Patients requiring vascular intervention—whether open surgery or endovascular procedures—typically are elderly and have comorbidities that make their overall care complicated. To achieve a successful outcome, the perioperative care of the vascular surgery patient requires meticulous attention to detail and knowledge about the possible pitfalls these patients can encounter. Even the most seemingly innocuous clinical symptom must be thoroughly investigated and potentially treated in order to achieve acceptable perioperative outcomes. Despite meticulous attention to detail, vascular patients often fall victim to their comorbidities or succumb to failure of the primary intervention.

In general, vascular problems are defects in plumbing, and in that regard, the “pipes” (arteries) can either clog or burst. Despite the localized anatomic defect that drives the presentation and surgical therapy, it is imperative that clinicians recognize vascular pathology as a systemic disease and not just a focal anatomic problem. The nature of atherosclerosis is that it affects the blood vessels of all circulatory beds: cardiac, peripheral, renal, and cerebral. Thus, patients who present with leg ischemia are at significantly higher risk than the general population for having myocardial infarctions, renal dysfunction, and cerebrovascular accidents. In fact, the average patient with critical limb ischemia has an estimated mortality rate of 50% at 5 years, with the predominant cause of death being cardiovascular (1). Furthermore, there is increasing evidence that the vascular occlusive process is proinflammatory in nature. These patients have elevated levels of C-reactive protein (CRP), interleukin (IL)-6, and soluble intercellular adhesion molecule-1. Elevated CRP has recently been shown to be a predictor of cardiovascular events among patients with peripheral artery disease (PAD) (2). Upregulation of inflammatory mediators may contribute to complications in the ICU.

In most series, patients with vascular occlusive disease have a high incidence of chronic obstructive pulmonary disease, evident or occult cardiac disease, diabetes, and renal insufficiency. The adverse pulmonary sequelae of arterial revascularization are frequently related to the ravages of smoking. In most reports of operative repair of PAD, the incidence of tobacco use among patients exceeds 50%, and often approaches 90%. In a study looking at femoral atherosclerosis using duplex ultrasound, smoking was the largest risk factor, more influential than exercise tolerance, hypertension, or hypercholesterolemia (3). We may choose a potentially less durable endovascular therapy for patients based on their condition and ability to tolerate general anesthesia. Although general endotracheal anesthesia (GETA) is still the most common type of anesthesia used in vascular patients, increasing evidence suggests that spinal or epidural anesthesia may be more appropriate. In a review of 14,788 patients in the National Surgical Quality Improvement Program (NSQIP) of the Department of Veterans Affairs, GETA was associated with a higher incidence of cardiac, pulmonary, and graft complications when compared to spinal or epidural anesthesia (4).

Patients with known vascular disease are assumed to have associated coronary artery disease, even though they may be asymptomatic. In a landmark study by Hertz et al., over 90% of patients undergoing peripheral vascular reconstruction had coronary artery disease evident by cardiac catheterization, and nearly one-third had multivessel disease (5). The goals of the American Heart Association/American College of Cardiology should be targeted, including a blood pressure less than 140/90 mmHg, serum low-density lipoprotein (LDL) less than 100 mg/dL, and hemoglobin A1c less than 7% (6). To achieve these goals, patients should potentially be on an aspirin, a β-blocker dosed to a target heart rate of 70 to 75, an angiotensin-converting enzyme (ACE) inhibitor or other antihypertensive therapy, and probably a statin (independent of baseline cholesterol levels). Earlier recommendations of widespread β-blocker usage have been since refuted, and at present, perioperative efforts should focus on avoidance of excessive hypotension or bradycardia may still be reasonable (7). Initiation of β-blockers in patients not previously on such medications likely should be avoided.

There is increasing evidence that patients with vascular disease should all be treated with a statin regardless of cholesterol levels (8). Statins have numerous effects other than reduction of cholesterol including anti-inflammatory, immunomodulatory, and anticoagulant effects. Moreover, abrupt discontinuation may lead to a rebound effect and possibly increase cardiovascular complications (9). It is our practice to routinely start patients on a statin preoperatively and continue it throughout the postoperative period. The antiplatelet drug clopidogrel is frequently used in vascular patients. Preoperatively we review the indications for this drug, and if the indications are compelling, such as the patient with a recent coronary stent placement, we will continue the drug through the perioperative period, recognizing that there may be a slightly increased incidence of wound complications. We do not hesitate to start the drug in patients who exhibit cardiac ischemia in the postoperative period.

The electrocardiogram (ECG) should be monitored continuously for any changes suggestive of ischemia. For the diabetic population, angina may present as nausea and must be interpreted as signs of myocardial ischemia until proven otherwise. Finally, cardiac dysrhythmias are often caused by ischemia, electrolyte disturbances, or fluid shifts in the postoperative period, and patients should be monitored closely for such events.

In order to decrease the risk of perioperative cardiac events in the vascular surgery patient population, much attention has been given to preoperative risk stratification. In the surgical and anesthesia literature, most vascular surgery procedures for occlusive or aneurysmal disease are placed in the high-risk category. The question is how to minimize the risk of perioperative cardiac complications. Data from several randomized, multicenter trials have shown that coronary revascularization
(percutaneous or open) before elective major vascular surgery does not decrease the overall mortality (10). Nevertheless, many clinicians request preoperative cardiology consultation to help determine existing cardiac function, usually with an ECG, an echocardiogram, or a chemical cardiac stress test.

Even without prior known elevated serum creatinine, many vascular patients have renal insufficiency as determined by creatinine clearance. Nephrotoxic effects of the IV contrast commonly used in revascularization procedures make postoperative renal dysfunction a constant threat. Moreover, periprative mortality after most vascular procedures is significantly increased in patients with renal failure (11). Strict monitoring of fluid balance, maintenance of serum electrolytes, appropriate dosing of nephrotoxic medications, adequate hydration, and resumption of chronic diuretics will all help to minimize the chance of postoperative renal dysfunction.

A majority of vascular patients have diabetes mellitus and this group is at higher risk for postoperative complications, both vascular and nonvascular. From a vascular perspective, patients with diabetes have a higher rate of postoperative amputations after peripheral bypass surgery for tissue loss (11). Diabetics are also at risk for other postoperative morbidities including postoperative wound infections. They should be maintained euglycemic, even if that requires a constant intravenous infusion of insulin, with target blood glucose of 80 to 110 mg/dL.

There is a subset of patients with vascular disease with underlying hypercoagulable states. The concern for a hypercoagulable state should be raised with patients with seemingly advanced atherosclerotic disease at a younger age. A careful history can assist with determining these patients, but when identified, they should be started on appropriate anticoagulation. Hematology consultation should be obtained, but may be of somewhat limited value in the setting of the acute thrombotic event. A growing concern in this population is the rapidly expanding number of anticoagulants that are available. More of them require less intensive monitoring as an outpatient and are less affected by dietary modifications than the traditional warfarin. The significant drawback is the inability to rapidly and reliably reverse their hematologic effects in the event of the need for emergency surgery.

**VASCULAR CARE IN THE INTENSIVE CARE UNIT**

All patients in an ICU have a propensity for developing venous thromboembolic events. Virchow’s triad dictates that patients at risk include those with stasis, endothelial injury, and a hypercoagulable state. In the postsurgical population, venous stasis is inevitably due to the patients’ relative immobility. Endothelial injury occurs during the course of the surgical procedure. It is our practice that all patients receive chemical and/or mechanical prophylaxis; we routinely use low–molecular-weight or unfractionated heparin and/or sequential compression devices when there is no existing contraindication. We avoid lower extremity sequential compression devices in patients with severe peripheral arterial occlusive disease, although the data for this practice are anecdotal. The incidence of heparin-induced thrombocytopenia is relatively rare, and when suggested by a decline in platelet count, we promptly cease all systemic or local heparin and transition to mechanical prophylaxis and use an alternate anticoagulant. In these instances, hematologic consultation proves quite insightful.

Stress gastritis is a constant threat in the vascular ICU patient and frequently manifests as blood-tinged nasogastric aspirate or frank hematemesis. Patients are routinely placed on either histamine-receptor blockers or proton pump inhibitors, irrespective of any clinically detected gastrointestinal hemorrhage. Opponents of this practice suggest that in doing so, one of the body’s natural defense mechanisms (gastric acidity) is altered, but we find that the risk of stress gastritis exceeds the diminution in host defenses.

Ventilator-associated pneumonia has been well documented to increase in-hospital mortality, length of stay, and overall cost of hospitalization. Early extubation and mobilization seem to be key preventative strategies to minimize this risk. We employ routine suctioning, aggressive bronchoscopy to control secretions, and head elevation for all our intubated patients. Once extubated, activity is encouraged and adequate pain control is important for patients with an abdominal or a thoracic incision.

The routine assessment of the vascular ICU patient includes not only all the usual cardiovascular, pulmonary, and metabolic parameters, but also frequent and detailed physical examinations. All incisions should be inspected for signs of early wound complications such as infection, separation, or hematoma. Objective assessment of distal perfusion should be performed regularly, even hourly, in the immediate postoperative period. This assessment includes looking at the extremity for cutaneous signs of malperfusion, assessing motor function, and palpating the major muscle groups for tenseness, which may signify compartment syndrome in patients who are too sedated to relate the classic “pain with passive motion.” The best examination, in our opinion, is to elevate the lower extremity by placing the hand behind the Achilles tendon and palpating the anterior calf compartment with the posterior leg off the bed. A patient should be alert enough to follow commands of simple dorsiflexion, again ensuring that the posterior knee is off the bed. (Dorsiflexing the foot with the heel resting on the bed can be achieved with flexion of the quadriceps muscles, thereby not testing the anterior calf compartment, which is the muscle group of interest.)

Some centers have advocated use of pressure monitoring devices to measure compartment pressures, but it has been our practice that if compartment syndrome is even suspected, it is imperative to perform fasciotomies emergently. This is best accomplished by either a one- or two-incision technique. All four calf compartments should be incised and released. Fasciotomies can be performed in the ICU setting using Bovie electrosurgery and sterile scissors. The underlying muscle should bulge when released, thereby confirming the diagnosis. The wound should be left open and treated with routine dressing changes with subsequent closure in several days to weeks when the swelling abates. The metabolic sequelae of compartment syndrome may consist of cellular lysis with release of potassium and myoglobin that may cause systemic hyperkalemia and possibly acute renal failure. We routinely check urine myoglobin and administer aggressive intravenous fluids to ensure brisk urine output of at least 100 ml/hr. Electrolytes are checked frequently and continuous telemetric cardiac monitoring is employed. The data supporting alkalization are weak and probably less imperative than fluid resuscitation, but on occasion, clinicians may choose to employ it.

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The distal perfusion of the critically ill vascular patient should receive the same attention as the cardiopulmonary status. Clearly, adequacy of perfusion should be assessed in patients who have undergone distal revascularization, but even for aortic reconstructive procedures, the risk of limb ischemia is not insignificant, and missing an acute ischemic extremity in a patient who is sedated and intubated can have catastrophic consequences. Each extremity should be assessed by checking for palpable pulses; if none are found, Doppler signals must be auscultated to assess the perfusion. Ample quantity of Doppler gel should be used and the Doppler probe should be positioned at 60 degrees from the long axis of blood flow to maximize the signal. Normal Doppler signals are described as triphasic: the initial forward flow of blood is due to left ventricular systolic ejection; the second (reversal) flow is due to the intrinsic resistance of the arterioles in the circulation; the third phase again is forward-directed flow, and is largely attributed to the elasticity of the aorta. Doppler signals distal to an obstruction may be characterized as biphasic or monophasic signals with the latter suggesting significantly diminished blood flow. Sometimes it is difficult to tell if the sound is venous or arterial. If the sound disappears with gentle pressure on the Doppler probe, it is likely a venous sound. Also, if the sound in one of the pedal pulses disappears with gentle compression around the forefoot, it may be a venous and not arterial sound. At the conclusion of any vascular procedure, extremity perfusion is assessed prior to leaving the operating room (OR). The operating surgeon should relay to the ICU team of physicians and nurses the quality and location of each Doppler signal or palpable pulse, as well as the frequency that he or she wants the perfusion assessed. Any change in the examination or inability of the examiner to detect the signal may potentially constitute an emergent trip back to the OR to restore perfusion. Loss of a palpable pulse even if the pulse remains by Doppler should always be cause for alarm and the operating team should be alerted.

All vascular surgery wounds should be examined daily for signs of infection. Of particular difficulty are the incisions made in the groins. The incidence of groin wound complications in the vascular surgery patient has been estimated to be up to 44% in some series (12,13). Although most surgeons try to close groin wounds with several layers of suture, any breakdown of the wound can be a significant complication. Groin wound breakdown is especially common in obese patients and efforts should be directed toward keeping this area dry and covered with sterile gauze. Most breakdowns can be treated with local therapy, usually routine dressing changes at the bedside with the possible addition of enzymatic debridement agents. On occasion, patients require surgical debridement either at the bedside or if more extensive, in the OR.

Although there has been a great deal of interest in new techniques and agents to expedite wound healing, few advances have impacted the overall rate of wound complications, possibly owing to the patient’s underlying systemic illnesses that translate into slow healing. The most disastrous complication of groin, or any other wound, breakdown is the exposure of the underlying vascular graft or anastomosis with the devastating potential for anastomotic disruption. When the bypass graft is noted to be exposed, patients should be scheduled for the OR for exploration and attempted reclosure of the wound, preferably with autogenous tissue such as a sartorius or rectus flap. Until the patient can go back to the OR, it is imperative that all health care personnel treating the patient be aware of exposed vasculature. We have instituted a “blowout precaution” protocol wherein patients are kept at bedrest and blood typed and crossed, and a large easily read sign is placed at the head of the bed. Any bleeding from the wound is a potential emergency. Immediate pressure should be held on the wound, the patient stabilized, and the operating team notified. We have on occasion had to rush back to the OR with a member of the team holding direct pressure on the wound until the patient is intubated and anesthetized, the surgeon scrubbed in, and the operative field prepped (even if this includes the team member’s gloved hand being prepped into the field).

For the vascular patient, meticulous care of the skin is mandatory, and even modest duration of pressure on the heel by the bed mattress can lead to skin breakdown and turn a successful revascularization into an amputation. Because a significant number of vascular patients have compromised distal perfusion, we try to keep patients’ heels off of the bed by placing the calves on pillows, which allows the weight of the leg to be borne over a larger atraumatic surface area. There is no substitute for frequent inspection of all pressure-sensitive areas and this should be part of the clinician’s and nurse’s practice.

Pharmacologic prophylaxis against thromboembolic events is the routine. However, many patients require systemic anticoagulation after vascular surgical procedures (14) such as with distal bypasses when there is compromised outflow or less than ideal conduit. The need for systemic anticoagulation must be balanced with the risk of bleeding complications, and usually we hold off full anticoagulation until postoperative day 2 or 3. We readily employ our institution’s “low-intensity” protocols balancing the need for anticoagulation with the risk of postoperative hemorrhage. As a matter of protocol, warfarin or similar longer-acting anticoagulants are not initiated until patients leave the ICU because of the frequent need for central lines or similar procedures. Any patient on systemic or prophylactic heparin is monitored for any decline in platelet count, and if seen, a heparin antibody panel is sent and all heparin products are discontinued. Regardless of the agent chosen, it is imperative that the anticoagulation be monitored closely, ideally with protocol-driven therapy (15).

As stated earlier, acute limb ischemia in the ICU setting can have disastrous consequences. Given the nature of patients in the modern ICU, this can happen in vascular patients and nonvascular patients alike. The pathologic differential includes embolic events (usually from cardiac, aortic, or rarely, venous sources) or in situ thrombosis of pre-existing atherosclerotic lesions that likely is a consequence of plaque instability and the aggregation of platelets, which then occludes the vessel. If identified acutely, there may be a role for intra-arterial thrombolysis, although in the setting of the postsurgical patient, this role is limited due to excessive bleeding risk. When an ischemic extremity is identified, patients should immediately be fully anticoagulated if tolerated while resources are being mobilized to further evaluate the problem. More aggressive intervention, either catheter-based therapy or open surgical thrombectomy, should be entertained. However, if the acute arterial occlusion is associated with motor or sensory deficits, then an emergent exploration is indicated. On rare occasions, patients present with acute lower extremity paralysis secondary to acute infrarenal aortic occlusion. There is often a delay in diagnosis owing to an investigation of neurologic causes of
the paraplegia. Absence of femoral pulses is a clue to the vascular nature of the paralysis. These patients typically require emergent procedures, often direct arterial reconstruction or extra-anatomic bypass, and despite operative success, the perioperative mortality rate exceeds 50% (16).

The acutely ischemic limb often is the upper extremities as well. In this setting, common ICU causes of arterial occlusion include sequelae of invasive monitoring, usually intra-arterial lines. In a recent review of brachial artery cannulations for cardiac catheterizations, the overall complication rate was an astonishing 36% (17). Not infrequently we are called to assess lack of distal perfusion in an extremity with an indwelling arterial line. The first step is to remove the catheter and to observe for restoration of perfusion. The collateral blood supply should also be assessed (usually the ulnar pulse in the event of radial artery occlusion) as well as the distal perfusion, including motor and sensory assessment. Choices of therapy include observation, systemic anticoagulation, local thrombolysis, and operative thrombectomy with the potential for bypass. As with lower extremity acute arterial occlusion, any motor dysfunction should be treated with emergent surgical exploration, arterial reconstruction, and consideration of fasciotomies. A brachial sheath hematoma that is associated with mild sensory deficits is also best treated with expeditious surgical exploration, decompression, and arterial reconstruction to avoid permanent damage to the median nerve that is enclosed in the brachial sheath, juxtaposed to the antecubital brachial artery.

The choice of invasive arterial and venous monitoring can represent a continuous challenge in any ICU patient, but in particular the vascular ICU patient. Lower extremity intra-venous and arterial lines are contraindicated in patients with peripheral arterial occlusive disease. In patients who have a functional arteriovenous fistula or graft for hemodialysis, every effort should be made to avoid the use of ipsilateral extremity noninvasive blood pressure cuffs, IVs, arterial lines, or central venous catheters. If a patient is identified as likely to require permanent vascular access in the future, duplex ultrasonography should be used to identify a potential extremity for future dialysis access, and the identified extremity should be preserved.

Various bleeding complications can occur in the postoperative vascular wound. These can range from simple “skin edge” bleeding to frank exsanguination from an exposed anastomosis. Skin edge bleeding may be a nuisance, and may be treated with manual compression, application of silver nitrate, or a simple suture. Hematomas are monitored closely. Recurrent blood transfusion requirements, overlying skin or wound compromise, deleterious mass effects, and hemodynamic instability are all indications for operative evacuation of the hematoma. Patients who have had percutaneous interventions (usually through the groin at the common femoral artery) should also be monitored for hematomas, and in these instances, simple manual compression may be adequate. Attempted femoral artery punctures that are aimed more cephalad may in fact be external iliac artery punctures. Compression for hemostasis may be ineffective due to the retroperitoneal location of the arteriotomy. A progressive hematoma in such a location more often requires surgical repair (open or endovascular). Additionally, patients with transient or sustained hypotension, or a decline in hematocrit, should be assessed for a retroperitoneal hematoma, usually with a CT scan using intravenous contrast in the arterial phase.

### SPECIFIC CONDITIONS

## Aneurysmal Disease

### Infra-renal Abdominal Aortic Aneurysm

Approximately 90% of the extracranial aneurysms found in the human body involve the infrarenal aorta. The natural history of aneurysms of the aorta is to expand and rupture. The tension of the thinning aortic wall can be estimated by the law of Laplace, which describes the relationship between aortic diameter and wall tension. The results of randomized trials and observational studies have led vascular surgeons to recommend operative repair when the diameter of the aorta reaches 5.5 cm in asymptomatic men (18), but the numeric value varies, especially with female patients. Most aneurysms are asymptomatic and many are discovered during radiographic workup of other problems. Patients who have symptomatic aneurysms generally complain of back or abdominal pain. Unless definitively attributable to other pathologies, these symptoms should be interpreted as a sign of impending rupture necessitating urgent repair. We no longer place pulmonary artery catheters routinely, but all patients have arterial lines and Foley catheters and most have central lines. All patients get a single dose of preoperative antibiotics, which are not continued postoperatively in the absence of ongoing infection. It is our routine to obtain preoperative transthoracic echocardiography, but mostly as a means of assessing perioperative care, as rarely do patients have correctable cardiomyopathies. Cardiology consultation is not routinely employed because all patients are assumed to have concomitant coronary artery disease and are medically treated appropriately as such.

### Endovascular Repair

Depending on patient anatomy and patient/physician preference, abdominal aortic aneurysm (AAA) repair can be performed either via an open or endovascular approach. The endovascular approach holds great appeal in terms of reduced physiologic insult to the patient. Typically, both common femoral arteries are accessed either percutaneously or via an open groin exposure, and the device is placed from within the arterial lumen using fluoroscopic guidance. The weakened arterial wall is bolstered from within with stents made of a malleable metal alloy and a woven fabric. At our institution, these patients rarely require admission to the ICU but are monitored for hematomas and lower extremity pulses. The devices used to deploy endovascular stents can be as large as 26 French, and these are introduced through femoral or external iliac arteries. There is a possibility of local arterial damage or dislodging of plaque that may embolize distally. Again, patients are assessed intraoperatively, and any change in the hard signs of distal perfusion postoperatively may reflect a surgical emergency. The likely pathologic culprits for acute limb ischemia after endovascular AAA repair include access site (common femoral artery) occlusion/dissection or endovascular stent limb thrombosis.

### Open Repair

Open aneurysms, on the other hand, require surgical ICU monitoring postoperatively. The overall perioperative mortality is approximately 5% (19). Because a prosthetic graft has been sewn to the abdominal aorta, the main concern is bleeding, and a recent review of over 20,000 Medicare beneficiaries reported a 1.2% incidence of reintervention for bleeding. Furthermore, because the blood supply
to the lower extremities is occluded intraoperatorily during the aortic repair, it is vital to objectively assess and document lower extremity perfusion. Lower extremity ischemic events after open AAA repairs occur in 2% to 5% of patients (20). As stated earlier, any inability to detect a Doppler signal or palpate a pulse when there previously was one is a potential surgical emergency.

A major complication of open AAA surgery is gastrointestinal problems. A large retrospective study estimated the incidence of postoperative prolonged ileus to be 11% and nonischemic diarrhea to be 7.1% (20). All patients will have a brief period of postoperative ileus that may be shortened by use of a retroperitoneal approach to aneurysmorrhaphy (21). However, the dreaded complication is colonic ischemia with an estimated prevalence of 0.6% (20), but a mortality of 55% to 90% depending on the severity, recognition and management, and patient reserve. Most instances present as bloody stools 3 to 5 days postoperatively but may occur as early as the first 24 hours after surgery and are cause for considerable concern. Warning signs include fever, abdominal pain, thrombocytopenia, unexplained leukocytosis, or lactic acidosis. Any suspicion of colonic ischemia should prompt endoscopic evaluation, with the obvious caveat that endoscopy will only view the mucosal changes, and cannot evaluate for transmural ischemia. However, in the appropriate clinical setting, mucosal ischemia may justify operative exploration with possibly colon resection and end colostomy. These patients require intensive invasive ICU monitoring, as they often progress to multisystem organ failure as a result of their colonic ischemia. Routine broad-spectrum antibiotics to include gram-negative and anaerobic coverage are used.

Other potential gastrointestinal complications known to occur include cholecystitis and pancreatitis. The latter is probably related to direct surgical trauma during aortic exposure and is usually self-limited. Cholecystitis may be ischemia-related or may be a variant of acalculous cholecystitis seen in ICU patients. Treatment options range from percutaneous cholecystostomy to surgical cholecystectomy. Much like the problem of colon ischemia in the setting of an aortic graft, an infected gallbladder should not be overlooked or minimized.

The incidence of postoperative renal dysfunction can be as high as 5.4% after open infrarenal aortic surgery, but dialysis requirement is much less at 0.6% (20). Renal dysfunction is significantly lower in patients who have undergone infra-renal aortic cross-clamp, thereby avoiding the obligate renal ischemia-reperfusion. The exact etiology of the renal dysfunction after infrarenal clamping is largely speculative, but may involve migration of atheroemboli leading to acute tubular necrosis or hypotension-induced renal dysfunction. In the early postoperative period, oliguria is most frequently due to intravascular depletion and not intrinsic renal dysfunction. However, patients with baseline renal insufficiency, those more than 2 days postoperative, or those who do not respond appropriately to intravenous fluid challenges should be investigated for acute tubular necrosis or other intrinsic (nonrenal) cause of oliguria. The initial management includes assessment of volume resuscitation, urine and serum electrolytes, and a renal artery duplex.

In the absence of other causes (e.g., colon ischemia), patients may experience postoperative thrombocytopenia. Although an inciting event or agent is not always identifiable, there are several likely etiologies. Before occluding the aorta in the OR, all patients are systemically heparinized, and although our practice is to reverse the anticoagulant effects of heparin toward the end of the case, the drug’s side effects (i.e., thrombocytopenia) may persist. Unless there is evidence of ongoing bleeding, mild thrombocytopenia is usually well tolerated.

The cohort of patients who get abdominal aneurysms may have coronary artery disease and are at risk for postoperative myocardial infarctions, dysrhythmias, and episodes of congestive heart failure. Johnston reported an incidence of myocardial infarctions (5.2%), heart failure (8.9%), and dysrhythmia requiring treatment (10.5%). The overall incidence of any perioperative cardiac event was 15.1% (20). Unless contraindicated, patients undergoing open aneurysm repair should be on a medical regimen consisting of a β-blocker with a target heart rate of less than 70, a statin (independent of serum cholesterol levels), and some form of antplatelet therapy, usually aspirin.

**Ruptured Aortic Aneurysms**

Whereas surgical repair of intact aneurysms is a prophylactic procedure, repair of ruptured aneurysms is an attempt at life-saving surgery. A meta-analysis found the operative mortality rate of ruptured AAA to be 48%, with a small decline in mortality for each decade from the 1950s to the 1990s (22) (much higher than an elective AAA repair of <5% mortality). With ruptured AAA, there are impressive fluid shifts that transpire during such an emergent operation, independent of overt blood loss. These fluid shifts, associated with the hypotension and the physiologic strain of an emergent procedure, contribute to a tenuous postoperative course. The incidence of colonic ischemia is significantly higher after ruptured aneurysm repair compared to elective open aneurysmorrhaphy, and some authors recommend empiric and routine endoscopic evaluation of the colonic mucosa.

**Juxtarenal or Suprarenal Aortic Aneurysms**

Most aortic aneurysms are infrarenal, meaning that the proximal extent of the dilated segment of aorta is caudal to the lowest renal artery. Therefore, operative repair usually can be performed with infrarenal aortic occlusion in the OR. If the aneurysm extends to the level of the renal arteries, or involves the paravisceral aorta, the repair becomes technically more challenging, and the postoperative complications escalate dramatically due to renal and possibly mesenteric ischemia-reperfusion. Depending on the length of intraoperative ischemia, there is a resultant release of pro- and anti-inflammatory cytokines that drives a systemic inflammatory reaction resulting in multisystem organ failure (23). There is considerable third spacing of fluid in the first 24 hours as edema collects in the interstitial spaces. Attempts to improve mortality and morbidity by a hybrid approach involving multiple visceral bypasses and endovascular repair of the aneurysm have met with mixed results (24).

If the thoracic cavity is violated as a part of the aneurysm repair, the patient will have an even greater risk of pulmonary complications. Routinely a chest tube is placed intraoperatorily to drain any pleural fluid that may accumulate. Adequate pain control is key in these patients.

**Infected Aortic Graft**

One of the more dreaded complications of aortic surgery is infection of the prosthesis, which happens in less than 2% of
Aortic surgery. This rarely happens in the early postoperative period, and the majority occurs months to years later with unexplained fevers and malaise, occult or clinically evident gastrointestinal bleeding, and a computed tomography (CT) scan that shows fluid around an aortic graft. These are serious, life-threatening surgical problems, and patients should be treated aggressively. Broad-spectrum antibiotics, appropriate intravenous resuscitation, and close hemodynamic monitoring should be undertaken. Patients should be medically optimized and prepared for a significant surgical challenge. The classic surgical remedy was a staged procedure of extravascular bypass (axillofemoral) with subsequent aortic graft explantation and oversawering of the infrarenal aortic stump. Although it remains debated, more often we elect to perform a single-stage aortic replacement using autogenous tissue (syndacetylated bilateral femoral veins), antibiotic-soaked prostheses, or cadaveric vessels. Explantation of an infected surgical graft remains among the most challenging cases performed by a vascular surgeon, and likely should be done only at institutions with significant local expertise and systematic resources. Each case is a balance of underlying pathology with patient physiologic reserve. Nevertheless, these patients are routinely sent to the ICU because some may become floridly septic after manipulation of the infected retroperitoneum. Compared to virginal aortic replacement surgery, excision and replacement of an infected aortic graft is associated with more profound fluid shifts postoperatively, an elevated incidence of organ dysfunction, and an overall higher rate of complications such as prolonged ventilator support, renal dysfunction, and bleeding. Local infection control proves to be particularly difficult with patients whose infected extends up to the level of the renal arteries or in whom the offending organism is a gram-negative pathogen, particularly *Pseudomonas*.

**Arterial Occlusive Disease**

Unlike aneurysmal disease, which tends to occur in certain segments of the arterial tree, occlusive disease can occur almost anywhere. Aortoiliac occlusive disease can be detected by the absence of a palpable femoral pulse and symptoms of lower extremity vascular compromise: claudication, tissue loss, or ischemic rest pain. The specific diagnosis and management of these problems are beyond the scope of this chapter. The most durable surgical solution for aortoiliac occlusive disease is an aortobifemoral (ABF) bypass. This is accomplished using a celiotomy incision as well as two groin incisions. The prosthetic graft (usually Dacron) is sewn to the aorta just below the renal arteries with similar complications as with open aneurysmorrhaphy (i.e., bleeding, postoperative ileus, colonic ischemia, renal dysfunction, lower extremity ischemia, cholecystitis, pancreatitis). The limbs of the bifurcated graft are then tunneled beneath the ureters and sewn into the femoral bifurcation, usually hooded onto the profunda femoris arteries. The groin incisions, similar to those used for infragenicular bypasses, should be monitored for wound breakdown, infection, and drainage. Wound complications and the intrinsic diminished sterility of groin incisions as opposed to abdominal incisions have been implicated in the elevated risk of aortic graft infections seen with ABF reconstruction compared to aortic reconstructions performed without concomitant groin incisions. Peripheral pulses are regularly monitored and any deviation from the immediate postoperative result is a potential emergency as it may represent a graft thrombosis. Another complication is distal embolization with ischemia of the toes (trash foot). Management is expectant and most often this resolves with minimal or no permanent tissue loss.

As endovascular technology has evolved, many iliac lesions are being treated with angioplasty and possible stent placement. Although better tolerated by patients because of the less invasive nature of the procedure, the stents may not be as durable as surgical bypass. A small subset of patients, namely patients under the age of 55, are believed to have better long-term vascular durability for infrarenal aortic reconstruction with autogenous tissue rather than Dacron (25). Femoral veins can be harvested and syndactylized to be used as aortic replacement. This requires more extensive operations with longer OR times and larger leg incisions, which can be a cause of significant morbidity.

As with any surgical procedure, redo aortic surgery is fraught with intraoperative and postoperative complications. Patients generally require longer recovery periods. If the decision is made to avoid operating in the same surgical field (abdomen and retroperitoneum), extra-anatomic bypasses may be performed, usually axillofemoral. These procedures are considered to be less invasive but less durable and still require the same vascular monitoring as any other bypass procedure. Although abdominal complications are not seen, patients still require groin and axillary incisions and there is significant subcutaneous tunneling for the graft placement. With rehabilitation, trapeze devices are contraindicated to avoid undue stress on a fresh arterial axillary anastomosis.

**Infrainguinal Bypasses**

Infrainguinal bypasses are commonly performed to alleviate symptoms of vascular compromise. The principles for vascular surgery are simple: the patient must have adequate inflow (usually inflow to the femoral artery), adequate outflow (of the popliteal, tibial, peroneal, or pedal arteries), and conduit (“pipe” to perform the bypass). The incisions that are made are often significant, and may not only be located on the extremity being reperfused, but also may be on either leg or either arm as a site of vein harvest. We are particularly aggressive about harvesting autogenous tissue for vein conduit as the patency of infrainguinal bypass grafts using autogenous tissue, especially the great saphenous vein, is clearly superior to that using prosthetic tissue (e.g., polytetrafluoroethylene [PTFE]) (26), and for bypasses to infrageniculate arteries, the patency is much better with even autogenous spliced conduit is superior to nonautogenous conduit. Furthermore, efforts at endoscopic vein harvest have shown worse long-term patency than standard vein harvest techniques, and as a result, distal bypass, although a “skin operation,” is associated with significant incision and hence the potential for wound complications. Other than wounds, predominant sources of morbidity from these procedures are arterial occlusion (which can be detected with routine close pulse/Doppler monitoring), bleeding, and cardiopulmonary systemic complications. The mortality from peripheral bypasses is estimated to be between 2% and 8%, and the cause of mortality is primarily cardiac, so aggressive cardiac medical management, judicious use of antplatelet therapy, and careful fluid status monitoring are essential (27,28).

Any revascularization procedure is associated with a reperfusion syndrome that is usually mild and well tolerated.
However, the reperfused extremity should always be monitored for compartment syndrome and acted upon early. Details about the technique of detecting compartment syndrome and fasciotomies have been described above. Electrolytes and cardiac rhythm should be monitored, and the urine assessed for myoglobinuria, even if that means a simple visual inspection of the urine color. Again, as a clinical rule, if compartment syndrome is suspected, it should be treated.

A major complication of any revascularization procedure is graft thrombosis with the highest risk in the immediate postoperative period most likely due to technical failure and/or platelet aggregation on a surgically damaged endothelium. Patients with “high-risk” grafts (i.e., multiple segments of vein sewn together as a conduit, small distal target arteries, or poor-quality arteries) are routinely systemically anticoagulated postoperatively with heparin (14). At our institution, there has been a slight increase in the incidence of postoperative wound hematomas, but the fraction that needs operative evacuation is small. In addition to full anticoagulation, patients with endovascular stents are routinely placed on clopidogrel to decrease the incidence of in-stent restenosis, although the data for this are limited and largely anecdotal. All patients should be on aspirin unless otherwise contraindicated.

**Carotid Endarterectomy**

Carotid endarterectomy (CEA) has been shown to decrease the chance of a future cerebrovascular accident in certain patients with carotid stenosis. The procedure involves a neck incision along the anterior border of the sternocleidomastoid muscle, and occlusion of the carotid artery to attain vascular control. Once occluded, the operating surgeon then may place a plastic shunt to reroute blood flow and allow distal perfusion while the endarterectomy is being performed. Although there are many intraoperative variables in technique (mode of anesthesia, whether or not to shunt, and type of shunt), the key outcome variable is perioperative stroke related to disruption of cerebral blood flow or embolic event from clamping an atherosclerotic vessel. Aspirin should be continued in the recovery phase, but full anticoagulation is seldom indicated unless carotid occlusion has occurred. Neurologic deficit may manifest itself upon awakening or occur in the early postoperative period. Any change in neurologic function that occurs after awakening with a normal neurologic examination should be reported to the operating team. Opinions vary whether to investigate with imaging or return directly to the OR depending on where in the recovery phase the patient is upon recognition of the alteration and whether the deficit is transient or seems to be dense and progressive.

Because of the baroreceptors in the carotid bulb, patients often experience large fluctuation in blood pressures, which should be targeted to the “normal systolic range” of 120 to 140 mmHg. Additionally, any wound hematoma, because the neck is a relative closed space, can cause carotid compression and resultant bradycardia or potentially airway compression. The operating team should be alerted if hematoma is suspected. Because the field of dissection is intimately associated with the cranial nerves, a detailed head and neck examination is mandatory at regular intervals. Particular attention should be paid to assessing the function of the marginal mandibular nerve and the hypoglossal nerve, which usually is mobilized and gently retracted cephalad during the course of a CEA. Headache and even seizure activity may be a manifestation of cerebral reperfusion syndrome. This is rarely seen in the immediate postoperative period, but may cause readmission for blood pressure control in the weeks after carotid endarterectomy. These patients should also have a CT scan because of the incidence of intracranial bleeding that accompanies these symptoms.

**Mesenteric Revascularization**

Mesenteric ischemia, whether acute or chronic, can have lethal consequences. The restoration of intestinal perfusion sets in motion a cascade of inflammatory cytokines that frequently progresses to the systemic inflammatory response syndrome, multisystem organ failure, and even death. After restoration of blood flow, patients typically have a period of hemodynamic stability for 24 to 48 hours after the procedure, but then progress to retaining more fluid and show signs of systemic inflammation, most often manifesting in pulmonary dysfunction. Subtle early changes such as a diminution in platelet count should elicit concern. To date, despite numerous anticytokine therapies, the treatment of the systemic inflammation is largely supportive (29). As this response is not uniform, efforts to predict which patient will progress to clinical deterioration have been unsuccessful. As with any other revascularization bypass, the patency of the mesenteric graft should be assessed objectively. Duplex ultrasound is noninvasive and is highly sensitive. Despite all the usual supportive measures, the average postoperative length of stay is over 3 weeks (30).

**VASCULAR TRAUMA**

The care of the trauma patient with vascular injuries shares many of the same principles as care of other vascular surgery patients with the exception that this cohort frequently, but not always, lacks the systemic comorbidities of the typical atherosclerotic vascular patient. Most extremity vascular injuries are associated with orthopedic fractures and dislocations; some injuries are nearly synonymous with vascular injuries, such as a posterior knee dislocation and popliteal artery injury. In the secondary survey as part of the Advanced Trauma Life Support (ATLS) evaluation of the trauma patient, extremity pulses should be assessed and clearly documented. For any patient recovering from an orthopedic procedure, the same attention to distal perfusion is merited. Any change in pulse examination or hard sign of vascular injury mandates radiographic evaluation, usually with an arteriogram, although a CT angiogram is occasionally sufficient.

Although most surgeons no longer explore extremities when a penetrating injury is in proximity to a vessel, penetrating trauma associated with hard signs of vascular injury (decreased distal perfusion, active arterial hemorrhage, or a rapidly expanding hematoma) should be evaluated immediately after life-saving measures are undertaken. Often, the area of interest is operatively explored and the vessel visually inspected. If injured, it is either repaired or blood is rerouted around the “blast field” (e.g., an external iliac artery injury in a contaminated field may be repaired with vessel ligation and a femoral–femoral bypass to perfuse the ipsilateral leg). Venous injuries are ligated unless easily repaired. Revascularization of an extremity that has been malperfused for greater than 6 hours increases the likelihood of a reperfusion syndrome and at the least, compartment syndromes should be considered.
and treated liberally. Naturally, vascular injury to an extremity that has too extensive musculoskeletal damage to be salvageable can be treated with simple ligation and amputation. The mangled extremity is a challenging problem facing vascular surgeons, but in general the combination of multiple orthopedic injuries, nerve injury, and arterial injury leads to a higher likelihood of a nonuseful extremity. It remains a significant challenge to primarily perform amputation unless the patient’s life is immediately threatened by the presence of the extremity. Most vascular surgeons elect to perform a bypass, tunneled in a relatively spared tissue plane, and then wait to assess the neurologic function over time.

Finally, trauma to an artery and adjacent vein can result in a traumatic arteriovenous fistula. This can occur even months after the inciting trauma, and unexplained extremity swelling, distal ischemic symptoms, heart failure, or an audible bruit over an extremity should alert the clinician to the presence of a fistula. Most often, it is of little consequence unless it is very proximal and/or the patient has limited cardiopulmonary reserve.

The perceived incidence of aortic trauma is increasing, possibly due to the increased use of CT scans in trauma management. In the abdomen, any central periaortic hematoma should be operatively evaluated. With the resolution of the current scanners we are seeing a number of intimal injuries and short segments of dissection in the infrarenal aorta, mesenteric and iliac vessels that previously were not detected. In the absence of hemodynamic compromise most of these can be observed. Our typical protocol is to repeat CT imaging in 48 to 72 hours, or to obtain a dedicated arterial duplex in the event of mesenteric or renal abnormalities. Thoracic aortic injuries are nearly uniformly treated with endovascular devices. Initial care is directed toward treating the urgent life-threatening injuries and controlling blood pressure with β-blockers. Open surgical repair is still a viable option, though in most series the morbidity is clearly greater.

Penetrating neck trauma can involve the carotid artery, which can be exposed readily in certain locations (zone 2) or require more extensive operations to expose adequately (zones 3 and 1). Our current management of neck trauma in the stable patient with a zone 2 injury is to cover the wound in the trauma bay, perform the global assessment of the patient including abdominal sonography and intravenous resuscitation, and then take the patient to the OR for exploration. Only then is the injury exposed because unroofing a clot and losing hemostasis is best done with good exposure in the OR. For more proximal or distal injuries, angiography (standard contrast angiography or CT angiography) plays a vital role in both diagnosing and planning either open or endovascular treatment.

Blunt trauma to the head can result in injury to the carotid or vertebral arteries. Because these injuries are relatively rare (<1% of blunt trauma patients), controversy remains about the best way to diagnose and treat these patients. The Eastern Association for the Surgery of Trauma (EAST) has recently published practice management guidelines on blunt cerebrovascular injury (31). They recommended screening, preferably with angiography, for blunt trauma patients who present with or develop an unexplained neurologic deficit or who have cervical spine fractures, LeFort II or III fractures, petrous bone fracture, or fracture through the foramen transversum, and for those with a Glasgow coma scale score <8 or diffuse axonal injury. Although CT angiography has been reportedly used as screening, some have questioned its sensitivity, although it is likely that the newest generation of devices may eventually be accurate enough for diagnosis in this situation (32). The most common lesion discovered is a dissection or intramural hematoma. Our preference is that these lesions should be treated with either full anticoagulation or an antiplatelet agent that should continue for 3 to 6 months, and reimaging at some interval to ensure no aneurysmal degeneration. Occasionally pseudoaneurysms are seen and endovascular repair seems to be the evolving treatment modality for this lesion. Morbidity from this lesion remains high because many patients present with a deficit. In one large series there was a 26% mortality and only 31% of patients were discharged to home. However, in the asymptomatic group that was treated with either anticoagulation or antiplatelet therapy, the failure rate was only 9% (33).

Traumatic amputations, although grossly impressive, typically are not life threatening. Traumatic amputations of a major extremity (digits not included) should be wrapped with warm gauze, and manual pressure applied while the protocol-driven trauma evaluation proceeds. Once other life-threatening injuries have been evaluated, the amputated stump may be examined. The treatment priority should be hemostasis and local debridement to remove large debris. Patients should be given tetanus toxoid if there are no other contraindications. Dressing changes should be initiated, and when stabilized, a formal, closed amputation can be undertaken, with an emphasis on leaving a functional stump for the patient to use.

HEMODIALYSIS

Although the annual mortality of patients on hemodialysis approaches 25%, many patients in the ICU are on chronic hemodialysis with functional fistulae or tunneled catheters. The extremity with the fistula should be preserved from invasive and noninvasive monitoring devices, and all IVs and central lines should be placed away from that extremity unless there are no other options. Because of the presence of the fistula, the extremity distal to it is at risk of ischemic events, and should be monitored closely. Additionally, tunneled catheters already in place should not be routinely used as a convenient intravenous line except in dire circumstances. These lines can often be a source of infection, and limiting their use to their intended purpose will decrease the chance of infection. When they are accessed for dialysis purposes, it is routine practice to “lock” the catheter with concentrated heparin to minimize the chance of a mechanical catheter complication. Flushing this heparin “lock” will systemically anticoagulate the patient, even if transiently.

Key Points

- Peripheral vascular disease is one manifestation of a systemic process that is proinflammatory in nature and affects the coronary, cerebral, and peripheral vasculature.
- Ninety-three percent of patients undergoing the most common vascular procedures (AAA repair, carotid endarterectomy, peripheral bypass) have documented coronary artery disease; all patients should be medically
managed accordingly. As a rule, coronary revascularization is not indicated for patients with stable coronary disease prior to major vascular reconstruction.

- Patients with diabetes can manifest angina as nausea, diaphoresis, or “indigestion.”
- Any objective change in the assessment of distal perfusion—either by palpation of pulses or auscultation of Doppler signals—is a potential surgical emergency.
- All patients with obstructive or aneurysmal vascular disease should be continued on a β-blocker, an aspirin, and a statin, unless otherwise contraindicated. Starting β-blockade may be deleterious if done immediately preoperatively.
- Compartment syndrome may be subtle, especially in the sedated ICU patient. The disappearance of pulses is a late finding. Clinicians should have a low threshold to perform fasciotomies.
- Colonic ischemia after aortic surgery may present as hematochezia or melena, or may be more insidious: leukocytosis, thrombocytopenia, or fevers.

References