treated for popliteal aneurysm should undergo sequential examinations for additional aneurysms.
While most popliteal aneurysms occur in elderly men, there is an interesting variant of popliteal aneurysm disease that develops as a complication of popliteal entrapment syndrome, a condition seen mostly in young male athletes. This condition was the subject of a case report by Lopez Garcia and coauthors in the Journal of Vascular Surgery, 2007. These authors reported the case of a 31-year-old male athlete who developed bilateral popliteal aneurysms and presented with acute thrombosis of one of these, necessitating emergency surgical treatment. The remaining aneurysm was electively resected and flow was reestablished with a saphenous vein. The authors noted that, on questioning, the patient had symptoms of intermittent claudication that had not been evaluated before the sudden development of limb-threatening ischemia. They noted that popliteal artery entrapment should be considered whenever a young patient without risk factors for peripheral vascular disease presents with intermittent claudication. They further explained that popliteal artery entrapment is a condition that occurs when abnormalities of the muscular and tendon attachments to the distal femur and proximal tibia and fibula compress the popliteal artery. The syndrome is classified into four main types, according to the system published by Delaney in 1971: the normal anatomic relationships dorsal to the knee are that the popliteal artery and vein pass in the midline between the medial and lateral heads of the gastrocnemius muscle; in Delaney’s classification, type 1 entrapment occurs because the popliteal artery passes medial to and then beneath the medial head of the gastrocnemius; in type 2, the medial head of the gastrocnemius attaches to the distal femur at a point more lateral than usual, compressing the artery; type 3 occurs when a slip of the gastrocnemius attaches more lateral than usual; and type 4 occurs when the popliteus muscle or a ligamentous band crosses laterally dorsal to the artery causing compression. The patients usually respond to surgical division of the constricting structures and popliteal aneurysm development is an unusual complication of this condition.

Management Principles for Popliteal Aneurysms

Hirsch and coauthors cited data pertinent to the natural history of popliteal aneurysms. Patients develop ischemic symptoms requiring operation or amputation in nearly 50% followed long term. The authors further cited several recent reports confirming that nearly half of the patients with popliteal aneurysms are symptomatic at the time of the initial aneurysm diagnosis due to distal ischemia produced by embolization from an intraneurysmal clot or by thrombosis of the aneurysm. Popliteal artery aneurysms can be approached with open or endovascular techniques. In the remaining sections of the discussion, we will review these approaches.

Open Operative Approaches

Hirsch and associates noted that outcomes of open operations for popliteal artery aneurysms are very satisfactory; 10-year graft patency rates approach 100% for operations performed for asymptomatic aneurysms and 80%–90% for operations performed after symptoms have developed. The currently recommended surgical procedures include a posterior approach, opening the aneurysm sac with suture ligation of all tributary vessels. Vascular continuity is reestablished with an interposition of autogenous vein or prosthetic graft for restoration of flow.

The most common open surgical procedure for treating a popliteal artery aneurysm uses proximal and distal ligation of the aneurysm and bypass of the aneurysm with autogenous vein, autogenous artery, or a prosthetic graft via a medial approach. One important complication of the medial approach is recurrence of the aneurysm with compression of the vascular and neural structures within the popliteal fossa. This is thought to occur because tributary vessels continue to feed blood into the aneurysm sac. The available procedures and their respective outcomes were described in a large population-based report from the Swedish vascular registry by Ravn and coauthors in the British Journal of Surgery, 2007. These authors described the results of popliteal aneurysm repairs performed in 571 patients. In all, 717 aneurysms were repaired. A review of the demographics of this group revealed that 96% of the patients were men and the mean age was 71. The most common procedure performed was autogenous vein...
bypass from the superficial femoral or proximal popliteal artery to the distal popliteal artery or one of the popliteal branches below the knee, with proximal and distal ligation of the popliteal artery to exclude the aneurysm. Immediate limb salvage was achieved in 94% of the limbs. Twelve percent of limbs were viable after emergency operation, but patients experienced symptoms and displayed signs of residual ischemia. Graft patency was 92% at one year.

Amputation rates fell gradually during the interval covered by this study. Most recent amputation rates were 5.7% overall and 12% for patients who underwent urgent or emergency operation for severe acute limb ischemia. Five-year survival was 70%, in keeping with the age and comorbid disease pattern for these patients. The authors noted that the five-year survival for this group was slightly lower than for the overall age-matched Swedish population. Ravn and coauthors noted that more than 95% of the aneurysms in this series that were operated on because of symptoms had intra-aneurysmal thrombus. They revis­ited, in the discussion section of their report, the problem of accurately predicting which patients with popliteal aneurysms who would become symptomatic. Because they observed symptoms in some aneurysms that were smaller than the 2 cm cutoff used for recommending elective operation in asymptomatic patients, they suggested that ultrasound surveillance be considered for these patients to detect aneurysm growth rates and thrombus formation.

Similar excellent results from both types of operations for popliteal aneurysms were reported from a multicenter case-matched analysis by Kropman and coauthors in the Journal of Vascular Surgery, 2007. This report described a group of patients who underwent medial approach saphenous vein bypass with proximal and distal ligation of the popliteal artery near the aneurysm and compared these with matched patients who underwent popliteal aneurysm repair using the posterior approach. Case matching was done using patient age, indication for aneurysm repair, co-morbid diseases, diameter of the aneurysm at the time of repair, number of outflow vessels, and the type of conduit used to reestablish blood flow. The preferred conduit for both approaches was the saphenous vein. The only significant difference between groups was that there were more bilateral aneurysms in the medial approach group. Overall graft patency evaluated at 12 months and two years was significantly better (100% and 96% vs. 84% and 80%) for patients who had the medial approach with a saphenous vein conduit. The authors ascribed this difference to two early graft occlusions in the posterior group, possibly from technical difficulties with the operative procedure. They noted that without these two events, the patency rates at all intervals were similar.

Overall patency at two years was not significantly different in the two groups and the number of postoperative interventions for conduit stenosis or occlusion also did not differ. Overall patency at two years was 80%. Aneurysm growth occurred in two patients in the medial group. The authors stressed that acceptable results are observed after both approaches and that aneurysm growth can occur in up to 22% of patients repaired using the medial approach. Kropman and colleagues believed that optimum protection against aneurysm growth is obtained with the posterior approach.

Additional data on outcomes of the posterior approach for repair of popliteal artery aneurysm were presented in an article by Zaraca and coauthors in Annals of Vascular Surgery, 2010. The authors reported a single-center, retrospective case series involving 35 patients and 49 repaired aneurysms. The authors noted that the posterior approach was preferred; the technique used required prone positioning of the patient and included exposure using a “lazy-S” incision in the popliteal fossa, with complete isolation of the aneurysm sac. The sac was opened and continuity of the artery was reestablished using greater saphenous vein in most cases. The authors noted that primary and assisted patency rates at six months were 97% for both groups, but long-term (eight-year) patency rates were significantly better for patients operated on with the posterior approach. Long-term amputation rates were not different when the groups were compared. The authors noted that the lower patency rates in patients operated on via the medial approach might be ascribed to the fact that a larger proportion of these patients had ischemic symptoms preoperatively and that all patients with extensive aneurysm disease extending above the adductor hiatus were operated on with a medial approach.

One concern relating to the posterior approach is the possible difficulty in harvesting the saphenous vein with the patient in the prone position. A description of techniques to accomplish saphenous or basilic vein harvesting for use as a reconstructive conduit was presented in an
article by Tal and coauthors\textsuperscript{91} in the \textit{Journal of Vascular Surgery}, 2010. The authors reported a small retrospective case series (five patients). They harvested the basilic vein from the arm opposite to the side of the aneurysm repair. They provided a helpful illustration of the patient positioning (Figure 5). The only drawback to using the basilic vein was that it was occasionally fragile and difficult to manipulate. Because of this, the provided illustration shows alternative incisions for possible saphenous vein harvest.

An additional concern about using venous and prosthetic conduits to repair popliteal aneurysms has been that motion of the knee joint might predispose to kinking and thrombosis of the conduit. An alternative technique was described in an article by Pareskavas and coauthors\textsuperscript{92} in the \textit{Journal of Vascular Surgery}, 2008. These authors presented a single-center retrospective case series of 37 popliteal aneurysm repairs. The authors used the ipsilateral superficial femoral artery as their preferred conduit for reconstruction of the popliteal artery. They harvested the artery in the upper third of the thigh and replaced the artery with a prosthetic graft. Thirty-five percent of patients had single-vessel runoff. There were no perioperative deaths or amputations. During the follow-up interval averaging three years, overall patency was 97\% and limb salvage was possible in all patients. The authors concluded that autogenous femoral artery is a safe and effective alternative conduit for popliteal artery reconstruction.

Ravn and coauthors\textsuperscript{93} provided long-term outcomes data from the Swedish Vascular Registry experience (reviewed earlier) in an article in the \textit{Journal of Vascular Surgery}, 2007. Data from 717 aneurysm repairs are reported. Long-term patency rates were better for patients operated on using the posterior approach (81\% vs. 72\%). Amputation rates were not significantly different for each approach.

Long-term results of popliteal aneurysm repair were the subjects of a report by Davies and coauthors\textsuperscript{94} in the \textit{European Journal of Vascular and Endovascular Surgery}, 2007. These authors examined 10-year patient survival and graft patency rates in a group of 48 patients who underwent 63 popliteal aneurysm repairs. As in the other reports reviewed in this section of the overview, the authors found lower patency rates and limb salvage rates in patients who underwent emergency aneurysm repairs. Graft patency and limb salvage rates at 10 years exceeded 90\%. The 10-year mortality rate for their patients was 20\%, reflecting the patterns of comorbid diseases in these patients.

Increased attractiveness of endovascular approaches for managing popliteal aneurysms has been driven by the recognition that many patients who are diagnosed with popliteal aneurysms that are progressively increasing in size and become candidates for elective operation have significant comorbid conditions that increase operative risk. A significant proportion of these patients face shortened life spans because of the associated health conditions; thus, a satisfactory short-term approach to treating the aneurysm(s) that is safe and does not expose the patient to a major surgical procedure under general anesthesia is desirable. Concurrently, improvements in endovascular

\begin{figure}
\centering
\includegraphics[width=\linewidth]{patient_positioning.png}
\caption{Patient positioning for the posterior approach for repair of a popliteal aneurysm with incisions for harvesting of basilic or saphenous vein. Reproduced from Tal and coauthors\textsuperscript{91} with permission.}
\end{figure}
techniques and the devices applicable to treating popliteal aneurysms have occurred. The rates of early thrombosis have progressively decreased and the frequency of needed secondary interventions has also decreased.

Cina and coauthors\textsuperscript{95} presented current data on outcomes of endovascular repair of popliteal aneurysm disease in the Journal of Vascular Surgery, 2010. These authors conducted a systematic review of available literature to determine comparative outcomes of endovascular vs. open repair of popliteal aneurysms. They found reports of data on 320 patients who underwent repair. Early patency rates were equivalent for endovascular and open repair. Long-term patency (three years or more) was better for open repair, but the difference did not reach statistical significance.

A multicenter retrospective study of endovascular repair of popliteal aneurysms was reported in an article by Midy and coauthors\textsuperscript{96} in the Journal of Vascular Surgery, 2010. These authors presented long-term patency rate data and the frequency of stent thrombosis and endoleak development. Data from 57 aneurysm repairs were reported. The mean follow-up interval was three years and no patients were lost to follow-up. The authors calculated Kaplan-Meier estimates of long-term graft patency, and found that overall patency was 87% and limb salvage was possible in nearly 97% of patients. Occlusion of the stent occurred in 16% of patients and endoleaks occurred in 10.5% of patients.

Additional outcomes data were presented in an article by Curi and coauthors\textsuperscript{97} in the Journal of Vascular Surgery, 2007. This article is supplied as a full-text reprint accompanying some formats of SRGS. These authors provided comparative data on 15 patients treated with endovascular repair and 42 patients treated with open repair techniques. Median follow-up was 16.5 months. There were no stent thromboses observed and endoleaks occurred in 20% of patients, all of whom were managed with endovascular repair. There was no difference in long-term overall patency rates when the open and endovascular repair groups were compared.

Acute Limb Ischemia

Acute limb ischemia is the most feared complication of popliteal aneurysm disease. Risk for mortality and amputation are significant in patients developing this complication. The common approaches to this patient group include preoperative or intraoperative thrombolysis, mechanical thrombectomy, and immediate or delayed repair of the aneurysm. Obviously, patients with severe ischemia are more likely to be treated with emergency operation because surgeons are often reluctant to delay efforts to reperfuse the ischemic limb in order to perform catheter-directed thrombolysis. In evaluating clinical case series, it is, therefore, important that data concerning the severity of ischemia are reported. The most commonly used ischemia grading system was proposed by Rutherford and coauthors\textsuperscript{98} in the Journal of Vascular Surgery, 1997 (Figure 6).

A helpful review of the problem of acute limb ischemia complicating popliteal artery aneurysms was by Robinson and Belkin\textsuperscript{99} in Seminars in Vascular Surgery, 2009. This article is supplied as a full-text reprint accompanying some formats of SRGS. The authors stressed that an acute clinical presentation of a popliteal aneurysm with significant limb ischemia can occur in up 50% of aneurysms. This condition is both life- and limb-threatening; mortality rates of up to 12% reported and amputation rates in the 25%–40% range have been reported in pub-
lished series. Robinson and Belkin noted that patients present with typical symptoms of leg ischemia (acute pain, pallor, diminished pulses)—the presence of and severity of neurologic deficit will be the main determinants of ischemia severity. On physical examination, the presence of a popliteal aneurysm may be suspected if there is a prominent popliteal pulse in the ischemic limb or in the opposite limb. A prominent aortic pulsation might be present because there is an increased frequency of abdominal aneurysms in patients with popliteal aneurysms.

Robinson and Belkin recommended stabilization and immediate transfer for percutaneous angiography in the operating room, followed by exploration and thrombectomy with reconstruction of the aneurysm via a medial approach for patients with ischemia plus a neurologic deficit (grade IIb and grade III ischemia). The authors noted that mechanical balloon thrombectomy via the aneurysm itself or the proximal origins of the runoff vessels may be difficult because the acute ischemic event occurs from loss of runoff caused by repeated episodes of embolization of thrombus from the aneurysm. When one or more runoff channels cannot be established with balloon thrombectomy from a proximal site, cutdown at the ankle level, with exposure of distal arteries and balloon thrombectomy from a distal site, may be necessary. Intraarterial thrombolysis may be useful, but may also be associated with bleeding risk. If runoff channels can be established, the aneurysm can be repaired using proximal and distal ligation, with bypass of the aneurysm using autogenous vein conduit. For patients with severe (grade III) ischemia, and for patients with severe comorbidity, primary amputation may be the best option because of the risk of rhabdomyolysis and renal failure that can occur with reperfusion of a severely ischemic limb. For patients with less severe ischemia and preserved neurologic function, the authors favored formal angiography with catheter-directed thrombolysis and delayed reconstruction of the aneurysm. The authors cautioned that although catheter-directed thrombolysis has been reported to establish suitable runoff in more than 80% of patients, bleeding complications have occurred, including stroke, from intracerebral hemorrhage in up to 25% of patients from several reported series. The decision to use thrombolysis needs to be considered carefully in light of the arterial anatomy and extent of runoff occlusion. The authors provided a helpful algorithm outlining a management approach for patients with acute limb ischemia from popliteal aneurysm (Figure 7).
Outcomes of the management of acute limb ischemia caused by popliteal aneurysm complications was the focus of an article by Kropman and coauthors in the *European Journal of Vascular and Endovascular Surgery*, 2010. These authors conducted a systematic review of available literature. The authors were able to find eight prospective and 25 retrospective studies providing data on 895 patients. The aggregated data showed no statistical difference in outcomes for patients having thrombolysis compared with patients undergoing mechanical thrombectomy. Amputation rates were similar with both approaches (14%). Mortality for open repair was 3.2%. The authors concluded that there is no strong data supporting the use of catheter-directed thrombolysis.

A similar view of the results of popliteal aneurysm repair in the face of limb-threatening ischemic symptoms was presented in a report by Aulivola and coauthors in the *Journal of Vascular Surgery*, 2004. This group compared results in 14 patients operated on urgently for aneurysm thrombosis with a group of 23 patients operated on electively. The medial approach with saphenous vein bypass and proximal and distal ligation was used in all patients. These authors reported patency rates exceeding 95% for elective as well as emergency patients. Preoperative thrombolysis was not employed often, and bleeding complications were observed in 75% of the patients where thrombolysis was used. The authors stressed the importance of bypass to a satisfactory outflow vessel and they attributed their good results to their practice of aggressively searching for the best outflow vessel as the target for the saphenous vein bypass. They did not observe aneurysm expansion during their follow-up. Long-term survival was equivalent in their patients who underwent elective and emergency operations.

Marty and coauthors provided additional outcomes analysis for patients with acute limb ischemia caused by popliteal aneurysm complications in the *Journal of Vascular Surgery*, 2002. These authors used preoperative catheter-directed thrombolysis to establish runoff channels in a single-center retrospective case series involving 13 patients. Thrombolysis was used in 12 of the 13 patients and at least one runoff channel was established in 77% of patients. Three patients required immediate surgery because of early lytic failure and all three underwent amputation. The mortality among patients who underwent thrombolysis was 15%. There were no episodes of significant bleeding, but all deaths were rhabdomyolysis or pulmonary embolism that occurred after reperfusion. The authors concluded that catheter-directed thrombolysis might be helpful in patients who can safely tolerate the delay in limb ischemia treatment.

### Visceral Artery Aneurysms

Aneurysms of the hepatic artery, celiac artery, pancreaticoduodenal artery, superior mesenteric artery, inferior mesenteric artery, splenic artery, and the renal arteries are included in discussions of visceral artery aneurysm disease. This section will review the diagnosis and management of aneurysms of the arteries supplying the liver and the gastrointestinal system.

The single article chosen for discussion in this section was by Sachdev-Ost in the *Mount Sinai Journal of Medicine*, 2010. This article is supplied as a full-text reprint accompanying some formats of *SRGS*. The author opened the review by emphasizing that the most important complication of aneurysms of the hepatic and mesenteric systems is aneurysm rupture. Because of this risk, true and false aneurysms of the hepatic and gastrointestinal arterial systems should be repaired when discovered in acceptable risk patients. The development of effective endovascular treatments has increased the opportunity for repair in higher risk patients.

### Hepatic Artery Aneurysms

The most common aneurysm reported in the hepatic and gastrointestinal circulation involves the hepatic artery. Sachdev-Ost noted that increasing use of nonoperative therapy for liver injuries (see discussion in *SRGS*, Vol. 38, No. 4), along with the increasing use of percutaneous biliary procedures, has been associated with an increase in false aneurysms of the intrahepatic branches of the hepatic artery. In fact, recent figures have confirmed that
false aneurysms have supplanted true aneurysms of the hepatic artery as the most common aneurysm type in the hepatic and gastrointestinal circulatory system.

With regard to true aneurysms of the hepatic artery, Sachdev-Ost indicated that the indications for intervention include symptomatic aneurysms and aneurysms >2 cm in diameter in good-risk patients (defined as life expectancy of more than two years and acceptable operative risk). Aneurysm rupture presents more frequently as rupture into the biliary system. The constellation of jaundice, biliary colic, and gastrointestinal hemorrhage (Quincke’s Triad) is a frequent clinical presentation of a ruptured hepatic artery aneurysm. Mortality for the operative treatment of ruptured hepatic artery aneurysms is reported to be 33%. Sachdev-Ost noted that in the largest reported series of hepatic artery aneurysms, 60% of patients were managed nonoperatively because of small aneurysm size or prohibitive operative risk. None of the observed patients ruptured during follow-up. The author cited data confirming that aneurysms of the extrahepatic circulation, particularly of the proper hepatic artery, are most often treated with open hepatic artery aneurysm. Mortality for the operative treatment of ruptured hepatic artery aneurysms is reported to be 33%. Sachdev-Ost noted that in the largest reported series of hepatic artery aneurysms, 60% of patients were managed nonoperatively because of small aneurysm size or prohibitive operative risk. None of the observed patients ruptured during follow-up. The author cited data confirming that aneurysms of the extrahepatic circulation, particularly of the proper hepatic artery, are most often treated with open hepatic artery aneurysm resection and interposition grafting with autogenous vein or prosthetic conduit. Other operative approaches include artery ligation, hepatic resection, and, occasionally, liver transplantation. Sachdev-Ost emphasized the importance of collateral hepatic circulation and stressed that arterial ligation should not be attempted unless there is documented patency of the portal vein.

Endovascular treatment of hepatic artery aneurysms includes coil embolization of intrahepatic true and false aneurysms and stent graft repair for aneurysms of the larger hepatic arteries. Technical success for endovascular management ranges up to 80%, according to data cited in the review.

**Celiac Artery Aneurysms**

According to Sachdev-Ost, celiac artery aneurysms are rare, accounting for 4% of visceral aneurysms. Atherosclerosis is the most common associated disease and aneurysms at other visceral and nonvisceral sites are found in more than two-thirds of patients. Celiac aneurysms may present with symptoms that mimic acute pancreatitis. Intervention with open repair is indicated in symptomatic patients and patients with large and/or growing aneurysms. Open operation is challenging: extended exposure using medial visceral rotation and/or thoracoabdominal incision is often required. Ligation of the vessels feeding the aneurysm is recommended when there is no liver disease and collateral circulation is adequate. If arterial
reconstruction is required, prosthetic conduit is recommended because of frequent kinking and occlusion of autogenous vein conduits. Inflow is obtained from the supraceliac aorta in most cases. A few reports of endovascular management are available, but large case series have not been reported. Endovascular occlusion of the aneurysm and feeding arteries may be appropriate for high-risk patients with adequate collateral circulation and normal liver function.

**Other Gastrointestinal Artery Aneurysms**

Aneurysms of the pancreaticoduodenal artery system and the inferior mesenteric artery are rare. The most frequent clinical presentation is aneurysm rupture, which carries a mortality risk in excess of 35%. When diagnosed before rupture, aneurysms of the pancreaticoduodenal artery should be managed with coil embolization if collateral circulation is adequate, since operative exposure and repair is very difficult.

**Pseudoaneurysms of Gastrointestinal Arteries**

Sachdev-Ost explained that pseudoaneurysm formation can occur secondary to trauma, infection, and inflammation. Pancreatitis can lead to the formation of pseudoaneurysms of the pancreaticoduodenal arterial system and the splenic artery. Endovascular management is preferred and can be achieved successfully, even in the setting of hemodynamic instability, according to the author’s experience.
hope you have found the information in this issue of SRGS helpful. Please join us for the second part of our three-issue series on vascular surgery, where we will review vascular occlusive disease and vasospastic conditions.

Thanks for reading SRGS!

Lewis Flint, MD, FACS
Editor in Chief
References | VASCULAR SURGERY, PART I
VOLUME 42 | 7 | 2016

References | VASCULAR SURGERY, PART I


1. The prevalence of abdominal aortic aneurysms is 1.5% in American males who are 45 years old. This prevalence rises to which of the following by age 75?
   a) 4%
   b) 2%
   c) 12.5%
   d) 16%
   e) 25%

2. An abdominal aortic aneurysm is diagnosed if the diameter of the aorta is increased by which of the following percentages?
   a) 12%
   b) 50%
   c) 30%
   d) 75%
   e) 100%

3. Data cited in the article by Kent and coauthors show that the mortality risk for open or endovascular repair of an abdominal aortic aneurysm discovered with ultrasound screening is which of the following?
   a) 3.5%
   b) 0.5%
   c) 6%
   d) 2%
   e) 11.5%

4. Women who are discovered to have an abdominal aortic aneurysm on ultrasound screening have an increased risk of which of the following percentages for a concomitant thoracic aortic aneurysm?
   a) 48%
   b) 12.5%
   c) 65%
   d) 2.5%
   e) 21%

5. Data cited in the article by MacSweeney and coauthors indicated that the annual growth rate for an abdominal aortic aneurysm diagnosed in a nonsmoking male was 0.09 cm. The annual growth rate in smokers was which of the following?
   a) 0.25 cm
   b) 0.07 cm
   c) 0.75 cm
   d) 1.0 cm
   e) 0.16 cm

6. The matrix metalloproteinase (MMP) enzyme system contributes to the growth of abdominal aortic aneurysms. The principle MMP component found in the walls of small aneurysms is which of the following?
   a) MMP 9
   b) MMP 2
   c) MMP 3
   d) MMP 4
   e) MMP 7

7. Aortic wall tissue from aneurysms treated surgically has been shown to have elevated levels of COX-2 receptors. The cell of origin of these receptors is which of the following?
   a) Neutrophils
   b) Fibroblasts
   c) Endothelial cells
   d) Macrophages
   e) Melanocytes
8. Statin drugs reduce aneurysm growth rates by reducing inflammation and stabilizing the MMP enzyme system. Evidence for improvement in inflammation is shown by which of the following?
   a) Reduced neutrophil counts
   b) Reduced levels of interleukin-6
   c) Reduced total white blood cell counts
   d) Reduced levels of C-reactive protein
   e) Absence of antibodies to pneumococcal organisms

9. Doxycycline is possibly effective in reducing the growth rate of abdominal aortic aneurysms. One of the most frequent side effects of this drug is which of the following?
   a) Decreased hearing
   b) Acceleration of cataract growth
   c) Elevated monocyte levels
   d) Tooth discoloration
   e) Pruritus

10. The diagnosis of an abdominal aortic aneurysm is suggested by which of the following findings on plain abdominal radiographs?
    a) Cephalad displacement of the duodenal shadow
    b) Obliteration of the left renal outline
    c) Displacement of the sigmoid colon to the left
    d) Calcification in the abdominal aortic wall
    e) Haziness of the retroperitoneal outline

11. Data from the UK small aneurysm trial showed a reduction in death rates for patients diagnosed with small abdominal aortic aneurysms. This reduction was attributed to which of the following?
    a) Surgical repair of small aneurysms
    b) Reduced numbers of women in the enrolled cohort
    c) Younger age of enrolled patients
    d) Reductions in the number of smokers following enrollment
    e) Reduced frequency of hypertension in enrollees

12. Reported mortality rates for open abdominal aortic aneurysm repair in high-volume institutions are which of the following?
    a) 3% or less
    b) 5–8%
    c) 10%
    d) 0.5%
    e) 14%

13. Data reported in the article by Teixeira and coauthors showed that there were reductions in which of the following groups of complications in patients undergoing retroperitoneal repair of abdominal aortic aneurysms?
    a) Postoperative infectious complications
    b) Pulmonary complications
    c) Incisional hernias
    d) Cardiac and renal complications
    e) Postoperative pain

14. Data from the article by van Marrewijck and coauthors indicate that the risk of delayed aneurysm rupture in patients who undergo endovascular repair of abdominal aortic aneurysms and who have no endoleak discovered on postoperative surveillance imaging is which of the following?
    a) 7.5%
    b) 2.5%
    c) 3.7%
    d) 10%
    e) 0.25%

15. Protocol-driven approaches for endovascular repair of ruptured abdominal aortic aneurysms have shown mortality rates of which of the following ranges?
    a) 13%–17%
    b) 25%–35%
    c) 50%–70%
    d) 4%–6%
    e) 42%–48%
16. Stanford type A thoracic aortic dissections involve which segment of the thoracic aorta?
   a) Aortic valve
   b) Ascending aorta
   c) Aortic arch
   d) Descending aorta
   e) Thoracic aorta at the level of the diaphragm

17. The most feared complication of Stanford type A thoracic aortic dissection is which of the following?
   a) Free rupture into the pleural space with exsanguination
   b) Occlusion of the carotid arteries
   c) Rupture into the pericardium with pericardial tamponade
   d) Disruption of the aortic valve
   e) Damage to the cardiac conduction system

18. Measures for prevention of spinal cord ischemia in patients undergoing repair of thoracic aortic aneurysms include all of the following except which one?
   a) Spinal fluid drainage
   b) Sequential aortic clamping
   c) Reattachment of segmental intercostal arteries
   d) Epidural anesthesia
   e) Mild hypothermia

19. Which of the following femoral artery aneurysms can be managed nonoperatively?
   a) Pseudoaneurysms larger than 3 cm in diameter
   b) Pseudoaneurysms in chronically anticoagulated patients
   c) Aneurysms resulting from interventional radiologic procedures that are smaller than 2.5 cm in diameter
   d) Aneurysms involving the common femoral artery that are larger than 3 cm in diameter
   e) Large aneurysms involving the profunda femoris artery

20. Popliteal artery aneurysms account for which percentage of lower extremity arterial aneurysms?
   a) 8%
   b) 17%
   c) 39%
   d) 70%
   e) 95%

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   Kent KC, Zwolak RM, Jaff MR et al.
   This article supplies useful guidance for cost-effective approaches to screening for abdominal aortic aneurysm in patients with and without risk factors for aneurysm development.

2. Medical management of small abdominal aortic aneurysms...53-60
   Baxter BT, Terrin MC, Dalman RL
   This report describes optimum nonoperative management of patients with small abdominal aortic aneurysms. Supporting data is provided.

3. The impact of exposure technique on perioperative complications in patients undergoing elective open abdominal aortic aneurysm repair...61-66
   Teixeira PG, Woo K, Abou-Zamzam AM, Zettervall SL, Schermerhorn ML, Weaver FA
   This report supplies data on the association of complications with exposure technique for patients undergoing open repair of abdominal aortic aneurysms.

4. Two-year outcomes after conventional or endovascular repair of abdominal aortic aneurysms...67-74
   Blankensteijn JD, de Jong SE, Prinssen M et al.
   The authors present data on early results of the endovascular repair of abdominal aneurysms and compare outcomes with patients managed with open repairs.

5. 10 years of emergency endovascular aneurysm repair for ruptured abdominal aortoiliac aneurysms: lessons learned...75-80
   Mayer D, Pfammatter T, Rancic Z, Hechelhammer L, Wilhelm M, Veith FJ, Lachat M
   Mayer and coauthors report their experience with endovascular repair of ruptured abdominal aneurysms and provide insight as to which patients are better treated with the open approach.

6. Risk of new aneurysms after surgery for popliteal artery aneurysm...81-85
   Ravn H, Wanhainen A, Bjorck M
   This article provides perspective on the mechanisms and risk factors for new aneurysms following the repair of popliteal artery aneurysms.

7. Mid-term outcomes of endovascular popliteal artery aneurysm repair...86-91
   Curi MA, Geraghty PJ, Merino OA et al.
   Curi and coauthors review clinical experience with endovascular approaches for managing popliteal artery aneurysms.

8. Acute limb ischemia due to popliteal artery aneurysm: a continuing surgical challenge...92-99
   Robinson WP, 3rd, Belkin M
   Robinson and Belkin review the principles of managing acute limb ischemia, the most feared complication of popliteal artery aneurysm disease.

9. Visceral artery aneurysms: review of current management options...100-107
   Sachdev-Ost U
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