Background
The use of synthetic material for reconstructive vascular surgery was first reported during the early 1950s. Infection involving vascular graft prostheses is an infrequent but devastating complication of reconstructive vascular graft surgery and is associated with a high morbidity and, in some situations, mortality. Improvements in surgical techniques and graft design, including the use of native venous or arterial tissue, have reduced the frequency of infection and severity of complications from vascular graft infection (VGI). However, these advances have also led to more frequent vascular graft procedures occurring in a patient population with multiple underlying comorbidities that would have previously disqualified them as candidates for vascular reconstructive surgery. Underlying comorbidities, such as diabetes mellitus or immune compromise, increase the risk of infection and serious infection-related complications. The major complications of VGI include sepsis, amputation, disruption of infected anastomotic suture line with rupture or pseudoaneurysm formation, embolization of infected thrombi, reinfection of reconstructed vascular grafts, enteric fistulae to the small or large bowel, bacteremic spread of infection to other sites, and death. VGIs can be categorized broadly into those that occur in an extracavitary location, primarily in the groin or lower extremities, or in an intracavitary location, primarily within the abdomen or less commonly within the thorax.

Frequency
The frequency of VGI depends on the anatomic location of the graft. The infection rate is 1.5% to 2% for most extracavitary grafts and as high as 6% with vascular grafts in the groin.1–9 For intracavitary grafts, the infection rate is ≈1% to 5%.1–6 Graft infection is most common after emergency procedures and after reoperation.1–4,10 Aortic graft erosion or fistulous communication into the duodenum or other areas of the bowel reportedly occurs in 1% to 2% of patients after aortic reconstruction.11,12

Microbiology
The microbiological cause of VGI has evolved over the years.1 In early published studies, Staphylococcus aureus was the predominant microorganism recovered.1–13 Improvements in surgical technique, administration of prophylactic antistaphylococcal antimicrobial therapy, and other factors have resulted in a changing microbiological epidemiology. Vascular graft surgery performed on patients with multiple underlying comorbidities and the increased frequency of emergency procedures have contributed to the changing spectrum of infection. Other factors such as changes in hospital flora, surgery in patients with complicated vascular anatomy, and multiple revisions of previous vascular surgery have resulted in a more diverse microbio-
logical spectrum of infection, which includes multidrug-resistant strains, polymicrobial infection, and *Candida* species. Gram-positive cocci accounts for at least two thirds of VGIs. Infections caused by coagulase-negative staphylococci are more common than those caused by *S. aureus*. Among *S. aureus* infections, methicillin-resistant *S. aureus* (MRSA) infections are increasing in frequency. *Pseudomonas aeruginosa* is now the most common cause of gram-negative infections and accounts for at least 10% of VGIs (Figure 1).

**Pathogenesis and Risk Factors for Infection**

Intraoperative bacterial contamination of the vascular graft is considered to be the most common cause of VGIs. The second most common cause of VGIs is a spread of infection from a contiguous site, such as a surgical wound infection or an intra-abdominal or pelvic abscess. As many as 30% of intra-abdominal VGIs occur as a result of erosion of a vascular graft into the duodenum and less commonly into the colon, with development of a fistulous communication between the abdominal aorta and the duodenum or colon. Other causes of VGI include bacterial colonization of a thrombus or direct inoculation of infection during an interventional surgical procedure, such as a percutaneous aspiration or drainage of an abscess or fluid collection. Less commonly, VGI results from a bacteremia. The risk of hematogenous infection of VGI is highest in the early postoperative period (<2 months postoperatively) and decreases over time because of partial endothelialization of the graft. Transient bacteremia from a gastrointestinal, genitourinary, or dental procedure can also cause VGI but is a much less common cause than is intraoperative contamination or wound infection.

Vogel and colleagues analyzed risk factors in almost 14,000 patients who had undergone abdominal aortic aneurysm repair. Bacteremia during the index hospitalization for repair was associated (odds ratio [OR], 4.2; 95% confidence interval [CI], 1.5–11.8) with aortic graft infection. In a separate study conducted over a 21-year period, groin infection (OR, 4.1; 95% CI, 1.6–10.7) and wound infection (OR, 5.1; 95% CI, 1.6–16.2) were significant risk factors for VGI.

**Clinical Presentations**

The clinical manifestations of VGI are highly variable and relate to whether the location is extracavitary or intracavitary, the pathogenesis of infection, and the duration of time since surgery.

**Extracavitary**

Extracavitary VGI most often occurs in the groin and much less frequently in the popliteal fossa or more distally in the leg. The clinical manifestations vary depending on whether the infection occurs early, <2 months postoperatively, or later. Early-onset infections are characterized by fever, chills (especially with *S. aureus* infection), leukocytosis, and other findings of sepsis. Physical findings can include wound erythema, abscess, sinus tract drainage, graft occlusion with distal ischemia, peripheral septic emboli, pseudoaneurysm formation, anastomotic rupture with hemorrhage (which may be life-threatening), erosion of the graft through the wound, and poor tissue incorporation of the graft.

Late-onset infection (>2 months postoperatively) is less often characterized by signs of systemic sepsis. In these cases, the infection often is indolent, with local stigmata of groin erythema, painful swelling, sinus tract drainage, lack of graft incorporation by surrounding tis-

<table>
<thead>
<tr>
<th>Microbiology of PPM/ICD Infections (n=189)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Culture negative: 7%</td>
</tr>
<tr>
<td>Fungal: 2%</td>
</tr>
<tr>
<td>Polymicrobial: 7%</td>
</tr>
<tr>
<td>Gram negative bacilli: 9%</td>
</tr>
<tr>
<td>Other Gram positive cocci: 4%</td>
</tr>
<tr>
<td>Methicillin-resistant <em>S. aureus</em>: 4%</td>
</tr>
<tr>
<td>Methicillin-sensitive <em>S. aureus</em>: 25%</td>
</tr>
<tr>
<td>Coagulate-negative staphylococci: 42%</td>
</tr>
</tbody>
</table>

**Figure 1. Microbiology of prosthetic vascular graft infections.**

ICD indicates implantable cardioverter-defibrillator; and PPM, permanent pacemaker. Reprinted from Sohail et al with permission from the American College of Cardiology Foundation. Copyright © 2007, the American College of Cardiology Foundation.
sue, pseudoaneurysm at the anastomotic site, and erosion of the graft through the skin.

The most obvious sign of a graft infection is a draining sinus tract. The clinical presentation of a pseudoaneurysm is variable. There can be little or no localized inflammatory response; a palpable, pulsatile mass; thrombosis of the graft with distal limb ischemia; or hemorrhage. In approximately half of the patients, a pseudoaneurysm at the anastomosis site presents with sudden onset of bleeding or ischemia that can be life- or limb-threatening.1,21 In patients who have undergone extracavitary lower extremity vascular reconstruction, the presence of a painful erythematous swelling in the groin, with or without a draining wound or sinus tract, is highly suggestive of an underlying VGI.

Szlajgi and colleagues22 first reported a classification of extracavitary VGI, which was refined and modified by Koenig and von Dongen,23 that shows the widely used modification proposed by Samson et al.24 The Samson modification provides guidance for selection of imaging techniques, options for medical and surgical management, management of complications, and prognosis.

The classification of group I through V infection proposed by Samson et al.24 might not always be readily apparent clinically, and these groups often overlap. For example, group I VGI can be indistinguishable from group II on physical examination. However, an open wound with drainage of pus or a draining sinus tract strongly suggests that this is not a group I infection. Contrariwise, the absence of an open draining wound or sinus tract does not exclude a group III, IV, or V infection. A visible graft with purulent drainage suggests a group III, IV, or V infection.

**Intracavitary**

In contrast to extracavitary VGI, intra-abdominal VGI may have no obvious physical findings to suggest infection. Intra-abdominal VGI can present months to years after graft placement.1,4-6 Symptomatic patients with intra-abdominal VGI may have abdominal pain, fever, leukocytosis, failure to thrive, and sepsis. The aortic graft can erode into the third or fourth portion of the duodenum, resulting in intermittent, polymicrobial bacteremia of fecal flora with a combination of aerobic and anaerobic microorganisms. Some blood cultures will contain a mix of enteric microorganisms, whereas other blood cultures contain the same or different microorganisms. These often include *Escherichia coli*, enterococci, and anaerobic microorganisms including *Bacteroides* species, fusobacteria, anaerobic cocci, and occasionally *Candida* species. In a patient who has undergone reconstructive surgery for abdominal aortic aneurysm, the development of sepsis with otherwise unexplained polymicrobial enteric bacteremia is highly suggestive of a VGI with duodenal erosion. Rarely, a VGI can cause a fistulous communication with the colon, with a similar presentation and polymicrobial enteric bacteremia.1,4-6

In addition to sepsis, gastrointestinal tract bleeding can occur, which ranges from minimal to massive with potential exsanguination. Depending on the location of the enteric fistula, bleeding can manifest as hematemesis, hematochezia, or melena. A prompt diagnosis of VGI associated with enteric fistula is critical. If untreated, the mortality rate is virtually 100%.1,6,11

Intrathoracic VGI often presents differently from intra-abdominal VGI. Intrathoracic VGI that involves the aortic root can present with signs and symptoms similar to those of infective endocarditis (IE) with fever, chills, heart failure, and disruption of the anastomotic suture line of the aortic root. Because intrathoracic VGIs are most often caused by *S aureus* or coagulase-negative staphylococci, sepsis with a high-grade sustained bacteremia is common with a high-grade sustained bacteremia. If the VGI is associated with surgery for native or prosthetic valve endocarditis, the clinical picture reflects the microbiological cause. Patients with viridans group streptococci or enterococci have a less virulent course than those with infection caused by *S aureus* or coagulase-negative staphylococci. Infection associated with repair of an aortic aneurysm or aortic dissection usually occurs within 3 months postoperatively and is most often the result of intraoperative contamination with staphylococci or gram-negative microorganisms, including *P aeruginosa*. Septic emboli can occur in the central nervous system (CNS) or peripherally. Anastomotic rupture can result in sudden massive hemorrhage, which is often fatal.

**Diagnosis**

**General Principles**

The principles for diagnosis of VGI include the following: (1) index of suspicion; (2) recognition of the differences in clinical presentations of extracavitary or intracavitary VGI; (3) time of onset postoperatively; (4) physical findings; (5) laboratory test results including cultures of blood, purulent material from a draining sinus, or aspirates of perigraft fluid and surgical specimens; and (6) imaging. The choice of an imaging modality depends on whether the VGI is extracavitary or intracavitary. In some cases, the diagnosis of VGI requires intraoperative confirmation.

**General Laboratory Tests and Culture Results**

Elevated peripheral white blood cell count and bioinflammatory markers (such as erythrocyte sedimentation rate and C-reactive protein) occur commonly but are not specific for VGI, especially among patients who have multiple underlying comorbidities. Contrariwise, normal inflammatory markers are uncommon in patients with VGI. To assess response to treatment, it can be useful to monitor biomarker levels over time in patients who have
undergone medical and surgical therapy or who continue to receive suppressive antimicrobial therapy.

Cultures obtained from ultrasound- or computed tomography (CT)-guided aspiration or from intraoperative specimens usually provide an accurate microbiological diagnosis. These results of cultures guide the choice of a specific antimicrobial agent or combination of antimicrobial agents and, when necessary, long-term suppressive therapy. The results of wound swab cultures from a draining sinus, such as from the groin, could represent skin flora or colonization and might not accurately reflect the causative microorganism. The microbiological cause can influence the surgical options. For example, VGIs caused by MRSA, P. aeruginosa, or other multidrug-resistant microorganisms are managed surgically differently from VGIs caused by more susceptible microorganisms as discussed below.

Role of Imaging and Interventional Techniques for the Diagnosis of VGI

General Principles
The choice of an imaging modality depends in part on the site of infection. For intracavitary VGI, a combination of imaging modalities might be necessary. Computed tomographic angiography (CTA) is most often used for diagnosis and to define anatomy for subsequent revascularization. Sinograms can be useful in highly selected patients, but other imaging modalities have diminished their utility. In addition, there is a risk of introducing pathogens into a perigraft area with high-pressure instillation of contrast material. Invasive angiography is rarely useful for the diagnosis of VGI. The choice of an imaging modality is best determined by consultation among experts in vascular surgery, infectious diseases, vascular medicine, and radiology.

Extracavitary VGI
Even when clinical or microbiological findings strongly suggest a VGI, imaging, most often ultrasonography or CTA, is used to support the diagnosis, determine the extent of the infection, identify a fluid collection for aspiration for culture, or detect a pseudoaneurysm or bleeding at the site of the anastomosis. A CTA is useful to define vascular anatomy to help guide medical and surgical treatment. Figure 2 shows an algorithm for the diagnosis of Samson I to V VGIs using a combination of clinical findings, ultrasonography, or other imaging modalities, and surgery.

It is reasonable to consider ultrasonography as the initial imaging procedure. Ultrasonography is used primarily, but not exclusively, in patients with extracavitary VGI. Compared with other imaging modalities, ultrasonography is less expensive, can be done quickly, including at the bedside, and does not expose patients to the potential risk of contrast-associated kidney injury. Pseudoaneurysm formation can be detected by ultrasonography. Ultrasonography can also identify a subcutaneous or perigraft fluid collection that could be aspirated for analysis, culture, cell count, and other studies used to differentiate a noninfected seroma from bleeding. A sinogram can demonstrate extension of a sinus tract to the graft, which might involve an anastomotic site. A potential risk of sinograms is that an infection can be introduced during the procedure by the high-pressure instillation of contrast material into the perigraft area.

In selected patients with suspected or established extracavitary VGI and indeterminate findings on ultrasound,
it is reasonable to perform CTA or magnetic resonance imaging (MRI) to identify perigraft fluid collection not attributable to recent (≤ 3 months) graft implantation; an increase in the size, location, and the consistency of the fluid; or an anastomotic pseudoaneurysm.\textsuperscript{27} CT-guided aspiration of fluid can be useful diagnostically instead of or in combination with ultrasound-guided aspiration. CT or MRI is useful to define the extent of infection preoperatively in patients with established extracavitary VGI.\textsuperscript{1} Positron emission tomography (PET)/CT imaging has been reported in patients with intracavitary VGI, but there are few reports regarding its utility. Some studies reported that PET/CT was useful in the diagnosis of extracavitary VGI.\textsuperscript{28–32} Until more data are available with PET/CT for extracavitary VGI diagnosis, other imaging modalities may be considered before a PET/CT is obtained. An indium-labeled white blood cell study can be considered, most often in combination with other imaging techniques in patients with indeterminate findings on ultrasonography, CTA, or MRI. Indium scans used alone were not useful to identify VGI in patients with no findings to suggest VGI.\textsuperscript{28–32} Indium scans can be falsely positive in the early postoperative period and have decreased sensitivity in patients who are receiving current or recent antimicrobial therapy.\textsuperscript{1,33–36}

**Recommendations for Imaging in Diagnosis of Extracavitary VGI**

1. It is reasonable to consider ultrasonography as the initial imaging procedure of choice (Class IIa; Level of Evidence B).
2. It is reasonable to consider CTA or MRI when extracavitary graft infection is suspected and there are indeterminate findings on ultrasonography (Class IIa; Level of Evidence B).
3. A PET/CT or indium-labeled white blood cell study scan may be considered when extracavitary graft infection is suspected and ultrasonography, CTA, or MRI findings are indeterminate (Class IIb; Level of Evidence B).

**Figure 3. Intra-abdominal vascular graft infection: algorithm for diagnosis.**

CTA indicates computed tomographic angiography; EGD, esophagogastroduodenoscopy; GI, gastrointestinal; IN, indium; MRA, magnetic resonance imaging; MRI, magnetic resonance angiography; and PET, positron emission tomography. *Combination of imaging tests is often necessary; see Table 2 for advantages and disadvantages of the different imaging modalities.

<table>
<thead>
<tr>
<th>Gastrointestinal Bleeding</th>
<th>No GI bleeding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymicrobial bacteremia</td>
<td>Monomicrobial bacteremia or negative blood culture</td>
</tr>
<tr>
<td>Enteric fistulae likely</td>
<td>Enteric fistulae less likely</td>
</tr>
<tr>
<td>EGD together with CTA</td>
<td>CTA</td>
</tr>
<tr>
<td>Nondiagnostic or risk of contrast kidney injury</td>
<td>Nondiagnostic or risk of contrast kidney injury</td>
</tr>
<tr>
<td>MRI/MRA; IN scan; PET/CT*</td>
<td>MRI, IN scan; PET/CT*</td>
</tr>
</tbody>
</table>

**Intra-Abdominal VGI**

Figure 3 shows an algorithm for the diagnosis of intra-abdominal VGI in patients with or without associated gastrointestinal bleeding. Patients with suspected VGI and aortoenteric fistula should undergo CTA, an esophagogastroduodenoscopy, followed by vascular imaging as soon as the patient is stable enough to tolerate the procedure.\textsuperscript{1,4,8,11,27} An esophagogastroduodenoscopy can demonstrate subtle or obvious erosion or a thrombus, which usually is located in the third or fourth portion of the duodenum overlaying the abdominal aortic aneurysm graft. The ulcer or thrombus should not be manipulated, because this can cause sudden massive bleeding.

The imaging modalities most widely used for the diagnosis of intra-abdominal VGI are CT, MRI, indium scanning, and PET/CT.\textsuperscript{1,28–32} Invasive angiography is rarely helpful for the diagnosis and has been replaced by CTA to determine anatomy for revascularization. Table 1 shows the utility, advantages, and disadvantages of specific imaging modalities for the diagnosis of intra-abdominal VGI.\textsuperscript{1} It is reasonable to consider CT imaging as the initial imaging procedure in patients with suspected intra-abdominal VGI. In the absence of recent manipulations,
Table 1. **VGIs: Imaging Advantages and Disadvantages**

<table>
<thead>
<tr>
<th>Modality</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasound</td>
<td>Most useful for extracavitary study</td>
<td>Limited use for intracavitary VGI</td>
</tr>
<tr>
<td></td>
<td>Can be performed at bedside</td>
<td>Cannot discriminate seroma, hematoma, abscess</td>
</tr>
<tr>
<td></td>
<td>Inexpensive</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No contrast kidney injury</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aspiration for analysis, study</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Detect pseudoneuromus</td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td>Sensitivity 85%–100%; specificity 85%–94%; Rapid result</td>
<td>Contrast kidney injury</td>
</tr>
<tr>
<td></td>
<td>Less expensive than MRI, PET/CT</td>
<td>Noncontrast with renal disease less diagnostic</td>
</tr>
<tr>
<td></td>
<td>Aspiration for analysis, study</td>
<td>Might not differentiate hematoma from inflammation, especially low-grade inflammation</td>
</tr>
<tr>
<td></td>
<td>CTA useful for surgical planning</td>
<td>Images degraded by metallic clips, spinal hardware</td>
</tr>
<tr>
<td>Magnetic resonance</td>
<td>Sensitivity 68%–85%; specificity 97%–100%; Use when CT nondiagnostic</td>
<td>More expensive than CT</td>
</tr>
<tr>
<td></td>
<td>No contrast kidney injury</td>
<td>No guided aspiration</td>
</tr>
<tr>
<td></td>
<td>Differentiate hematoma, inflammation, infection</td>
<td>Limited use in patients with intracardiac devices</td>
</tr>
<tr>
<td></td>
<td>Good soft tissue resolution</td>
<td>MRI/MRA can detect mycotic aneurysm, bleeding, enteral fistula</td>
</tr>
<tr>
<td>Indium-labeled WBC</td>
<td>Sensitivity 67%–73%; specificity 87%; No contrast kidney injury</td>
<td>Results take ≥24 h</td>
</tr>
<tr>
<td>scan (in-scan)</td>
<td>Use when CT nondiagnostic</td>
<td>Decreased sensitivity with recent antimicrobial therapy</td>
</tr>
<tr>
<td></td>
<td>False-positive result in early postoperative period</td>
<td>False-negative result</td>
</tr>
<tr>
<td></td>
<td>Use in combination with other imaging</td>
<td></td>
</tr>
<tr>
<td>PET</td>
<td>Sensitivity 78%–96%; specificity 70%–93%;</td>
<td>Less experience than with other imaging</td>
</tr>
<tr>
<td></td>
<td>No contrast kidney injury</td>
<td>Does not identify specific anatomic location</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Expensive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use in combination with other imaging</td>
</tr>
</tbody>
</table>

CT indicates computed tomography; CTA, computed tomography angiography; MRA, magnetic resonance angiography; MRI, magnetic resonance imaging; PET, positron emission tomography; VGI, vascular graft infection; and WBC, white blood cell study.

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the presence of perigraft air is highly suggestive of VGI. CT findings often suggestive of infection include perigraft fluid with fat stranding, lack of fat plane between graft and bowel, and anastomotic leakage or aneurysm. Perigraft fluid is usually reabsorbed within 3 months postoperatively, and perigraft air is usually absorbed within the first week or so, although it can persist for as long as 2 months postoperatively.1,28,37–39 Intra-abdominal VGI can occur many months to years after surgery and might not have the CT findings typically seen in early infection.28,39,40 In these patients, MRI can be considered if the CT findings are inconclusive.1,40–42 MRI can be superior to CT to identify subtle perigraft inflammatory changes when CT images are degraded by metallic clips in the abdomen, and it can differentiate hematoma from inflammatory changes in the perigraft area.40 However, the role of MRI used alone for the diagnosis of VGI is not defined. In one study, the sensitivity was relatively low at 68%, but the specificity was high (97%).40 MRI combined with an indium scan can be considered in patients with inconclusive MRI or CT findings.40 Used alone, indium scans have lower sensitivity and specificity than other imaging techniques.1,33–35

Several studies have reported that PET/CT is useful for the diagnosis of intra-abdominal VGI.1,28–32,42–46 Three recent studies summarized the role of PET/CT for the diagnosis of VGI.30–32 Although there were variables in imaging techniques and patient selection among these studies and other studies, the sensitivity and specificity of PET/CT were similar to those reported with standard CT for the diagnosis of VGI.28–32,39,43–46 (Table 1). PET/CT may be less precise than conventional CT to identify the anatomic location of VGI. A linear, diffuse, homogeneous uptake over a blood vessel is not indicative of VGI, whereas a focal uptake over a blood vessel on PET/CT is highly suggestive of VGI.32

Sah et al31 reported that the use of a 5-point visual grading score increased the accuracy of PET/CT for the diagnosis of VGI. The administration of antimicrobial therapy before PET/CT decreased the sensitivity and specificity of the diagnosis of VGI.31 There are currently no published studies that demonstrate a clear benefit of serial PET/CT to follow the response to antimicrobial therapy for VGI.32 The use of PET/MRI for the diagnosis of VGI is being evaluated.32 PET/CT alone or in combination with other imaging modalities can be considered if the results of standard CT studies are inconclusive for the diagnosis of VGI.28–32,43–46 On the basis of the published studies, it is reasonable to use standard CT as the initial imaging modality for the diagnosis of VGI.30–32

**Intrathoracic VGI**

Imaging studies are necessary to confirm the diagnosis and define the extent of infection and vascular anatomy. Diagnostic tests including CTA or MRI with or without an
indium scan should be used in combination with blood culture results and echocardiography findings.\textsuperscript{1} Echocardiography alone cannot diagnose infection but can define anatomy, valvular dehiscence, graft anastomotic disruption, fistulae, or aneurysm formation. There are few published data for the use of PET/CT for the diagnosis of intrathoracic VGI. Angiography is not helpful for the diagnosis of VGI. It is used rarely to define complex anatomy before resection or revascularization.

**Recommendations for Diagnosis of Intracavitary VGI**

1. In patients with gastrointestinal tract bleeding and suspected intra-abdominal VGI, an esophagogastroduodenoscopy and CTA are recommended (Class I; Level of Evidence B).
2. In patients with suspected intra-abdominal VGI, it is reasonable to obtain a CTA as the initial imaging procedure (Class IIa; Level of Evidence B).
3. In patients with suspected intra-abdominal VGI and indeterminate CTA findings, an MRI, PET/CT, or indium white blood cell study scan may be considered (Class IIb; Level of Evidence C).
4. In patients with suspected intrathoracic VGI, echocardiography, CTA, and MRI used in combination with clinical findings and blood culture results are recommended for diagnosis (Class I; Level of Evidence B).

**Management of VGI**

**General Principles**

A multidisciplinary approach that includes specialists in cardiology, vascular medicine, vascular and cardiovascular surgery, radiology, infectious diseases, and in selected cases, plastic surgery is recommended for the successful management of VGI. The care team should also include specialists who assist in management of diabetes mellitus, smoking cessation, obesity, lower extremity ulcerations, lymphedema, vascular stasis, and other conditions that impair wound healing and increase the risk of infection.

The selection and duration of antimicrobial therapy depend on the causative microorganisms, the location and type of graft infection, and other factors that are discussed below in the sections on management of specific VGI.

**Recommendation for Management of VGI:**

**General Principles**

1. A multidisciplinary team approach including specialists in vascular and cardiovascular surgery, vascular medicine, cardiology, infectious diseases, and radiology is recommended (Class I; Level of Evidence B).

**Management**

**Extracavitary VGI**

There is no widely accepted procedure of choice nor standardized surgical therapy for management of extra-
cavitary VGI. The choice of a specific surgical procedure should be individualized for each patient.

The Samson classification (Figure 4) helps define the extent and type of VGI, guides the selection of medical and surgical options, and determines prognosis.

**Samson I and II VGIs.** Antimicrobial therapy alone, with or without débridement, is reasonable for patients with Samson class I or II VGI (Figure 5). These infections should be treated as soft tissue infection that does not involve the graft. Unless there is recovery of a causative microorganism from cultures of wound drainage from purulent material or fluid from ultrasound-guided aspiration, antimicrobial therapy usually is empiric and should be directed against *Staphylococcus* and *gram-negative bacilli*.

If a specific microorganism is identified, therapy should be adjusted accordingly. Antimicrobial therapy can be administered either intravenously or orally, depending on the susceptibility of the causative microorganism, bioavailability of the antimicrobial agent, absorption from the gastrointestinal tract, severity of infection, and response to treatment. A 2- to 4-week duration of antimicrobial therapy is reasonable (Figure 5). Samson class I infections usually do not require incision, drainage, and débridement. Samson class II infections are often associated with an open, draining wound. Careful and thorough débridement of infected tissue is necessary to prevent extension of infection to the vascular graft. Samson class II infections may benefit from use of a vacuum-assisted closure device and occasionally from a muscle flap to achieve wound coverage, eliminate dead space, and promote healing. In these patients, it is important to achieve satisfactory wound coverage to prevent deep extension of infection to involve the graft. Samson II infections have a higher risk of subsequent involvement of the vascular graft than do Samson I infections.

**Samson III and IV VGIs.** Zetenne and colleagues proposed a useful and practical guide for management of patients with Samson III and IV VGIs. O’Connor et al published a comprehensive meta-analysis of treatment options. Others reported observations pertinent to patient selection for specific surgical procedures, advantages and disadvantages of each procedure, results of treatment, and recommendation for management of complications. Figure 4 illustrates an algorithm of medical and surgical options for Samson groups III and IV.

All patients should have meticulous débridement of all infected material and tissue. Usually, multiple surgical débridements are necessary to enable wound coverage with a muscle flap and, in some cases, a vacuum-assisted closure device. Deep surgical specimens should be sent for culture and susceptibility for general bacteria, anaerobic microorganisms, and fungi, as well as for mycobacteria in selected patients. Broad-spectrum antimicrobial therapy should be administered until the results of culture and sensitivity are reported, at which time therapy should be adjusted appropriately. It is reasonable to administer antimicrobial therapy for a duration of 4 to 6 weeks (Figure 5).

There are insufficient data regarding the use of antibiotic beads or powders to supplement aggressive surgical débridement and local wound care. Some surgeons use these when there is gross purulence present in the wound and graft salvage is attempted; however, there are no published data that demonstrate efficacy of the use of antibiotic beads for such purpose. The more important precepts for management of these VGIs are discussed in this section and on techniques for graft preservation. Close follow-up and aftercare is imperative to optimize the chance of successful outcome. The selection of a specific surgical option must be individualized for each patient and may be dependent in part on the experience of individual vascular surgeons. There is no widely accepted consensus as to the procedure of choice for management of Samson class III or IV VGI. A discussion of the selection of a specific surgical option

### Figure 5. Antimicrobial therapy for extracavitary VGI.

<table>
<thead>
<tr>
<th>Samson I, II</th>
<th>Samson III-IV</th>
<th>Samson V</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-4 weeks IV/PO</td>
<td>4-6 weeks IV</td>
<td>4-6 weeks IV</td>
</tr>
<tr>
<td>3-6 months PO</td>
<td></td>
<td>6 month PO</td>
</tr>
</tbody>
</table>

**Possible lifelong suppressive therapy**
- MRSA
- *P. aeroginosa*, multidrug-resistant *Candida* or other fungi
- Multiple surgical procedures for VGI
- Emergency surgery for VGI, reconstruction with nitinol-bonded graft
- Extensive perigraft infection
- Poor candidate for reoperation

*References 1–4, 6, 8–10, 14, 16, 22, 24, 27.*
(Figure 4), the advantages and disadvantages for each procedure, and the outcome and management of complications follows.

**Graft Preservation.** For Samson group III, reports indicated better outcomes in selected patients treated with graft preservation rather than with graft resection in situ reconstruction.25,26,47–50 Calligaro and colleagues16 reported that patients with early-onset Samson group III infection (<2 months postoperatively) were more likely to have successful graft preservation than were patients with later onset of infection. Late-onset Samson group III VGI was more likely to have nonpatent grafts or disrupted anastomosis and could be considered for graft resection and in situ reconstruction rather than preservation.16

Successful graft preservation with Samson group IV depends somewhat on the microorganism causing the infection and whether there is anastomotic disruption. Numerous studies suggest that graft preservation or in situ reconstruction should not be attempted in patients with infection caused by MRSA, *P aeruginosa*, or multidrug-resistant microorganisms.25,26,50–53 In these cases, extra-anatomic revascularization followed by graft excision is reasonable. With infection caused by other microorganisms, if the anastomosis is intact, graft preservation or in situ reconstruction might be possible.14,25,26,41,47,51,54–56 For common femoral artery reconstruction, autogenous venous in situ reconstruction may be necessary to preserve the deep femoral artery. Meticulous, often multiple débridements are necessary.25,26,57–60 Many authorities suggest adjunctive wound irrigation therapy with povidone iodine solution, which may also contain antibiotic drugs.25,26 Suction-irrigation catheters to bathe the exposed prosthetic material with antibiotic-containing solutions have been used in patients with large abscesses or gross purulence next to the graft or in patients with infections caused by a multidrug-resistant microorganism. Zetenne et al25,26 suggested serial quantitative bacterial cultures should be performed and that graft preservation should not be attempted until the colony count of the causative microorganism was <10³ colony-forming units per gram of tissue. If repeated wound débridements, wound irrigation, and systemic antibiotic therapy do not result in quantitative cultures <10³ colony-forming units per gram of tissue, in situ reconstruction rather than graft preservation is suggested by these authors.

The wound is then covered by a muscle flap.25,26,55,56,60–63 Meticulous débridement and antimicrobial therapy are vital to the success of muscle flap coverage.26,59,64,65 Muscle flaps obliterate the dead space, promote healing, increase vascular supply and oxygen tension, augment the effects of antimicrobial therapy, protect the wound from contamination with other microorganisms, and protect the graft from desiccation and thrombosis.25,52,55,56,60,66,67 The choice of a rotational or transpositional muscle flap should be made in consultation with vascular and plastic surgeons. Some surgeons have recommended wound coverage with a vacuum-assisted closure device, either alone or as a possible bridge to muscle flap.65,66,68 The use of a wound vacuum-assisted closure device enhances healing by negative pressure and simplifies wound care by nursing staff but should not be applied if purulence is present in the wound. The use of a vacuum-assisted closure device without subsequent muscle flap should be restricted to selected patients in whom muscle flap may not be an option.

**In Situ Reconstruction.** In situ reconstruction methods include rifampin-bonded or silver-coated synthetic vascular grafts, cryopreserved or fresh arterial allografts, and autogenous venous grafts.1,4,14,69–83 (Figure 4). The selection of a specific conduit must be individualized and is somewhat dependent on the personal experience of the vascular surgeon. There is no consensus about which specific material should be chosen for reconstruction.69 There are certain circumstances that favor one material over the other, and there are advantages and disadvantages of each, as discussed below.

**RIFAMPIN-BONDED OR SILVER-COATED SYNTHETIC GRAFTS.** These grafts are preferable for patients who might not tolerate the prolonged surgery that is often required for arterial allografts or autogenous venous graft in situ reconstruction. Although the reinfection rates with rifampin-bonded or silver-coated synthetic grafts are reportedly low,69 arterial allografts or venous autografts are more resistant to infection than are rifampin-bonded synthetic grafts.4 There are insufficient published data to compare infectious rates with silver-coated grafts.

**Cryopreserved or Fresh Arterial Allografts or Autogenous Superficial Femoral Venous Grafts.** These grafts have been used extensively for in situ reconstruction.1,4,25,26,69,83 Arterial allografts and autogenous venous grafts are associated with a lower infection rate than that which occurs with synthetic material, such as rifampin-bonded grafts.1,4,14,69 Autogenous venous grafts might have longer patency than arterial allografts because of graft degeneration that occurs over time with arterial allografts.84 Although autogenous superficial femoral venous autografts might have a higher long-term patency rate than arterial allografts,69 the disadvantage of their use is the prolonged operative time required for vein harvesting, which might not be tolerated in some patients, and the potential for long-term venous stasis morbidity.

**Extra-Anatomic Revascularization Followed by Graft Excision.** This procedure was long considered the preferred surgical approach for Samson group III or IV VGI because of a theoretical decreased risk of infection attributable to avoiding graft preservation or in situ.
reconstruction of a new graft in an infected area.54,59,85–87 However, this procedure is associated with significant morbidity, including persistent infection at the site of vascular stump ligation blowout of the aortic stump, with potentially life-threatening hemorrhage, as well as the risk of infection in the new graft. In addition, thrombosis can occur within the extra-anatomic graft, resulting in lower extremity amputation.1,4 For Samson group III or IV VGI, extra-anatomic revascularization followed by graft resection is reasonable only for patients with infection caused by MRSA, P aeruginosa, or multidrug-resistant microorganisms or for patients for whom graft preservation or in situ reconstruction has failed.5,25,26,69,83

For Samson group V VGI, extra-anatomic revascularization followed by graft excision is reasonable5,25,26,69,83 (Figure 4). Graft preservation or in situ reconstruction should be attempted only in patients who are considered to be unacceptable surgical candidates for extra-anatomic revascularization. This includes patients with a high risk of operative mortality, patients in whom previous surgical procedures have failed, patients who have no viable anatomic options for revascularization, and patients in whom underlying comorbidities suggest a short life expectancy.

Postoperative Antimicrobial Therapy and Follow-up

For patients with Samson I and II VGIs, a duration of postoperative antimicrobial therapy of 2 to 4 weeks with a combination of intravenous or orally administered antibiotic drugs is reasonable (Figure 5). Most do not recommend a longer period of oral therapy afterward.1,4,13,25–27,49,50,69

For patients with Samson group III and IV VGIs, 4 to 6 weeks of intravenous or oral therapy is reasonable. A follow-up period of oral antibiotic drugs for 6 weeks to 6 months after completion of the initial course of therapy can be considered.† The decision to administer an additional course of oral therapy must be individualized for each patient and should be made in consultation with vascular surgeons and infectious disease specialists.

For patients with Samson group V VGI, 4 to 6 weeks of initial intravenous or oral therapy is reasonable. Subsequently, at least 6 months of oral therapy may be considered.

For patients with Samson group III, IV, or V VGI, lifelong suppressive therapy may be considered for the following: (1) those with MRSA or P aeruginosa infection, multidrug-resistant strains, or Candida species; (2) those who have undergone multiple surgical procedures; (3) those who have had emergency surgery for VGI; (4) after graft preservation or in situ reconstruction in patients who have extensive perigraft infections, especially those patients who had rifampin-bonded synthetic graft reconstruction; and (5) group III, IV, or V patients who are poor candidates for reoperation. In these patients, the benefits of lifelong suppressive antimicrobial therapy could exceed the risk of adverse reaction to antibiotic drugs or development of antibiotic resistance. In fact, this might be the best, if not only, option in these patients and might not only extend life but also improve the quality of remaining life, increase mobility, and reduce frequency of readmission to hospital. Patients who receive lifelong suppressive therapy should be evaluated initially at 2- to 3-month intervals and thereafter at 6-month intervals to ensure that they are tolerating antimicrobial therapy satisfactorily and to monitor control of infection.1,4,15,16,25–27,49,50,69

Postoperative follow-up is important for patients with extracavitary VGI regardless of the Samson grade of infection or the surgical procedure used. Close surveillance of the graft is reasonable during the first 2 years when the risk of recurrence of infection is highest.1,4,25,26,55,86,88 Patients should have a physical examination, laboratory tests including complete blood count and differential, biomarkers of inflammation such as erythrocyte sedimentation rate and C-reactive protein, and an ultrasound examination every 3 to 6 months for 2 years. For patients with Samson group III, IV, or V VGI, lifelong follow-up with ultrasound every 6 to 12 months is reasonable.1,4,25,26,55,86,88

Extracavitary VGIs: Recommendations for Management: Antimicrobial Therapy

1. For patients with Samson class I or II VGI, a trial of antimicrobial therapy with or without surgical debridement for 2 or 4 weeks is reasonable (Class IIa; Level of Evidence B).

2. For Samson class III or IV VGI, postoperative antimicrobial therapy for 4 to 6 weeks is reasonable (Class IIa; Level of Evidence B). After the initial therapy, a course of oral antimicrobial therapy for 6 weeks to 6 months may be considered (Class IIb; Level of Evidence B).

3. For Samson class V VGI, postoperative antimicrobial therapy for 4 to 6 weeks administered parenterally followed by at least 6 months of therapy administered orally may be considered (Class IIb; Level of Evidence B).

4. For Samson class III, IV, or V VGI, long-term suppressive antimicrobial therapy may be considered for infection caused by MRSA, Pseudomonas, multidrug-resistant microorganisms, Candida, or other fungal species; for those patients who have undergone emergency or multiple surgeries; for patients with graft preservation or in situ reconstruction with extensive perigraft infection; or for

†References 1, 4, 15, 16, 25–27, 49, 50, 69.
patients who are poor candidates for reoperation (Class IIb; Level of Evidence B).

Extracavitary VGIs: Recommendations for Management: Surgical Therapy

1. For Samson class III infection, which occurs early (<2 months postoperatively), it is reasonable to consider graft preservation rather than graft excision and reconstruction (Class IIa; Level of Evidence B).

2. For Samson class III infection, which occurs after 2 months postoperatively, graft excision and reconstruction may be considered instead of graft preservation (Class IIb; Level of Evidence B).

3. For Samson class III or IV infection caused by MRSA, Pseudomonas, or multidrug-resistant microorganisms, or for patients for whom graft preservation or in situ reconstruction has failed, it is reasonable to perform extra-anatomic revascularization followed by graft excision instead of graft preservation or in situ reconstruction (Class IIa; Level of Evidence B).

4. For Samson class V VGI, extra-anatomic revascularization followed by graft excision is reasonable (Class IIa; Level of Evidence B).

5. For Samson class III, IV, or V VGI, ultrasound examination every 3 to 6 months for 2 years, followed by lifelong ultrasound examination every 6 to 12 months, is reasonable (Class IIa; Level of Evidence B).

Prognosis of Extracavitary VGI

The prognosis depends on many factors, including successful management of underlying comorbidities and risk factors, the microorganism that caused infection, the extent of infection according to Samson classification groups I through V, and recurrence of infection. Samson groups I and II have the best long-term prognosis. Recurrent VGI can develop in these patients, more often in those with Samson group II than Samson group I. The major complications for Samson groups III to V include operative mortality, recurrence of infection, and lower extremity amputation. Patients with infection caused by MRSA, P aeruginosa, or other multidrug-resistant microorganisms have a worse outcome than those with infections caused by more susceptible microorganisms.‡ Calligaro et al† reported that late-onset (>2 months postoperatively) infections were more likely to develop occluded grafts and require graft reconstruction. Operative mortality ranges from 0% to 18%, amputation from 0% to 16%, and recurrence of infection from 0% to 18%. The higher complication rates trend upward with increasingly higher Samson classification.§

Intra-Abdominal

Surgical Options. A number of general principles are important for the optimal surgical management of intra-abdominal VGI. These include (1) drainage of abscess before definitive surgical management of the VGI, provided that the patient is stable hemodynamically and there is no adjacent pseudoaneurysm that can rupture during drainage of the abscess; (2) bypass of renal or visceral arteries, which might be necessary to reduce physiological stress and lower the risk of systemic inflammatory response; (3) careful débridement of the devitalized periaortic tissue after explantation of the infected vascular graft before insertion of a new graft or extra-anatomic revascularization; (4) the elimination of dead space and circumferential coverage of the new graft or aortic stump by omentum, and in some cases, if technically feasible, a muscle flap for the use of peritoneum or retroperitoneal fat if omental use is not possible; and (5) placement of antibiotic drug–loaded beads in the operative area, although there are insufficient data that demonstrate their efficacy.

The surgical options for intra-abdominal VGI are shown in Figure 6. There is no standardized surgical option, and certain circumstances favor one option over another. Each of these surgical options has advantages and disadvantages, and the selection of a specific surgical option must be individualized (Table 2). In addition, the personal experience of the surgical team with a specific option influences the decision to select one procedure over another. The roles for each procedure, advantages, disadvantages, complications, and outcomes are discussed in the next sections and shown in Figure 6 and Table 2.

Extra-Anatomic Revascularization and Graft Excision. This procedure, first performed in the 1960s, was accepted as the standard of care against which other procedures were measured.¶ In selected patients, it is still considered to be the treatment of choice. However, the major disadvantages of extra-anatomic bypass followed by graft excision are lower short- and long-term patency rates of the bypass graft; a 2-stage, lengthy surgical procedure; relatively high rate of amputation of the lower extremity; risk of rupture of the stump at the aortic suture line, with potentially life-threatening hemorrhage; and difficulty establishing an extra-anatomic revascularization route in the inguinal region.‡,4,6,74,100

A 2-stage rather than a single-stage procedure is preferred. First, an extra-anatomic bypass is performed and next, an excision of the infected graft with débridement is done.¶ Revascularization by axillofemoral bypass of the lower extremities is ideally performed before


§References 3, 25, 26, 48–50, 69–77, 81, 82, 92.
Excision of the infected aortic graft to minimize ischemia. Either during the same procedure or preferably at least 24 to 48 hours after revascularization, a complete excision of the infected graft is performed. The 24- to 48-hour waiting period before graft excision can reduce lower extremity ischemia and associated limb loss.4,6,8,92,93,101 Reilly et al97 reported 26% mortality when graft excision was performed during the same procedure.

A 2-stage procedure should be considered only in patients who are stable hemodynamically. In patients who present with hemorrhage from a ruptured graft, emergency intervention is necessary to control bleeding, and extra-anatomic revascularization of the lower extremities is performed after bleeding from the aortic stump is controlled. Most patients who present with sepsis, such as from an aortoenteric fistula, can be stabilized by aggressive medical therapy and antibiotic drugs to allow time for extra-anatomic revascularization before graft excision. O’Connor et al4 published a meta-analysis comparing different surgical procedures for intra-abdominal VGI. This study compared results of extra-anatomic bypass, rifampin-bonded synthetic prostheses, cryopreserved arterial allograft, and autogenous venous grafts. Extra-anatomic bypass procedures had higher amputation rates and early mortality (P<0.05) than rifampin-bonded prostheses; higher conduit failure (P<0.05) than cryopreserved arterial allografts; higher reinfec tion rate (P<0.05) than autogenous venous grafts; and overall higher (P<0.05) complication rates, reinfec tion, and mortality than any in situ reconstructive surgical procedure. These and other studies have called into question whether extra-anatomic bypass and graft excision is still the surgical treatment of choice for intra-abdominal VGI.||

However, the results of a meta-analysis showing inferiority of extra-anatomic bypass and graft resection must be interpreted with caution. Inclusion or exclusion criteria in individual studies, referral bias, and the higher number of patients with aortoenteric fistulae reportedly treated with extra-anatomic bypass and graft excision could have adversely impacted results. Selection of a greater number of higher-risk patients who would be expected to have a higher complication rate and mortality, independent of the type of surgical procedure used, could also have affected results.

**Graft Excision and In Situ Reconstruction.**

**CRYOPRESERVED OR FRESH ARTERIAL ALLOGRAFT.** Chiesa et al2 reported 68 patients, 57 with cryopreserved and 11 with fresh arterial allografts. In this study, there were no differences observed in outcome with fresh compared with cryopreserved allografts, although the number of patients who received fresh arterial allografts was small. A number of other studies have reported extensive use of cryopreserved arterial allografts, including in patients with aortoenteric fistulae.5,76,107

Compared with in situ rifampin-bonded prosthetic reconstruction, the major advantage of arterial allografts is higher resistance to infection.2,75–77,107,108 The major disadvantages are as follows: (1) They can be less durable than prosthetic grafts because they degenerate over time, probably because of prolonged storage before use and immune rejection of aortic allograft tissue.2,4,76 (2)
Their use is associated with complication rates of 16% to 23%, including intraoperative rupture of the allograft because of friability and anastomotic bleeding.4,76 (3) They might not be suitable for emergency procedures because they have to be preordered, and the necessary length, diameter, shape, and sizing might not be available. In the study by Chiesa et al,2 the presence of an aortoenteric fistula was a negative predictive factor for early perioperative mortality. The mortality at 3 years in patients with aortoenteric fistula was 58% compared with 37% of patients without aortoenteric fistula. In the meta-analysis published by O’Connor et al,4 cryopreserved arterial allografts compared with extra-anatomic revascularization and graft excision had fewer conduit failures, reinfection rates, and better outcomes (P<0.05).

Most authorities do not recommend the use of low-dose immunosuppressive therapy to prevent rejection in patients with cryopreserved or fresh arterial allografts.2,4,76 This recommendation is based on the concern that graft infection could be increased by the use of immunosuppressive therapy.

**Autogenous Venous Grafts.** In the meta-analysis by O’Connor et al,4 reinfection rates were lowest (P<0.05) with the use of autogenous venous graft, followed closely by cryopreserved arterial allografts. Late mortality was also lowest with autogenous venous and cryopreserved arterial allografts. Disadvantages of autogenous venous allografts include the following: (1) A longer operative time is needed for vein harvest; (2) older patients or those with multiple comorbidities and higher surgical risks might not be able to tolerate longer, more extensive surgery; (3) a history of deep vein thrombosis is a relative contraindication for use of venous autografts; (4) longer patency rate than arterial allograft29; and (5) a risk of venous morbidity in the lower extremity on the side of the harvest.

In situ autogenous venous graft replacement might be most appropriate in younger patients who have a longer life expectancy. Although venous autografts appear to be associated with the lowest infection rate, the experience with their use in patients with MRSA and Pseudomonas infections is limited.14,83

### Table 2. Surgical Management of Intra-Abdominal Vascular Graft Infections: Options and Advantages and Disadvantages

<table>
<thead>
<tr>
<th>Advantages/Disadvantages</th>
<th>Extra-anatomic bypass, revascularization, graft excision</th>
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<tbody>
<tr>
<td>Theoretical lower risk of infection because excision of infected graft and no reconstruction in infected area</td>
<td>Two-stage procedure, longer operating time</td>
</tr>
<tr>
<td>Can be used for MRSA, <em>Pseudomonas</em>, multiple antibiotic resistance</td>
<td>Difficulty in establishing revascularization route</td>
</tr>
<tr>
<td>In situ reconstruction: cryopreserved or fresh arterial allograft</td>
<td>Conduit failure, lower patency rate</td>
</tr>
<tr>
<td>Can be used in some emergency situations, including aortoenteric fistula</td>
<td>Amputation of lower extremities (20%–30%)</td>
</tr>
<tr>
<td>Lower infection rate than rifampin-bonded grafts and extra-anatomic bypass</td>
<td>Decreased blood supply to inferior mesenteric and internal iliac arteries</td>
</tr>
<tr>
<td>Shorter surgical time than venous autografts</td>
<td>Aortic stump infection, possible blowout (10%–20%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Advantages/Disadvantages</th>
<th>Venous autograft</th>
</tr>
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<tbody>
<tr>
<td>Lowest infection rate</td>
<td>Longer operating time than arterial allograft</td>
</tr>
<tr>
<td>Lower patency rate than arterial allograft</td>
<td>Patients with history of DVT not candidates</td>
</tr>
<tr>
<td>Can be used in some aortoenteric fistulae</td>
<td>Not suitable for MRSA, <em>Pseudomonas</em>, or multiple antibiotic drug resistance</td>
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<table>
<thead>
<tr>
<th>Advantages/Disadvantages</th>
<th>Rifampin-bonded synthetic graft</th>
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<tbody>
<tr>
<td>Can be used in emergency surgery</td>
<td>Higher infection rate than arterial allografts or venous autografts</td>
</tr>
<tr>
<td>Shorter operating time than for extra-anatomic, arterial allograft, venous autograft</td>
<td>Not suitable for MRSA, <em>Pseudomonas</em>, multiple drug resistance</td>
</tr>
<tr>
<td>Lowest amputation and early mortality rates</td>
<td>Potential long-term development of rifampin resistance</td>
</tr>
</tbody>
</table>

**DVT** indicates deep vein thrombosis; and MRSA, methicillin-resistant *Staphylococcus aureus.*
compared outcomes in 52 patients who underwent resection of the infected portion of the vascular graft and in situ reconstruction with rifampin-bonded synthetic grafts with those of patients who underwent axillofemoral reconstruction and excision of the infected vascular graft. Graft reinfection was 11.5% with in situ reconstruction compared with 17% in axillofemoral reconstruction (P=NS). Infection rates were unrelated to the specific microorganism. The 5-year primary patency rates with in situ or axillofemoral reconstruction were 89% and 48%, respectively (P=0.01), and limb salvage rates were 100% and 89%, respectively (P=0.06). The rates of major complications or procedure-related deaths with in situ or axillofemoral reconstruction were 30% and 60%, respectively (P=0.04). For patients with large perigraft abscess, the authors suggested axillofemoral rather than in situ reconstruction. For other patients, resection of the infected portion of the grafts and in situ reconstruction with rifampin-bonded synthetic graft was a safe, effective alternative to axillofemoral reconstruction.

Studies compared in situ reconstruction with synthetic silver-coated grafts with cryopreserved arterial homografts and concluded that the use of a silver-coated graft is a safe, effective, and less expensive alternative to cryopreserved arterial homografts. As with rifampin-bonded grafts, reinfection rates were higher with silver-coated grafts than with the use of cryopreserved arterial homografts. The major advantages of rifampin-bonded or silver-coated synthetic grafts were lower amputation rates, fewer conduit failures, lower earlier mortality rates, and the fact that they can be used in emergency surgery.

Theoretically, because these synthetic grafts contain antibacterial substances, the risk of reinfection should be lower; however, in a meta-analysis by O’Connor et al, reinfection rates with rifampin-bonded prostheses were higher than for arterial allografts or venous autografts. This is most likely the result of in situ interposition of synthetic material in an infected tissue bed. A potential disadvantage of rifampin-bonded prosthesis is the development of rifampin resistance, which is not a concern with silver-coated synthetic grafts.

Bandyk et al and O’Connor et al suggested that rifampin-bonded or silver-coated grafts should be considered for patients with infection caused by less virulent microorganisms, such as coagulase-negative staphylococci or streptococci. These authors suggested that rifampin-bonded synthetic grafts should not be used in patients with aortoenteric fistulae or in infections caused by MRSA or Pseudomonas or with extensive perigraft abscess because of the risk of reinfection.

**Aortoenteric Fistula.** The treatment of an aortic VGI with enteric erosion or fistula is dependent on hemodynamic stability, comorbidities, and anatomy. It is important to control the risk of bleeding of the supraceliac or suprarenal aorta above the enteric communication either by direct surgical exposure or by balloon occlusions. These steps are critical for patients who are unstable hemodynamically. After the aorta and iliac arteries are cross-clamped, a circumferential piece of the prosthetic graft connected with the bowel is resected so that the bowel can be packed out of the operative field to minimize local contamination and to improve exposure for aortic reconstruction. Large bowel defects can be quickly and temporarily oversewn. Definitive repair of the bowel is performed after the aortic reconstruction has been completed and covered by the omentum. Aortic reconstruction should be limited to the infected segment. A limited reconstruction in elective cases has been associated with lower mortality and fewer major adverse events and bowel complications than if the entire aortic graft is removed.

In the past, the "gold standard" management of these patients was extra-anatomic bypass surgery followed by graft excision. In selected patients, that might still be the procedure of choice; however, because of the high rates of mortality and potential complications, including limb loss, numerous studies have suggested that alternative surgical options might be preferable to extra-anatomic bypass and graft excision. For patients with aortoenteric fistula caused by methicillin-sensitive *S. aureus* or less virulent microorganisms, such as coagulase-negative staphylococci, streptococci, susceptible enterococci, or susceptible enteric gram-negative bacilli, graft excision and in situ reconstruction with either cryopreserved or fresh arterial allograft, venous autograft, or rifampin-bonded synthetic graft are reasonable. In emergency cases or in patients with multiple underlying comorbidities, an advantage of arterial allografts over venous autografts is a shorter operating time. Potential disadvantages of arterial allografts over venous autografts are the difficulty with obtaining a suitable size and length and the potential for arterial degeneration. Although no differences in outcome have been reported with cryopreserved compared with fresh arterial allografts, there are some differences and potential advantages with the use of cryopreserved allografts. Unlike fresh arterial allografts, the use of cryopreserved allografts increases the availability of suitable size and length of surgical conduits for emergency use, and blood and human leukocyte antigen compatibility can be matched with allografts, which could reduce rejection compared with fresh arterial allografts. Finally, cryopreserved arterial allografts might be more likely than fresh grafts to be virus free and could be less likely than fresh allografts to develop mid- or long-term aneurysms, presumably because of less rejection with cryopreserved than with fresh allografts.

The preponderance of experience favors the use of cryopreserved arterial allografts over the use of fresh arterial
allografts. Because of lower infection rates, femoral venous autografts might be preferable to aortic allografts or rifampin-bonded synthetic grafts in hemodynamically stable patients with extensive perigraft infection or infection caused by MRSA, \textit{Pseudomonas}, or antibiotic drug-resistant microorganisms.\textsuperscript{2,4,14,83}

Because earlier studies reported high morbidity, mortality, and reinfection rates, rifampin-bonded grafts were not recommended for in situ reconstruction of VGI and aortoenteric fistula; however, recent studies in selected patients reported more favorable results.\textsuperscript{106} Oderich et al\textsuperscript{106} reported 54 selected patients treated with rifampin-bonded graft in situ reconstruction. Operative mortality in hemodynamically stable patients was 2%, reinfection rate was 4%, and 5-year graft patency and limb survival rates were 92% and 100%, respectively. The improved outcomes in this study could have resulted from several factors: (1) patient selection, because those with large perigraft abscess or extensive purulence and those with infection caused by MRSA or \textit{Pseudomonas} species were excluded; (2) resection of only the infected portion, not the entire vascular graft, which reduced operative time, postoperative physiological stress, and ischemia; (3) circumferential coverage of the graft with omentum; and (4) administration of long-term suppressive antimicrobial therapy.

The potential advantages of rifampin-bonded grafts over arterial or venous grafts are their more reliable availability and ability to be used in emergencies, shorter operative time, and lower cost. A potential disadvantage is a possibly higher reinfection rate. However, in the study by Oderich et al,\textsuperscript{106} reinfection rates in selected patients were similar to those of patients with arterial or venous grafts.

In a small number of patients with aortoenteric fistulae, endovascular therapy (EVT) was used as a bridge procedure to control bleeding and stabilize hemodynamics. After stabilization, the majority of patients underwent device removal and in situ or axillofemoral reconstruction. The role of EVT in the treatment of vascular infection is discussed when the management of mycotic aneurysms (MAs) is discussed in Mycotic Aneurysms.

\textbf{Extensive Intra-Abdominal Abscess or Gross Purulence Around the Grafts or Infection Caused by MRSA, Pseudomonas, or Multiply Antibiotic-Resistant Microorganisms.} In these patients, with or without an aortoenteric fistula, extra-anatomic bypass grafting followed by graft excision may be considered.\textsuperscript{4,92-99,111} The primary reason for this recommendation is because of the risk of recurrent infection that can occur with in situ reconstruction.\textsuperscript{4,92-99,111} The major disadvantages of extra-anatomic bypass grafting and graft excision are as follows: (1) a 2-stage procedure is required; (2) conduit failure with amputation of lower extremities has been observed in 20% to 30% of patients; (3) blood supply is decreased with ischemia to the inferior mesenteric and internal iliac arteries; and (4) residual infection of the aortic stump with blowout occurs in 10% to 20% of patients.\textsuperscript{4} Theoretically, the risk of recurrent infection should be lower with this procedure, because the VGI is resected with no in situ reconstruction in an infected tissue bed; however, in the meta-analysis published by O’Connor et al,\textsuperscript{4} the infection rate was highest with this procedure, followed by rifampin-bonded, then arterial allograft, and lowest with venous autograft.

\textbf{Summary of Recommendations for Surgical Management of Intra-Abdominal VGI.} There is no consensus about the procedure of choice for the surgical management of intra-abdominal VGI infections. The choice of therapy should be individualized for each patient and depends in part on personal preferences, experience of individual surgeons, and availability of equipment and resources.

Figure 6 outlines an algorithm for the management of intra-abdominal VGI. The importance of a team approach involving vascular and plastic surgeons, experts in vascular medicine and infectious diseases, the microbiology laboratory, and, in selected patients, a clinical pharmacologist cannot be overemphasized.

For patients who have life-threatening bleeding or sepsis, emergency surgery is necessary. The most important goals are surgical control of bleeding, drainage of abscess, control of sepsis, and hemodynamic stabilization. Patients can be categorized into those who need emergency surgery to control bleeding and sepsis and those who do not require emergency surgery. There could be fewer surgical options available in an emergency. For patients who cannot be stabilized long enough to select the most appropriate surgical option, endovascular bridge therapy might be the only realistic option.

\textbf{Recommendations for Surgical Management of Intra-Abdominal VGI}

1. In patients who have no aortoenteric fistula, graft excision and in situ reconstruction with cryopreserved, arterial allograft, or venous autograft or rifampin-bonded synthetic graft is reasonable (Class Ila; Level of Evidence B).

2. In patients with aortoenteric fistula, graft excision and in situ reconstruction with either cryopreserved or fresh arterial allograft or venous autograft or rifampin-bonded synthetic graft is reasonable (Class Ila; Level of Evidence B).

3. In patients with infection caused by MRSA, \textit{Pseudomonas}, or multidrug-resistant microorganisms or those with extensive intra-abdominal abscess or perigraft purulence, extra-anatomic bypass revascularization followed by graft excision may be considered (Class Iib; Level of Evidence C).
Postoperative Antimicrobial Therapy for Intra-Abdominal VGI. Figure 6 shows an antimicrobial therapy strategy that may be considered. The selection of a specific regimen for intravenous or oral therapy should be made in consultation with an infectious diseases specialist and the microbiology laboratory. Postoperative parenteral antimicrobial therapy for 6 weeks is reasonable; in some cases, oral antibiotic drugs can be administered depending on absorption from the gastrointestinal tract and whether bioavailability is reasonable.1,2,4,5,8,14,106 A combination of antimicrobial agents might be necessary, especially in patients with Pseudomonas or multidrug-resistant microorganisms. After completion of the initial 6 weeks of postoperative antibiotic therapy, an additional 3 to 6 months of oral antimicrobial therapy may be considered. The decision to administer 3 to 6 months of additional oral antimicrobial therapy should be individualized for each patient and could depend on the microorganism recovered from cultures and the presence of persistently elevated biomarkers of inflammation, such as erythrocyte sedimentation rate and C-reactive protein. In some cases, there may be no effective or safe oral antimicrobial agent for use in these patients, and consultation with an infectious diseases expert will be necessary.

In selected patients, lifelong suppressive antimicrobial therapy may be considered (Figure 6). The most likely candidates for lifelong suppressive therapy are patients with rifampin-bonded synthesis grafts in situ reconstruction, in situ reconstruction with arterial or venous grafts and extensive perigraft infection, or infection caused by MRSA, Pseudomonas, or multidrug-resistant microorganism, provided that an effective, safe oral antimicrobial agent is available. In cases in which lifelong oral suppressive therapy is not technically feasible or is ineffective, intravenous administration of chronic antimicrobial suppressive therapy 2 or 3 times weekly should be considered. These decisions must be individualized for each patient and made in close consultation with vascular surgeons, infectious diseases experts, the microbiology laboratory, and, in some cases, a clinical pharmacist.

Recommendations for Antimicrobial Therapy of Intra-Abdominal VGI

1. Postoperative parenteral antimicrobial therapy is reasonable for 6 weeks (Class IIa; Level of Evidence B); an additional 3 to 6 months of oral antimicrobial therapy may be considered (Class IIb; Level of Evidence C).
2. After the initial course of antimicrobial therapy, lifelong suppressive antimicrobial therapy may be considered in patients with extensive perigraft infection or infection caused by MRSA, Pseudomonas, or multidrug-resistant microorganisms (Class IIb; Level of Evidence C).

Prognosis for Intra-Abdominal VGI. Yaeger et al92,93 reported a 15-year experience with 60 patients with intra-abdominal VGI. The perioperative mortality rate was 13% of those who survived surgery; the 2- and 5-year survival rates were 97% and 82%, respectively. The 5-year axillofemoral bypass graft patency rate was 73%. Seeger86 reported an early mortality rate of 19%, an amputation rate of <5%, and early graft failure or infection in 20%. In this study, after 30 months, 58% of patients survived without amputation.

Intrathoracic VGI

These patients can present as an acute surgical emergency associated with aortic VGI with bronchial or esophageal erosions or fistulae. There could be initial herald bleeding similar to that in patients with abdominal aortoenteric erosion or fistula with intermittent bleeding, or they could present with sudden, catastrophic hemorrhage. Patients with either type of bleeding require prompt or emergent evaluation and treatment depending on their hemodynamic stability. In patients who are unstable, it is preferable to perform a CTA to define aortic anatomy and plan treatment options. These patients usually require in situ graft replacement, because extra-anatomic reconstruction is rarely an option. An ascending aorta–to–upper abdominal aortic bypass might be possible in selected stable patients. In these patients, the infected graft is removed and the ends of the aorta are debrided to healthy-appearing tissue and oversewn. Buttress of suture lines with fascia lata and coverage of the new graft or the aortic stumps with omentum, a latissimus dorsi or serratus muscle flap, or a pleuropereicardial vascularized pedicle to separate the graft from the defect in the esophagus or bronchus are important surgical adjuncts. Large esophageal defects might require diversion, whereas large bronchial defects might necessitate a lobectomy.

In patients without an esophageal or bronchial fistula, the majority of these infections involve a synthetic arterial allograft used to treat aortic aneurysm, dissection, or complications of IE and aortic root abscess or repair of the aorta damaged from blunt trauma. Unlike intra-abdominal VGI, there are fewer surgical options for successful management. The use of a cryopreserved or fresh arterial allograft for treatment of intrathoracic VGI is reasonable.1,2,4 The potential advantages of cryopreserved allografts compared with fresh arterial allografts are listed in Table 2. If technically feasible, viable omentum or muscle flap coverage of aortic allograft is used to promote healing and reduce infection.1,2,4,5,8,14,106

There are insufficient published data to recommend the use of venous autografts for the treatment of intrathoracic VGI. The use of a synthetic graft, including rifampin-bonded graft, is associated with a higher infection
rate, and such use should be avoided unless there are no other surgical options.4

It is reasonable to administer antimicrobial therapy postoperatively for 4 to 6 weeks.1,2,4,5,8,14,106 The decision to administer a course of oral antibiotic therapy thereafter or, in selected patients, chronic suppressive antibiotic therapy must be individualized for each patient and should be made in consultation with the surgical team, infectious diseases specialists, and the microbiology laboratory. Currently, there are insufficient data to make a recommendation for longer postoperative courses or for chronic suppressive antimicrobial therapy. However, because of the risk of recurrence of infection, the high morbidity and mortality, and the fact that many of these patients could not tolerate another extensive surgical reconstruction, the administration of oral antibiotic therapy for at least 3 to 6 months and possibly lifelong suppressive therapy may be considered in selected patients.

Recommendations for Management of Intrathoracic Infected Vascular Graft

1. In situ repair of cryopreserved arterial allografts is reasonable (Class IIa; Level of Evidence B).
2. Postoperative parenteral antimicrobial therapy for 4 to 6 weeks is reasonable (Class IIa; Level of Evidence B).
3. In patients with a high risk of morbidity and mortality, those who cannot tolerate extensive reconstructive surgery, or those with in situ repair using a synthetic graft, lifelong suppressive antimicrobial therapy may be considered (Class IIb; Level of Evidence C).

MYCOTIC ANEURYSMS

Background and General Discussion

As discussed by Peters et al,112 Osler113–115 first described a ruptured aortic aneurysm in a patient with IE and used the term mycotic endarteritis.112–115 Church116 reported a ruptured middle cerebral artery aneurysm in a young patient with mitral valve IE. The term mycotic aneurysm was used to describe all infectious aneurysms and has become common usage since that time, although the term mycotic is now used to describe fungal infections. Recently, especially in vascular and neurological literature, the term infectious aneurysm has replaced the use of mycotic aneurysm; however, because the term mycotic aneurysm is so widely used and understood, for the purpose of this document we will use this term. MAs can be characterized by anatomic location as intracavitary (within the thorax or abdomen), peripheral (primarily in the extremity and less often in the carotid arteries), and intracranial.

Frequency

Although MAs are thought to occur uncommonly, the true incidence of MA is difficult to determine. Published series probably underestimate the true incidence, because MAs can be asymptomatic and are diagnosed only at autopsy. In general, MA occurs in the following order of frequency: intracavitary, peripheral, and intracranial arteries, respectively.117 Previous studies reported the frequency of atherosclerotic aortic aneurysms and intracavitary MA but did not address MAs located elsewhere. In 22,000 autopsies performed at Boston City Hospital from 1902 through 1951, aortic aneurysms were detected in 1% to 5% of autopsies, but MAs were reported in only 1.5% of these.118 At Mayo Clinic, from 1925 through 1954, 178 aneurysms were found among 20,000 autopsies, but only 6 of these were thought to be MAs.119 MAs are rare in children,120 and a form associated with umbilical artery catheterization in newborns occurs rarely.121

Pathogenesis

Four mechanisms have been proposed to cause MA122–125: (1) Septic microemboli to the vasa vorumor or a septic embolism that has occluded a blood vessel, often at a branch point. Bacterial infection extends from the vasa vorum toward the vessel wall, which results in weakening of the wall and aneurysmal formation. In the latter situation, bacteria escape from the emboli, infect the intima, and proceed outward through the vessel wall. (2) Direct extension from a contiguous focus to infect the arterial wall. (3) Hematogenous infection of the intima during bacteremia originating from a distal site. The bacteria can enter through an atherosclerotic plaque or infect a preexisting aneurysm. (4) Direct blood vessel contamination or trauma. This can occur as a result of intraoperative infection such as with vascular graft surgery, invasive procedures such as intravascular catheterization and manipulation, intravenous drug use (IVDU), or traumatic vascular injury as a result of gunshot wound or other penetrating trauma.

The risk factors for infection, microbiological cause, clinical presentation, diagnosis, and management of MA differ depending on anatomic location and will be considered separately in the following discussion.

Intracranial MA

Intracranial MAs (ICMAs) occur less commonly than intracavitary or peripheral MAs, and they are more difficult to diagnose. ICMAs can be asymptomatic or can present with sudden catastrophic, life-threatening, or fatal intracranial hemorrhage. They are managed differently from MAs located elsewhere in the vascular system.
**Frequency and Anatomic Location**

ICMAs represent 0.7% to 6.5% of all intracranial aneurysms. Neurological complications are common among patients with IE and occur in 20% to 55% of patients with native valve or prosthetic valve endocarditis. The large majority of cases of ICMA occur in association with left-sided IE or prosthetic valve endocarditis. ICMAs occur in 2% to 10% of cases of IE. Because many cases of ICMA are asymptomatic, the true incidence is probably considerably higher. ICMA most often occurs as a result of hematogenous spread or, less likely, as a result of contiguous spread. Hematogenous spread results from septic microemboli to the vasa vasmorum, with spread of infection internally through the vessel wall, or as a result of septic emboli that lodge at a distal branching point, with spread of infection through the adventitia through the muscularis of the vessel wall. ICMAs have a different morphological appearance and anatomic location compared with congenital berry aneurysms. ICMAs are usually saccular with a poorly defined wide base or absent neck or fusiform shape with a thin friable wall, are more peripherally located, and can be multiple in number, whereas congenital berry aneurysms are more often single, more proximally located, and usually saccular with a well-defined neck.

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**Microbiology**

The microbiological cause of ICMAs depends on whether they are associated with IE or are a result of contiguous spread of infection. S. aureus and viridans group streptococci are the most common causes of IE and ICMA. Less commonly, enterococci, coagulase-negative staphylococci, HACEK group (HACEK indicates Haemophilus species, Aggregatibacter species, Cardiobacterium hominis, Eikenella corrodens, and Kingella species), and other gram-negative bacilli, such as P. aeruginosa, can cause ICMA. Partially treated IE with negative blood cultures can also cause ICMA, and in these cases, a specific microbiological cause usually is not identified.

**Clinical Presentation**

Because ≈20% of ICMAs are diagnosed at autopsy and are asymptomatic, the true natural history of patients with ICMA is unknown. The clinical symptoms reflect the underlying associated condition, such as IE or from contiguous spread from meningitis, cavernous sinus thrombosis, sinusitis, or other underlying conditions. Patients with ICMA associated with IE often have fever, headache, seizures, altered sensorium, or hemiparesis; however, these same neurological complications commonly occur in patients with IE who do not have ICMA. Multiple ICMAs occur in up to 25% of cases. ICMA most often occurs as a result of hematogenous spread or, less likely, as a result of contiguous spread. Hematogenous spread results from septic microemboli to the vasa vasmorum, with spread of infection internally through the vessel wall, or as a result of septic emboli that lodge at a distal branching point, with spread of infection through the adventitia through the muscularis of the vessel wall. ICMAs have a different morphological appearance and anatomic location compared with congenital berry aneurysms. ICMAs are usually saccular with a poorly defined wide base or absent neck or fusiform shape with a thin friable wall, are more peripherally located, and can be multiple in number, whereas congenital berry aneurysms are more often single, more proximally located, and usually saccular with a well-defined neck.

**When ICMA is caused by contiguous extension, the microbiological cause reflects the underlying condition.** In addition to staphylococci and streptococci, Streptococcus pneumoniae, Haemophilus species, anaerobic microorganisms, and fungi including Candida, Aspergillus, and Zygomycetes, or mycobacteria may be recovered. Rarely, ICMA can be caused by a viral infection, such as varicella-zoster. HIV has been reported to cause ICMA in patients with AIDS. ICMA most often occurs as a result of hematogenous spread or, less likely, as a result of contiguous spread. Hematogenous spread results from septic microemboli to the vasa vasmorum, with spread of infection internally through the vessel wall, or as a result of septic emboli that lodge at a distal branching point, with spread of infection through the adventitia through the muscularis of the vessel wall. ICMAs have a different morphological appearance and anatomic location compared with congenital berry aneurysms. ICMAs are usually saccular with a poorly defined wide base or absent neck or fusiform shape with a thin friable wall, are more peripherally located, and can be multiple in number, whereas congenital berry aneurysms are more often single, more proximally located, and usually saccular with a well-defined neck.

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When ICMA results from septic emboli, patients may initially present with symptoms of ischemic stroke in the territory of the occluded distal branch vessel, although such strokes can be silent depending on the eloquence of the territory affected.

Patients with ICMA resulting from contiguous spread can also present with hemorrhage from an acute rupture. Other findings in these patients include focal neurological signs, acute exacerbation of meningeal signs as a result of rupture into the meninges, and, depending on the location, proptosis, otorrhea, papilledema, ocular or facial palsy, epistaxis, or signs of cavernous sinus thrombosis. Vessel narrowing or vasospasm can also be a feature of infectious vascular involvement related to contiguous spread, which results in ischemic strokes often affecting multiple brain territories because of the proximal vessels involved.

In summary, the clinical signs and symptoms of patients with ICMA are diverse and can occur commonly in patients with IE or other CNS infections who do not have ICMA. Accordingly, any patient with these underlying predisposing conditions who develops severe, localized, unremitting headache; focal neurological findings; stroke; or acute intracerebral or subarachnoid hemorrhage should be suspected of having ICMA.

**Diagnosis**

The diagnosis of ICMA depends on a combination of an index of suspicion in a susceptible host, clinical signs, and physical findings and is confirmed by radiographic imaging or during surgery. Strategies for successful management of ICMA depend on an accurate diagnosis and management of the different underlying conditions and the differentiation of ICMA from congenital berry aneurysm.

Early diagnosis of an ICMA is critical to optimize therapy and reduce complications. Table 3 shows factors important in the differential diagnosis among ICMAs associated with IE, contiguous spread, and noninfectious congenital berry aneurysm. The medical and surgical management of patients with ICMA is quite different from that of a berry aneurysm, as discussed in Treatment.

There are no clinical findings or laboratory tests that are specific for the diagnosis of ICMA. In patients who are suspected of having an ICMA, the diagnosis must be confirmed radiographically or at surgery. Prompt cerebrovascular imaging should be performed to identify possible ICMA or CNS bleeding in any patient with IE who develops severe localized headache, neurological deficits, or meningeal signs and can even be considered in patients without symptoms because of the risk of ICMA in these patients. There is insufficient evidence to recommend dedicated cerebrovascular imaging to detect ICMA in all patients with meningitis, cavernous sinus thrombosis, orbital cellulitis, or sinusitis; however, dedicated imaging for possible ICMA should be performed in these patients if there is intracranial bleeding, focal neurological abnormalities, or cranial nerve abnormalities, especially those involving ocular muscles.

**Imaging Modalities**

For the diagnosis of intracranial aneurysms >5 mm in diameter, multiple-slice CTA with 3-dimensional reconstruction, magnetic resonance angiography (MRA) with 3-dimensional reconstruction, and digital subtraction angiography (DSA) appear to be roughly equivalent. Cerebral MRI is reasonable in patients with IE with CNS signs or symptoms and may be considered even in those without neurological symptoms to detect emboli and bleeding. These findings help guide decisions regarding medical and surgical management, especially timing of possible cardiac valve replacement surgery.

Some authorities suggest conventional angiography for the detection of ICMAs, especially those <3 mm in diameter. Some studies have shown that CTA could be as effective as DSA in identifying intracranial aneurysms, but others have reported that CTA had lower sensitivity, especially in detecting small aneurysms (<3 mm). The sensitivity of MRA is similar to similar to CTA for the detection of aneurysms, and MRA is associated with fewer procedure-related risks than DSA.

There is insufficient evidence to recommend a specific imaging modality for the diagnosis of ICMA. DSA is generally safe but is an invasive procedure that is associated with a small risk (<1%) of complications, including contrast-induced kidney injury or neurological deficits (<0.5%). In several studies, DSA still offered diagnostic advantage over CTA or MRA for the detection of cerebral aneurysms, whereas other studies reported comparable diagnostic utility. Accordingly, it is reasonable to recommend either CTA with 3-dimensional reconstruction, MRA, or DSA as an initial screening imaging procedure for ICMAs. If these imaging tests are negative and there is a high index of suspicion for ICMA, then conventional angiography may be reasonable.

The selection of a specific imaging technique can also depend on the availability of specific imaging equipment and the experience and preference of individual centers with the use of an imaging technique. Because ICMA can develop during antimicrobial therapy, in selected patients, especially those with focal neurological findings or CNS bleeding, repeat imaging in 2 to 4 weeks after an initial negative procedure may be considered. The role of imaging to monitor patients with a diagnosis of ICMA to guide medical and surgical therapy is discussed in Diagnosis and Treatment.

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Additional notes:

1. TBD, 2016

2. Circulation. 2016;134:00-00. DOI: 10.1161/CIR.0000000000000457
Table 3. Intracranial Mycotic Aneurysm or Berry Aneurysm: Differential Diagnosis

<table>
<thead>
<tr>
<th>Myotic Endocarditis</th>
<th>Other Causes: Meningitis, Cavernous Sinus Thrombosis, Sinusitis, Orbital</th>
<th>Congenital Berry Aneurysm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age, y</strong></td>
<td>≤45</td>
<td>&gt;45</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td>Peripherally: middle cerebral &gt; posterior, anterior</td>
<td>Proximal: circle of Willis, posterior communicating artery</td>
</tr>
<tr>
<td><strong>Size, shape; single, multiple</strong></td>
<td>Variable size; saccular (≥50%) with poorly defined neck; fusiform (30%–35%) with friable wall; multiple (25%–40%); stenosis or occlusion close to aneurysm</td>
<td>Size few mm to ≥1 cm; saccular with narrow, well-defined neck; single</td>
</tr>
<tr>
<td><strong>Focal neurological findings</strong></td>
<td>Common (≥50%) Stroke (≥20%) Seizures (≥15%)</td>
<td>Less common than with IE; depends on underlying conditions (ie, meningitis)</td>
</tr>
<tr>
<td><strong>Cranial nerve findings</strong></td>
<td>Ocular palsy (≥25%) Facial palsy (&lt;25%) Homogenous hemianopsia, papilledema (≤10%)</td>
<td>Depends on underlying conditions; with cavernous sinus thrombosis, ocular palsy (≥50%)</td>
</tr>
<tr>
<td><strong>Other clinical symptoms</strong></td>
<td>Depends on IE: fever, headache, heart failure</td>
<td>Headache, fever common; meningeal symptoms in &gt;90% with meningitis</td>
</tr>
<tr>
<td><strong>Bleeding</strong></td>
<td>Intracerebral &gt;&gt; subarachnoid</td>
<td>Depends on location; with cavernous sinus thrombosis, intraventricular bleeding in ≤15%</td>
</tr>
<tr>
<td><strong>Microbiology</strong></td>
<td>Staphylococci, viridans group streptococci; less common: enterococci; other streptococci; HACEK</td>
<td>Depends on underlying conditions. With meningitis: Neisseria meningitidis; <em>Streptococcus pneumoniae</em>, Haemophilus sp. Cavernous sinus thrombosis or sinusitis: <em>S pneumoniae</em>, staphylococci; <em>Haemophilus</em> sp. anaerobes; <em>Candida</em>, <em>Aspergillus</em></td>
</tr>
<tr>
<td></td>
<td>Culture negative</td>
<td>Culture negative</td>
</tr>
</tbody>
</table>

HACEK indicates *Haemophilus* species, *Aggregatibacter* species, *Cardiobacterium hominis*, *Eikenella corrodens*, and *Kingella* species; and IE, infective endocarditis.

**Recommendations for Imaging for the Diagnosis of ICMA**

1. Cerebrovascular imaging should be performed to detect ICMA or CNS bleeding in all patients with IE or contiguous spread of infection who develop severe localized headache, neurological deficits, or meningeal signs (Class I; Level of Evidence B).
2. Cerebrovascular imaging may be considered in all patients with left-sided IE who have no CNS signs or symptoms (Class IIb; Level of Evidence C).
3. Either CTA, MRA, or DSA is reasonable as the initial imaging test for detection of ICMA (Class Ila; Level of Evidence B).
4. Conventional angiography for detection of suspected ICMA is reasonable in patients with negative CTA, MRA, or DSA imaging results (Class Ila; Level of Evidence B).

**Treatment**

The management of ICMA is somewhat controversial. The most important factor in the management of ICMA is rupture. It is not possible to predict accurately the natural history of ICMA: which will rupture, and which will not. Rupture can occur in small or large ICMA. Although rupture is more likely in ICMA that increase in size during antimicrobial therapy, those that remain stable or decrease in size can also rupture, even after completion of a course of antimicrobial therapy.

ICMAs are uncommon, and not surprisingly, there are no published randomized controlled studies to define the optimal therapy of ICMA. In addition, there are no widely accepted guidelines or studies comparing antimicrobial therapy alone with EVT or neurosurgical repair. Proposed treatment strategies are based on retrospective reviews, anecdotal experience, and expert opinion.

References 112, 117, 126, 127, 141–143, 162, 163, 168, 169.

**References 112, 117, 126, 127, 141–143, 162, 168, 169.**

**References 112, 117, 126, 127, 141–143, 162, 168, 169.**
the lack of widely accepted guidelines, there are 3 basic therapeutic options, used alone or in combination: antimicrobial therapy, EVT, and neurosurgery. The principles of management include evaluation and control of the underlying condition, protection of the brain from damage from rupture of the ICMA, definitive management of the ICMA itself, and appropriate follow-up to prevent complications. Therapeutic decisions should be individualized for each patient, and patients should be managed with an integrated team approach including but not limited to specialists in neurology, neurosurgery, neurovascular radiology, vascular medicine and vascular surgery, cardiology, infectious diseases, and microbiology laboratory. The discussion that follows reviews published data, with the results of antimicrobial therapy, EVT, neurosurgical management, and follow-up, and provides a summary of what we believe to be a reasonable and prudent integrated strategy for management.

**Antimicrobial Therapy**

All patients with ICMA should receive antimicrobial therapy. Although the choice of a specific antimicrobial regimen is beyond the scope of this document, certain general principles apply. The underlying condition associated with ICMA influences the choice of therapy. Most cases of ICMA are associated with IE, and antimicrobial therapy should be directed against the specific microorganism recovered from blood cultures or cardiac valve tissue culture; if cultures are negative, empiric therapy should be administered. The choice of antimicrobial therapy for ICMA associated with contiguous spread of infection should be based on the specific causative microorganism, or if none is identified, empiric therapy should be chosen based on the underlying condition.

A minimum of 4 to 6 weeks of parenteral antimicrobial therapy is reasonable. The use of such therapy alone for the treatment of ICMA has variable success rates. There are no controlled studies, but there are numerous anecdotal case reports on the natural history of unruptured ICMA treated with antibiotic drugs alone. Several studies reported successful healing of ICMA with antibiotic drugs alone. Corr et al. reported 18 patients with ICMA treated with antibiotic drugs alone. Complete resolution occurred in 33%, enlargement in 17%, and a decrease in size in 17%, and 33% remained stable in size. Bartakke et al. reported complete disappearance of ICMA in 29% of patients; 18.5% had a decrease in size, 22% had an increase in size, 15% were unchanged, and 15% developed additional ICMA during treatment. In another study among 20 patients with ICMA, ICMA either resolved or disappeared in 50%, and 50% showed no change or enlargement in size during antibiotic therapy. Ducruet et al. published a comprehensive review of 27 studies comprising 287 patients with ICMA in the English language literature. In this review, ≈30% of ICMA resolved on antimicrobial therapy alone, 20% decreased in size, 20% increased in size, and 15% were unchanged.

What is clear from these studies is that the natural history of ICMA and response to antibiotic therapy are highly variable and unpredictable. What is not clear is which factors predict the likelihood of rupture of ICMA during antimicrobial therapy and, therefore, which would prompt early intervention. Disappearance of the ICMA, a decrease in size or stability in size and shape, and slow filling of ICMA radiographically during antimicrobial therapy and on follow-up imaging studies are generally associated with a lower risk of rupture. However, rupture can still occur despite an initial small size or decrease in size of ICMA during antibiotic therapy. The decision to treat patients with antimicrobial therapy alone must be individualized for each patient. It is reasonable to monitor patients during antimicrobial therapy with weekly imaging for changes in the ICMA, such as an increase in size or leaking of the aneurysm that might suggest risk of rupture. It is reasonable to manage patients in a facility with prompt availability of experienced endovascular specialists and neurosurgeons to intervene emergently for impending or actual rupture of ICMA.

### Recommendations for Antimicrobial Therapy in Patients With ICMA

1. A minimum of 4 to 6 weeks of parenteral antimicrobial therapy is reasonable (Class IIa; Level of Evidence B).
2. It is reasonable to image patients weekly during antimicrobial therapy for changes in the MA that suggest impending or actual rupture (Class IIa; Level of Evidence B).
3. It is reasonable to manage patients in a facility with prompt availability of experienced endovascular specialists and neurosurgeons to intervene emergently for impending or actual rupture (Class IIa; Level of Evidence C).

### Endovascular Treatment

Numerous studies have reported experience with EVT for the management of ICMA. EVT is used to occlude the ICMA by use of detachable coils, preferred for proximal ICMA, or with liquid embolic agents (N-butyl cyanoacrylate or Onyx [ev3, Inc]) for more distally located aneurysms. Table 4 shows the advantages and disadvantages of EVT compared with neurosurgery, as well as patients who are candidates for either EVT or neurosurgery. The primary advantages of EVT are as...
Table 4. Treatment of Intracranial Mycotic Aneurysms With Endovascular Therapy or Neurosurgery: Advantages, Disadvantages, and Selection of Patients

<table>
<thead>
<tr>
<th>Endovascular therapy</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Selection of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Less invasive than neurosurgery</td>
<td>Sacrifice parent artery with potential ischemic complications, especially in eloquent neural areas</td>
<td>No rupture</td>
</tr>
<tr>
<td></td>
<td>Option to use sedation, not general anesthesia</td>
<td>Not suitable with rupture and increased ICP and mass effect</td>
<td>Rupture, no mass effect, noneloquent neural area</td>
</tr>
<tr>
<td></td>
<td>Proximal, distal, single, or multiple mycotic aneurysms treated with same procedure</td>
<td>Theoretical risk of infection with use of foreign body coil or glue</td>
<td>Unstable aneurysms in noneloquent neural area</td>
</tr>
<tr>
<td></td>
<td>Risk of rupture less than with neurosurgery</td>
<td></td>
<td>Patients who require urgent cardiovascular surgery</td>
</tr>
<tr>
<td></td>
<td>Does not delay cardiovascular surgery</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Can be performed in patients with high risk of cardiovascular complications</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Multiple procedures possible for subsequent mycotic aneurysms</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Neurosurgery</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Selection of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Can be used in cases with rupture, increased ICP, and mass effect and in patients with no rupture and eloquent neural area or in cases of failed EVT</td>
<td>Delays cardiovascular surgery for 3–4 wk because of risk of intracranial bleeding</td>
<td>Rupture with increased ICP with mass effect</td>
</tr>
<tr>
<td></td>
<td>Surgical clipping of aneurysm can result in bleeding because of friable wall</td>
<td>Clipping of aneurysm can result in bleeding because of friable wall</td>
<td>No rupture, located in eloquent neural area</td>
</tr>
<tr>
<td></td>
<td>Technically difficult in distal circulation</td>
<td></td>
<td>EVT failed or not technically feasible</td>
</tr>
</tbody>
</table>

EVT indicates endovascular therapy; and ICP, increased intracranial pressure.

follows: (1) The procedure is less invasive than neurosurgery and can be performed with sedation rather than general anesthesia; (2) single or multiple and proximal or distal ICMAs can be treated during the same procedure; (3) the risk of rupture of a friable aneurysm wall is low; (4) unlike neurosurgery, EVT does not delay necessary cardiac valve replacement or other cardiac surgery that could be performed shortly after EVT‡‡; (5) EVT is preferable to neurosurgery in patients considered to have high risk of cardiovascular complications during the surgical procedure; and (6) EVT can be repeated in patients who develop additional ICMAs after the initial EVT. There are several potential disadvantages of EVT that could favor neurosurgery: (1) EVT usually results in partial or complete parent artery occlusion, which could result in ischemic complications, especially in areas of eloquent brain function. However, the rate of ischemic complications is low, possibly because most strokes occur before EVT is done, and collateral circulation likely reduces the risk of ischemia. Neurosurgery is considered preferable to EVT if the ICMA threatens eloquent neural territory.112,127,135,162 (2) EVT is not appropriate for patients who have had rupture with increased intracranial pressure and mass effect. Neurosurgery is necessary in these patients. (3) There is a theoretical risk of infection associated with the introduction of foreign material, such as a coil or glue, into an infected blood vessel. Despite this concern, no infectious complications have yet been reported after EVT.112,127,135,162 All patients reported to be treated with EVT were receiving concomitant antimicrobial therapy, which might have prevented infection.

There are no trials comparing EVT with neurosurgery for the management of ICMA,180 nor is it likely that such studies could reasonably be conducted. ICMA is a relatively uncommon condition in a diverse population and has differences in clinical presentation, course, and anatomic location. There are too many confounding variables to make a comparative study feasible or even safe to do. Recognizing these limitations, it is reasonable that EVT be used in selected patients for the initial management of ICMA.§§ The choice of EVT or neurosurgery, or in some cases both, should be individualized for these patients.

Neurosurgery

Before the development of EVT, neurosurgery was the standard of care of management of ICMA.112,125,127,135,162 Although improvements in surgical technique, especially developments in microvascular procedures, have decreased morbidity and mortality, neurosurgery for ICMA remains a challenging, often technically difficult, and potentially risky procedure. Surgical clipping is technically more difficult for ICMA than for berry aneurysms. Compared with a berry aneurysm, ICMAs are more friable and lack a well-defined neck, which increases the risk of rupture during the procedure. A location of ICMA in distal branches of the anterior circulation and difficulty in identifying the precise anatomic site pose additional problems for neurosurgical management. Finally, patients who

‡‡References 112, 127, 135, 142, 162, 171, 181, 184, 185.
§§References 112, 117, 127, 135, 142, 162, 184.
undergo urgent neurosurgery might also require cardiac valve replacement or other cardiac surgery. If possible, it is reasonable to postpone cardiac valve surgery for a minimum of 2 but preferably 3 to 4 weeks after neurosurgery, because the use of anticoagulant therapy during cardiovascular surgery can cause intracranial bleeding at the operative site.125,128,130,170

Neurosurgical intervention for ICMA is reasonable only in selected patients and depends on the neurological prognosis and the cardiovascular fitness of the patient to tolerate neurosurgery. Such patients include the following groups: (1) patients with ruptured ICMA with a mass effect who require urgent neurosurgery to evacuate the hematoma, reduce intracranial pressure, and control bleeding; (2) patients with ICMA involving an artery that supplies eloquent neural tissue (surgical techniques that preserve vascular flow offer an advantage over EVT); and (3) patients with ruptured ICMAs in noneloquent neural tissue with no mass effect for whom EVT has failed.112,117,127,135,142,162,184

Improvements in microvascular surgery have increased the likelihood of preserving blood flow to eloquent neural tissue. A segment of the MA is excised to ensure healthy, uninvolved arterial vessel margins and end-to-end reanastomosis is possible.112,161 Larger ICMAs may be trapped and bypassed using a segment of a superficial temporal artery, a radial artery, or a saphenous vein graft.112,162,188 Reinfection after these procedures is low.

We acknowledge that our strategy for management of ICMA is based on the collective experience published in numerous small series, case reports, uncontrolled anecdotal reports, and expert opinion. However, until more data are available, we believe that the algorithm shown in Figure 7 may be considered for the management of patients with ICMA.

Summary of Recommendations for Management of Patients With ICMA

1. Endovascular therapy is reasonable in selected patients for the initial management of ICMA (Class IIa; Level of Evidence B).
2. Neurosurgical intervention for ICMA is reasonable in patients with a. rupture of ICMA with a mass effect to evacuate a hematoma, reduce intracranial pressure, and control bleeding (Class IIa; Level of Evidence B).
b. an ICMA involving an artery that supplies eloquent neural tissue to preserve vascular flow (Class IIa; Level of Evidence B); and
c. ruptured ICMA in noneloquent neural tissue with no mass effect in patients for whom EVT has failed (Class IIa; Level of Evidence B).

3. If no rupture occurs and cardiac valve replacement or other cardiovascular surgery is necessary, it is reasonable that EVT should be performed first (Class IIa; Level of Evidence B). If no cardiovascular surgery is necessary and the ICMA has decreased in size or has disappeared on imaging, it is reasonable to continue antimicrobial therapy to complete a 4- to 6-week course (Class IIa; Level of Evidence B).

4. Serial imaging is reasonable at 1- to 2-week intervals for at least the first 6 weeks of therapy to ensure proper response to treatment, to ensure there are no signs to suggest impending rupture, and to evaluate for development of additional ICMAs during therapy (Class IIa; Level of Evidence B).

5. In patients with IE and focal neurological deficits who have initial imaging studies that do not demonstrate an ICMA, repeat imaging may be considered at least once during therapy to ensure that an ICMA did not develop during therapy (Class IIb; Level of Evidence B).

6. In stable patients who undergo neurosurgery, it is reasonable to wait at least 2 but preferably 3 to 4 weeks before they undergo cardiac valve replacement or other cardiovascular surgery because of the risk of intracerebral bleeding caused by anticoagulant therapy during cardiovascular surgery (Class IIb; Level of Evidence B).

7. The use of a bioprosthetic cardiac valve instead of a mechanical valve may be considered because of the long-term requirements for anticoagulant therapy with mechanical prostheses and the risk of CNS bleeding (Class IIb; Level of Evidence C).

Prognosis

It is difficult to draw valid conclusions concerning the outcome of patients with ICMA, for many reasons: (1) ICMA is a relatively rare condition, and there are no controlled studies. (2) Reviews of reported series often span decades during which radiologic modalities, interventional techniques, microvascular surgery, and management of underlying conditions evolved and improved over time. (3) The analysis of cases is subject to bias in uncontrolled studies and variations in management among individual institutions. (4) Some patients might have been considered unsuitable candidates for EVT or neurosurgery, resulting in higher-risk patients requiring antimicrobial therapy alone, which could impact mortality rates from antimicrobial therapy alone. (5) Some patients present with sudden, often catastrophic or fatal hemorrhage from rupture of undiagnosed ICMA that may have responded to therapy if diagnosed before rupture.

Given the above limitations in analysis of outcome data, it is clear that ICMA is a serious life-threatening condition with a high mortality. Reported mortality rates have ranged widely from 12% to 90% depending on rupture, underlying condition, virulence of the underlying infection, and other factors.

There are certain factors that have consistently influenced outcome. Patients who have rupture of an ICMA have worse outcomes than those who do not.

Patients with multiple ICMAs have worse outcomes than those with a single ICMA. Mortality was significantly higher for older people and for those with meningitis and ICMA located in the vertebrobasilar territory. Mortality of ICMA is reportedly higher in association with meningitis than with IE. This higher mortality with meningitis could be because ICMAs are more often located in the vertebrobasilar territory with higher frequency of stroke, are more proximal, and are more likely to bleed. In contrast, ICMAs associated with IE are more often in the carotid territory, are more often distal and probably less likely to bleed, and are more likely to respond to antimicrobial therapy. Fungal ICMA, especially aspergillus, is associated with a high mortality rate that approaches 90% to 100%.

Most series, the size of the ICMA did not influence outcome, nor did it predict the likelihood of rupture.

Because of the small number of diverse patients in uncontrolled noncomparative studies, it is not possible to draw valid conclusions about outcomes comparing results of antimicrobial therapy alone with EVT or with neurosurgery. There appears to be a trend among published studies that shows lower mortality with EVT-treated patients (7%–61%) than with antibiotic therapy alone (20%–83%). Mortality after neurosurgery is higher than with antibiotic drugs alone or with EVT, but this likely reflects the selection of patients for neurosurgery who more often had rupture with increased intracranial pressure from mass effect, or that the neurosurgery was performed as the last option in a desperately ill patient with a predicted high mortality independent of the neurosurgical procedure.

Finally, patients with ICMA usually have serious underlying infections that independently are associated with a relatively high mortality. Control of the underlying infectious disease must be the first objective for successful management of ICMA. Cardiac failure associated with severe native valve or prosthetic valve infection, multiorgan failure, and multiple comorbidities are common in patients.
with ICMA, and these factors could be the most important determining factors in the outcome of patients with ICMA.

**Thoracic and Abdominal Aortic MAs**

Thoracic and abdominal aortic MAs are relatively uncommon and account for 0.7% to 4.5% of all aortic aneurysms. The most common locations are in the abdominal aorta (=70%) and thoracic aorta (=30%); visceral MAs are rare (accounting for <1%).

Because most intra-abdominal MAs occur in patients with severe atherosclerosis, men predominate over women by 3:1. The average age is >65 years, and there is a strong association with cigarette smoking and diabetes mellitus. Eight-five percent of atherosclerotic aneurysms are located in the infrarenal segment, whereas most aortic MAs are located in the suprarenal portion of the aorta. Thoracic MA is often associated with recent reconstructive aortic surgery, IE, or prosthetic valve endocarditis.

Renal transplant recipients can develop MA related to perinephric infections. Among 640 renal transplant recipients over 8 years at the University of Minnesota, 8 (1%) developed MAs, and 6 of these 8 occurred in the external iliac artery.

**Pathogenesis**

The pathophysiology of aortic MA is somewhat different from ICMA or peripheral MA. The 5 mechanisms for the development of aortic MA are as follows: (1) The normal intima of the aorta is quite resistant to infection. If the intima is damaged by atherosclerosis or the development of plaques or ulcers, the damaged endothelium can be colonized and infected during bacteremia with the development of an infected atherosclerotic aneurysm. (2) Infection can occur as a result of either bacteremic or contiguous spread of infection to the vasa vasorum. The infection then proceeds inward toward the vessel wall, causing a localized infection with thinning of the vessel wall and the development of an MA. (3) Infection can result from contiguous spread from a gastrointestinal source, such as gastroenteritis, especially caused by Salmonella nontyphoidal species or by extension from vertebral osteomyelitis. This leads to the development of a primary abdominal aortic MA or, less commonly, a secondary MA involving a preexisting atherosclerotic aneurysm. (4) Infection of the ascending or descending aorta can develop as a result of damage to the endothelium resulting from a congenital abnormality, such as cystic necrosis or coarctation, which makes the blood vessel more susceptible to infection from bacteremia or contiguous spread. (5) MA in the sinus of Valsalva or the aortic arch may be associated with reconstructive surgery, IE, or prosthetic valve endocarditis. A sinus of Valsalva MA is most common in the right or noncoronary sinus and can rupture into the right ventricle, right atrium, or pericardial sac with tamponade or cause coronary artery occlusion.

**Microbiology**

The microbiological spectrum of aortic MA is evolving and may depend on geographic conditions. Staphylococci, including *S aureus* and coagulase-negative staphylococci, in recent years have emerged as the most common cause of aortic MA and account for roughly 50% to 60% of cases. Previously, gram-negative bacilli, especially nontyphoidal Salmonella, were more common than staphylococci, but now they account for at least 30% to 40% of cases.

*Salmonella enteritidis, Salmonella choleraesuis,* and other nontyphoidal strains are more common causes of abdominal aortic MA in Asia. *Salmonella* nontyphoidal strains have a special predilection to infect vascular tissue. The mechanism for this is poorly understood. The presumed portal of entry is the gastrointestinal tract. Translocation of *Salmonella* species or transient bacteremia is thought to gain access to the aorta through plaques associated with atherosclerotic disease. Lumbar spine osteomyelitis has been reported to be present in up to one-third of patients with aortic MAs caused by Salmonella species. *S enteritidis* was recovered in 40% of cases and *S choleraesuis* in 32%. Approximately 25% of patients aged ≥50 years with *Salmonella* species bacteremia have an endovascular focus of infection.

Other gram-negative bacilli can also cause aortic MA. *Arizona* species, especially *A hinshawii,* cause gastroenteritis and other infectious diseases similar to those of *Salmonella* species and can infect the abdominal aorta, especially in elderly diabetic men with a history of cigarette smoking and atherosclerotic peripheral vascular disease. Many other species of gram-negative bacilli, anaerobic microorganisms, and occasionally *Candida* and other fungi have been reported to cause infection of atherosclerotic aneurysms. *Listeria monocytogenes* is a cause of gastroenteritis and has been reported to cause endovascular infections, including aortic MA. *Mycobacterium tuberculosis* rarely causes aortic MA, probably as a result of erosion of the aortic wall from a contiguous focus, most often from vertebral osteomyelitis.

**Clinical Presentation**

The clinical findings associated with intra-abdominal aortic MA are nonspecific. The classic triad of fever, pain, and a pulsatile abdominal mass reported in previous studies is actually rather uncommon. In patients with intra-abdominal MA, fever is present in ≥70% of patients and is uncommon in patients with uninfected atherosclerotic abdominal aneurysms. Back pain is present in at least 65% to 90% of cases and less commonly occurs in patients with uninfected atherosclerotic aneurysms. It can be difficult to differentiate inflammatory, noninfected
abdominal aortic aneurysms from an MA. Inflammatory abdominal aortic aneurysms account for 5% to 10% of all abdominal aortic aneurysms.\textsuperscript{210,211} Inflammatory abdominal aortic aneurysms usually occur in older men with a history of cigarette smoking or diabetes mellitus, but fever is less common than with MA. An aortoenteric fistula and MA should be suspected in patients with a recent or remote abdominal aortic aneurysm repair. These patients can have a long asymptomatic period before the onset of the current illness.\textsuperscript{212} Up to 4% of patients who have undergone repair of abdominal aortic aneurysm develop aortoenteric fistulae.\textsuperscript{213}

Intrathoracic MAs usually present with fever, chest and interscapular pain, and findings commonly seen in patients with IE, prosthetic valve endocarditis, or infection involving an ascending or descending thoracic aorta.\textsuperscript{9,125,191}

Superior mesenteric aneurysms account for only 8% to 10% of visceral artery aneurysms, but when they occur, they are usually an MA.\textsuperscript{214} They often cause abdominal pain that can be acute, and they can be associated with fever and, rarely, a palpable pulsatile mass in the epigastrium. Gastrointestinal hemorrhage can occur and can be catastrophic.\textsuperscript{163,214,215} Hepatic artery MAs are less common than visceral artery aneurysms and can present with fever, colicky upper abdominal pain, hemobilia, jaundice, and gastrointestinal hemorrhage.\textsuperscript{215} Renal artery MAs are uncommon and usually present with fever, hematuria, and elevated blood pressure.\textsuperscript{216}

A complete or contained rupture of an intrathoracic or intra-abdominal MA occurs in at least 50% to 75% of patients. These MAs rupture into the retroperitoneal or peritoneal space (50%), duodenum (12%), pleural cavity (10%), esophagus, mediastinum, or pericardium in 3% to 5% of cases.\textsuperscript{9,125,163,217} An impending or contained rupture can be associated with severe pain, hemodynamic instability, or a sudden, catastrophic rupture with shock and a high mortality.\textsuperscript{9,125,163}

**Diagnosis**

The diagnosis of aortic MA depends on an index of suspicion in a susceptible host; recognition of the clinical presentations and physical findings; laboratory test results, including blood cultures; and imaging. The susceptible history, clinical, and physical findings are discussed in Clinical Presentation.

**Laboratory Findings**

There are no laboratory test results that are specific for aortic MA. Patients with aortic MA usually have leukocytosis (65%–85% of cases) and elevated inflammatory markers such as erythrocyte sedimentation rate or C-reactive protein (75%–80%); however, noninfected inflammatory abdominal aortic aneurysms also have these findings. Unlike noninfected inflammatory abdominal aortic aneurysms, MAs have positive blood cultures in 50% to 90% of cases; however, many patients with MA have received recent antibiotic therapy, and blood cultures are negative in 25% to 50% of these patients.

Blood cultures can remain positive in patients with aortic MA despite antibiotic therapy. Sustained bacteremia is characteristic of endovascular infection. In a patient with gastrointestinal bleeding, sustained polymicrobial bacteremia caused by aerobic and anaerobic microorganisms, often with Candida, that persists despite appropriate antibiotic therapy suggests a fistulous communication between the abdominal aorta and the third portion of the duodenum.\textsuperscript{94,213,218}

Sustained bacteremia caused by certain microorganisms has a high association with endovascular infection, including MA. The mere presence of these microorganisms in multiple positive blood cultures suggests that endovascular infection must be excluded before an alternative source of bacteremia is considered. Sustained Salmonella nontyphoidal bacteremia in a patient with abdominal aortic aneurysm is highly suggestive of arteritis or MA.\textsuperscript{200–203} Sustained Salmonella nontyphoidal bacteremia can cause distal site infection, including vertebral osteomyelitis, septic arthritis, hepatic abscess, or other infection, but these distal infections are usually the result of Salmonella endovascular infection, not the cause of the endovascular infection. In addition to positive blood cultures, stool cultures can also be positive for nontyphoidal Salmonella.

Multiple positive blood cultures for Streptococcus labirotrophia (nutritionally variant viridans streptococci) or HACEK microorganisms are highly suggestive of endovascular infection.\textsuperscript{169} Patients with sinus of Valsalva aneurysm or thoracic aortic aneurysm and multiple positive blood cultures for these microorganisms should be considered to have IE with MA until proven otherwise.

**Imaging**

Because clinical findings and routine laboratory test results are nonspecific, imaging plays a critical role in the rapid diagnosis and management of aortic MA. Among imaging modalities, CTA is reasonable as the initial imaging procedure of choice for aortic aneurysm.\textsuperscript{148,163,192,219} Findings on CTA are important to differentiate abdominal MA from a noninfected bland atherosclerotic aortic aneurysm.\textsuperscript{9,102,125,163,191,219}

CTA allows for rapid examination in a patient who may be unstable and require urgent surgical intervention. CTA defines the precise location, can detect impending rupture, defines vascular anatomy for reconstructive surgery, identifies associated complications, and provides serial imaging to monitor expanding or unstable aneurysms. The major disadvantage is the potential for contrast-induced kidney injury in patients who often have multiple underlying comorbidities for renal disease.

Table 5 shows findings on CTA that are helpful for the diagnosis and management of aortic MA.\textsuperscript{148,163,191,192,219} The typical appearance is a saccular aneurysm with an
irregular lobular contour. Absent or minimal calcification is suggestive of MA. Others, however, have reported that calcium was frequently present and was not helpful to differentiate an MA from an atherosclerotic aneurysm. However, the majority of studies suggest that absence of calcium is more often seen in MA than in atherosclerotic aneurysms. Mural thrombi were reported more frequently with atherosclerotic aneurysm.

Periortic soft tissue stranding, fluid, a concentric inflammatory response, and contiguous mass are commonly seen in aortic MAs. Although uncommon, the presence of periortic gas confirms the diagnosis of MA. The association of adjacent vertebral body abnormalities was reported by McHenry et al, who viewed 70 cases of vertebral osteomyelitis and MA.

Rapid enlargement of MAs and an enlarging periortic inflammatory mass or hematoma are ominous signs of contained or impending rupture. These findings suggest urgent surgical intervention.

There are a limited number of published studies using MRI, MRA, DSA, PET/CT, or nuclear medicine scans for the diagnosis of aortic MA. Compared with CTA, MRA requires longer examination time, is susceptible to motion artifact, has lower spatial resolution, and has smaller volume imaging cover. These imaging modalities may be useful in selected patients, but there are insufficient published data to recommend their routine use for diagnosis. Conventional arteriography is rarely useful diagnostically. Ultrasonography has limited utility for aortic MA. Transesophageal echocardiography is reasonable in patients with MA of the sinus of Valsalva and thoracic aortic MA.

### Recommendations for Imaging and Diagnosis of Aortic MA

1. CT or CTA is reasonable as the initial imaging modality for diagnosis (Class Ila; Level of Evidence B).

2. Transesophageal echocardiography or cardiac MRI is reasonable for diagnosis of sinus of Valsalva or thoracic MA (Class Ila; Level of Evidence B).

### Management of Patients With Intrathoracic or Intra-Abdominal MA

There are no published randomized prospective studies for the medical management of patients with intrathoracic or intra-abdominal MA, nor is it likely there will be. There are a number of reasons why such studies would be difficult to accomplish. (1) Intrathoracic and intra-abdominal MAs are rare diseases. (2) Randomized, multicenter controlled studies would require many years to accrue sufficient patients and would likely require participation of multiple centers throughout the world. (3) Standardization would be difficult if not impossible in a population of patients that is highly diverse, who have multiple underlying comorbidities, and for whom there are global and regional differences in microbiological cause, variable availability of technical equipment for diagnosis, and differences in experience and expertise of medical and surgical subspecialties. (4) During the long time period necessary to complete such a study, new techniques and innovations would likely be introduced that could make the treatment options obsolete or possibly even hazardous.

Not surprisingly, there is no consensus among authorities on the optimal management of these patients. Most published studies contain a relatively small number of patients and a review of the literature or are expert opinion or single-case reports. The few studies that contain relatively larger numbers of patients might span 2 decades or longer and contain diverse patient populations without standardized therapy. The following represents what we believe may be considered for the management of patients with intrathoracic or intra-abdominal MA and is based on our review of published literature and the collective opinion and personal experience of this writing group. Intrathoracic or intra-abdominal MAs are life-threatening infections with a high morbidity and mortality. We believe the choice of medical and surgical man-

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**Table 5. Computed Tomographic Imaging Characteristics of Aortic Mycotic Aneurysm Compared With Atherosclerotic Aneurysm**

<table>
<thead>
<tr>
<th>Location, %</th>
<th>Mycotic</th>
<th>Atherosclerotic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aortic</td>
<td>30–40</td>
<td>15–20</td>
</tr>
<tr>
<td>Suprarenal</td>
<td>5–15</td>
<td>5–7</td>
</tr>
<tr>
<td>Infrarenal</td>
<td>15–25</td>
<td>75–90</td>
</tr>
<tr>
<td>Shape</td>
<td>Lobular, irregular, sacular</td>
<td>Fusiform &gt; sacular</td>
</tr>
<tr>
<td>Intimal calcifications</td>
<td>Less common, but can occur</td>
<td>Common</td>
</tr>
<tr>
<td>Mural thrombosis</td>
<td>Uncommon</td>
<td>Common</td>
</tr>
<tr>
<td>Evolution</td>
<td>Rapidly changing</td>
<td>Chronic, stable</td>
</tr>
<tr>
<td>Periortic findings</td>
<td>Common</td>
<td>Uncommon</td>
</tr>
<tr>
<td>Stranding, encasing or contiguous mass</td>
<td>Concentric inflammation</td>
<td>Hematoma, gas*</td>
</tr>
</tbody>
</table>

*Presence of gas is uncommon, but if visible, it is highly suggestive of mycotic aneurysm.

Data derived from Chen et al, Lee et al, Macedo et al, Colin et al, and Lin et al.

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**References**

9, 125, 163, 191, 219, 224–226.
management should be individualized for each patient and should be executed via a team approach that involves experts in vascular diseases and surgery, cardiology and cardiovascular surgery, diagnostic and interventional radiology, critical care medicine, infectious diseases, and microbiology in a facility with access to these experts and services on an emergency basis.

The therapeutic options include a combination of antimicrobial therapy, open vascular surgery, EVT, and a combination or hybrid technique of open surgery together with EVT.

Antimicrobial Therapy

The choice of antimicrobial therapy should be based on the identification and susceptibilities of the specific microorganism, and if possible, bactericidal therapy should be administered. The choice of a specific antimicrobial agent is beyond the scope of this document. Depending on whether these patients have received prior antimicrobial therapy, blood cultures may be positive in only 40% to 50% of patients, and intraoperative tissue cultures may be negative in one-third of patients; therefore, empiric therapy is often necessary. Most authorities believe at least 6 weeks to 6 months of antimicrobial therapy postoperatively may be considered. In some cases, lifelong suppressive antimicrobial therapy may be considered and individualized for each patient. The selection of patients for 6 weeks to 6 months or lifelong suppressive therapy is discussed in Treatment.

Antimicrobial therapy used alone for the treatment of aortic MA has been reported to have an associated mortality rate of 60% to 100%. The use of antimicrobial therapy alone may be considered only in patients who are unfit for surgery or who refuse surgery or EVT, or for palliative care.

Recommendations for General Principles of Management and Antimicrobial Therapy for Patients With Aortic MA

1. Patients should be managed by a team of experts in vascular diseases and surgery, cardiology and cardiovascular surgery, critical care medicine (intensivists), radiology, infectious diseases, and microbiology in a facility with emergency access to these services (Class I; Level of Evidence C).

Antimicrobial Therapy

1. A duration of 6 weeks to 6 months of antimicrobial therapy may be considered (Class IIb, Level of Evidence B); in some cases, lifelong suppressive therapy may be considered (Class IIb; Level of Evidence B).

2. Antimicrobial therapy alone may be considered only for patients who are unfit for surgery or who refuse surgery or EVT, or for palliative care (Class IIb; Level of Evidence B).
Vascular Infections

CLINICAL STATEMENTS AND GUIDELINES

Options for Management

The choice and timing of an optimal procedure should be individualized and depend on a number of factors. These include rupture or impending rupture, presence of an enterovascular fistula, response to initial antimicrobial therapy, single or multiple MAs, location of MA (intrathoracic or intra-abdominal), presence of gross purulence surrounding the MA or adjacent vertebral infection, and underlying comorbidities.

The options for management include open surgical resection with extra-anatomic revascularization or in situ reconstruction, EVT, or a combination of these procedures. For MAs located in the thoracic or suprarenal aorta, extra-anatomic revascularization and resection of the MA are usually not technically feasible. In these patients, the options are resection of the MA and in situ reconstruction, EVT, or a combination of these procedures. An algorithm that may be considered for the management of intra-abdominal MAs is shown in Figure 8.

Open Surgical Resection With Extra-Anatomic Revascularization. Numerous studies have reported results of resection and extra-anatomic revascularization compared with in situ reconstruction in patients primarily with infrarenal aortic MA, which was once considered to be the surgical procedure of choice for patients with aortic MA.*** There are no published randomized controlled studies that compare in situ with extra-anatomic reconstruction. Although in selected patients, resection and extra-anatomic revascularization may be appropriate, for the majority of patients, resection and in situ revascularization rather than extra-anatomic reconstruction are reasonable.††† Table 6 shows the advantages and disadvantages of in situ versus extra-anatomic reconstructions.

For the surgical management of infrarenal aortic MA, extra-anatomic revascularization followed by resection may be considered only for the following selected patients: (1) those with the presence of gross pus in the intraoperative field, (2) those with retroperitoneal or psoas abscess, (3) those with adjacent vertebral osteomyelitis, (4) those with inadequate response preoperatively to antimicrobial therapy with persistence of fever and signs of sepsis, and (5) selected patients with aortoenteric fistula. One study201 suggested that patients with nontyphoidal Salmonella infection should be treated with resection and extra-anatomic reconstruction. In this report of 92 patients, the survival rate was 71% for patients treated

### Table 6. Management of Aortic Mycotic Aneurysm: Comparison of Resection and Extra-Anatomic Reconstruction, In Situ Reconstruction, or Endovascular Device Repair

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Potential Indications*</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra-anatomic reconstruction</td>
<td>Infra-renal location with gross purulence, psoas or retroperitoneal dosing, vertebral osteomyelitis, inadequate response to antibiotic therapy, selected aortoenteric fistulae</td>
<td>Avoids placement of foreign body in infected area</td>
<td>Not technically feasible for thoracic, suprarenal, or visceral location or for emergency use Long operating time Long-term patency rates low Stump blowout Limb is ischemic, amputation Reinfection rate higher than for in situ reconstruction Ischemic colitis</td>
</tr>
<tr>
<td>In situ reconstruction</td>
<td>Thoracic, suprarenal, infra-renal, or visceral location Selected aortoenteric fistulae</td>
<td>More versatile than extra-anatomic: Fewer long-term complications, higher patency rates, lower recurrent infection rate, shorter operating time Polyester grafts† available for emergency surgery Selected aortoenteric fistulae</td>
<td>Theoretical risk of infection because of interposition of foreign material in infected site</td>
</tr>
<tr>
<td>Endovascular device repair</td>
<td>Bridge procedure‡: hemodynamic instability, uncontrolled bleeding, rupture or impending rupture, selected patients with aortoenteric fistulae, patients who are not fit for open surgery</td>
<td>Emergency stabilization Low early morbidity, mortality Less invasive No cross-clamping of aorta: spinal cord injury, reperfusion injury</td>
<td>Persistent infections and device infections Higher long-term morbidity, mortality with device retention Requires device explantation, reconstruction</td>
</tr>
</tbody>
</table>

*Potential indication; must be individualized for each patient.
†Polyester grafts, rifampin soaked or silver coated; less experience reported with cryopreserved arterial allografts or venous autografts.
‡Bridge procedure, used to stabilize patients until device explantation and arterial reconstruction.

***References 102, 163, 189, 195, 212, 217, 227, 232-234.
†††References 9, 11, 27, 102, 106, 125, 189, 195, 217, 227, 235.
with resection and extra-anatomic reconstruction compared with 51% of those treated with in situ reconstruction.\textsuperscript{201} Nontyphoidal Salmonella infection occurs more commonly in Asian and southeast Asian countries than in Western countries.

The disadvantages of extra-anatomic reconstruction are the relatively high rate of vascular complications outlined above. Extra-anatomic revascularization is usually not technically feasible with suprarenal or thoracic MA or in patients with rupture or impending rupture.\textsuperscript{9,11,27,106,125,189}

**Open Surgical Repair With In Situ Reconstruction.** Many studies have reported results of resection of an infected aortic MA with in situ reconstruction, and this has become the procedure of choice for most patients with aortic MA.\textsuperscript{‡‡‡}

The major advantages of in situ over extra-anatomic reconstruction are the following: (1) Rifampin-soaked polyester or other conduits are readily available, especially in patients with rupture or impending rupture who require urgent surgical intervention. (2) For technical reasons, in situ reconstruction is more versatile than extra-anatomic reconstruction for thoracic, suprarenal, or visceral artery MA; the latter requires renal and visceral artery revascularization. (3) There are fewer long-term complications, such as limb amputation, aortic stump rupture, and recurrent infection. (4) Selected patients with aortoenteric fistulae have a lower risk of complications. (5) Higher long-term survival rates have been achieved. The major theoretical disadvantage of in situ reconstruction is the potential risk of reinfection because a foreign body material is used as an interposition graft in infected vascular tissue, often with surrounding purulence (Table 6).

In numerous studies, recurrence or persistence of infection after in situ reconstruction is low.\textsuperscript{§§§} The relatively low rate of infection could be related to a number of factors. Polyester grafts are often coated in rifampin or are silver impregnated, which can decrease the risk of infection. The use of autogenous venous grafts or cryopreserved arterial allografts can reduce the risk of infection in patients with VGI surgery. Although there are limited data, the use of these grafts could also reduce the risk of infection in patients with MA and in situ reconstruction. In addition, the operative bed is meticulously debrided and the in situ graft wrapped with omentum, which increases the vascular supply, eliminates dead space, and protects the graft from the infected bed.\textsuperscript{66,102,237} Finally, the relatively low rate of infection associated with in situ reconstruction may in part reflect patient selection. Extra-anatomic reconstruction is often preferred in patients who would be expected to have a higher risk of recurrent infection.

It is difficult to compare accurately the postoperative reinfection rates associated with in situ compared with extra-anatomic reconstruction because of the relatively small number of patients in comparative noncontrolled studies, nonstandardized antimicrobial therapy, patient variables, and selection bias. Reported reinfection rates associated with in situ reconstruction have ranged from 0% to 22%.\textsuperscript{§§§} In a literature review, Kyriakides and colleagues\textsuperscript{105} reported that 20% of patients with in situ reconstruction eventually required reoperation and extra-anatomic revascularization because of infection. However, the majority of studies suggest a trend toward higher infection rates associated with extra-anatomic compared with in situ reconstruction.\textsuperscript{125,189,236}

It is difficult to draw valid conclusions regarding complications and outcomes in patients treated with in situ versus extra-anatomic reconstruction. Most studies comparing in situ with extra-anatomic reconstruction contain a preponderance of patients treated with either in situ or extra-anatomic reconstruction. There is considerable selection bias, the study period was often >2 decades long, and the patient populations were quite diverse. Recently reported studies of patients with infrarenal MA offer the best opportunity to compare outcomes, because there are relatively larger numbers of patients in each treatment group. Lee et al\textsuperscript{189} reported 28 patients with infrarenal MA; 13 had in situ repair, and 15 had extra-anatomic reconstruction. Perioperative mortality among in situ and extra-anatomic reconstruction was 8% and 27%, respectively (P=NS). Early or late vascular complications occurred in no patients with in situ reconstruction and in 53% of patients with extra-anatomic surgery (P=0.44). Among patients who survived initial hospitalization, the long-term results were similar in both groups. Other studies have reported complications associated with extra-anatomic reconstruction that include stump disruption (8%–19%), limb amputation (17%–27%), and reinfection (8%–22%).\textsuperscript{125,189,195,217,227,236} In summary, a strategy of resection and in situ reconstruction is reasonable for most patients with thoracic, suprarenal, or visceral artery MA and in selected patients with infrarenal MA. For patients with infrarenal MA with gross purulence, retroperitoneal or psoas abscess, adjacent vertebral abscess, and possibly Salmonella nontyphoidal infection, extra-anatomic revascularization and resection may be considered.

**Endovascular Treatment.** EVT of abdominal aortic aneurysm was first reported in 1986 and is now widely used for noninfected aortic aneurysms.\textsuperscript{238} Semba et al\textsuperscript{239} were the first to report successful EVT of thoracic aortic MA in 1998. Since that initial report, numerous studies...
have reported the use of EVT for aortic MA. Kan et al.\textsuperscript{197} reported 41 cases of abdominal aortic MA; 20 patients were treated with EVT and 21 with open surgical therapy. Mortality at 1 month was 5% in both groups of patients; however, mortality at 2 years was 10.5% in the EVT group compared with 45% in the open surgical group (P<0.05). At 24 months, among survivors, the aneurysm-related event-free rates were 78% and 80%, respectively, in the EVT and open surgical groups. Risk factors that predicted poor outcome with EVT were persistent signs of sepsis preoperatively despite appropriate antimicrobial therapy and the presence of an aortoenteric fistula. In this study, EVT itself was not a predictor of a poor outcome.

In an earlier meta-analysis of 22 reports of 48 patients with thoracic or abdominal aortic MA, these authors observed a 30-day survival rate of 90% and a 2-year survival rate of 82% with EVT.\textsuperscript{199} Risk factors that predicted a poor outcome were persistent preoperative sepsis, aortoenteric fistula, and rupture, which were similar to those observed in the later study by Kan et al.\textsuperscript{198} Factors that were associated with favorable outcome were antibiotic therapy administered for at least 1 week preoperatively and the placement of image-guided drains to treat infection before EVT.\textsuperscript{198,199,240}

Razavi and Razavi\textsuperscript{241} reported a literature review of 52 articles concerning 91 patients with aortic MA treated with open surgical repair or EVT. Among patients treated with open surgical treatment, the 30-day mortality rate was 11% to 43% compared with 5.6% after EVT. However, late mortality and complication rates were higher with EVT (20%) than with open surgery (3%–14%). Factors that were associated with unfavorable outcome were antibiotic therapy administered for at least 1 week preoperatively and the placement of image-guided drains to treat infection before EVT.\textsuperscript{198,199,240}

Vallejo et al.\textsuperscript{190} reported 19 aortic MA in 17 patients; 12 of them had thoracic MAs, and 5 had abdominal MAs. In situ reconstruction can be technically difficult in patients with thoracic or suprarenal MA. In patients with acute rupture, EVT can be a life-saving bridge procedure to later open surgical repair. After initial placement of the EVT device, explantation of the device and open surgical resection may be considered for patients with aortic MA who have the following complications: rupture to later open surgical treatment in patients with aortic MA who have the following complications: rupture with unstable hemodynamics, uncontrolled bleeding associated with aortoenteric or aortobronchial fistula, or concurrent comorbid conditions associated with a high operative risk of morbidity and mortality, which makes them unfit for open surgical repair. In these 3 groups of selected patients, EVT may be a life-saving procedure to stabilize patients and serve as a bridge to open surgical treatment. After initial placement of the EVT device, explantation of the device and open surgical resection of the aortic MA and reconstruction may be considered in patients who can tolerate an open procedure.\textsuperscript{189,227,228,241–248} There is insufficient data to recommend EVT as the procedure of choice for patients with aortic MA (Figure 8).

**Recommendations for Surgical or Endovascular Management of Patients With Aortic MA:**

**Open Surgical Resection With Extra-Anatomic Revascularization**

1. For the majority of patients with aortic MA, resection and in situ revascularization rather than extra-anatomic revascularization and resection is reasonable (Class IIa; Level of Evidence B).

2. Extra-anatomic revascularization followed by resection may be considered for patients with infrarenal MA only for the following (Class IIb; Level of Evidence C):
   a. gross pus in the operative field,
   b. retroperitoneal or psoas abscess,
   c. adjacent vertebral osteomyelitis,
   d. inadequate response to preoperative antimicrobial therapy, or
   e. aortoenteric fistula.
3. Endovascular therapy
   a. EVT may be considered as a bridge therapy to later open surgical management in these patients (Class IIb; Level of Evidence C):
      i. those with rupture with unstable hemodynamics,
      ii. those with uncontrolled bleeding with aortoenteric fistula or aortobronchial fistula, or
      iii. those who are unfit for open surgical repair because of underlying comorbid conditions.
   b. After initial placement of the endovascular device, removal of the device, resection of the aortic MA, and aortic reconstruction may be considered (Class IIb; Level of Evidence C).

Additional Factors in Management of Aortic MA

There are a number of specific circumstances that should be considered in the management of selected patients. These include rupture, aortic fistulae (enteric, bronchial, or esophageal), visceral artery MA, and removal of the endograft device after EVT.

Rupture. Rupture is the most serious life-threatening complication of aortic MA and has been reported to occur in 50% to 85%. Free rupture occurs less commonly than a contained rupture, and either free or contained rupture has been associated with a higher mortality rate than unruptured MA in numerous reports. Weis-Müller et al reported a 90-day mortality rate among 66 patients treated for aortic MA. All patients with free rupture died, and the mortality rate (42%) for free or contained rupture was significantly higher (P<0.05) than for patients whose aneurysms did not rupture. This experience was similar to that observed in numerous other studies.

Free rupture with hemodynamic instability represents a surgical emergency. There may not be sufficient time or the patient may be too unstable for open surgery. In patients with free or contained rupture, EVT may be considered to stabilize hemodynamics and as a bridge to subsequent open in situ repair (Figure 8).

Recommendation for Management of Rupture or Contained Rupture of Aortic MA

1. Endovascular device therapy may be considered in patients who are unstable hemodynamically or who are unable to tolerate an open surgical procedure as a bridge procedure to later open surgical repair (Class IIb; Level of Evidence C).

Fistulous Communication. Aortofistulous communications are uncommon or rare life-threatening complications of aortic vascular surgery and vascular infections. In decreasing order of frequency, fistulous communications occur with (1) the bowel lumen, usually the third portion of the duodenum; (2) bronchus; and (3) esophagus.

Aortoenteric Fistulae With Duodenum. Primary aortoenteric fistulae into the duodenum associated with aortic MA are less common than are secondary aortoenteric fistulae, which result from erosion of an aortic vascular graft placed for repair of abdominal aortic aneurysm or occlusive disease. Aortoenteric fistula, which occurs at the suture line, occurs in up to 4% of patients after repair of abdominal aortic aneurysm. Aortoenteric fistula was first reported by Brock in 1953. Herberer reported the first successful repair. Since that initial report, numerous authors have reported treatment with either open surgical repair or EVT.

Patients with aortoenteric fistulae present with sepsis and polymicrobial bacteremia with blood cultures containing bowel flora and may have acute, potentially life-threatening gastrointestinal bleeding. Imaging procedures for the diagnosis of aortoenteric fistula are discussed in the section on VGI. Aortoenteric fistulae are a life-threatening condition requiring emergency intervention with either open surgical reconstruction or EVT. The immediate goals for management are control of gastrointestinal bleeding to stabilize hemodynamics, maintenance of distal arterial perfusion, and control of infection. Open surgical reconstruction can achieve these goals but is associated with a high morbidity and mortality and with VGI. EVT for treatment of aortoenteric fistula was first described by Oliva et al and Summar and colleagues.

The selection of open reconstructive surgery, EVT, or a combination of both must be individualized for each patient. In a multicenter study with a small number of patients, Kakko et al compared EVT (8 patients) and open surgical repair (17 patients). In this study, there were no in-hospital deaths after EVT, compared with a 35% in-hospital mortality rate among patients who underwent open repair (P=NS). Morbidity was significantly (P<0.028) higher after open repair (77%) than with EVT (25%). Morbid complications included recurrence of gastrointestinal bleeding, ischemic limb, and limb loss. Among surviving patients, the early advantages of EVT over open surgery were not sustained after surgery. Among EVT-treated patients compared with open surgery, the postprocedure rates of events were recurrence of fistulae 49% and 22%, sepsis 72% and 30%, reoperation 70% and 36%, and survival 15% and 38%, respectively. The number of preoperative symptoms (2 versus 1) was the most important factor in predicting outcome.
These authors concluded that EVT may be useful as a bridge therapy to open surgical repair to control acute complications such as gastrointestinal bleeding and hemodynamic instability. The morbidity and mortality were higher in patients when the EVT device was not removed and open reconstruction was not performed. Similar experience with short- and long-term outcomes associated with EVT and open repair for aortoenteric fistula were reported by Lew et al.244 and Antoniou and colleagues.243

EVT may be considered as a bridge to open surgical repair of aortoenteric fistula. The advantages of EVT over open surgical repair in select patients may include lower early morbidity and mortality, emergency control and stabilization of gastrointestinal bleeding and hemodynamics, its reduced degree of invasiveness and better tolerance in older patients with multiple underlying comorbidities, and avoidance of aortic cross-clamping with its physiological consequences, including potential spinal cord injury and reperfusion injury. The major disadvantages of EVT are persistence of infection and higher long-term morbidity, including limb loss and mortality.

Figure 8 shows an algorithm that may be considered in patients with aortoenteric fistula. There are insufficient published data in a small number of patients with aortoenteric fistulae to draw valid conclusions regarding the duration of postoperative antibiotic therapy with either in situ repair or EVT. In either case, a foreign body is placed in an area of high-grade infection at the site of aortoenteric fistula. Because the risk of recurrent infection and morbidity and mortality are high, after an initial period of 6 to 8 weeks of parenteral antibiotic therapy, lifelong suppressive therapy may be considered.213,248,253 Infections of transcutaneous aortic valve or transpulmonary valve replacements are considered prosthetic valve infections. The diagnosis and management of these infections are outside the scope of this statement and are addressed in another scientific statement or guideline.

**Recommendations for Management of Aortoenteric Fistula With Duodenal**

1. Endovascular therapy may be considered as a bridge to open repair (Class IIb; Level of Evidence C).
2. After an initial period of 6 weeks to 6 months of antimicrobial therapy, lifelong suppressive therapy may be considered, especially in patients with a retained EVT device (Class IIb; Level of Evidence C).

**Aortobronchial Fistula.** Aortobronchial fistula is a rare condition with a fistulous communication between the thoracic aorta and the adjacent tracheobronchial system.213,256-258 Aortobronchial fistula can occur in association with MA, atherosclerotic aneurysm, trauma, or other causes.256-258 Clinically, these patients present with sepsis and hemoptysis that may be intermittent or massive with possible exsanguination. There are no specific diagnostic tests, but aortobronchial fistula should be suspected in patients with underlying risk factors, sepsis, and hemoptysis. CTA may not demonstrate a definite fistulous communication, but the presence of periaortic gas bubbles in an at-risk patient is suggestive of the diagnosis. Angiography or bronchoscopy may demonstrate a fistula but must be performed with extreme caution, because the procedure could potentially dislodge a clot occluding a fistula and induce massive, possibly fatal hemorrhage.213,259,260

A high index of suspicion is vital for an accurate and prompt diagnosis of aortobronchial fistula.

If untreated, the mortality rate is virtually 100%. Despite the advantages in surgical techniques, open in situ repair has a high mortality, ranging from 15% to 41%.213,257 The high mortality rate associated with in situ repair is related to thoracotomy in a critically ill patient, cross-clamping of the descending aorta with possible spinal cord injury or reperfusion injury, and complications including rupture from in situ repair or attempts at arterial bypass.213,257,259

Chuter et al.261 first reported thoracic endovascular aortic repair (TEVAR) in 1996. Bailey et al.257 reported 11 patients with TEVAR, which represents the largest series of patients treated with TEVAR for aortobronchial fistula. Of these 11 patients, 10 (91%) had successful repair. One patient developed endoleak and required reintervention with another device replacement. No other patients required additional intervention. In this study, TEVAR was not considered as bridge therapy but was considered a definitive surgical treatment option. Although this was a small series of patients, TEVAR represents a promising alternative to in situ repair for a rare condition associated with a high mortality rate. Riesenman et al.258 published a review of 67 patients from 32 separate reports of aortobronchial fistula treated with TEVAR. The 30-day mortality rate was 1.5%. Aortobronchial fistula occurred in 6 patients (9%); 3 of them were successfully re-treated, and 3 died. The frequency of successful device explantation was not specifically reported in the review.

There are insufficient data to make a definitive statement regarding postprocedure antibiotic therapy. In the report by Bailey et al.257 only 2 of the 11 patients received long-term antibiotic therapy, and there were no recurrences of infection. However, because TEVAR places a foreign body in an infected area, after an initial period of 6 to 8 weeks of antibiotic therapy, lifelong suppressive antibiotic therapy may be considered.213,248,253,256,258

Although a relatively small number of patients with aortobronchial fistula have been treated with TEVAR on the basis of published data thus far, we believe that TEVAR may be considered as preferable to open surgical therapy for aortobronchial fistula. TEVAR may be considered as an emergency procedure to control potentially massive
exsanguinating hemorrhage, stabilize hemodynamics, and lower morbidity and mortality compared with open surgical repair of aortobronchial fistula. Unlike patients with aortoenteric fistula, in whom EVT is considered as a bridge procedure to later open repair and device explantation, in selected patients with aortobronchial fistula, TEVAR retention of the endovascular device may be considered. This approach may be considered instead of in situ reconstruction because of the associated high surgical risks. Aortobronchial fistula is a rare condition, and more data are needed to clarify the short- and long-term risks of TEVAR.

**Recommendations for Management of Aortobronchial Fistula**

1. **Transthoracic endovascular repair may be considered as preferable to open surgical repair because of the high operative risk with open surgical repair as a temporizing measure or in patients who cannot tolerate open repair (Class IIb; Level of Evidence C).**

2. **In patients with a retained endovascular device, after an initial period of 6 to 8 weeks of antimicrobial therapy, lifelong suppressive therapy may be considered (Class IIb; Level of Evidence C).**

**Aortoesophageal Fistula**. Aortoesophageal fistula is a very rare condition and is more often secondary to esophageal cancer, trauma, presence of a foreign body, or erosion of a vascular graft into the esophagus, or less commonly primarily caused by a thoracic artery MA or thoracic artery infection.256,262 These represent <10% of all aortoenteric fistulae and occur in 1.9% of patients who undergo TEVAR for treatment of thoracic artery aneurysm.213,231,241,244,256,262 Either primary or secondary aortoenteric fistula is a highly lethal condition with a 100% mortality rate if not diagnosed and treated promptly. These patients present with a sepsis syndrome, hemodynamic instability, and hematemesis.256,262 CTA usually does not demonstrate a fistulous communication, but the presence of esophageal wall thickening and peri-esophageal gas bubbles together with the clinical syndrome in an at-risk patient is highly suggestive of aortoenteric fistula. Because this is such an uncommon condition, there are no definitive guidelines for optimal management, and therapeutic options must be individualized for each patient. The goals of management are the same as for aortoenteric fistula or aortobronchial fistula: control of bleeding, hemodynamic stabilization, repair of the fistula, and control of sepsis. The three options for management are open surgical repair, TEVAR, or a combination of these procedures. There are a number of reports of single cases or small numbers of cases and multicenter retrospective reviews.213,253,256 Chiesa et al256 published the largest series from multicenter studies in Italy and included 14 cases. The consensus opinion of these authors and other published reports is that TEVAR can be a lifesaving emergency procedure to control bleeding and help stabilize hemodynamics, but it should be a bridge to subsequent device explantation and open in situ surgical repair of the aortoesophageal fistula. The recurrence rate of infection after TEVAR ranges from 33% to 60% without explantation, and the mortality rate ranges from 40% to 60%. The number of patients is too small and the population too diverse to draw valid conclusions. In summary, in patients with aortoesophageal fistula, we believe that TEVAR may be considered as an initial procedure to control bleeding and stabilize hemodynamics and as bridge therapy for subsequent device explantation and open surgical repair of the fistula. Long-term, possibly lifelong suppressive antibiotic therapy may be considered in patients with TEVAR or in situ repair.213,248,253,256,258

**Recommendations for Management of Aortoesophageal Fistula**

1. **Thoracic EVT may be considered to control bleeding and stabilize hemodynamics and as bridge therapy to device explantation and open surgical repair (Class IIb; Level of Evidence C).**

2. **After an initial period of 6 to 8 weeks of antimicrobial therapy, lifelong suppressive antibiotic therapy may be considered with EVT or in situ repair (Class IIb; Level of Evidence C).**

**Visceral Artery MA.** Visceral artery MAs are a rare complication of a rare infection; they account for ≤1% of intra-abdominal MAs.263–269 They most often involve the superior mesenteric artery but have been described in the liver, spleen, and kidney. Clinically, they can cause fever and (rarely) a pulsatile abdominal mass, and depending on the location, they may be associated with acute gastrointestinal bleeding, hemobilia, or hematuria. Because visceral artery MA is rare, there are no large published studies for diagnosis. The imaging modalities appear to be similar to those for other intra-abdominal MAs. CTA has been reported to have a 95% sensitivity for the diagnosis of visceral artery MA.189

Because the number of patients with visceral artery MA is so small, there are no consensus guidelines for optimal management. A number of studies outline the management of patients with visceral artery aneurysm.189,263–270 Because the risk of rupture of visceral artery aneurysm is high and is associated with a high mortality, either open surgical intervention or EVT may be considered.263–270 Open surgical treatment usually involves ligation and resection of the aneurysm with or without revascularization; EVT may require a combina-
tion of coil embolization of branching arteries for stent placement in the aneurysm. Künzle et al\textsuperscript{264} reported 3 patients with visceral artery MA treated with EVT; 1 patient died of underlying cancer, and the other 2 survived with retained devices and no recurrence of infection. Stone et al\textsuperscript{263} reported 2 MAs among 306 patients with visceral artery aneurysms (0.6%). Both of these patients were treated successfully with ligation and excision of the MA. There are no published data on optimal antimicrobial therapy. If EVT therapy is selected, a foreign body is placed in an infected vascular field. The long-term risk of potentially fatal hemorrhage or other complications after EVT therapy is unknown. On the basis of experience with EVT for retained devices for MAs located in other anatomic locations, long-term suppressive antibiotic drugs may be considered.

**Recommendations for Management of Visceral Artery MA**

1. Either open surgical resection or EVT may be considered for visceral artery MA (Class IIb; Level of Evidence C).
2. After EVT, if there is a retained device, lifelong suppressive antimicrobial therapy may be considered (Class IIb; Level of Evidence C).

**Endovascular Device Infection.** Endovascular device treatment of aortic aneurysms was initially developed as an alternative management tool for patients who were considered to be unfit for traditional open surgical repair because of underlying comorbidities or high risk for surgical complications, or for emergency temporizing control of rupture or impending rupture of aortic aneurysm. However, as more experience was gained with this procedure, many authorities considered EVT as the procedure of choice for the management of aortic aneurysms in patients with suitable anatomy.\textsuperscript{171,238,271–273} EVT has a number of advantages over open surgical repair, including lower perioperative morbidity and mortality. EVT may be used for emergency management of rupture, may result in a shorter hospitalization, and may have outcome measures similar to those of traditional open procedures. However, infection of an EVT device used for TEVAR or endovascular abdominal repair of aortic aneurysms or other conditions may be more complex and difficult to manage than infection associated with open procedures. Chalmers et al\textsuperscript{274} reported the first case of EVT graft infection in 1993. The incidence of infection associated with EVT is low (0.2%–5%) and is similar to that for open surgical repair.\textsuperscript{8,213,256,275–278}

Infections associated with endovascular abdominal repair are reportedly lower, \(\approx 1\%\), than for TEVAR (up to 5%).\textsuperscript{8,213,256,275–278} The higher TEVAR infection rates could relate to the complexity of thoracic compared with aortic EVT, higher patient comorbidity, and a small increased risk of fistulous communication with the bronchus or esophagus. Infection of endovascular devices falls into 2 broad categories: those that occur in association with repair of uninfected aortic aneurysms and those that are used for treatment of MA, including MAs associated with aortic, enteric, or aortobronchial fistulae. Infections are more likely with repair of MAs because the device is placed in vascular tissue that is already infected.

Among patients with EVT for uninfected aortic aneurysm, the cause of infection is thought to be related to several factors. The endovascular device can become infected because of intraoperative contamination. These infections are usually caused by staphylococci or streptococci and less commonly by gram-negative bacilli, including \textit{P. aeruginosa}.\textsuperscript{213,256,275–279} An endograft is more susceptible to infection until endothelialization of the device occurs, usually 2 months after placement.\textsuperscript{280} Endothelialization makes the device less susceptible to hematogenous infection from a distal focus. Other factors include placement of the device under emergency conditions or in a procedure room instead of an operating room, secondary infection of unevacuated thrombus around the device, the presence of an endoleak, and erosion of the device through the aorta with development of a fistulous communication to the bronchus, esophagus, or bowel.\textsuperscript{5,213,256–258,262}

The onset of infection is usually within 2 to 3 months after the procedure. Infections that occur later are more often caused by coagulase-negative staphylococci or other less virulent microorganisms, including \textit{Candida} species. Infections associated with a fistulous communication depend on the location of the fistula. The clinical and physical findings are nonspecific. Patients usually have a sepsis syndrome with or without abdominal pain, and blood cultures may be positive in only 20% to 30% of patients. The diagnosis requires a combination of index of suspicion and imaging findings. CTA findings suggestive of infection include enhancing perigraft fluid or soft tissues or visible gas bubbles.\textsuperscript{275} Indium-labeled white blood cell studies or PET/CT studies have also been reported to be helpful for diagnosis.\textsuperscript{275,277} The number of reported cases is too small to make a strong recommendation for the imaging procedure of choice.

A number of studies reported results of explantation of infected EVT devices and reconstruction.\textsuperscript{213,251,256,275–279} A small number of patients with infected EVT devices did not undergo explantation because they were considered medically or surgically unfit to undergo explantation and reconstruction. The mortality rate in these patients ranged from 36% to 100%,\textsuperscript{275–279} Cernohorsky et al\textsuperscript{277} reported no difference in mortality between patients with device explantation versus retention, but the number of patients in each group was too small to draw valid conclusions. Fatima et al\textsuperscript{275} published data on the largest number of patients treated in a single center. In this study, there were 24 patients, 21 with endovascular ab-
dominal repair and 3 with TEVAR; 4 of these patients had aortoenteric fistulae, and 1 had aortobronchial fistula complicating device infection. In this study, development of an aortobronchial fistula as a result of EVT placement occurred in only 0.3% of all endograft procedures performed at Mayo Clinic. The authors postulated that the development of EVT graft enteric fistula occurred as a result of graft migration or severe angulation causing repetitive friction wear or mucosal tear.

Although there is no consensus regarding optimal surgical management, the general principles for device removal and vascular reconstruction are essentially the same as for patients with infected vascular grafts discussed in the section on VGI. There is more published experience with device infection in endovascular abdominal repair than with TEVAR. The management differs for these 2 groups of patients. For an endovascular abdominal repair device infection, device removal and extra-anatomic revascularization, especially in patients with gross intraoperative purulence, was once considered to be the preferred option, but now explantation and in situ reconstruction may be considered. In situ reconstruction has been reported using rifampin-bonded polyester graft, venous autograft, or cryopreserved arterial allografts, but the number of patients is too small to draw valid conclusions about whether one material is preferable. The choice of a polyester graft, venous autograft, or cryopreserved allograft should be individualized for each patient, and the advantages and disadvantages are discussed in detail under Treatment of VGI. The risk of infection after device explantation and in situ reconstruction is low (≈4%) and is similar to the infection rate after open surgical resection and reconstruction for VGI. There are only a few reported cases of device infection for TEVAR, and device removal and in situ repair may be considered for these patients. Device extraction and extra-anatomic revascularization are usually not technically feasible.

The management of infected endovascular devices in these situations is discussed in Endovascular Device Infection. TEVAR is considered to be an emergency, potentially life-saving procedure to control bleeding and stabilize a patient hemodynamically and is a bridge, temporizing procedure until definitive open in situ reconstruction and device explantation can be performed.

There is no consensus agreement about the duration of antimicrobial therapy. The number of patients is too small to draw valid conclusions. Endovascular devices that are inserted into a vascular bed that is infected are by definition infected. On the basis of the limited reported experience, at least 6 weeks of initial parenteral therapy may be considered. For patients with retained devices, lifelong suppressive antimicrobial therapy may be considered in those who are not candidates for device extraction and open surgical repair.

### Recommendations for Management of Endovascular Device Infection

1. For abdominal or thoracic endovascular device infection, device explantation and in situ reconstruction may be considered (Class IIb; Level of Evidence C).
2. For the treatment of infected endovascular devices after explantation, at least 6 weeks of antimicrobial therapy may be considered (Class IIb; Level of Evidence C).
3. For retained infected endovascular devices, lifelong suppressive antimicrobial therapy may be considered (Class IIb; Level of Evidence C).

### Prognosis of Aortic MA

Aortic MA is a serious, life-threatening infection. The prognosis of intrathoracic or intra-abdominal MA varies substantially and depends on many factors, including location, rupture or impending rupture, presence of aortoenteric or aortobronchial fistula, underlying comorbidities, and other factors. The prognosis of aortic MA is discussed in the individual sections.

### Peripheral MA

Compared with intracranial or aortic MA, patients with peripheral MAs have a more consistent and recognizable clinical presentation. The diagnosis is more straightforward, and the morbidity and mortality are lower. The majority of patients with peripheral MAs are IVDUs. Accordingly, unlike patients with ICMAs or aortic MAs, for whom long-term follow-up data to measure outcome are often available, the population of patients who are IVDUs are often lost to follow-up or continue to inject drugs into the same peripheral artery that was treated surgically for MA. These and other factors complicate the management of these patients.

### Frequency

The overall frequency of MAs, in decreasing order, is aortic, peripheral, cerebral, and visceral. The most common anatomic location for peripheral MAs in decreasing order of frequency is femoral, humeral, and axillary. MAs involving the popliteal or external carotid artery are rare.

### Pathogenesis, Risk Factors, and Microbiological Cause

The anatomic location reflects the sites that are most readily accessible to IVDUs. It is estimated that peripheral MAs occur in ≈0.14% of those who inject drugs. Maliphant and Scott estimated that the average duration of continuous intravenous injection of drugs is 7.7 years until the user exhausts the accessible peripheral veins and begins to inject drugs intraarterially. Femoral arteries are more readily accessible to IVDUs than are humeral or axillary arteries.
The injection of drugs and the nonsterile liquid used to suspend the illicit drugs causes local tissue necrosis and damage to the arterial wall and can cause arterial thrombosis. This results in an environment highly favorable to bacterial infection. The bacteria may be injected directly into the arterial wall and bloodstream or into the surrounding soft tissue. Either way, infection causes weakening of the arterial wall and the development of the MA and, in some cases, an infected thrombus with peripheral septic emboli. IVDUs may also have IE, which results in continuous bacteremia. The localized tissue necrosis caused by drug injection creates a favorable environment for infection caused by IE-related bacteria. The infection can spread to the arterial wall and result in the formation of an MA.

Less commonly, peripheral MAs can occur in non-IVDUs, such as patients with IE and bacteremia, vascular surgery, percutaneous arterial puncture or catheterization, or trauma such as from a gunshot wound.125

The most common microorganisms causing peripheral MA are S aureus, which are frequently MRSA.125,163,281–285 Less commonly, coagulase-negative staphylococci, gram-negative bacilli, Candida, and other microorganisms have been recovered, and in IVDUs, infection can be polymicrobial.125

Clinical Presentation

Patients often present with an erythematous, painful, pulsatile mass. Fever is absent in 50% to 60% of patients and is not a reliable predictor of peripheral MA. Cellulitis or soft tissue abscess in the site is common. Septic embolization may occur. Some IVDUs can have significant gangrenous changes and critical limb ischemia caused by the infection, localized tissue necrosis from injection of foreign material, or arterial thrombosis.125,163

Diagnosis

Clinical findings in an IVDU are highly suggestive of the diagnosis of peripheral MA. Elevated white blood cell count and inflammatory biological markers occur frequently but are nonspecific laboratory findings. Blood cultures are reportedly positive in 30% to 60% of patients.125,163,286,287 Many patients with peripheral MAs have received antibiotic drugs before presentation, which can render blood cultures negative.

The diagnosis of peripheral MA is most often confirmed by imaging. Ultrasonography or CTA may be considered for the diagnosis.162,281,288 Ultrasonography is useful to distinguish cellulitis or abscess from MA.163 To-and-fro filling of a pseudoaneurysm demonstrated by Doppler ultrasonography is suggestive of an MA in susceptible patients.163,287 Doppler ultrasonography has a reported 94% sensitivity and 97% specificity of pseudoaneurysm but does not distinguish an infected from a noninfected aneurysm. The ultrasound or CTA findings should be correlated with findings on physical examination and laboratory test results for the diagnosis.

Recommendation for Imaging for the Diagnosis of Peripheral MA

1. Ultrasonography or CTA or both may be considered for the diagnosis of peripheral MA (Class IIb; Level of Evidence B).

Management

There are no published, randomized prospective studies that define the optimal management of patients with peripheral MAs. Because of the risk of rupture with potential exsanguinating hemorrhage or limb loss, prompt surgical intervention is necessary. In addition to antimicrobial therapy, surgical options include ligation only, resection and in situ reconstruction, or resection with extra-anatomic revascularization.

A number of studies report ligation without revascularization.240,281,288–291 Postoperative ischemia and claudication occurred in 33% to 97% of patients, hemorrhage in 18% to 44%, and limb amputation in 5% to 33%.240,281,288–291 Ligation only of an MA involving the femoral artery is associated with a higher risk of postoperative claudication or amputation than with ligation of MA in the superficial femoral or tibial arteries.163,281,285 Popliteal artery ligation carries a risk of amputation or severe chronic ischemia.

Devecioglu et al281 reported 33 cases of peripheral MA; 20 had ligation and in situ reconstruction, and 6 had ligation and extra-anatomic revascularization. In situ reconstruction with an autogenous vein was preferred in the study. Other studies reported in situ reconstruction with cryopreserved arterial allografts.25,269,283,292 Postoperative complications occurred in at least 24% to 39% of patients and included suture line rupture and hemorrhage, recurrent infection, thrombosis of graft, claudication, or limb amputation in 6% to 33% of patients.281,283,293 These authors did not recommend in situ reconstruction with synthetic graft material because of a high infection rate, including some studies that had a 100% rate of re-infection after in situ reconstruction with synthetic material.281,293–295

The third surgical option is ligation and extra-anatomic revascularization.281,285 In these studies, extra-anatomic revascularization was performed because of extensive necrosis or purulence in the operative field, which made in situ reconstruction technically not possible. Complications included persistent infection, stump rupture, failure to maintain long-term patency of the extra-anatomic graft, and limb claudication or amputation.

It is difficult to compare complication rates among these 3 surgical options, because many of these patients are IVDUs who continue to inject drugs into the ligated or reconstructed area. There are insufficient data to recommend a specific surgical procedure, and the choice must be individualized for each patient. There are no prospective studies that define the optimal duration of postoperative antibiotic therapy. Like the choice of a
surgical procedure, the duration of antimicrobial therapy must be individualized. A 6-week postoperative course of antibiotic therapy may be considered. In selected patients with gross purulence intraoperatively treated with in situ reconstruction or extra-anatomic revascularization, after the initial 6-week course of antimicrobial therapy, an additional 6-month period of therapy or, in some cases, lifelong suppressive therapy may be considered.

Recommendations for Postoperative Antimicrobial Therapy for Patients With Peripheral MA

1. In patients with peripheral MAs, a 6-week course of antimicrobial therapy may be considered (Class IIb; Level of Evidence B).
2. In patients with gross intraoperative purulence, MRSA, or infection caused by a multidrug-resistant microorganism or Candida species, a 6-month course of antimicrobial therapy may be considered. In selected patients, lifelong suppressive therapy may be considered (Class IIb; Level of Evidence B).

PREVENTION OF INFECTIONS OF VASCULAR GRAFTS OR ENDOVASCULAR DEVICES AND STENTS

The administration of antimicrobial agents for the prevention of infection of vascular grafts, endovascular devices, or stents may be considered as primary or secondary prophylaxis. Primary prophylaxis refers to the administration of antimicrobial prophylactic therapy to prevent perioperative infections. Secondary prophylaxis refers to the administration of antimicrobial therapy intended to prevent infection as a result of transient bacteremia associated with an invasive procedure, such as a dental procedure.

Primary Prophylaxis

Perioperative or intraoperative antimicrobial therapy for patients who undergo vascular graft surgery or intravascular device placement is a longstanding, widely accepted expectation and standard of care. However, there are few randomized, prospective, placebo-controlled blinded studies that demonstrate clear efficacy of prophylactic therapy to prevent graft or endovascular device infections. The frequency of vascular graft or endovascular device infection ranges from 0.2% to 5%.1–9,213,256,275–278 Because of the low frequency of infections, a large number of patients would be required to demonstrate efficacy of primary prophylaxis. In addition, because primary prophylaxis is such a long established standard of care and infections are associated with a high morbidity and mortality, patients and healthcare providers might understandably be reluctant to participate in placebo-controlled studies.

Kaiser et al296 reported a controlled, randomized, prospective, double-blinded study in patients undergoing clean vascular graft surgery that compared placebo (237 patients) with perioperative cefazolin (225 patients). There was a significantly (P<0.001) higher rate of wound infections among the placebo group (6.8%) than among the cefazolin recipients (0.9%). The 2 infections that occurred in the cefazolin recipients were class II groin wound infections without involvement of the vascular graft. Among the 16 wound infections in the placebo group, 4 had class III groin infection with involvement of the vascular graft; 2 of them died, and 2 underwent above-the-knee amputation. Patients in both the placebo group and the cefazolin group had perioperative skin application of topical antibacterial substances, most often povidone-iodine.

Hopkins297 reviewed published studies in English language literature that compared placebo with antimicrobial therapy. Although the number of patients reported was relatively small, the wound infection rates among patients in the placebo group ranged from 16.7% to 22.6% compared with 0% to 5.8% among those who received perioperative antimicrobial prophylaxis.

On the basis of these studies, the use of a β-lactam antibiotic for perioperative prophylaxis to prevent wound infection is reasonable for patients who undergo clean vascular graft surgery.296–298 There are insufficient published data to recommend vancomycin for perioperative prophylaxis. It is unlikely that placebo-controlled, blinded studies will be published for primary prophylaxis in patients who undergo endovascular device placement; however, the administration of a perioperative β-lactam antibiotic may be considered.

Recommendations for Primary Antimicrobial Prophylaxis Perioperatively for Clean Vascular Graft Surgery or Placement of an Endovascular Device

1. Perioperative administration of a β-lactam antibiotic to prevent wound infection is reasonable for patients who undergo clean vascular graft surgery (Class IIa; Level of Evidence B).
2. Perioperative administration of a β-lactam antibiotic may be considered for patients who undergo placement of an endovascular device (Class IIb; Level of Evidence C).

Secondary Prophylaxis

There is a longstanding perception that dental procedures can cause distal infection as a result of transient bacteremia that occurs commonly during the procedure. In the
Vascular Infections

Vascular Infections

post–antibiotic drug era, antimicrobial prophylaxis for dental procedures has been suggested for >25 medical conditions (eg, valvular heart disease or in patients who have implanted devices, such as a joint arthroplasty). The efficacy of secondary prophylaxis for dental procedures is unproven and is based largely on the potentially devastating consequences of infections in these patients rather than on scientific evidence. There are no published evidence-based studies that document the efficacy of antimicrobial therapy to prevent these infections in patients who undergo a dental procedure. The American Heart Association does not recommend antimicrobial prophylaxis for prevention of vascular graft or endovascular graft infection in patients who undergo a dental procedure or in uninfected patients who undergo a urologic or gastrointestinal tract procedure.

FOOTNOTES

The American Heart Association makes every effort to avoid any actual or potential conflicts of interest that may arise as a result of an outside relationship or a personal, professional, or business interest of a member of the writing panel. Specifically, all members of the writing group are required to complete and submit a Disclosure Questionnaire showing all such relationships that might be perceived as real or potential conflicts of interest.

This statement was approved by the American Heart Association Committee on Rheumatic Fever, Endocarditis, and Kawasaki Disease of the Council on Cardiovascular Disease in the Young; Council on Cardiovascular and Stroke Nursing Council on Cardiovascular Radiology and Intervention; Council on Cardiovascular Surgery and Anesthesia; Council on Peripheral Vascular Disease; and Stroke Council. Vascular graft infections, mycotic aneurysms, and endovascular infections: a scientific statement from the American Heart Association. Circulation. 2016;134:•••–•••. doi: 10.1161/CIR.0000000000000457.

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<tbody>
<tr>
<td>Walter R. Wilson</td>
<td>Mayo Clinic</td>
<td>None</td>
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<tr>
<td>Sepideh Amin-Hanjani</td>
<td>University of Illinois at Chicago</td>
<td>None</td>
<td>None</td>
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<tr>
<td>Larry M. Baddour</td>
<td>Mayo Clinic</td>
<td>None</td>
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<td>Robert S. Baltimore</td>
<td>Yale University School of Medicine</td>
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<td>Ann F. Bolger</td>
<td>UCSF</td>
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<tr>
<td>Thomas C. Bower</td>
<td>Mayo Clinic</td>
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<tr>
<td>Mark A. Creager</td>
<td>Brigham &amp; Women’s Hospital</td>
<td>None</td>
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<tr>
<td>Rabih O. Darouiche</td>
<td>Infectious Disease Section and Center for Prostheses Infection, Veterans Affairs</td>
<td>None</td>
<td>None</td>
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<tr>
<td>Colin P. Derdeyn</td>
<td>University of Iowa</td>
<td>None</td>
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<tr>
<td>Matthew E. Levison</td>
<td>Drexel University College of Medicine</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Merck†</td>
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<tr>
<td>Peter B. Lockhart</td>
<td>Carolinas Medical Center</td>
<td>None</td>
<td>None</td>
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<tr>
<td>Patrick T. O’Gara</td>
<td>Brigham &amp; Women’s Hospital</td>
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<tr>
<td>Basel Ramlawi</td>
<td>Valley Health System, Heart &amp; Vascular Center</td>
<td>None</td>
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<td>None</td>
<td>None</td>
<td>Sorin Inc*; Medtronic*</td>
<td>None</td>
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<tr>
<td>Kathryn A. Taubert</td>
<td>American Heart Association</td>
<td>None</td>
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<tr>
<td>James H. Black</td>
<td>Johns Hopkins University</td>
<td>None</td>
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<tr>
<td>Matteo Trezzi</td>
<td>Bambino Gesù Children’s Hospital IRCCS (Italy)</td>
<td>None</td>
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REFERENCES


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Circulation. published online October 13, 2016;
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

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