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Selected Readings in General Surgery (SRGS) is a topic oriented, in-depth review of the field of general surgery presented eight times annually as an educational offering of the Division of Education of the American College of Surgeons. The mission of the Division of Education is to improve the quality of surgical care through lifelong learning, based on educational programs and products designed to enhance the competence or performance of practicing surgeons, surgery residents, and members of the surgical team. The intent of the publication is to analyze relevant medical literature to give the surgeon the knowledge necessary to practice state-of-the-art surgery. To accomplish this goal, the editor selects 100–125 pertinent articles from the literature for each issue. Each article is reviewed and an overview is written that places the content of these articles in the perspective of the best, day-to-day, clinical practice. In addition to the overview, 12–18 full-text articles are reprinted in each issue.

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Welcome to Selected Readings in General Surgery (SRGS): Vascular Surgery, Part III. Several important topic areas will be covered in this final issue of our three-part vascular series. In the opening section, we will summarize current approaches to managing arterial and venous injuries. Following this, we will review the current status of a set of important and potentially preventable complications encountered in surgical practice: venous thromboembolism (VTE). After reviewing current guidelines and data relevant to the diagnosis and management of symptomatic venous thrombosis and pulmonary embolus, we will shift our focus to the diagnosis and management of varicose veins, chronic venous insufficiency, and postthrombotic syndrome (PTS). Following the review of venous diseases, we will discuss articles on the diagnosis and management of patients requiring hemodialysis access. Vascular Surgery, Part III will conclude with a review of pertinent literature on vasospastic disease and nonarteriosclerotic occlusive vascular disease.

As in our preceding issues, I would like to express my gratitude to Girma Tefera, MD, FACS, who provided editorial assistance for this vascular surgery series.
Arterial & Venous Injuries

Five comprehensive reports have provided guidance for surgeons who manage vascular injuries; these reports will form the basis of this section of the review; the first four of these reports, three by Feliciano and coauthors and one by Sperry and coauthors, are supplied as full-text reprints accompanying some formats of SRGS. As we review articles focusing on effective means of diagnosing and managing vascular trauma, we will refer to these reports repeatedly. We will also include related work that will help illuminate important concepts in this clinical area.

Historical Perspectives

Advances in diagnostic modalities and surgical techniques have permitted major progress in the management of arterial trauma. Much of the refinement of our methods of managing arterial injuries has been stimulated by experiences with the care of combat casualties. Arterial injuries were predominantly treated by ligation during World War II and the subsequent amputation rate for lower extremity arterial injuries in that conflict approached 50%. Outcomes of arterial injuries sustained in combat during World War II were documented in an article by Debakey and Simeone in Annals of Surgery, 1946. In the discussion section of the article, the authors asserted that repairing arterial injuries, with restoration of perfusion to an ischemic limb, was not feasible in combat medical care facilities. The authors cited several reasons for this assertion: the most important of these were the very long delays from wounding until the patient arrived at a hospital capable of vascular repair, the frequency of exposure of the repaired injury and infection of the tissues surrounding the repair, and the scarcity of surgeons trained in vascular surgery.

Feliciano and coauthors dealt with approaches to diagnosing and managing peripheral vascular injuries in a clinical guidance article published in the Journal of Trauma and Acute Care Surgery, 2011. According to the authors, the first recorded repair of an arterial injury was by Hallowell in 1759. Clear descriptions of successful techniques for anastomosing blood vessels were produced by Carrel and Guthrie in an article published in 1907. Carrel replaced arteries with segments of vein in experimental animals and found that these conduits were successful in restoring the distal circulation as long as competent venous valves were not present in the venous segment chosen as the conduit. The anastomotic technique chosen by Carrel was the triangulation technique using three anchoring sutures, in a manner similar to current practice.

William Halsted was interested in operative procedures performed on the vascular system and encouraged Bertram Moses Bernheim, a faculty member at Johns Hopkins Hospital, to investigate this area. Bernheim’s research showed that long-term success of implanted vascular conduits could be achieved by using fine suture lubricated with liquid petrolatum jelly. This technique overcame the difficulties posed by the unavailability of suture attached directly to the needle. A clear description of the technique for successful use of reversed saphenous vein conduits is found in Bernheim’s book on vascular surgery published in 1913. There is evidence that researchers at the Johns Hopkins Hospital discovered heparin in 1915 as well, but clinical use of heparin as an anticoagulant did not occur until after World War II. Bernheim took vascular surgery instruments and suture material to Europe during World War I but concluded that vascular repair was not feasible under combat conditions. He cited many of the same obstacles noted by Debakey and Simeone.

On the basis of experience in World War II and the outcomes data recorded in the article by De Bakey and Simeone, the concept of primary ligation as the preferred approach to managing vascular injuries sustained in combat was incorporated into military medical doctrine. Direct suture repair or replacement of injured blood vessels with reversed saphenous vein conduits became feasible for surgeons caring for injured soldiers in the Korean War. Efforts made, during that conflict, to shorten the interval from injury to definitive care using helicopter evacuation and placement of Mobile Army Surgical Hospitals (MASH) near the battlefield positively influenced success rates for injury management, including vascular injuries. Additional progress in managing vascular injuries was made during the Vietnam conflict and the clinical results, recorded in the Vietnam Vascular Registry, documented a reduction in amputation rates to less than 15%. Large civilian series have confirmed these results.
The article by Feliciano and coauthors and the textbook chapter on vascular injuries by Frykberg and Schinco stressed the variety of clinical patterns that vascular injuries can take. In addition to lacerations and transections, contusions, true aneurysm formation, false aneurysm formation, intimal flaps, and arteriovenous fistulas are possible. The extent of clinical symptoms varies according to the type of injuring agent, the extent of force transfer, the degree of associated skeletal and soft tissue injury, the presence of concomitant venous injury, the effects of collateral circulation, and the amount of previous and ongoing blood loss.

**General Aspects of Peripheral Vascular Injuries**

Vascular injuries are encountered uncommonly in civilian trauma practice. Major arterial injuries requiring intervention are observed in less than 5% of the total population of injured patients. Most vascular injuries involve arteries and veins of the extremities; the clinical guidance article by Feliciano and coauthors cited data confirming that up to 70% of vascular injuries seen in U.S. trauma centers involve vessels of the upper and lower extremities, with the femoral artery of the thigh being the most commonly injured vessel. Additional data cited by the authors showed that most extremity vascular injuries are due to penetrating mechanisms. Low-velocity gunshot wounds cause 50% of these injuries and stab wounds cause 30% of the injuries. Blunt vascular injury frequencies vary from 5% to 25% of those reported, depending on the data source.

The main danger of extremity vascular injuries is mortality due to exsanguination. With continued military and civilian efforts to increase the use of wound compression and tourniquets to control bleeding in the prehospital and early inpatient care phases, death from exsanguination has decreased. Data supporting the benefit of tourniquet use to reduce blood loss from combat-related vascular injuries were presented in an article by Kragh and coauthors in *Annals of Surgery*, 2009. The authors conducted a prospective study of tourniquet use at a single military hospital in Iraq. They analyzed outcomes from nearly 2,900 casualties. Tourniquets were applied to 309 injured extremities. The data analysis disclosed that prehospital tourniquet application before development of hemorrhagic shock after extremity injury was associated with a mortality of 10%, while delayed tourniquet application after arrival at the hospital had a mortality risk of 24%. All delayed tourniquet applications were in patients with clinical signs of shock.

Passos and coauthors focused on using tourniquets to control bleeding in civilian vascular injuries in *Injury*, 2014. The article was a retrospective review of data from two Canadian trauma centers; outcomes in 190 patients seen over a nine-year interval were recorded. Fourteen patients had severe blood loss and profound hypotension. Eight patients in this group had tourniquets applied in the prehospital phase of care or within one hour of arrival at the hospital; all eight patients survived. Six patients with massive blood loss did not have tourniquets applied and all died. The authors concluded that their data suggests a potential benefit for tourniquet use in patients with extremity vascular injuries and massive hemorrhage.

The most important secondary complication of vascular injury is limb loss. Predictors of limb salvage have focused on lower extremity injuries. Prolongation of the interval from injury to revascularization beyond six hours, overall injury severity, and the extent of skeletal, neurologic, and soft tissue damage (usually reported as the mangled extremity score) have been cited as predictors of limb loss in patients with lower extremity injuries. Data cited by Feliciano and coauthors show that penetrating injury results in amputation in 2%–6% of patients. Blunt injuries result in limb loss in 10%–20% of patients mainly because of associated fractures and extensive nerve and soft tissue injuries.

The abiding belief among surgeons caring for patients with extremity vascular injuries is that injuries to upper extremity vessels do not carry the same limb-loss risks as injuries to lower extremity vessels. Possible reasons for improved results in upper extremity injuries include more effective collateral circulation in the upper extremity, redundancy of the innervation to distal extremity structures, and observed lower frequency of postrevascularization compartment syndromes. Simmons and coauthors presented data that support improved outcomes for vascular injuries of the upper extremities in the *Journal of Trauma*, 2008. The authors reported 41
patients with brachial artery injuries. In this group, there were four deaths and among the 37 surviving patients, four amputations were required. More than 90% of patients underwent vascular reconstruction. In 28 patients with overtly ischemic limbs on admission, 24 were revascularized successfully with limb salvage. Amputation was required in only four of 23 patients with significant neurologic deficit. Although more severe injuries and higher mangled extremity scores were associated with amputation, these indicators were not predictive of amputation. The authors concluded that an aggressive approach to revascularization is indicated in patients with upper extremity vascular injuries. Successful limb salvage can be achieved despite the presence of severe injuries and prolonged prerevascularization intervals.

The article by Feliciano and coauthors reviewed the fundamental principles of initial resuscitation and assessment that are applied consistent with the principles articulated in the Advanced Trauma Life Support® (ATLS®) course of the American College of Surgeons (ACS). Airway management and control of hemorrhage should proceed simultaneously. Judicious restoration of lost blood volume is undertaken using massive transfusion protocols as necessary. Transections of blood vessels from penetrating trauma incite a vasoconstrictor response at the cut ends of the vessel and intrinsic vascular smooth muscle contraction in the artery proximal and distal to the transection causing retraction of the vessel ends into the tissue. Thus, vessel transection, in general, results in a lowered potential for blood loss compared with lacerations of vessels wherein remaining intact portions of the vessel wall tend to hold the artery in place and hold the lumen of the vessel open so that blood loss continues. An exception to this general rule is encountered in patients where retraction and vasoconstriction are prevented because of extensive soft tissue damage surrounding the transected vessel or where these intrinsic hemostatic measures are curtailed by contusion of the vessel wall proximal and distal to the transection site.

The potential for vascular injury occurrence depends on the injury mechanism, the location of the injury, and the amount of energy delivered to the injury area. Penetrating injury mechanisms such as stab wounds or low-velocity gunshot wounds may not impart enough injury to the vessel to result in damage. Arteries in areas such as the neck and axilla are mobile; low-energy transfer events may simply move the vessel rather than injure it. When energy transfer increases and/or immobilization of the artery occur from anchoring of the vessel within fascial envelopes, injury is more likely to occur. Examples include the tethering effect of the retropleural fascial envelope of the thoracic aorta near the isthmus when blunt force is applied to the chest wall, blunt injuries to the distal internal carotid and vertebral arteries in patients with cervical spine and skull base fractures, and high-velocity gunshot wounds that traverse the neck.

**Vascular Injuries in Elderly Patients & Children**

Konstantinidis and coauthors queried the National Trauma Data Bank to determine the frequency and clinical characteristics of vascular injuries occurring in patients older than 65; their report was published in the *Journal of Trauma*, 2011. Their data analysis disclosed that older patients comprised 7.6% of the patients with vascular injuries. Older patients were also more likely to sustain injuries from blunt mechanisms. Compared with younger patients, whose injuries tended to be located in the extremities, older patients were more likely to suffer injuries to thoracic vessels. One-third of the older patient cohort sustained blunt thoracic aortic injuries compared with 13% of younger patients. Of interest is that the risk of thoracic aortic injuries increased linearly with increasing age. Older patients had, overall, a fourfold increase in mortality risk if a vascular injury was diagnosed.

Barmparas and coauthors analyzed data from the National Trauma Data Bank for patients 16 years of age or less with vascular injuries in the *Journal of Pediatric Surgery*, 2010. A review of the data confirmed that vascular injuries are unusual in the pediatric age group, with a 0.6% frequency of injury compared with 1.6% in patients older than 16. Thoracic vascular injuries were also rare, and the most common injury location was the upper extremities. Overall, pediatric patients were significantly less likely to die from vascular injuries compared with the older cohort.
Contrasting data concerning injury frequency, mechanism, management, and outcomes in pediatric patients were reported in a retrospective case series from an urban Level 1 trauma center; the data were reported in an article by Corneille and coauthors18 in the Journal of Trauma, 2011. The authors reviewed medical record data on more than 8,000 patients younger than 16 admitted to a single trauma center in a 13-year interval. Major vascular injuries were sustained by 116 patients (1.4%)—111 arterial injuries and 33 venous injuries. Penetrating injury mechanisms were recorded in nearly 60% of the patients; 37 patients died and 36 of these had penetrating torso injuries. In surviving patients with extremity injuries, limb salvage was achieved in nearly 98% of patients.

**Contributions from Recent Military Experience with Vascular Injuries**

Combat medical experience has consistently led to improvements in surgical practice. Experiences of surgeons in Korea led to rapid progress in the care of vascular injuries. Vascular injury repair and reconstruction reduced the amputation rate significantly, as previously mentioned. In Vietnam, refinements in air evacuation techniques shortened the interval from injury to definitive care, and injury mortality rates were reduced significantly. Surgeons who gained experience in Korea and Vietnam brought their knowledge and experience to civilian surgical practice. The result led to many important advances, including the development of organized prehospital care, the identification of trauma centers, and the development of standards for trauma care and trauma systems, as well as the ATLS program.

The recent major conflicts in Iraq and Afghanistan have been unique; practices known to improve outcomes in civilian trauma systems (standardized prehospital care interventions, rapid evacuation, a tiered system of injury care facilities, trauma registries, performance improvement conferences, and multidisciplinary clinical research) are important components of military injury care systems. Clinical practices pioneered in civilian trauma centers, such as abbreviated operation (damage control) and measures to avoid hypothermia, acidosis, and coagulopathy, have been used successfully in recent wars.

Specific practices to improve the early care of patients with vascular injuries have emerged from recent combat medical experiences. These include the use of tourniquets to reduce blood loss (discussed previously) and the use of indwelling shunts or temporary prosthetic vascular grafts to reperfuse an area of ischemic tissue while accomplishing external fracture fixation, management of other sites of blood loss, and patient evacuation to a higher level of care.

Taller and coauthors19 discussed indwelling vascular shunts in the Journal of Trauma, 2008. The authors prospectively studied 23 shunt placements in 17 patients with major vascular injuries. Patient outcomes data at 30 days after injury were reported. Twenty-two of 23 shunts were patent after patient evacuation to a higher level of care facility. All patients with patent shunts had successful revascularization and no amputations were necessary in a 30-day follow-up interval.

Data confirming the value of shunts in civilian vascular injuries were presented by Subramanian and coauthors20 in the Journal of Trauma, 2008. The article reported experience from the Grady Memorial Hospital in Atlanta, GA. This is an extremely busy and very experienced Level 1 trauma center dealing with the full spectrum of urban injuries. This report reviewed experience with nearly 800 patients with vascular injuries who were seen during a 10-year interval; 101 shunts were placed in 67 patients and 82 of these were placed in the arterial system, with the remainder placed in veins. The shunts were placed to facilitate a “damage control” strategy, to permit fracture fixation, or to facilitate limb reimplantation. Seven patients died or underwent early amputation. Sixty patients remained for analysis. Seven of the 60 patients died, with one death deemed preventable from loss of airway. Shunt thrombosis was observed in 5% of patients. Of the shunts used, more than 60% were Argyle® shunts. Shunt thrombosis and end organ loss was a particular problem when shunts were placed for truncal injuries. Bowel necrosis and death were observed in all three patients who had shunts placed in the superior mesenteric artery. Ten patients required secondary amputation after shunt placement, but these amputations were required for massive soft tissue and nerve injury and not for shunt failure. The authors affirmed that placement of temporary intravascular shunts is a valuable approach for provision of distal perfusion in extremity vessels. The
shunts allow time for necessary patient resuscitation and for stabilization of complex fractures. Shunts were left in place, on average, for more than 24 hours and these conduits functioned satisfactorily in most patients. The authors confirmed the findings of other authors who have reported high amputation rates associated with combined injuries to the popliteal artery and popliteal vein. The discussion section of the report assessed the advantages and disadvantages of the various types of shunts and readers are encouraged to review this text.

Vertrees and coauthors reported the results of prosthetic graft placement in the early care of combat vascular injuries in the *Journal of Trauma,* 2009. The authors queried the combat injury registry and found that polytetrafluoroethylene grafts were placed in 14 patients. The most common artery injured was the femoral artery and the indication for placement of the prosthetic graft was an extensive tissue injury with no available autologous conduit. There were no deaths, no instances of late hemorrhage from the prosthetic grafts, and all patients underwent subsequent autologous vein reconstruction. Follow-up data was available for a mean interval of 427 days. There were three late amputations because of infection and/or extensive nerve injury. All three patients had functioning vascular conduits at the time of amputation. The authors concluded that prosthetic grafts may be successfully used as temporary conduits in patients with major vascular injuries.

**Editorial Comment**

Available data support the conclusion that combat experience from the Iraq and Afghanistan conflicts has documented using intravascular shunts to establish distal blood flow if definitive repair is not appropriate because of patient instability or the lack of clinical resources. The placement of intravascular shunts in patients with combat injuries has permitted the restoration of distal perfusion. Argyle™ shunts, Javid™ shunts, Pruitt-Inahara shunts, small-chest tubes, and feeding tubes have been used and patency has been preserved for intervals exceeding 12 hours in some cases. The shunts have facilitated transferring patients with vascular injuries from the combat zone to hospitals where vascular reconstructions can successfully be performed.

**Clinical Diagnosis of Vascular Injuries**

The clinical guidance article by Feliciano and coauthors recommended careful physical examination (searching for clinical evidence of vascular injuries) as the most dependable means of detecting injury, avoiding the morbidity of negative exploration, and reducing the interval from injury to reestablishment of blood flow. This interval should not exceed 6–8 hours to assure optimal distal tissue perfusion and minimal disability resulting from the vascular injury. Traditionally, clinical signs of vascular injuries have been divided into two groups: “hard signs” and “soft signs.” The hard signs of vascular injuries include massive hemorrhage, expanding or pulsatile hematoma, absent pulses, and signs of distal ischemia. Soft signs of vascular injuries include proximity of a visible injury to a major vessel, signs of adjacent nerve injury, stable hematoma, history of hemorrhage before arriving at the hospital, and unexplained hypotension.

Experience in the combat theaters of World War II, Korea, and Vietnam gave rise to a belief that any form of vascular injury was likely to lead to late complications such as false aneurysm or arteriovenous fistula if the injury could not be repaired as soon as possible. This management philosophy led to the practice of “exploration for proximity,” an approach that dictated formal vessel exploration for any evidence of soft or hard signs of injury and for wounds in proximity to the estimated location of a major vessel. Over time, as quality and availability of vascular imaging increased, formal exploration was undertaken for patients with hard signs of injury; contrast angiography (more recently, contrast-enhanced computerized tomographic [CT] angiography) was done for patients exhibiting soft signs to exclude vascular injuries.

As an understanding of vascular injuries evolved, it became obvious that most of the trivial injuries documented by contrast angiography in patients exhibiting soft signs of vascular injuries were of limited clinical significance. As imaging technology and clinical experience have increased, ultrasound imaging, CT angiography, and magnetic resonance imaging (MRI) are used with increasing frequency.

The current management paradigm is described in the 2011 clinical guidance article (Figure 1). The authors recommended immediate operation for patients with hard signs of injury. For patients who require localization of the
injury prior to exploration but who have clinical evidence of significant blood loss can have surgeon-performed contrast angiography in the emergency department or operating room. Ultrasound imaging may be an appropriate substitute for this if equipment and expertise are available. Assistance from an experienced vascular surgeon can facilitate contrast angiography and ultrasound imaging. Tomita and coauthors\(^2\) focused on the benefits of vascular surgical assistance in the setting of a vascular injury or other complex operative procedures in *JAMA-Surgery*, 2016. The report provided data on the use of vascular surgery assistance for complex procedures in 299 patients. Although the report did not provide data exclusively on vascular trauma patients, the analysis of the experience of the authors showed that the availability of vascular surgery expertise improved the efficiency of managing complex procedures and provided a valuable means of managing hemorrhage and vascular repairs.

If the injury is in an area difficult to access surgically (such as Zone 3 of the neck), if surrounding skeletal structures make it difficult to elicit hard signs (such as injuries in the area of the shoulder girdle), or if there is likely to be significant morbidity associated with a negative exploration (such as median sternotomy for suspected thoracic outlet vascular injury), imaging to exclude injury can be performed in stable patients. Feliciano and coauthors\(^1,2\) confirmed that digital subtraction angiography has become one of the preferred options for stable patients along with CT angiography.

Additional situations where exclusion imaging should be considered include shotgun wounds, where an extended length of artery may be involved from multiple missiles, and skeletal injuries where suspicion of vascular injury persists after realignment of the fracture or reduction of a joint dislocation. For high-risk injuries, such as long-bone...
fracture with a pulse deficit on initial examination or knee dislocation, Feliciano and coauthors recommended that the physical examination be supplemented by an assessment of the ankle-brachial pressure index (ABI) or the arterial pressure index or API (ratio of upper extremity systolic pressure to systolic pressure distal to the area or injury). If both indices are equal to or greater than 0.9, a significant vascular injury is unlikely.

A potential disadvantage of contrast angiography is that while detailed vascular imaging may require that the angiogram be performed in the radiology suite, personnel and equipment may not be available at all times or there might be a delay while resources are mobilized. CT imaging with 16–64 slice machines is now commonly used in the initial evaluation of injured patients and these examinations offer the opportunity for detailed vascular imaging using computer-assisted image reconstruction.

Feliciano and coauthors cited data confirming that minor intimal defects discovered on contrast angiography will heal without intervention in more than 90% of affected patients. When there are no associated injuries that would prevent the use of anticoagulation, patients may be treated with heparin or aspirin and discharged home if there is no evidence of decreased distal extremity perfusion after observation.

The most recent guidelines for localizing vascular injuries of the lower extremities with imaging were promulgated by the Eastern Association for the Surgery of Trauma and presented in an article by Fox and coauthors in the Journal of Trauma and Acute Care Surgery, 2012. The authors cited data from a systematic review of the literature that support the increased use of CT angiography for definitive diagnosis of extremity vascular injuries. Additional data that support CT angiography’s potential for achieving a rapid and accurate diagnosis of extremity vascular injuries were presented in an article by Seamon and coauthors in the Journal of Trauma, 2009. The authors reported experience with 21 patients who underwent 22 upper or lower extremity CT angiograms for suspected vascular injuries. Notably, more than 90% of the patients had penetrating mechanisms of injury and half of the patients had associated long-bone fractures. All patients had ABI examinations and the ABI was 0.9 or less in all. The mean ABI averaged 0.72 for the entire group. The authors stated that CT angiogram images were available in less than one hour after patient admission and this compared favorably to contrast angiography that took, on average, more than two hours to complete. All vascular injuries observed on CT angiography were confirmed by contrast angiography, formal vascular exploration, or both. The authors found that CT angiography had sensitivity and specificity of 100% in their patients and that, if this test were used as the principle means of diagnosing vascular injuries, significant savings in hospital costs and time would be realized.

**Editorial Comment**

From my perspective, it is worth noting that these recently reported data, when added to the growing body of published information supporting the use of CT angiography for nontrauma vascular emergencies and elective vascular imaging, strongly suggest that this technique will likely supplant contrast angiography in confirming clinical suspicion of vascular injuries. It is likely that contrast angiography will continue to be useful for evaluating complex vascular injuries in the operating room. Also, contrast angiography will, of course, be necessary for patients selected to receive endovascular intervention treatment—endovascular approaches are likely to increase in the future, as these techniques become more widely available, and surgeons caring for injured patients would be wise to increase their familiarity with these techniques for the benefit of injured patients.

**Definitive Management of Vascular Injuries**

In their clinical guidance article, Feliciano and coauthors presented fundamental principles of clinical management that will lead to the successful restoration of blood flow after an extremity vascular injury in the Journal of Trauma and Acute Care Surgery, 2013. An algorithm that describes important features of vascular injury treatment was presented in the article (Figure 2).

Approaches for repairing documented vascular injuries are evolving. If immediate operation is indicated, good results can be expected when the following time-tested principles are used: adequate vessel exposure, proximal
and distal control, debridement of obviously damaged vascular tissue, and repair of the injury by direct suture, end-to-end anastomosis, or interposition vein graft using the saphenous vein from an uninjured extremity. Feliciano and coauthors stressed the importance of preparing the area of injury to include skin preparation and draping of all areas where vessel exposure may be necessary and areas where fasciotomy may be necessary. If saphenous vein harvest is anticipated, preparation of a suitable area of the uninjured lower extremity will be necessary.

Proximal and distal vascular control need to be achieved as rapidly as possible. In elective vascular operations, anticoagulation with heparin is used concomitant with vascular clamping. The association of injuries to the brain, abdominal organs, and other areas has raised questions about the safety of anticoagulation in injured patients. Humphries and coauthors24 investigated the effectiveness of heparin anticoagulation in patients with vascular injuries in *JAMA-Surgery*, 2016. The authors reported data on 123 patients seen in a single institution over an 8-year interval. The data analysis showed that the risk of limb loss was not increased in patients who did not receive anticoagulation. Of interest was that operative blood loss did not increase in patients who received heparin. Instances of bleeding from other injury sites were not reported. The authors suggested that routine heparin anticoagulation was not necessary for patients with vascular injury, but they acknowledged that the small size of their study did not provide strong evidence in support of this conclusion.

Where complete transection of the vessel with minimal adjacent tissue injury to the involved vessel is encountered, minimal debridement with end-to-end anastomosis using fine non-absorbable monofilament suture is indicated. If end-to-end anastomosis is not possible because of vascular damage, saphenous vein interposition graft is indicated. Feliciano and coauthors confirmed that ringed PTFE prostheses are acceptable if saphenous vein is unavailable.
Feliciano and coauthors also emphasized that a repaired vessel should not be left exposed. If a soft tissue injury is large and muscle coverage is not possible, consultation with reconstructive surgeons is indicated. If muscle coverage cannot be achieved with muscle transfer, extra-anatomic bypass may be considered. Recent experience cited by the authors supports the use of negative-pressure dressings in patients where soft tissue coverage is not possible. In unstable patients, temporary coverage with porcine xenograft material may be considered. The clinical guidance document provides information on managing challenging situations such as the mangled extremity and readers are encouraged to review this material.

Repair of concomitant venous injuries is recommended based on experiences with combat vascular trauma in the Vietnam conflict. Experience in civilian centers has suggested that venous injuries documented at the time of arterial exploration should be repaired, if possible, especially when there is high risk of limb loss or failure of the arterial repair because of extensive skeletal and soft tissue injury, leading to loss of venous drainage channels. In the textbook chapter by Frykberg and Schinco,12 the authors stressed that the majority of repaired veins will thrombose, but this will not usually occur until venous collateral circulation develops. They further emphasized that most of these veins will recanalize and that thrombosed vein repairs do not pose a significant risk for complications, such as progression of thrombus, to proximal veins and pulmonary embolus.

Data supporting this position were presented in a report from Quan and coauthors25 in the Journal of Vascular Surgery, 2008. In this article, the authors reviewed experience with 82 patients with 103 injuries to named veins resulting from combat injuries incurred by soldiers in the Iraq and Afghanistan wars. Blast injuries caused the venous injuries in more than two-thirds of the instances. Gunshot wounds caused the remainder of the injuries; only three injuries were caused by blunt mechanisms from vehicle crashes. Signs of phlegmasia were present in only two patients. The majority of the patients were treated with venous ligation; venous repair was done for 37% of the injured veins. The authors stated that the incidence of documented thrombosis of a repaired vein was recorded in 16% of repairs. Pulmonary embolus was diagnosed in three patients. There was no difference in the risk of pulmonary embolus whether veins were ligated or repaired. The authors did not report data to determine whether thromboses of the injured veins were or were not the origins of the pulmonary emboli reported. Based on this experience, the authors suggested that clinical conditions should determine the need for venous repair or venous ligation. There appears to be no need to alter the approach to deep venous thrombosis prophylaxis based on whether veins are repaired or ligated.

Johnson26 reviewed endovascular approaches for repairing extremity vascular injuries in Seminars in Interventional Radiology, 2010. According to the author, endovascular approaches may be particularly useful for injuries in specific anatomic regions such as the neck, the subclavian area, and the lower extremities. Data cited by the author supported the conclusion that use of endovascular approaches is increasing. Available data reviewed by the author suggest that the ideal candidate for endovascular repair of an arterial injury is a patient with a localized injury with minimal soft tissue damage. Good results from endovascular repairs are obtained in areas where the risk of injury to nearby nerves during open surgical repair is increased. The author pointed out that the only absolute contraindication to an endovascular approach is the inability to cross the area of the injury with an intravascular wire. Data cited by the author support the conclusion that endovascular approaches may be useful for hemorrhage control (endovascular aortic balloon occlusion). Other data showed that the embolization of bleeding sites using endovascular approaches is well accepted for managing injured patients with pelvic fracture, for example.
Thoracic, Cervical & Abdominal Vascular Injuries

In this section, we will review new developments in the diagnosis and management of vascular injuries in specific anatomic areas. Significant improvements have occurred from the use of modern diagnostic and therapeutic approaches to injuries of the thoracic aorta. In addition, the potential for blunt injuries to the carotid and vertebral arteries to cause devastating central nervous system ischemia in patients who arrive at the hospital neurologically intact has been recognized, and clinical presentation patterns that suggest the diagnosis of these injuries have been described. Open operative repair of injuries to the distal internal carotid and vertebral arteries is usually not feasible, and therapeutic anticoagulation is frequently used with success. Endovascular interventions for these injuries are useful in selected patients. Adjunctive interventions used to improve outcomes of patients with vascular injuries will be reviewed as well as the pathophysiology of compartment syndrome. Following this, the indications for, diagnosis of, and techniques of, extremity fasciotomies will be discussed.

Injuries to the Thoracic Aorta

According to Neschis and coauthors\textsuperscript{27} in their article in \textit{New England Journal of Medicine}, 2008, blunt aortic injury occurs in less than 1% of motor vehicle crashes but is responsible for 16% of annual motor vehicle fatalities in the United States. Blunt aortic injury is the second most common cause of death in motor vehicle crash victims, behind traumatic brain injury. More than 80% of patients with blunt thoracic aortic injuries will die before reaching the hospital. Patients who do survive to reach the hospital will succumb without definitive treatment.

Recent research into motor vehicle crash characteristics has helped define the types of impacts that increase the risk of blunt thoracic aortic injuries. Neschis and associates explained that frontal impact is the primary source of force transfer in most aortic injuries, but there is increasing awareness of the importance of side impacts as a cause of thoracic aortic rupture. The authors cited data confirming that 42% of patients dying of thoracic aortic injuries were involved in side-impact crashes. The authors listed deceleration (a decrease of more than 20 mph), primary impact on the injured person’s side of the vehicle, and the intrusion of the auto frame into the passenger compartment of more than 15 inches as the main factors associated with thoracic aortic injuries.

Michetti and coauthors\textsuperscript{28} reported additional data on the importance of crash characteristics in predicting the likelihood of blunt thoracic aortic injuries in the \textit{Journal of Trauma}, 2007. The authors analyzed data from the National Automotive Sampling System database for the years 1988 to 2002. This database contains not only crash-analysis data but also hospital and autopsy findings. The analysis reported in this article evaluated relationships among variables such as the primary direction of force, the change in velocity, the position of the injured occupant within the vehicle, the use and deployment of restraint devices, injured occupant vehicle characteristics, and striking vehicle characteristics. Logistic regression analysis was used to examine relationships between crash characteristics, the occurrence of aortic injuries, and mortality. The database contained information on 789 patients with aortic injuries. The incidence of aortic injuries was 1.2%; overall mortality of aortic injuries was 92%, with 63% of patients dying before reaching the hospital. Twenty-five percent of patients who were triaged to a trauma center survived the aortic injury compared with 10% survival in patients triaged to nontrauma centers. Thoracic aortic injuries were the primary cause of death in more than three-quarters of the deaths of patients reaching the hospital.

When crash characteristics were analyzed for patients with thoracic aortic injury, 57% of the impacts were frontal, and 35% of impacts were from the side. Drivers suffered thoracic aortic injuries in 71% of instances and front seat passengers were injured in 23% of instances. Michetti and colleagues associated restraint use and protection against aortic injuries. This observation contrasts sharply with a statement made in the report by Neschis and associates,\textsuperscript{27} where they reported that increasing restraint use has not been associated with a reduction in the frequency of aortic injuries.
Michetti and colleagues presented data on the influence of deceleration in thoracic aortic injuries. They found that the risk of an aortic injury in the data they examined began to rise sharply at decelerations greater than 20 km/h and that the mean deceleration in the patient data they analyzed was 50 km/h. The authors further emphasized that the main crash characteristics associated with a high risk for thoracic aortic injuries are frontal or left-side impacts, high speed (large deceleration), and the lack of restraint use. The authors stated that crash data were more predictive of injury presence than were clinical data presented on admission to the hospital. This observation suggests that clinicians may wish to query prehospital care personnel about patterns of vehicle damage, direction of impact, restraint use, and speed to raise suspicion of injury presence. Because data presented show that the mortality rate for aortic injuries was more than 75%, even if patients reach a trauma center, improved diagnosis and earlier treatment might improve outcomes.

Neschis and associates discussed the mechanism of aortic rupture. They stressed that the most common site of injury is at the aortic isthmus where the descending aorta enters the retropleural space. The pleural membrane and the ligamentum arteriosum tether the aorta at this point, rendering the descending aorta immobile while the ascending and transverse arch segments of the aorta are mobile. They also explained that torsion and stretching of the aorta because of deceleration, combined with the “osseus pinch” mechanism (wherein the aorta may be trapped between the anterior chest wall and the spinal column) may combine to produce the initial intima and media injury. This progresses at variable rates to involve the outer adventitia layer of the aorta; when this layer is breached, rupture, massive bleeding, and death occur. The authors added that sudden elevations of intraabdominal pressure from deceleration may also produce aortic intimal and media injury by a “water hammer” effect.

The importance of sudden elevations in intraabdominal pressure in producing an aortic injury is reinforced by the observation that diaphragmatic rupture and aortic injury coexist in a significant number of patients. Additional data relevant to this topic was presented in an animal study reported by Stemper and coauthors in the Journal of Trauma, 2007. The authors removed the isthmus areas of porcine aortas and subjected the specimens to stretch at various levels. They observed a distinct sequence of failures of the aortic wall, beginning with intimal injury and proceeding, with increased force application, to involve the media and then the adventitia. The authors postulated that this sequence occurs in traumatic aortic injuries and that patient presentation may occur at any point along the progression through various stages of the injury.

This basic concept is supported by additional experimental evidence found in a report by Schmoker and coauthors in the Journal of Trauma, 2008. The authors applied pneumatic compression forces to porcine aortas and found that the aortic isthmus was particularly susceptible to injury. Forces lower than 120 psi produced intima and media injuries; forces exceeding 120 psi consistently produced aortic transection and rupture. Areas other than the isthmus also ruptured with the application of forces exceeding 120 psi. They concluded that pneumatic pressure loading of the aorta provides a coherent model explaining the sequence of an aortic wall injury observed in patients injured by blunt trauma.

Diagnosing Thoracic Aortic Injuries

Neschis and coauthors next discussed the diagnosis of blunt aortic injuries. The data discussed previously, documenting very high in-hospital mortality for patients with blunt aortic injuries, suggests weaknesses in the diagnostic process. There have been several findings on plain chest radiographs associated with aortic injuries. These include widened mediastinum, absence of the aorta-pulmonary window, depression of the left mainstem bronchus, apical hematoma, rightward shift of the tracheal shadow, and widening of the left paraspinal line without spine fracture. There is a significant risk of aortic injury in patients with an unremarkable plain chest radiograph, leading to the conclusion that plain x-ray evidence is undependable for identifying patients at risk for aortic injury.

With the advent of helical CT scanning, contrast radiography is no longer used as a screening study. Patients with the potential for an aortic injury as indicated by crash history are candidates for CT scanning; data cited by Neschis and associates documented that sensitivities and specificities in numerous reports of this modality approach 100%. Other options for diagnosis include intravascular ultrasound, MRI, and transesophageal echocardiography.
Data on these modalities are not yet sufficiently convincing to support a recommendation that any of these supplant helical CT scanning as the screening study of choice for aortic injuries.

Additional data on diagnosing thoracic aortic injuries were available from a multicenter study of contemporary approaches to aortic injuries sponsored by the American Association for the Surgery of Trauma (AAST). The article, by Demetriades and coauthors,31 was in the Journal of Trauma, 2008, and is the second multicenter study of this type of injury. The report stressed the differences in approach as time has passed and additional data on the injuries have accumulated. According to the multicenter study, helical CT scanning was used in 93% of patients with aortography in 8% and transesophageal echocardiography in 1%.

With increasing use of CT scanning, the so-called “minimal” aortic injury has been identified: these are small intimal tears that may not have clinical significance. In fact, as Neschis and colleagues27 discussed, these injuries are not seen when contrast aortography is used to investigate CT findings of minimal injuries. The authors suggested that intimal tears of smaller than 1 cm that are not associated with periaortic hemorrhage or pseudoaneurysm can be followed with sequential CT scanning with a high degree of patient safety. The authors cited data suggesting that the risk of pseudoaneurysm development approaches 50% in patients with intimal tears associated with any additional aortic findings such as periaortic hematoma. Neschis and colleagues stated that their approach to this higher risk group of patients with small injuries is to place an aortic endograft if the patient has favorable anatomy.

**Open Operative Repair of Thoracic Aortic Injuries**

Traditionally, early open surgical repair using the “clamp and sew” technique has been suggested for patients with traumatic thoracic aortic injuries. Accumulated data have revealed that the presence of severe associated injuries and complicated aortic tears, leading to prolonged cross clamp times, produced mortality rates in excess of 16%, with rates of paraplegia of 19%. As the influences of these factors have been appreciated, increased use of delayed operation has been studied.

Neschis and associates cited a prospective study that documented the safety of beta-blocker therapy supplemented, if necessary, with vasodilators to reduce the aortic pressure wave velocity and to reduce the stress on the aortic wall. The objective of treatment is to achieve a systolic blood pressure of 100 mmHg in young patients and 110–120 mmHg in older patients. There were no aortic ruptures during the period of nonoperative therapy in the cited study. Neschis and colleagues stated that this approach permits stabilization of associated injuries and, potentially, improved outcomes of operative or endovascular interventions.

The multicenter study of aortic injuries by Demetriades and coauthors31 documented a trend toward delayed management, with a change in mean time to definitive repair from 23 hours in an earlier multicenter study to more than 53 hours in the later study. Demetriades and colleagues found that there are no data to support the superiority of the delayed approach. Data are available documenting no increased mortality risk for the delayed approach, but, that said, several studies have documented the prolonged hospital stay and increased ICU days with attendant costs for patients treated in a delayed fashion.

Delayed operation is preferred for high-risk patients with multiple associated injuries. Bilateral pulmonary injury with inadequate oxygenation, traumatic brain injury with Glasgow coma score <10, and concomitant usage of damage-control approaches to intraabdominal visceral injuries are examples of instances where delayed operation is desirable. For low-risk patients with few or no severe associated injuries, a short interval of delay with early operation for definitive repair of the thoracic aortic injury is preferred.

Major improvements in outcomes, particularly the risk of paraplegia, occurred with the introduction of partial bypass techniques for aortic injury repair. The use of bypass techniques to reduce mortality and paraplegia rates was described by Neschis and coauthors.27 The authors reported that early efforts to improve perfusion in the aorta, distal to the site of cross clamping, were attempted using a bypass prosthetic shunt from the proximal aorta to the thoracic aorta distal to the injury site. Modest improvements in rates of paraplegia were reported with the use of the shunt, but results from several centers varied and many surgeons reported equivalent rates of paraplegia with and without shunting.
The relationship of aortic clamp time to the rates of complications including paraplegia, however, was well documented, and selective shunting was used to attempt matching of the operative technique to the risk of paraplegia for a given patient. When partial bypass techniques became available, these offered the opportunity to “cool down” the patient with attendant spinal cord protection, control of distal aortic perfusion pressure, and the option to place an oxygenator in the circuit so that distal perfusion could be accomplished with oxygenated blood. The provision of oxygenated blood to the systemic circulation has significant value if single lung ventilation is not possible because of a pulmonary injury. The authors stated that centrifugal pumps and heparinized tubing offer the additional possibility of avoiding systemic anticoagulation. As the use of bypass techniques increased, rates of paraplegia fell to below 3%. Neschis and associates reported a consecutive series of 73 patients from their unit without an instance of paraplegia. These impressive results are tempered in a citation by these authors of a multicenter study reporting the experience of more than 50 trauma centers. The overall mortality for traumatic thoracic aortic injuries was reported as 31% for patients treated operatively and the paraplegia rate was 8.1%.

Detailed descriptions of the technique of aortic repair using a left atrial to femoral artery bypass technique using a centrifugal pump were provided in an article by Moore and coauthors in Annals of Surgery, 2004. The authors are all trauma surgeons and the clinical experiences described are those of trauma surgeons and not cardiothoracic or vascular surgeons. While it is recognized that trauma surgeons might not wish to take on the responsibility of serving as a primary surgeon for these patients and that the bypass equipment might be controlled by specialists other than the trauma surgeon, familiarity with the techniques described in this report will be valuable for surgeons coordinating the care of patients with thoracic aortic injuries or serving as first assistants to surgeons who are performing these repairs. Moore and colleagues described the preparation of the patient and explained that intubation with a double lumen tube and unilateral right lung ventilation provides optimum exposure of the thoracic aorta. The aorta is exposed via a conventional posterolateral thoracotomy incision through the fourth left intercostal space. Patient position on the operating table is adjusted so that simultaneous thoracotomy and left femoral artery exposure is facilitated. The fourth rib is divided at the angle of the rib to improve exposure. If adequate oxygenation with single lung ventilation is possible, the left lung is collapsed. Control of the left superior pulmonary vein, left subclavian artery proximal to the vertebral and internal mammary branches, and distal aorta are achieved within the chest while a second team isolates the superficial, common, and profunda femoris arteries on the left. The authors preferred bypass from the left superior pulmonary vein to the left femoral artery although multiple reports document the feasibility of bypass from the left atrium to the distal thoracic aorta.

Moore and colleagues recognized the ongoing debate over the necessity of systemic anticoagulation when using the centrifugal pump. When there is no contraindication to anticoagulation, they preferred to use heparin in a dose of 100 U/kg to achieve an activated whole blood clotting time of between 200 and 250 seconds. The authors stressed the necessity for optimal preparation before cross clamping the aorta to ensure that cross-clamp time is minimized. Several technical features of the suture repair were emphasized in their description, including the need for care in suturing the medial portion of the aortic suture line because the aorta is thin in this area; there is also a risk of recurrent laryngeal nerve injury. According to the authors, a few aortic injuries can be managed with direct suture and that the injury patterns are variable, so 18–20 mm, gel-impregnated Dacron or PTFE grafts should be available if needed. The authors concluded by emphasizing the need to document adequacy of circulation in the left upper and left lower extremity once all cannulas have been removed and perfusion is restored.

Endovascular Management of Thoracic Aortic Injuries

Neschis and coauthors stated that endovascular repairs are now feasible and early reports have documented the potential for improved outcomes including lowered risk for mortality and paraplegia. The authors conducted a review of the world’s literature showing that clinical experience is limited with only 220 patients reported worldwide; of interest, however, is that mortality was 6.8%. Early
experience with endovascular repair in the authors’ unit disclosed an overall mortality of 12.8% in a series of 39 patients. There were no instances of paraplegia among the 39 patients.

Data from a multicenter study of endovascular repairs of thoracic aortic injuries sponsored by the American Association for the Surgery of Trauma (AAST) were presented by Demetriades and coauthors in the Journal of Trauma, 2008. The data offer a useful “snapshot” of current trauma practice. Endovascular repair was chosen for nearly two-thirds of the nearly 200 patients treated and reported in the multicenter study. This observation strongly suggested that contemporary trauma practice favors the use of endovascular interventions regardless of the lack of long-term follow-up and the persistent reports of device-related complications. Demetriades and coauthors reported that 20% of the patients in the multicenter study developed 32 device-related complications. This report subjected the patient data to careful multivariate logistic regression analysis. After adjusting for associated injuries, patient age, and other factors, endovascular repair was associated with a statistically significant improvement in mortality and a paraplegia rate of less than 1%.

A systematic review of the available literature relevant to repair of thoracic vascular injuries using endovascular stents was by Hershberger and coauthors in the Journal of Trauma, 2009. The authors cited data from multiple studies confirming an excellent record of technical success. Available data also documented a reduced mortality risk for endovascular repair (6%–10% vs. 19%–28% for open repairs) and a low rate of paraplegia (less than 3%). Hershberger and colleagues stressed that long-term follow-up data are scarce and the risk of device-related complications cannot be estimated accurately based on their review. They emphasized the difficulty in obtaining long-term follow-up data in trauma patients and strongly urged the development of long-term follow-up protocols for this patient group.

A report of findings from a multicenter data analysis conducted by an ad hoc committee of representatives from one national vascular society, two thoracic surgical societies, and one radiologic society was by Dake and coauthors in the Journal of Vascular Surgery, 2011. The authors reported early and one-year outcomes on 60 patients who sustained thoracic aortic injuries from blunt trauma. All patients were severely injured (mean injury severity score of 39) and more than half the patients required surgical procedures for associated injuries. Technical success was achieved in all patients and overall mortality was 9.1% at 30 days. The mortality risk rose to 14% at one year. There were no complications related to the endograft during the follow-up interval. Paraplegia developed in one patient. The authors concluded that endovascular management of blunt thoracic aortic injuries has acceptable outcomes.

Another systematic review performed in support of clinical practice guidelines was commissioned by the Society for Vascular Surgery and reported in an article by Lee and coauthors in the Journal of Vascular Surgery, 2011. The guidelines dealt with eight important areas generated from a systematic review of evidence that was graded for quality based on standard criteria. The committee recommended that endovascular repair be the standard option for management of thoracic aortic injuries due to blunt trauma and that open repair should be used for patients whose aortic anatomy is unsuitable for endovascular repair. Young age should not be an indication for open repair. Endovascular repair was recommended within the first 24 hours of hospitalization in stable patients although later repair, when associated injuries have been stabilized, is safe if strict control of blood pressure and aortic flow velocity with beta-blocking drugs is achieved. The committee recommended observation with repeat imaging for patients with “minimal” aortic injuries (grades I and II on the injury scale). Per the authors, endovascular devices are needed to better fit the aortic curvature in young patients. Most committee members favored a short interval of systemic heparinization during the endovascular repair, but the committee advised that careful risk assessment is required, particularly in patients with a brain injury and potential extrathoracic sites of bleeding. Most committee members favored repair under general anesthesia, selective use of carotid-subclavian bypass after coverage of the orifice of the left subclavian artery by the endograft, and open femoral access for placement of the endograft. The committee recommended against routine spinal fluid drainage. There was not uniform agreement on the best plan for long-term follow-up. Some members favored an-
nual imaging, others favored longer intervals between imaging if there were no signs of device abnormalities at one year after placement.

Celis and coauthors\textsuperscript{36} retrospectively reviewed a single-center experience over a 12-year interval in the Journal of Vascular Surgery, 2012. Ninety-one patients with traumatic aortic injuries were treated and 41 patients underwent open repair. The authors confirmed that the last open repair was performed in 2007. Mortality risk for patients treated with endovascular stents was 6% and there were no instances of paraplegia in patients treated with stent grafts. The authors confirmed that the use of abdominal aortic extender cuffs has increased in frequency and this change should lead to fewer device-related complications during long-term follow-up.

**Editorial Comment**

From the perspective of the editor, it seems obvious that continued improvement of endovascular devices that have design features for the specific anatomic characteristics of the thoracic aortas of young patients will drive future trends in the management of this important injury. There will likely always be a proportion of patients for whom open repair is desirable; surgeons caring for these patients will be well served to maintain familiarity with the technical features of the open operation. The one aspect of endovascular therapy that remains a major unknown is the rate of long-term complications of these devices. The endovascular grafts placed in trauma patients are actually designed for older patients with larger aortic lumens. What will occur over the long term as the recipients’ aortas change is unknown. Furthermore, most of the endovascular devices placed in the thoracic aorta for chronic disease are placed in patients whose life expectancies are significantly shorter than the typical trauma patient. Long-term follow-up protocols with routine data entry into trauma registries, locally and nationally, are sorely needed. It behooves surgeons caring for injured patients to emphasize the need for continued follow up and devise programs to ensure such follow up. Only when long-term data are available will the early confidence in endovascular repair of thoracic aortic injuries be fully justified.

**Cervical Vessel Injuries**

The management of penetrating injuries to the arteries and veins of the neck is closely aligned to management protocols for vascular injuries in other regions. The morbidity attendant to carotid and vertebral artery injuries is intimately tied to associated airway compromise from direct airway injury or compression of the airway from hematoma, the degree of external bleeding, and ischemic brain damage resulting from reductions of blood flow in the injured artery(ies).

Penetrating neck injuries can present management challenges to the surgeon because there are many important vascular, aero-digestive, and neural structures closely apposed in a small space. These structures occupy anatomic locations that might be difficult to surgically expose. For example, the left carotid artery arises from the aortic arch in the upper thorax and the first few centimeters of the vessel are located behind the sternum, upper rib cage, and clavicle. Distally, exposure of the internal carotid artery at the base of the skull may require extensive surgical maneuvers. Given these facts, it is interesting that more than half of the penetrating injuries of the neck do not cause significant damage—thus, it is not surprising that selective management protocols have developed for cervical vascular injuries in ways similar to vascular injuries of the extremities.

The optimal approach to the diagnosis and management of carotid and vertebral artery injuries was described in a clinical guidance document by Sperry and coauthors\textsuperscript{4} in the Journal of Trauma and Acute Care Surgery, 2013. The document was sponsored by the Western Trauma Association and is supplied as a full-text reprint accompanying some formats of SRGS. Traditionally, management protocols have divided the neck into three zones. Zone 1 encompasses the base of the neck and the thoracic outlet and is bounded by the sternal notch and clavicles. The incisions necessary to expose structures in Zone 1 include median sternotomy, upper chest thoracotomies, and base of the neck incisions that sometime require resection of the clavicle. These incisions carry inherent morbidity, thereby making the cost of a negative exploration of Zone 1 significant, in terms of patient recovery. In addition, the majority of patients with injury to the vessels in Zone 1 present with a contained hematoma rather than ongoing bleeding. These facts have driven the trend toward selec-
tive nonoperative management of injuries in this area in the hemodynamically stable patient with no discrete clinical signs of major vascular injury.

Zone 2 is the area between the clavicles and the angle of the mandible. This area is easiest to explore using standard anterior neck incisions. Zone 3 is that portion of the neck between the angle of the mandible and the base of the skull. Vascular exposure in this area is quite difficult and, as maneuvers such as anterior dislocation of the temporal-mandibular joint and combined neck exploration and craniotomy are occasionally necessary for treatment of injuries in this area.

The clinical guidance document provided a useful algorithm for management of vascular injuries of the neck (Figure 3). Evaluation of hemodynamically stable patients with Zone 1 injuries using CT imaging (to include CT angiography) is recommended. Endovascular approaches have increasingly been used for management of Zone 1 vascular injuries. Routine surgical exploration with exposure of all areas of potential injury has been the time-honored approach for penetrating injuries in Zone 2 that have violated the platysma muscle. Obviously, the potential for serious vascular injury will depend on the destructive force of the injuring agent, with stab wounds imparting less energy to tissue compared with gunshot wounds. The practice of routine exploration of all wounds that penetrate the platysma muscle, regardless of clinical signs, however, resulted in a large number of negative

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**Figure 3**

Algorithm for management of penetrating neck injuries. Reproduced from Sperry and coauthors with permission.
surgical explorations; this gave rise to the development of selective approaches that combine evaluation of clinical signs and the use of adjunctive imaging.

Clinical signs of vascular injuries in the neck include active bleeding, shock, expanding or pulsatile hematoma, and the presence of a cervical bruit. These are considered “hard signs” of injury. The clinical guidance document recommends immediate transfer of patients with hard signs of vascular injury to the operating room for exploration of the neck; short delay of transfer in order to secure a dependable airway is acceptable. For patients who have penetration of the platysma muscle and no clinical signs of injury, observation without imaging or other intervention is recommended. Patients with “soft signs” of vascular injury, include those with voice change, hemoptysis, dysphagia, and the presence of a widened upper mediastinum on plain chest radiograph. The authors cited several clinical series documenting the safety of selective approaches to hemodynamically stable patients with Zone 2 injuries where hard signs of vascular injury are not present. The use of multidetector CT imaging with CT angiography has offered increasing accuracy for the detection of vascular and visceral injuries. The addition of CT imaging to the early evaluation of stable patients increases diagnostic accuracy. If surgical exploration of Zone 2 injuries is chosen, anterior incisions parallel to the sternomastoid muscles or a collar incision affords adequate exposure. Conventional reconstructive approaches to arterial injuries using lateral suture repair, anastomosis, or vein graft interposition are employed as needed. Ligation has been used for carotid injuries in patients who present with profound fixed neurologic deficits and coma. The clinical guidance document recommends against ligation of the carotid artery regardless of neurologic status. Ligation is appropriate for jugular venous injuries although bilateral ligation of the internal jugular veins should be avoided because of the risk of brain injury mediated by increased venous pressure.

Control of an injury to the proximal vertebral artery in Zone 3 of the neck will frequently require extension of neck incision along with one of the additional exposure maneuvers mentioned. Ligation has been used for vertebral artery injuries within the vertebral foramen where exposure is difficult. Balloon occlusion of the arterial bleeding point may be used if bleeding persists after proximal ligation. If the injured vertebral artery is large, suggesting that it is the dominant vessel providing inflow into the posterior cerebral circulation, surgical exposure and repair may be necessary to avoid central nervous system symptoms. Fortunately, cerebral collateralization is usually sufficient to provide perfusion to the brain if the patient is neurologically normal before operation; direct reconstruction of an injured vertebral artery within the vertebral foramen is not often necessary.

**Management of Blunt Carotid & Vertebral Artery Injuries**

Injury to cervical vessels from blunt trauma is a rare event observed in significantly less than one percent of injured patients. Blunt injury to the carotid and vertebral arteries has drawn increased interest as reports of severe ischemic brain injury developing suddenly in patients originally admitted with few, if any, neurological deficits, have increased. It might well be the case that this injury will be diagnosed with greater frequency as trauma centers experience an increasing number of patients injured in motor vehicle crashes, and who are therefore at an increased risk of blunt injury to the carotid and vertebral arteries.

A classic article describing and classifying mechanisms of injury and clinical signs of vessel injury was by Biffl and coauthors in the *World Journal of Surgery*, 2001. The authors reasoned that the anatomy of the carotid and vertebral arteries within the skull and neck may predispose to stretch injury because these arteries have both mobile portions (carotid artery within Zone 2 of the neck, vertebral artery within Zone 1 of the neck) and anatomic areas where the arteries are tethered (carotid artery at the base of the skull and within the cavernous sinus and vertebral artery within the vertebral foramen). These anatomic arrangements offer the opportunity for stretch injuries to occur when there is hyperextension of the neck. In addition, direct neck trauma from strangulation or seat belt/airbag impact is an understandable mechanism of carotid or vertebral artery injury.

Biffl and colleagues cited data proposing a four-part classification scheme for blunt injuries to the carotid and vertebral arteries. Type I injuries were caused by a direct
blow to the neck, type II injuries result from hyperextension and rotational forces applied to the neck, type III injuries are often a consequence of intraoral trauma, and type IV injuries result from basilar skull fractures. Biffl and associates stressed that type II injuries are the most common injuries and that might be explained because the lateral articular processes and pedicles of the upper three cervical vertebrae project more anteriorly than those of the lower cervical vertebrae. The distal cervical internal carotid artery is therefore more prone to stretch injury because of this anatomic arrangement. Torsion of the atlanto-occipital joint may also cause stretch injury. The authors report that there are recurring reports of severe ischemic brain injury from “trivial” trauma, and that early detection of most or all of these injuries is challenging.

Biffl and associates explained that the most common pathogenesis of injury is intimal disruption. Ischemic brain injury might result from thrombus formation, distal embolization, or separation of the intima and media from the adventitia leading to dissection and vessel occlusion. Additionally, partial transections of the arteries lead to pseudoaneurysm formation. The authors detailed the clinical symptoms that, if identified, might lead to the diagnosis of arterial injury, including neck, oral, ear, face, or periorbital pain, and posttraumatic headache. Horner syndrome or partial Horner syndrome after injury is also suggestive of the diagnosis. Clinical features such as oral or nasal hemorrhage of arterial blood, cervical bruit, expanding hematoma, CT scan evidence of cerebral infarction, and unexplained neurologic deficit are additional diagnostic clues.

Unfortunately, most patients who sustain a blunt injury to the carotid or vertebral arteries are victims of significant blunt injury and have severe associated injuries that may make the detection of many of these symptoms and signs difficult. Another challenging feature is that some patients have a “latent period” before cerebral ischemic symptoms occur. Clearly, making the diagnosis before symptom development offers an attractive opportunity to begin therapy and, perhaps, prevent stroke. Biffl and colleagues cited data supporting the adoption of an aggressive diagnostic protocol to detect injuries early so that treatment can begin. The authors explained that the risk factors for the presence of blunt injury to the carotid and/or vertebral body include injury mechanisms consistent with hyperextension and/or cervical rotation impact. Markers of this mechanism include Le Fort II or III facial fractures, cervical contusions, complex mandibular fractures, and upper cervical spine fracture or distraction. Near-hanging injury mechanism and the presence of diffuse axonal brain injury without clear signs of direct brain trauma also are important clinical indicators. The authors cited data from their own and others’ series, and revealed that the presence of one risk factor is associated with a 20% chance of arterial injury and that the discovery of arterial injury increases to more than 90% when four risk factors are present.

Biffl and associates pointed out that the aggressive use of angiography in patients at risk has increased the discovery of these injuries. They also acknowledged that the use of early angiography for patients at risk for these injuries is a labor-intensive obligation for trauma centers. They reported that the practice in their trauma center of delaying angiography until the day after admission has resulted in missed injuries; they stressed that alternative diagnostic avenues need to be developed. The data revealed that Doppler ultrasound imaging has not been useful. Per the authors, conventional CT angiography has not been sufficiently accurate and more data on the use of MRI need to be generated.

Data supporting the utility of aggressive diagnostic protocols using contrast angiography appeared in an article by Cothren and coauthors in the American Journal of Surgery, 2005. The authors reported data from reviews of diagnostic angiograms performed in 727 patients. Carotid and/or vertebral artery injury was discovered in 244 patients. One hundred eighty-seven asymptomatic patients were treated with heparin, and the authors estimated they averted 32 strokes using this approach. By analyzing the costs of long-term care for a patient with a completed stroke, they suggest that screening is probably cost effective.

A recent article by Paulus and coauthors in the Journal of Trauma and Acute Care Surgery, 2014, presented data on the use of 64-channel multidetector CT imaging for diagnosis of blunt cerebrovascular injuries. The authors reported data on 594 patients with suspicion of blunt cerebrovascular injury who underwent both 64-channel CT imaging and digital subtraction contrast angiography.
Outcomes data for 594 patients seen at a single institution over a 12-month interval were reported; 128 patients (22%) had injuries demonstrated in 163 vessels. Carotid artery injuries were found in 61% of patients and vertebral artery injuries in 39% of patients. Sensitivity was 64-channel CT imaging was 68% (improved from 51% for 32-channel imaging previously reported from this center) with specificity of 92%. False negative studies occurred in 20 patients (52 vessels). CT-imaging yielded a positive predictive value of 36% and a negative predictive value of 97.5%. The authors concluded that while patients with negative CT imaging and no neurologic deficit could be managed using CT imaging only, close monitoring of the success of this approach is needed. This article was presented to the plenary session of the annual meeting of the American Association for the Surgery of Trauma in 2012. In the discussion that accompanies the paper the authors elaborated on their protocol: CT imaging is used for screening and not for diagnosis. A patient with a negative CT study and no contraindication to treatment with anticoagulation or aspirin is treated based on risk factors for cerebrovascular injury. Patients in high-risk categories with negative CT imaging undergo contrast subtraction angiography within 24 hours of injury. It is noteworthy that all CT images and subtraction angiograms are interpreted by attending radiologists who are in the hospital 24 hours a day, seven days a week. These data and other information presented in the discussion section of the presentation supports the conclusion that 64-channel CT imaging is the screening study of choice for these patients.

There is ongoing analysis attempting to determine whether clinical data can predict the presence of blunt carotid or vertebral artery injury. An analysis of skull base fracture patterns was reported in an article by York and coauthors from the American Journal of Radiology, 2005. The authors detected carotid canal fractures in CT scans following blunt injury. They found 21 carotid canal fractures in 17 patients from a total group of 43 patients who were evaluated with both CT scan and cerebral angiography. Six patients with carotid canal fracture had internal carotid artery injury yielding a sensitivity of 60% and specificity of 67% for the presence of carotid artery injury with this fracture pattern. The authors concluded that accuracy and negative predictive value for this fracture pattern is only moderately helpful in assisting clinicians attempting to detect blunt carotid artery injury.

The relationship of cervical spine fracture patterns to the presence of carotid and vertebral artery injuries has offered a more dependable set of clues to the presence of these injuries. Data supporting this position are in an article by Cothren and coauthors in Surgery, 2007. Data gathering began in 1996 and continues. The authors reported on 258 patients diagnosed with carotid and/or vertebral artery injuries; 125 patients had cervical spine fractures. The predominant fracture patterns seen in patients with documented vascular injuries were subluxations, fractures in the C1–C3 area, and fractures extending into the foramen transversarium. The authors concluded that applying aggressive screening approaches using angiography in patients with these fracture patterns would result in a 30% rate of positive angiograms. They acknowledged that this aggressive use of angiography is labor intensive and cite early encouraging results of the use of CT angiography. It is possible that additional experience with multidetector CT angiography will permit the emergence of this technique as a useful diagnostic modality.

An article documenting the risk factors for blunt carotid and vertebral artery injuries by Berne and coauthors was in the Journal of Vascular Surgery, 2010. The authors reported data on 102 patients with blunt injuries to the carotid or vertebral arteries confirmed by CT angiography. Fifty-seven percent of patients had vertebral artery injuries and 43% had carotid artery injuries. Multivariate logistic regression was used to determine injury risk factors. Cervical spine fracture, mandibular fracture, and basilar skull fracture were strongly predictive of concomitant blunt cerebrovascular injuries. Injury severity score and low emergency department Glasgow Coma Score were less strongly predictive but still statistically significant. The authors concluded that CT angiographic screening for injuries should be done in patients with a high-risk mechanism of injury (as reviewed earlier) and the presence of one or more risk factors.

MRI is potentially valuable as a means of diagnosing carotid and vertebral artery injuries. This topic is discussed in an article by Ren and coauthors in the
Journal of Trauma, 2007. Three hundred nineteen patients were evaluated with MRI, and vertebral artery injury was diagnosed in 52 of these; all 52 patients had concomitant high-risk cervical spine injuries. The authors also report an experimental study where cervical spine fracture was induced in dogs; MRI and contrast angiography were performed in evaluating 28 arteries. In the experimental study the false positive rate for MRI was 5%. There were no false negative studies. The authors concluded that MRI is a potentially useful modality in patients at risk for blunt carotid and vertebral artery injuries based on cervical spine fracture patterns. The principle disadvantage of MRI is the difficulty in positioning necessary equipment (ventilators, external fixation devices) for support of the patient so that imaging can be safely performed.

Protocols that use screening imaging to detect blunt cerebrovascular injuries usually classify injuries into grades using the Denver classification system (Figure 4). Surgeons caring for these patients have discovered that there are patients with findings on screening imaging that do not fit into the Denver classification system and knowledge of the natural history of this group of injuries is limited. An article that presented data on outcomes of patients with indefinite blunt cerebrovascular injuries was by Crawford and coauthors in JAMA-Surgery, 2015. The authors reported on 100 patients with 138 injured vessels seen in a single center over nearly seven years. Fifty-nine patients had indeterminate findings on screening imaging. Resolution occurred as documented by serial imaging in 39% of patients and findings remained indeterminate in 36% of patients; progression to a true injury according to the Denver classification scheme occurred in 25% of patients. Cerebral symptoms developed in 5% of indeterminate patients. The authors concluded that indeterminate injuries were not completely benign and recommended that these be treated with serial imaging and antiplatelet therapy.

Despite efforts to grade injuries to predict the risk of blunt cerebrovascular injury, a small proportion of patients with documented injuries is missed and is at risk for significant neurologic damage. Data on the effectiveness of expanded screening criteria for detecting blunt cerebrovascular injuries were presented in an article by Geddes and coauthors in the American Journal of Surgery, 2016. These authors added clinical features such as complex skull fracture, scalp degloving injury, upper rib fractures, and mandible fractures. Using a before-and-after design, the authors were able to document a significant increase in the rate of injury detection using expanded criteria. The proportion of missed injuries was reduced from 20% to 5% using the expanded screening criteria. The authors emphasized that screening is an important means of reducing missed injuries but is not perfect; therefore, clinician vigilance is encouraged. The screening criteria led these authors to develop a modified management algorithm for blunt cerebrovascular injuries (Figure 5).

A relatively small proportion of patients with blunt carotid and vertebral artery injuries are candidates for open operation. Most of the injuries are dissections and false aneurysms and are located in anatomic areas difficult or impossible to approach with open surgical exposure. Anticoagulant and/or antiplatelet drug use has emerged as the principle means of therapy for these injuries. Data are available to document the reduction of stroke risk with these drugs. Data have been produced to show that patients admitted with blunt carotid and/or vertebral artery injuries and neurologic deficits improve with anticoagulation.
Diagnosis is generally made with contrast angiography and follow-up CT angiography is used to document the progress of pseudoaneurysms, dissections, or arteriovenous fistulas discovered in these patients. Endovascular interventions have been suggested to occlude pseudoaneurysms and other abnormalities that persist or enlarge under observation.

**Nonoperative Management of Blunt Cervical Arterial Injuries**

Cothren and coworkers\(^{47}\) reported on a group of 422 blunt cervical vascular injuries in 301 patients in *Archives of Surgery*, 2009. Injury diagnoses were confirmed by screening CT angiography. Twenty-two patients had neurologic deficits on admission and five additional patients had strokes following vascular stenting procedures. Injuries were graded according to the injury scale reviewed previously. Stroke was diagnosed in 0.5% of patients treated with heparin or antiplatelet agents. The stroke rate in untreated patients was 21.5%. No significant bleeding episodes occurred. The authors concluded that heparin therapy and antiplatelet therapy are both effective and safe. Heparin therapy is indicated in patients with higher grade (II-V) injuries and antiplatelet therapy is indicated for lower grade injuries.

Dr. Timothy Fabian, a leading contributor to the knowledge base of surgeons who deal with blunt injuries to the distal internal carotid and vertebral arteries, presented the annual Scudder Oration at the ACS Clinical Congress on October 2, 2012.\(^{48}\) Dr. Fabian cited data indicating that 20% of patients with blunt injury to the...
persistent or progressive pseudoaneurysm, dissection, or arteriovenous fistula following blunt carotid artery injuries is a surgical challenge. Endovascular stenting has been suggested as an approach to these complications. In addition, stenting has been proposed as a means of maintaining cerebral perfusion in patients who have progression of dissection with the development of neurologic symptoms or vessel occlusion to the point of threatened stroke.

Cothren and coauthors59 reviewed their experience with 46 patients who developed carotid artery pseudoaneurysms after blunt injuries in Archives of Surgery, 2005. In this patient group, 23 were treated with stents and 23 were not; this was not a randomized study. In the 19 patients who were asymptomatic at the time of stent placement, there were three strokes observed post-stent placement. These were associated with stent occlusion. In at least one patient, post-stent placement anticoagulation was not therapeutic. There was one subclavian dissection that complicated stent placement. Of asymptomatic patients (n=19) who received adequate anticoagulant therapy alone, there was one neurologic event. The authors concluded from this experience that the risks of stent placement outweigh the benefits.

Cohen and coauthors60 reported a contrasting experience within a small group of patients in Stroke, 2005. The authors placed stents in 10 patients who had sustained blunt injury to the carotid artery. Progressive dissection was noted, threatening vessel occlusion and stroke in five patients. Two patients had contraindications to anticoagulation and the remaining three patients had progression of neurologic symptoms on therapeutic anticoagulation therapy. In a follow-up period of more than one year, the authors did not observe stent occlusion, stent stenosis, or new neurologic symptoms. These data contrast with the less encouraging data presented previously and suggest that additional research may yield improved results for carotid stenting. Readers should heed that all patients in this small series had carotid dissection and all were symptomatic. These patients, therefore, contrast sharply with the asymptomatic patients reviewed above.

DuBose and coauthors55 reported an extensive literature review dealing with the use of stents for internal carotid artery injuries in the Journal of Trauma, 2008. The authors explored the hypothesis that results of stent placement are sufficiently satisfactory to warrant continued evaluation. They reviewed the reports of 113 evaluable patients between 1994 and 2007. Stents were usually placed for injuries resulting from blunt trauma and the lesion most commonly stented was pseudoaneurysm. Successful stent placement was defined as complete obliteration of the lesion with restoration of normal brain blood flow; this result occurred in 76% of patients. Local complications of stenting were seen in 3% of patients. Postoperative anticoagulation was achieved with antiplatelet agents in most patients. Nearly 90% of patients underwent follow-up imaging for an interval of two weeks to two years. Stents were patent in 80% of patients; stent occlusion occurred in 10% and leak occurred in 5% of patients. Stent-associated mortality was less than 1%. The authors
commented that stenting is an attractive alternative for managing pseudoaneurysms. The natural history and clinical significance of pseudoaneurysms are not fully known, although the risk of enlargement with thromboembolization and stroke is a continuing concern. The authors concluded that additional trials of stenting in patients with carotid artery injuries are needed because this approach is associated with low mortality and acceptable and improving stent-patency rates with few poststent neurologic events.

In his Scudder Oration, Fabian \(^5\) presented data from his unit supporting the success of selective endovascular stenting for patients with persistent arterial lesions observed on follow-up imaging that might predispose to vessel thrombosis or embolization with resulting ischemic brain injury.

**Editorial Comment**

It is safe to say that the prospects for improved imaging and effective endovascular management of selected complications of blunt carotid artery injury are exciting. It seems clear that anticoagulation, with the agent chosen according to injury grade, will reduce the rate of stroke. Stroke is seen in up to 40% of patients sustaining blunt carotid artery injury with higher injury grades associated with higher stroke risk. Stroke risk for patients with vertebral artery injury hovers in the 20% range regardless of grade of injury. Contraindications to anticoagulation therapy have contracted, and currently only patients with significant cerebral or intraspinal hemorrhage and ongoing sources of visceral or fracture bleeding represent absolute contraindications to anticoagulant therapy. Small subarachnoid hemorrhage and punctate cerebral hemorrhages are not barriers to carefully monitored anticoagulant therapy. The at-risk population for carotid and vertebral artery injury is not fully known. Some patterns of injury that should raise suspicion and prompt screening have been reviewed.

**Management of Abdominal Vascular Injuries**

Feliciano and coauthors \(^3\) offered an overview of abdominal vascular injury management in the *Journal of Trauma and Acute Care Surgery*, 2015. This article is supplied as a full-text reprint accompanying some formats of SRGS. The authors emphasized their conclusion that strong evidence to support management protocols for abdominal vascular injuries is lacking and most of the recommendations made in their article were based on expert opinion. Nonetheless, the recommendations that are summarized in two algorithms (Figure 6 and Figure 7) present logical approaches that can be used by most surgeons who are called upon to care for patients with these injuries. Data cited in the article confirms the fact that abdominal vascular injury is not uncommon in centers dealing with significant numbers of patients with penetrating injuries due to firearms. The reported data confirmed that 24.6% of patients with gunshot wounds to the abdomen have an injury to a named vessel. Patients with hemodynamic instability should be transferred to the operating room for exploration. Blood for transfusion is obtained and initiation of a massive transfusion protocol is recommended. Preoperative antibiotic administration is recommended. When it is necessary to transport a patient with ongoing bleeding to the operating room, premovement left anterior thoracotomy with aortic cross clamping may be considered. Recent data has suggested that endovascular balloon occlusion of the aorta may also have benefit. \(^52, 53\) Feliciano and coauthors \(^3\) explained that managing abdominal vascular injuries will vary depending on whether there is a contained hematoma or ongoing bleeding. In patients with ongoing bleeding, associated visceral injuries are expeditiously closed with clamps or staples. When the hematoma is stable, rapid staple or suture closure of visceral lacerations is recommended so that the operative field can be cleared of clamps. The approach to a hematoma or to ongoing bleeding is adjusted depending on the location of the suspected injury. For example, a midline upper abdominal hematoma or bleeding may be caused by an injury to the aorta or the inferior vena cava. Exposure for these injuries and for hematomas presenting to the left of the midline above the mesocolon can be facilitated with left visceral rotation. This maneuver divides...
### Figure 6
Algorithm for initial approach to abdominal vascular injuries. Reproduced from Feliciano and coauthors with permission.

- **Algorithm for initial approach to abdominal vascular injuries.**
  - **Abdominal trauma with hypotension and/or peritonitis and/or FAST (blind):**
    - **Consider preliminary resuscitative left thoracotomy if systolic BP <70mm, patient is deteriorating, and direct operating room.**
    - **Zone 1 (spleen):**
      - **Splanchnicoccecal (peritoneal):**
        - Perform left medial visceral rotation.
        - Divide left lobe of the liver.
        - Obtain proximal control of left mesocolic, left colic, and splenic arteries.
        - No early injury — Perform right medial visceral rotation to expose inferior vena cava. Obtain proximal and distal control of vena cava and iliac veins if needed.
    - **Zone 2 (general):**
      - **Infrarenalmesenteric (peritoneal):**
        - Obtain proximal control of renal veins, (optional)
    - **Zone 2 (lateral):**
      - **Infrarenalmesenteric (infrarenal):**
        - Obtain proximal control of infrarenal abdominal aorta.
    - **Zone 3 (iliac):**
      - **Infrarenalmesenteric (iliac):**
        - Obtain proximal control of iliac vessels. (optional)
  - **Portal area (both):**
    - Perform Pringle maneuver for proximal control.
    - Obtain iliac clamps or clamp, if possible.
    - Closed common bile duct away from common hepatic artery and portal vein.
    - **Retrohepatic area (both):**
      - Do not open hematoma unless it is ruptured, pulsatile, or rapidly expanding.

### Figure 7
Algorithm for definitive management of abdominal vascular injuries. Reproduced from Feliciano and coauthors with permission.

- **Algorithm for definitive management of abdominal vascular injuries.**
  - **Abdominal trauma with hypotension and/or peritonitis and/or FAST (blind):**
    - **Type and crossmatch/capillary studies or TEG/isoantibodies:**
    - **Consider preliminary resuscitative left thoracotomy if systolic BP <70mm, patient is deteriorating, and direct operating room.**
    - **Zone 1 (spleen):**
      - **Splanchnicoccecal (peritoneal):**
        - Perform left medial visceral rotation.
        - Divide left lobe of the liver.
        - Obtain proximal control of left mesocolic, left colic, and splenic arteries.
        - No early injury — Perform right medial visceral rotation to expose inferior vena cava. Obtain proximal and distal control of vena cava and iliac veins if needed.
    - **Zone 2 (general):**
      - **Infrarenalmesenteric (peritoneal):**
        - Obtain proximal control of renal veins, (optional)
    - **Zone 2 (lateral):**
      - **Infrarenalmesenteric (infrarenal):**
        - Obtain proximal control of infrarenal abdominal aorta.
    - **Zone 3 (iliac):**
      - **Infrarenalmesenteric (iliac):**
        - Obtain proximal control of iliac vessels. (optional)
  - **Portal area (both):**
    - Perform Pringle maneuver for proximal control.
    - Obtain iliac clamps or clamp, if possible.
    - Closed common bile duct away from common hepatic artery and portal vein.
    - **Retrohepatic area (both):**
      - Do not open hematoma unless it is ruptured, pulsatile, or rapidly expanding.

the retroperitoneal covering membrane at the line of Toldt and rotates the colon, pancreas, spleen, and stomach to the right. The kidney may or may not be included in the rotation depending on the need for exposure and the risk of associated renal injury. The clinical guidance article indicated that inframesocolic hematomas and bleeding due to an aortic injury is most often caused by an injury at the uppermost limit of the hematoma or the inframesocolic space. Per the article, when the patient is stable and “damage-control” approaches are not used, repair of arterial and venous injuries are preferred. In situations where expeditious management is required, ligation of arterial injuries to proximal visceral arteries (celiac axis) is acceptable, as is ligation of venous injuries to the right renal vein, iliac vein, and inframesocolic inferior vena cava.

The authors provided additional guidance on using compression to control hemorrhage and expose individual vessels. Readers are encouraged to review this material.

Endovascular Repair of Abdominal & Pelvic Vascular Injuries

Arthurs and coauthors summarized their experience with endovascular approaches to vascular injuries in *Surgical Clinics of North America*, 2007. They confirmed that endovascular management of vascular injuries is useful for carefully selected patients sustaining blunt injuries to the carotid and vertebral arteries. This topic was reviewed in detail in an earlier section of this review. Another area where endovascular management has led to improved outcomes in terms of mortality and paraplegia risk is in patients with blunt injuries to the thoracic aorta. This type of injury also was discussed in a previous section of this review.

Endovascular injury management may be useful for patients with abdominal and pelvic artery and vein injuries. Stent grafts placement in abdominal vessels would provide a method of repairing the vascular injury and avoiding the exposure of a vascular repair to contamination from a nearby gastrointestinal or genitourinary injury. Arthurs and colleagues cited data indicating that stent graft repairs of injuries to the abdominal aorta, the iliac arteries, the renal arteries, and the popliteal arteries are feasible and associated with an early technical success rate of 94%. The authors stated that patients who can be stabilized after penetrating or blunt abdominal injury with significant retroperitoneal hematoma formation can undergo imaging for diagnosis. Identifying a vascular injury that can safely be occluded with endovascular coils or covered with an endovascular stent offers an opportunity to repair the injury without the risk attendant to placing a vascular suture line and/or conduit adjacent to a gastrointestinal or pancreatic injury. There is not a sufficient number of reported patients to establish an accurate risk-benefit analysis for this approach. Additional data will be helpful in documenting the effectiveness of endovascular approaches for abdominal vascular injuries.

It is well known that angiographic coil occlusion of bleeding pelvic branches of the internal iliac system is a valuable approach in patients with pelvic fractures. Boufi and coauthors reported data on outcomes of coil embolization and stent graft placement in hemodynamically unstable patients with pelvic bleeding in *Annals of Vascular Surgery*, 2011. The authors reported a single-center case series of 16 patients who sustained blunt injuries to retroperitoneal vessels. All patients were admitted with overt clinical evidence of hemorrhagic shock. Coil embolization was used in 13 patients with ongoing bleeding from pelvic vessels lacerated by pelvic fractures. Three patients had stent placements. Two of these were placed in the proximal common and internal iliac arteries in patients with pelvic fractures who had undergone coil occlusion of the contralateral internal iliac artery. A single stent graft was placed for a blunt injury of the abdominal aorta. One stented patient survived. The other two patients died of complications of hemorrhagic shock. Early hemorrhage control was achieved in all stented patients, with no patient requiring repeat endovascular intervention or open operation for hemorrhage control. The authors concluded that endovascular approaches may be helpful for selected patients with injuries to retroperitoneal arteries.

A report on endovascular repairs for major torso vascular injuries was by Gilani and coauthors in the *Journal of Trauma and Acute Care Surgery*, 2012. The authors used endovascular balloon occlusion via an open femoral access approach to facilitate endovascular stent repair of subclavian and axillary artery injuries in eight patients. Technical success was achieved in all patients and one-year follow-up showed no device-related complications or need for follow-up procedures.
**Adjuncts to Vascular Injury Repair**

Two adjuncts to vascular repair will be discussed in this section. The first is fasciotomy, currently used liberally as an intervention before revascularization to prevent compartment syndrome. Compartment syndrome is reviewed in the book chapter by Frykberg and Schinco referenced earlier.12 The ischemic injury to muscle that leads to the reperfusion syndrome increases capillary permeability, and the transvascular movement of fluid into the muscle cells and interstitium leads to an increase in intracompartamental pressure because of the rigid resistance of fascial sheaths. Another important component of compartment syndrome observed after a vascular injury is loss of venous outflow. Venous outflow can be lost because of preexisting venous obstruction, a direct venous injury, or loss of venous collaterals from fractures or a soft tissue injury.

Compartment syndrome may be encountered independent of ischemic injury to muscle in association with fractures and soft-tissue contusion. Whatever the mechanism, fasciotomy is performed to open up these “tight” compartments and reduce the pressure-related ischemic injury to nerve and muscle that might result. Frykberg and Schinco provided a description of the pathophysiologic events that accompany the subsequent reperfusion of ischemic muscle. The most dangerous consequence of this reperfusion syndrome is the release of potassium and acid metabolite products into the systemic circulation. This life-threatening set of events is associated with, but is distinct from, compartment syndrome. Uptake of the byproducts of ischemic tissue into the systemic circulation on reperfusion can result in cardiac arrest, acidosis, hemoglobinuria, myoglobinuria, and renal failure.

Olson and Glasgow57 offered a comprehensive review of the diverse circumstances under which compartment syndrome might occur in the *Journal of the American Academy of Orthopaedic Surgeons*, 2005. Compartment syndrome is seen most frequently in conjunction with fractures of the tibia, with fracture of the distal radius being the second most common accompanying injury. Soft tissue injury without fracture might also be a cause of compartment syndrome. The authors stressed that this condition can also be seen in patients receiving chronic anticoagulant therapy and who sustain soft tissue trauma. It is important for clinicians to remember that compartment syndromes may be seen with open wounds. The presence of an open wound does not mean that the fascial compartment has been decompressed. According to Olson and Glasgow, fascia, epimysium, and skin can each serve as the restricting membrane that must be opened to decompress nerve and muscle tissue rendered ischemic by the increasing tissue pressure. Ischemic damage to nerve and muscles occurs at varying compartment pressures. The critical feature is, apparently, a rise in tissue pressure to a point that causes venous collapse. Rising venous pressure proximal to the tissue-pressure-induced venous occlusion causes additional increases in tissue pressure. Another etiologic mechanism is reperfusion of previously ischemic tissue, as discussed by Frykberg and Schinco.12 The reperfusion of ischemic muscle releases myoglobin and inflammatory mediators that cause increased capillary permeability; the fluid transported into the interstitial compartment also causes increased tissue pressure. Increased tissue pressure gives rise to irregular patterns of disrupted muscle and nerve-blood flow which, if allowed to persist, results in irreversible damage first to nerves and then to muscle.

Olson and Glasgow57 affirmed that the most important feature of the compartment syndrome diagnosis is a heightened index of suspicion. Many patients at risk for compartment syndrome cannot participate normally in the physical examination process. Because of this, the classic “early” signs of compartment syndrome, such as loss of sensation in the web spaces of the fingers or toes, pain on passive movement of the muscles of the compartment, and pain in the area of the compartment, can be missed. Palpable firmness in the compartment and paralysis are late signs that might indicate that irreversible damage has already occurred. Compartment pressure measurements might be useful in situations where the patient is at risk and the diagnosis is in doubt. Olson and Glasgow discussed each of the techniques for measuring compartment pressures in detail. It is worth noting that recognizing the importance of compartment syndrome associated with a vascular injury has prompted surgeons caring for patients with vascular injuries to perform presumptive fasciotomy before revascularization of the extremity—especially when the interval between injury and definitive revascularization is more than four hours and where there are associated complex fractures and soft tissue injuries.
Compartment Syndrome Management

Once compartment syndrome is suspected or when presumptive fasciotomy is chosen as the preferred approach, the fascial compartments of the injured extremity are opened and the muscle compartments are completely decompressed. For the upper extremity, one incision is fashioned in the midline along the extensor surface of the forearm. On the palmar surface of the forearm, the incision is curvilinear and may be extended across the median transverse ligament at the wrist onto the palmar surface of the hand and onto the fingers if compartment syndrome of the hand is threatened. Critical to the success of an upper extremity fasciotomy is decompression of the medial, radial, and ulnar nerves vulnerable to damage from increased compartment pressure. Fasciotomy of the lower extremity is also accomplished via two incisions: one is located on the medial surface of the leg and the other is on the lateral surface of the leg. The medial incision is made dorsal to the lateral surface of the tibia and extends from a point 1–2 cm distal to the tibial tubercle and extends for the entire length of the tibia. The lateral incision is located parallel to the fibula and this incision extends for the entire length of the fibula. The potential courses of the saphenous and the peroneal nerves should be recalled so that precautions to prevent damage to these nerves can be taken. All four fascial compartments of the leg will need to be opened. This can be facilitated via transverse incisions placed near the midpoints of the medial and lateral skin incisions. These permit entry into each of the four compartments.

Pharmacologic Adjuncts for Vascular Injuries

Pharmacologic adjuncts are frequently used, especially for high-risk repairs of arterial injuries, to help improve patency rates. Drugs used include intraarterial infusions of vasodilators, such as papaverine (30–60 mg total dose), for the purpose of dilating the outflow vascular bed. Intraoperative and postoperative anticoagulation with systemic unfractionated heparin or low-molecular-weight heparin are also used; many vascular surgeons employ intravenous infusions of Dextran. Antiplatelet agents such as aspirin and clopidogrel bisulfate can be used postoperatively. Situations where these adjuncts are most often used include temporary intraarterial or intravenous shunt use and high-risk arterial and venous reconstructions, including those performed after an extended interval of ischemia and where collateral channels are likely to be interrupted (complex injuries with fractures and soft tissue injuries). Unfortunately, no strong evidence supports a protocol for using these agents and there are no convincing data that there is a beneficial effect on patency or limb salvage. An appropriate approach will, therefore, need to be chosen on a patient-specific basis. Careful risk assessment is necessary to balance the risk of bleeding from systemic anticoagulants (especially low-molecular-weight heparin).

Venous Diseases

Diseases of the venous system are major causes of mortality and morbidity as well as diminished quality of life. Venous thromboembolism affects thousands of patients each year and venous thromboembolism is the second leading cause of death in patients with cancer. Coleman and coauthors58 reviewed the epidemiology and health burden of venous thromboembolic disease (VTE) in Current Problems in Surgery, 2015. Data cited by the authors confirmed the incidence of VTE: 108 per 100,000 person-years in Caucasians and 78 per 100,000 person-years in African Americans. VTE is also associated with decreased short- and long-term mortality compared with control patients without the disease. Postoperative VTE rates vary according to the patient population studied and the type and uniformity of prophylaxis use; estimates provided in the review article indicate rates of 1%–2% overall. High-risk groups for postoperative VTE include patients with cancer and inflammatory bowel disease. Patients with critical limb ischemia who require amputation are also at a high risk, with VTE rates in this patient group ranging from 9% to 13%. Although it might be expected that obesity would increase the risk of postoperative VTE, data from bariatric surgery centers show that postoperative VTE occurs in 0.05%–2% in patients undergoing bariatric surgery. VTE risk factors, in addition to the stress of a surgical procedure, include a personal and/or family history of VTE, immobilization, malignancy, and thrombophilic
disorders (antithrombin deficiency, protein C and S deficiency), and inherited disorders (Factor V Leiden). The authors recommended that evaluation for thrombophilic disorders be considered in patients who present with an unprovoked VTE, especially if the patient has a positive family history, multiple recurrences of VTE, or VTE prior to age 40.

In the following sections, we will review literature references that outline the major scientific research that has provided a more complete understanding of the process of thrombus formation. Following that discussion, the topic of venous thromboembolism will be discussed. Complications of deep venous thrombosis include pulmonary embolism, the postthrombotic syndrome, varicose veins, and chronic venous insufficiency. In addition, varicose vein disease can occur independently of deep venous obstruction. Articles relevant to these topics will be reviewed in the following sections.

Surgeons are currently under pressure to make certain that perioperative venous thromboembolism is, to the extent possible, prevented. National and regional quality assessment efforts award scores based on rates of venous thromboembolism and reimbursement rates are based, in part, on these scores. Whether assessments of VTE prevention and postdischarge VTE rates are actually markers of quality in health care institutions and health care systems has been challenged. The Colorectal Writing Group provided data showing that postoperative VTE rates have remained low over time despite increased use of perioperative VTE prophylaxis interventions were presented in JAMA-Surgery, 2015. The authors reported data from a single state-wide registry that included data on more than 16,000 patients gathered over a five-year interval. The data analysis showed that VTE prophylaxis use increased from 31.6% of patients in the first year of the study to over 90% in the final year of the study. Perioperative VTE rate was 2.2% and this did not change over the course of the study. The data confirmed that older patients, patients undergoing emergency procedures, patients with a history of VTE, and patients undergoing operations for inflammatory bowel disease were at higher risk for developing postoperative VTE. In the discussion section of the article, the authors suggested that one reason for the apparent lack of effect of VTE prophylaxis on VTE rates may be that VTE is diagnosed more frequently with increased use of imaging surveillance protocols and that a large proportion of the VTE events diagnosed are clinically silent and probably not associated with increased morbidity. In an editorial that accompanied this article, de Virgilio and Kim agreed that surveillance practices may be contributing to the lack of reduction of VTE events despite increased use of prophylaxis. The authors cautioned that basing reimbursement on the use of VTE prophylaxis may lead to increased use of prolonged prophylaxis protocols that could increase bleeding complications.

Holcomb and coauthors presented additional evidence that surveillance practices influence the reported rates of VTE events in JAMA-Surgery, 2015. The authors reported data on nearly 26,000 patients recorded in the Veterans’ Affairs Health System National Surgical Quality Improvement database. The data covered a four-year interval. The data analysis showed that the rate of VTE diagnosis was significantly related to the frequency of use of VTE surveillance protocols. The authors also confirmed that compliance with national quality requirements as promulgated by the Surgical Care Improvement Project (SCIP) was not statistically associated with hospital VTE rates or surveillance rates. In an editorial that accompanied the article, Upchurch opined that the SCIP requirements for VTE prevention are not an accurate assessment of quality care because VTE prophylaxis is not being used uniformly in the highest risk patient groups. Upchurch recommended that future guidelines be developed that would adequately assess and assign risk so that truly accurate quality measures can be developed.

Yang and Bilimoria offered an additional opinion that surveillance bias and inadequate risk assessment and assignment may be causing the lack of effect of VTE prophylaxis on VTE rates in JAMA, 2016. The authors recommended that accurate reporting of the rates of use of the three most important measures of VTE prevention, early ambulation, use of compression stockings, and use of VTE chemoprophylaxis combined with accurate assessment and assignment of risk could improve the appropriateness of using VTE prevention as a measure of healthcare quality.

A final reason for the lack of association of VTE prevention intervention use and VTE rates is that a significant proportion of reported VTE events are not actually preventable; this issue was considered in an article
by Haut and coauthors in *JAMA-Surgery*, 2015. The authors queried a single-state database and obtained outcomes data on 128 patients with documented VTE events. The data analysis showed that half of these patients had optimum VTE preventive efforts and yet still developed VTE. The authors concluded that a significant proportion of in-hospital VTE events were not preventable and were not markers of decreased health care quality.

### Venous Thromboembolism

Our discussion of the clinical problem of venous thromboembolism will begin with a review of the basic mechanisms of thrombus formation; factors that facilitate pathologic thrombus formation will be considered. Thrombus formation has, traditionally, been understood to result from the interaction of factors induced by Virchow’s triad of stasis, hypercoagulability, and vessel-wall damage. Recent research has focused on the role of endothelial damage and induction of pathologic thrombin generation as drivers of thrombosis that complicates various forms of arterial and venous disease.

### Mechanisms of Thrombosis & Thrombus Dissolution

Coleman and coauthors presented a brief summary of the pathophysiology of venous thrombosis. They emphasized that platelet aggregation is the most important element of the clot formation process. Current data indicate that platelet aggregation begins with injury to or inflammation of the venous endothelium. The interaction of the injured or inflamed endothelium with platelets is mediated by receptors of the mammalian integrin family. Megakaryocyte-specific glycoprotein IIb/IIIa binds fibrinogen, von Willebrand factor, fibronectin, vitronectin, and thrombospondin to activated platelets and this action accelerates platelet aggregation and clot formation. The critical role of the platelet was confirmed by data cited in the article showing that antiplatelet therapy reduces risk for recurrent VTE.

Myers presented additional information relevant to the pathophysiology of thrombus formation in *Phlebology*, 2015. Data cited in the article show that tissue factor is also an important component of the inflammatory response pattern that leads to clot formation. Tissue factor derived from the vein wall is important when direct endothelial injury leads to thrombosis, while circulating tissue factor from a remote site may contribute to thrombus formation in patients who have no endothelial injury. Other data have shown that P and E selectin are also contributors to thrombus formation. In animal models, inhibition of P-selectin has decreased thrombogenesis.

Another article dealing with the mechanism of thrombus formation was by Furie and Furie in the *New England Journal of Medicine*, 2008. The authors began by emphasizing that the main function of the endothelial lining of the vasculature is to maintain blood flow. Factors produced by the endothelial lining, including nitric oxide, prostacyclin, and CD39-4 (an ectonucleotidase) work together to prevent intravascular thrombus formation.

The authors then stressed that the process of thrombus formation is the main defense mechanism for preserving an intact high-pressure vascular system. Thrombosis serves the critical purpose of sealing breaches in the vascular system and preventing death or disability that results from blood loss. The early events of thrombus formation at the site of vessel injury are set in motion when a breach in the endothelium exposes collagen and tissue factor. The exposed collagen serves to attract and activate platelets while tissue factor initiates the chemical reactions that result in thrombin formation and the downstream conversion of fibrinogen to fibrin. Thrombin generation also serves to amplify platelet activation. These two pathways work in parallel, and the predominance of one pathway over the other is a function of the normal or pathologic process that triggers the coagulation mechanism.

Activated platelets adhere to the area of endothelial damage because of the interactions of platelet glycoproteins with the exposed collagen and collagen-bound Von Willebrand factor located in the vessel wall. Shear stress at the site of the vessel wall is a main determinant for which pathway of platelet adhesion predominates. Platelet activation and release of platelet granules are also functions of the platelet glycoproteins. Tissue-factor-mediated activation of platelets does not necessarily require disruption of
the endothelial surface of the vessel. By forming a complex with Factor VIIa, tissue factor can activate Factor IX and this activation initiates the proteolytic cascade that results in thrombin generation. Platelet activation resulting from the processes inherent to this pathway results in release of platelet thromboxane, serotonin, and ADP. These factors tend to activate additional platelets. This process, however, does not completely explain the mechanism of thrombus formation absent endothelial disruption. It is possible that injured but still intact endothelium is stimulated to activate endothelial cell surface adhesion molecules and these serve to initiate thrombus formation. The redundancy of the mechanisms of platelet activation makes it challenging to develop drugs that target this process.

Recruitment of platelets into the forming thrombus is not a uniform process—some platelets will be recruited into the thrombus and remain, while others will be loosely associated with the thrombus and may even disengage from the thrombus. Fibrinogen and Von Willebrand factors are important in the process of platelet recruitment and incorporation into the thrombus; fibrinogen functions primarily at low-shear rates and Von Willebrand factor at high-shear rates. Several ligands serve to modulate platelet-to-platelet adhesion and drive the development of thrombus architecture. Platelet granules are released during this process and the various factors released from platelets play crucial roles in thrombus formation.

Furie and Furie continued with a discussion of tissue factor. While this factor resides in vessel walls, there is also evidence that tissue factor is expressed on circulating leucocytes and, possibly, other circulating cells. Circulating tissue factor may be responsible for pathologic thrombus formation. Future research will likely clarify these important areas. Tissue factor is known to exist in circulating microparticles. These may supply the tissue factor to sites of injured but intact endothelium, and thrombus formation would be initiated.

The enzyme protein disulfide isomerase is a potentially vital component of the process of changing the tissue factor that travels within circulating microparticles from an inactive to an active form. It is inefficient to recruit necessary factors for thrombin generation that might be initiated by activation of microparticle tissue factor; multiple cofactors must be activated for the burst of thrombin generation necessary to form a thrombus. How disease processes, such as cancer and atherosclerosis, might participate in this interaction of proteins, enzymes, and cofactors is a current focus of research.

Microparticles bearing activatable tissue factor are recoverable from blood of patients with malignant disease, giving rise to experiments incriminating this source of tissue factor as important in the predisposition to venous thromboembolism observed in this patient group. Adenocarcinomas, in particular, are active producers of microparticles containing activatable tissue factor.

Heparin-Induced Thrombocytopenia

Thrombocytopenia in patients treated with unfractionated or low-molecular-weight heparin was discussed in the clinical practice guidelines document promulgated by the National Comprehensive Cancer Network (NCCN) in 2016. The guidelines document is available free at nccn.org. The document indicated that heparin-induced thrombocytopenia (HIT) incidence ranges from 0.2% to 2.7%; HIT risk increases with increasing duration of heparin treatment. HIT develops when heparin binds to platelet factor 4 and forms immunogenic complexes that stimulate the clearance and activation of platelets. This action leads to platelet consumption and the development of a prothrombotic state. Clinical manifestations of HIT are thrombocytopenia and the formation of necrotic lesions at injection sites, along with arterial or venous thrombotic events. Onset of HIT is typically observed after 5–10 days of heparin therapy, although a rapid onset variant of HIT has been described occurring in patients with a prior history of heparin therapy. Diagnosis of HIT is confirmed by observation of thrombocytopenia and other clinical phenomena and confirmation of the diagnosis by confirming the presence of PF-4/heparin antibodies. Diagnosis is complicated by the fact that most HIT antibodies do not cause thrombocytopenia. Because of this, a negative antibody test is most helpful, since this will exclude HIT as a diagnosis. The probability of HIT can be estimated using the 4Ts scoring system, which awards 0–2 points for each of the following findings: thrombocytopenia, the timing of the onset of thrombocytopenia, presence of clinical sequelae, and evidence of other causes of thrombocytopenia. Low-risk patients have scores of 0–3 and high-risk patients have scores of 6–8.
This scoring system has greater negative predictive value than positive predictive value. In patients who are at high risk for HIT, discontinuation of heparin and therapy with fondaparinux or a direct thrombin inhibitor can be considered. Cessation of warfarin will be necessary if a direct thrombin inhibitor is used.

Risk of Venous Thromboembolism in Select Patient Groups

Available evidence supports the conclusion that there are several acute and chronic conditions that are associated with increased risk for venous thromboembolism; in these specific patient groups, interventions to prevent venous thromboembolism are indicated. Balancing the risk of venous thromboembolism against the risk of bleeding associated with the anticoagulant drug prophylaxis in postoperative and injured patients continues to be a challenging judgment task for clinicians. Accurate risk assessment is essential when these decisions are made. General surgeons will participate actively in the care of some of these groups of patients. We will briefly discuss these problems in this section. We will also focus on establishing the risk for deep vein thrombosis and clinically significant pulmonary embolism, evaluation of strategies to accurately assign risk, the effective use of available diagnostic strategies, and the safe use of available preventive interventions.

Injured patients have been identified as a group exposed to an increased risk of venous thromboembolism. Prevention strategies for this group of patients have evolved from practice patterns developed for prevention of venous thromboembolism in high-risk medical and surgical patients. Individual patient groups identified for prevention strategies include multiple-injury patients who are more than 50 years of age, patients with lower-extremity long-bone fractures, patients with pelvic and acetabular fractures, patients with traumatic brain injuries, and patients with spinal cord injuries. The events leading to deep vein thrombosis in injured patients are diverse. Immobility resulting from brain and spinal cord injury leads to stasis and lower-extremity thrombosis. Femoral vein thrombosis can result from the use of femoral vein catheters and subclavian thrombosis can be caused by central venous lines. Direct injury to veins can occur from pelvic and acetabular fractures and these thrombi may propagate and embolize. The timing of postinjury pulmonary embolus covers a wide range; available data, discussed below, suggest that significant, life-threatening pulmonary embolus can occur early after an injury.

According to an article by Menaker and coauthors, a significant pulmonary embolus can occur as early as three days after an injury. The challenge for clinicians caring for these patients is to balance the protective effect of pharmacologic agents, such as unfractionated heparin and low-molecular-weight heparin, and endovascular interventions, such as inferior vena cava filter placement, with the risks of bleeding attendant to the use of anticoagulant drugs and the risks of complications arising from indwelling vena cava filters. Furthermore, multiple-injury patients are at risk for bleeding from associated abdominal, central nervous system, and thoracic visceral injuries. Because of this, preventive interventions are delayed because of concerns that therapy could aggravate bleeding and make the injuries worse. Added to this challenge is the recognition that true prophylaxis is not possible in the trauma patient population because the stimulus resulting in activation of the coagulation mechanism has occurred hours, and sometimes days, before preventive treatment can be implemented.

Karcutskie and coauthors provided data relevant to assessing risk factors for VTE in injured patients in JAMA-Surgery, 2016. The authors reviewed outcomes data on 1,137 patients admitted to a single level 1 trauma center over a four-year interval. Blunt injuries occurred in 813 patients and penetrating trauma was the injuring mechanism in the remainder. The authors used logistic regression statistical techniques to identify risk factors for postinjury VTE. The overall rate of VTE was 9.1% and there was no significant difference in the overall VTE rate when the blunt and penetrating groups were compared. The statistical analysis of the data showed that blunt trauma patient risk factors for VTE had differences in risk factor patterns compared with patients sustaining penetrating trauma. Risk factors in blunt injury patients included pelvic fracture, Glasgow coma score of 8 or less, and a history of receiving four more units of transfused blood. For penetrating injury patients, age 40–59, ligation
or repair of a vascular injury, and abdominal injury score >2 were significant risk factors for VTE. The authors assessed risk for VTE with the Greenfield risk assessment score. Risk scores were elevated in blunt and penetrating injury patients who developed VTE and the authors concluded that risk assessment scores >5 could be used to select patients for chemoprophylaxis. The authors concluded that risk factor assessment could have value when added to the risk assessment score for determining the need for chemoprophylaxis of VTE after an injury. In an editorial that accompanied this article, Ramos and Brewster stated that the rate of VTE of 9% reported in the Karcutskie article suggests that additional effort is needed to determine accurate VTE risk. Thromboelastography testing has the potential to document the onset of a hypercoagulable state following injury and this might be used to determine the need for and timing of preventive interventions. Ramos and Brewster also emphasized the need for trials of newer chemoprophylactic drugs to help reduce the frequency of VTE in injured patients.

Additional perspective on risk assessment for VTE in blunt injury patients was presented in an article by Tachino and coauthors in Critical Care Medicine, 2014. The authors reported data on 600 blunt injury patients seen in two trauma centers over a 14-month interval. The authors used the Greenfield risk assessment score and found that lower extremity fracture, pelvic fracture, transfusion of more than four units, and Glasgow coma score of 8 or less combined with an elevated D-dimer level identified high-risk patients with a sensitivity of 100% and a specificity of 57%. They concluded that extracting these variables from the Greenfield score and adding D-dimer assessment identified blunt injury patients who were at high risk for VTE.

Data from studies in trauma patients show that frequencies of VTE can be reduced in patients who are screened for venous thrombosis with ultrasound and who receive prophylactic interventions such as lower extremity compression devices and chemoprophylaxis with low-molecular-weight heparin. This practice is challenging in injured patients because of delays in beginning preventive interventions, missed doses of chemoprophylaxis agents, and bleeding events. An example of this research was provided in an article by Adams and coauthors in the Journal of Trauma, 2008. The authors conducted a retrospective review of data gathered prospectively in a Level 1 trauma center. Their analysis focused on a group of patients admitted to the trauma service for more than two days. Nearly 3,000 patients were eligible for analysis and these patients were seen during an interval of four years. The authors conducted aggressive preventive interventions using intermittent pneumatic compression devices and low-molecular-weight heparin. Patients were screened with duplex ultrasound at weekly intervals. This report documented a frequency of deep venous thrombosis of 3.2% despite aggressive prevention efforts. Twenty patients were diagnosed with pulmonary embolus (0.7%) and one of these was fatal. Because these patients were multiple-injury patients, low-molecular-weight heparin was given to less than two-thirds of the patients. Eighty-six percent of the venous thromboembolic events were detected by surveillance duplex ultrasound. Significant bleeding requiring transfusion was observed in 5 patients who received low-molecular-weight heparin. This is a major bleeding event frequency of approximately 5%. Inferior vena cava filters were placed in 76 patients and no filter-related complications were observed. The authors concluded that aggressive efforts to prevent and detect VTE were effective, but bleeding complications were significant and elimination of VTE events in injured patients was not observed. This report is valuable because it defines the frequency of venous thromboembolism in a diverse group of injured patients. It is worth noting that the risk of fatal pulmonary embolus in this group was very low.

Haut and coauthors provided additional data on the frequency of deep vein thrombosis in trauma patients in the Journal of Trauma, 2009. The authors analyzed data from the National Trauma Data Bank and identified trauma centers that were actively using ultrasound for the detection of deep vein thrombosis. They reviewed data from nearly 500,000 trauma patients screened for deep vein thrombosis with ultrasound. They found a 2% frequency of deep venous thrombosis (detected by ultrasound) in this patient group.
Additional data reported by Gathers\textsuperscript{34} and Mendez\textsuperscript{75} show that preventive measures reduce risk of VTE events in high-risk patients with central nervous system injuries even when preventive measures are delayed until five days after injury.

Low-molecular-weight heparins and anti-factor XA agents are increasingly used for chemoprevention of VTE in injured patients. Ongoing research has been focused on the most effective way of monitoring the effects of the drugs and adjusting the dosage for optimum prevention of VTE and the best protection against bleeding events.

Two monitoring approaches have been used (thromboelastography and anti-factor XA measurement). These topics were studied in articles by Ko\textsuperscript{76} and Connelly.\textsuperscript{77} The data presented in these articles showed that monitoring with thromboelastography and anti-factor XA levels was feasible, but errors in timing of measurements and failure of clinicians to adjust chemoprophylaxis agent dosages in response to the measurements was common. The authors concluded that additional research and educational efforts were necessary to improve monitoring protocols and compliance with these protocols.

Prophylactic inferior vena cava filter placement has been employed to reduce the risk of pulmonary embolism in high-risk injured patients. Cohen-Levy and co-authors\textsuperscript{78} reported data from a long-term retrospective analysis of patient outcomes in a single center in \textit{Critical Care Medicine}, 2015. The authors reported a 12-year experience involving 231 patients with pelvic fractures. Outcomes, in terms of frequency of pulmonary embolus, were assessed in 57 patients who had filter placement and 39 patients who did not have filter placement. The data analysis showed that the frequency of pulmonary embolus was similar in the two groups. The authors concluded that an increased rate of prophylactic filter placement had not reduced the risk of pulmonary embolus. These findings suggest that there may be sources of pulmonary embolus other than the lower extremities in injured patients and/or that pulmonary blood clots may not be emboli but in situ thromboses in the pulmonary circulation.

### Venous Thromboembolism & Malignancy

Venous thromboembolism is a common cause of mortality and morbidity in patients with malignant disease. Recently updated guidelines from the NCCN (available for free at \textit{www.nccn.org}) cited data indicating that up to 12.6\% of patients with a diagnosis of cancer will experience a VTE event during treatment for the malignancy. Cancer-related factors that contribute to the occurrence of VTE include secretion of procoagulant substances such as tissue factor by cancer cells, compression of veins by tumor, and immobilization associated with cancer treatment. The biologic basis and epidemiology of venous thromboembolism in patients with cancer were discussed in an article by Khorana\textsuperscript{79} in \textit{Annals of Oncology}, 2009. Venous thromboembolism is the second most common cause of death in patients with cancer. Complications of thromboembolism negatively impact quality of life and significantly increase the cost of caring for cancer patients. Khorana cited data suggesting that tissue factor produced by cancer cells and stromal cells can activate the hemostatic system and produce a hypercoagulable state. The use of chemotherapy and hormonal therapy for malignancies such as breast cancer further adds to the risk of thromboembolism. Combination therapy with anticancer drugs also contributes to increased risk. The use of antiangiogenic agents in combination with chemotherapy drugs increased the risk of thromboembolism in malignant tumors commonly encountered by general surgeons, including cancers of the stomach, colon-rectum, and pancreas, according to data cited in the article.

Patient factors, tumor site, and mechanical factors such as operation and presence of central venous catheters need to be considered when attempting to quantify patient risk of thromboembolism. Important patient factors include older age, African-American ethnicity, female gender, and history of inherited thrombophilic states. Disease factors include high-risk tumor site and use of adjunctive anticancer drugs. Khorana provided a table listing tumor sites according to thromboembolism risk for patients receiving chemotherapy (Figure 8). Khorana concluded the article by discussing the use of various antithrombotic agents in cancer patients. He cited data that confirmed the effectiveness and safety of low-molecular-weight heparin in patients undergoing operation for
malignancy. With treatment, venous thromboembolism rates range from 5% to 15% with significant bleeding encountered in 4%–6% of treated patients.

De Martino and coauthors reviewed data on the frequency of deep venous thrombosis and pulmonary embolus in patients undergoing surgery for cancer in the Journal of Vascular Surgery, 2012. The authors queried the database of the National Surgical Quality Improvement Project and identified nearly 44,000 patients who underwent surgery for a cancer diagnosis from 2007 to 2009. Venous thromboembolism and pulmonary embolus rates were analyzed. The lowest risk of venous thromboembolism was observed in patients undergoing breast cancer operations (DVT=0.2%, pulmonary embolism=0.1%). The highest risk of DVT and pulmonary embolus (6.1% and 2.4%, respectively) was observed in patients undergoing esophagectomy. For common general surgery operations (gastrectomy, colon-rectal resection, hepatectomy, and pancreatectomy), total thromboembolism risk ranged from 2.4% to 3.4%. The authors emphasized that current guidelines for venous thromboembolism prophylaxis do not alter dosing or duration of therapy according to tumor site. They hypothesized that venous thromboembolism management based on tumor site and magnitude of operation might lead to reduced thromboembolism rates and lowered cost of care for cancer patients.

Since surgeons commonly treat patients with colon cancer, which has an associated risk of deep vein thrombosis, it is important to review the principles of perioperative prevention for patients with this disease. The NCCN guidelines recommended treatment of patients undergoing surgical procedures for cancer with low-dose unfractionated heparin or low-molecular-weight heparin. Compression stockings combined with heparin therapy is an acceptable alternative for surgical patients. Pneumatic compression devices may be considered in patients with contraindications to unfractionated or low-molecular-weight heparin. The guidelines recommend that treatment be continued for four weeks after discharge.

A challenging question for clinicians caring for patients at risk for malignant disease is whether screening for cancer should be performed in patients who are diagnosed with an unprovoked DVT or pulmonary embolus. This topic was discussed in two recent articles. The two reports cited data from several high-quality studies that showed no clearly definable benefit for screening with interventions such as abdominal and pelvic CT imaging and mammography in patients who were diagnosed with an unprovoked VTE event. Both authors concluded that the topic is controversial but currently available evidence does not support the use of screening for cancer in this patient group.
Venous Thromboembolism in Patients Undergoing Bariatric Surgery

Obesity is not, alone, associated with a documented increase in venous thromboembolism risk. Body mass index (BMI) >25 is awarded one point in the Caprini scoring system for thromboembolism risk and, accordingly, places the patient in the low-risk category, according to the practice guidelines document by Gould and coauthors. Massive morbid obesity is often associated with obesity-related complications such as sleep apnea, obesity hypoventilation syndrome, and cardiovascular disease. These factors add to patient risk. The use of open obesity bypass operation is more often required in these high-risk patients. Recognizing these factors, it is not surprising that bariatric surgery patients deemed low risk, according to the Caprini risk scoring system, who undergo short-duration operations done laparoscopically, would not require pharmacologic thromboembolism prophylaxis.

Data confirming this observation were presented in an article by Clements and coauthors in the Journal of the American College of Surgeons, 2009. The authors reported outcomes on 957 patients undergoing laparoscopic Roux-en-Y gastric bypass by a single surgeon. Low-risk patients were treated with graduated compression stockings and early ambulation if operating times were less than 120 minutes. In this group of patients, the incidence of DVT was 0.3% and pulmonary embolus occurred in 0.1% of patients. The authors concluded that omission of pharmacologic prophylaxis in these patients was not associated with increased risk of venous thromboembolism.

Venous Thromboembolism in Elective Surgery Patients

Venous thromboembolism is an unusual but potentially lethal postoperative complication. The occurrence of fatal pulmonary embolus and recognition of the disabling complications of proximal deep venous thrombosis and obstruction of venous outflow have combined to stimulate vigorous efforts to develop effective prevention protocols. In contrast to patients who develop venous thromboembolism after an acute or chronic inciting event, preventing postoperative thromboembolism following elective operations represents an opportunity to use true prophylaxis. This is true because the preventive intervention can be used before the onset of the event that predisposes patients to venous thromboembolism.

Given this fact, it is not surprising to learn that patients in certain risk categories have very low probabilities of venous thromboembolism. These risk categories include young patients who undergo operations with short durations of general anesthesia and who have no significant risk factors for a hypercoagulable state, such as malignant disease or prior history of deep vein thrombosis. For these groups, risk of venous thromboembolism is less than 1% and the risk of fatal pulmonary embolus is 0.3%, according to several studies. Patients in higher-risk categories include patients over 50, patients who undergo major open abdominal operations requiring more than one hour of general anesthesia, patients with associated medical comorbidities, including hypertension and atherosclerotic cardiovascular disease, and patients who require operations to treat cancer.

Practice guidelines for the prevention of venous thromboembolism in nonorthopedic surgery patients have been developed by the American College of Chest Physicians. The guidelines were published in an article by Gould and coauthors in Chest, 2012. A summary of the guidelines is available for free from the National Guideline Clearinghouse at www.guideline.gov. The guidelines document encourages surgeons to evaluate patients for thromboembolism risk and to use thromboembolism prophylaxis based on the risk assessment. The most commonly used pharmacologic agents for prophylaxis are unfractionated heparin, low-molecular-weight heparin, and Fondaparinux. The guidelines document recommended preferential use of low-molecular-weight heparin. Fondaparinux is not recommended as a first-line prophylaxis agent primarily because of the cost of the agent. General dosing guidelines for the most commonly used agents are presented in a summary table (Figure 9).
Determining Venous Thromboembolism Risk

The practice guidelines document and other reports encourage assessment of venous thromboembolism risk using the Caprini scoring system (Figure 10). Risk stratification was achieved according to guidance included in the practice guidelines document. A Caprini score of 0–1 represents a very low-risk patient group in which no prophylaxis is needed. A score of 2 defines a low-risk group. Scores of 3–4 define moderate risk and a score ≥5 defines a group at high risk for venous thromboembolism. The use of anticoagulants for prevention of venous thromboembolism is indicated for patients in the moderate and high-risk categories according to the guidelines document.

A recent systematic review by Pannucci and coauthors in Annals of Surgery, 2017, concluded that the Caprini risk score was a dependable means of determining the need for anticoagulant drugs for VTE prophylaxis. The authors concluded that measures such as early ambulation and compression stockings are adequate for patients with Caprini scores of <7, with anticoagulant drugs reserved for patients with scores of 7 or higher.

Rogers and coauthors focused on preventing venous thromboembolism in elective surgery patients in the Journal of the American College of Surgeons, 2007. This report analyzed data from the Patient Safety in Surgery database, reviewing 183,000 patients; 1,162 instances of venous thromboembolism were identified. In each identified patient, confirmation of the diagnosis of venous thromboembolism was obtained from ultrasound, venography, or CT venography. The definition of venous thromboembolism was assured by recording that the patient was treated with heparin or performance of vena cava interruption by clipping or filter insertion. Thirty-day outcomes were recorded from individual chart reviews. Gastrointestinal operations were the most common type of procedure in this study. Venous thromboembolism was confirmed in 0.6% of patients. Risk factors for venous thromboembolism consisted mainly of markers of increased operative risk such as higher ASA scores, medical comorbidity (diabetes, stroke, congestive heart failure), and preoperative weight loss of greater than 10% of body weight. Elevated creatinine levels, leucocytosis, preoperative chemotherapy, and preoperative transfusion of more than four units of packed red blood cells were also risk factors for venous thromboembolism. Overall mortality for patients developing venous thromboembolism was 11%.

The association of transfusion with venous thromboembolism was further analyzed in an article authored by Nillson and coauthors in Archives of Surgery in 2007. This report used a large administrative database in Maryland and was able to review data from more than 14,000 patients. The authors confirmed that perioperative transfusion was associated with an almost two-fold increase in venous thromboembolism in women but not in men. The authors cautioned that careful risk assessment and

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**Figure 9**

Dosing recommendations for chemoprophylaxis for VTE in elective surgery patients.

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<table>
<thead>
<tr>
<th>VENOUS THROMBOEMBOLISM</th>
<th>CHEMICAL PROPHYLAXIS DOSING</th>
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</thead>
<tbody>
<tr>
<td>UNFRACTIONATED HEPARIN</td>
<td>5000 units subcutaneously three times daily or intravenous loading dose of 5000 units then 1500 units/hour. Dosing level and timing may vary depending on DVT and bleeding risk assessment.</td>
</tr>
<tr>
<td>LOW MOLECULAR WEIGHT HEPARIN</td>
<td>Dosing based on patient weight and renal function. Refer to local pharmacy guidelines</td>
</tr>
<tr>
<td>FONDAPARINUX</td>
<td>2.5 mg subcutaneously once daily. Timing of beginning dosing and duration of therapy may vary depending on DVT and bleeding risk assessment.</td>
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</table>
prophylaxis is especially important in women. They also recommended that additional larger studies be done to confirm their findings.

Rogers and coauthors provided a detailed table of risk analysis for their patient group. The authors recommended venous thromboembolism prevention using risk-adjusted protocols: compression devices for younger low-risk patients and anticoagulant-based programs for high-risk patients.

Additional data on risks of venous thromboembolism after abdominal and thoracic operations were found in an article by Mukherjee and coauthors in the Journal of Gastrointestinal Surgery, 2008. This report used data from the Nationwide Inpatient Sample to review almost 400,000 patients undergoing bariatric, colorectal, esophageal, gastric, hepatic, renal, pancreatic, and splenic procedures. The overall incidence of venous thromboembolism was 1.5% and the overall death rate was 4%. Mortality after diagnosis of venous thromboembolism was 13%. The highest risk category was splenectomy and the lowest was after bariatric operations. The authors opined that the lowered risk of venous thromboembolism after bariatric operations might be because of effective prophylaxis; however, other data cited in the article suggested that obesity may not be a discrete risk factor for venous thromboembolism. Data in a report by Kothari and coauthors, for example, disclosed no instances of deep venous thrombosis in more than 400 patients. While all of these patients received prophylaxis with unfractionated heparin or enoxaparin, the complete elimination of venous thromboembolism in a truly high-risk category of patients would be unusual. The authors concluded that risk stratification is possible and that risk could should be assigned when choosing the most appropriate method of venous thromboembolism prevention.

Risk factors for significant symptomatic pulmonary embolus as a postoperative complication was the topic of an article by Hope and coauthors that appeared in the American Journal of Surgery in 2007. The authors reviewed a group of 115 patients who developed postoperative pulmonary embolus. Associated risk factors for pulmonary embolus were older age, medical comorbidity, and duration of operation of more than 150 minutes, higher ASA score, and perioperative blood loss of more than 300 mL. This risk pattern provides additional support for the risk assignment categories discussed above.

Table 7—Caprini Risk Assessment Model

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<th>1 Point</th>
<th>2 Points</th>
<th>3 Points</th>
<th>5 Points</th>
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<tr>
<td>Age 41-60 y</td>
<td>Age 61-74 y</td>
<td>Age ≥ 75 y</td>
<td>Stroke (&lt; 1 mo)</td>
</tr>
<tr>
<td>Minor surgery</td>
<td>Arthroscopic surgery</td>
<td>History of VTE</td>
<td>Elective arthroplasty</td>
</tr>
<tr>
<td>BMI &gt; 25 kg/m²</td>
<td>Major open surgery (&gt; 45 min)</td>
<td>Family history of VTE</td>
<td>Hip, pelvis, or leg fracture</td>
</tr>
<tr>
<td>Swollen legs</td>
<td>Laparoscopic surgery (&gt; 45 min)</td>
<td>Factor V Leiden</td>
<td>Acute spinal cord injury</td>
</tr>
<tr>
<td>Varicose veins</td>
<td>Malignancy</td>
<td>Prothrombin 20210A</td>
<td></td>
</tr>
<tr>
<td>Pregnancy or postpartum</td>
<td>Confined to bed (&gt; 72 h)</td>
<td>Lupus anticoagulant</td>
<td></td>
</tr>
<tr>
<td>History of unexplained or recurrent spontaneous abortion</td>
<td>Immobilizing plaster cast</td>
<td>Anticardiolipin antibodies</td>
<td></td>
</tr>
<tr>
<td>Oral contraceptives or hormone replacement</td>
<td>Central venous access</td>
<td>Elevated serum homocysteine</td>
<td></td>
</tr>
<tr>
<td>Sepsis (&lt;1 mo)</td>
<td></td>
<td>Heparin-induced thrombocytopenia</td>
<td></td>
</tr>
<tr>
<td>Serious lung disease, including pneumonia (&lt; 1 mo)</td>
<td></td>
<td>Other congenital or acquired thrombophilia</td>
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<tr>
<td>Abnormal pulmonary function</td>
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<tr>
<td>Acute myocardial infarction</td>
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<tr>
<td>Congestive heart failure (&lt;1 mo)</td>
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<tr>
<td>History of inflammatory bowel disease</td>
<td></td>
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<tr>
<td>Medical patient at bed rest</td>
<td></td>
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</tr>
</tbody>
</table>

Figure 10 The Caprini venous thromboembolism risk scoring system. Reproduced from Gould and coauthors with permission.
Qadan and coauthors presented data on frequencies of VTE and the adequacy of prophylaxis in Surgery, 2008. Data from studies suggesting heparin or enoxaparin prophylaxis for all or most patients undergoing general surgery operations have identified a risk of venous thromboembolism of up to 30% for this patient group. These rates were reported by Geerts and coauthors in Chest, 2004; these alarming thromboembolism rates were drawn from data not stratified according to thromboembolism risk. Qadan and associates reviewed data from four large administrative databases. In each of the databases, the frequencies of deep venous thrombosis and pulmonary embolus were less than 0.5% for all operations. Operations associated with the highest frequency of venous thromboembolism were colorectal procedures and joint replacement. Of interest is that bariatric operations were not recognized as a high-risk category. The authors strongly supported preventive protocols for venous thromboembolism that feature careful risk assessment and anticoagulant prophylaxis used for high-risk patients.

Available data from recent studies suggests that surgeons are capable of accurately assessing venous thromboembolism risk and achieving a high level of guideline compliance with the result being a very low rate of venous thromboembolism mortality and morbidity. An article by Qadan and coauthors in Annals of Surgery, 2011, assessed risk-adjusted outcomes in a large administrative database. The data analysis disclosed that thromboembolism prophylaxis with anticoagulants was withheld in 11% of patients undergoing colorectal resection who were judged to be at low risk for thromboembolism. The rate of venous thromboembolism in this patient group was 0.3% compared with a rate of 3.1% in patients judged to be at moderate to high risk who all were given anticoagulant prophylaxis.

The above findings suggest that accurate risk assessment is possible, but there are high-risk patients who will develop venous thromboembolism despite adequate prophylaxis. These findings were confirmed in an article by Shackford and coauthors in Surgery, 2008. The authors reported a 10-year, single-center experience that included nearly 38,000 patients treated on general surgery, vascular, and trauma patient care services. The overall compliance with guidelines from the American College of Chest Physicians was 84%. Despite this high compliance rate, venous thromboembolism was diagnosed in 0.46% of patients. Out of the thromboembolic events that were diagnosed, 37% were believed to be influenced by a lack of guideline compliance. Sixty-three percent of the events occurred in patients with complete guideline compliance. The authors hypothesized that the nonpreventable events occurred because of increased patient risk, increasingly aggressive efforts to diagnose venous thromboembolism with imaging, and the fact that some events will occur despite guideline compliance.

Additional data on the association of operative procedure duration and postoperative VTE was presented in an article by Kim and coauthors in JAMA-Surgery, 2015. The authors queried the ACS National Surgical Quality Improvement Program® database and analyzed outcomes data on nearly 1.5 million patients treated in 315 hospitals in the United States. The overall rate of VTE was 0.96%. Pulmonary embolus rate was 0.33%. The authors were able to identify a linear correlation between operative procedure duration and the risk for VTE. The Caprini risk scoring system includes estimated operative duration in the risk scoring system, but the other commonly used risk scoring system, the Rogers score, does not. The Caprini scoring system rates operations of less than 45 minutes in length as “minor” procedures and operations lasting more than 45 minutes as “major” procedures. The authors recommended that operative duration be considered when assigning risk for VTE in surgical patients.

Another factor that impacts the success of VTE prophylaxis in surgical patients is missed or delayed dosing. A study that examined the impact of these factors was by Ramanathan and coauthors in Surgery, 2016. The authors evaluated medical records data on 10,318 patients. Venous thromboembolism was diagnosed in 131 patients; optimum prophylaxis (no missed or delayed drug doses, use of early ambulation) was confirmed in 24% of patients with VTE. The remaining patients experienced missed or delayed dosing of chemoprophylactic agents. The authors concluded that improved protocols that strive to ensure optimum compliance with dosing schedules could decrease the risk for VTE in patients undergoing surgical procedures. They recommended improvements in electronic health records that could assist in achieving this goal.
Editorial Comment

It now is possible to identify low-risk injured patients where thromboembolism prevention can be withheld. In the face of active prevention and surveillance protocols applied to high-risk patients, venous thromboembolism rates are low but not zero, indicating that prevention, although effective, does not provide complete protection. These observations of imperfect prevention suggest that occult vein thrombosis, away from the typical lower extremity locations, could give rise to embolization. This and other related topics are reviewed in the next section.

Diagnosis & Management of Deep Vein Thrombosis

Symptomatic deep venous thrombosis of the lower extremities is characterized by swelling and pain. Signs of inflammation, such as fever and leukocytosis, may be present. As discussed previously, proximal lower extremity deep vein thrombosis is often asymptomatic. When clinical suspicion arises, confirmation of the diagnosis with imaging is necessary. Compression duplex ultrasound is the confirmatory study most often used.

Orbell and coauthors98 discussed the advantages and limitations of the various imaging approaches in the British Journal of Surgery, 2008. The authors conducted an extensive literature review to compile a summary of advantages and limitations of the various imaging techniques available to the clinician considering a deep vein thrombosis diagnosis. The advantages of duplex ultrasound are low cost and availability. The limitations of this test are that detection of new thrombi is difficult in a limb that has previously harbored a proximal venous thrombus. Furthermore, ultrasound detection of a clot in the calf and in the iliofemoral junction areas above the inguinal ligament is undependable. CT venography has the advantage of being readily available, and imaging of the lower and upper extremity veins can be combined with thoracic imaging to detect a concomitant pulmonary embolus.

The actual level of accuracy of CT imaging of the pelvic veins is a matter of debate, however. MRI is currently an expensive test and is available on a limited basis. Given the progress that has been made in improving the quality and accuracy of both CT and MRI, it is likely that these tests will continue to improve and will serve a valuable role in the future, along with ultrasonography.

Practice guidelines for the management of symptomatic deep venous thrombosis of the lower extremity have been promulgated by the American College of Chest Physicians. The guidelines were published in an article by Kearon and coauthors99 in Chest, 2012 and were recently updated.100 The updated guidelines document is available from the American College of Chest Physicians website at www.chestnet.org. A summary of the guideline content is available for free on the National Guideline Clearinghouse website: guideline.gov. The updated guidelines supply recommendations for patients with high or low suspicion of deep venous thrombosis based on clinical examination. If there is high suspicion of thrombosis, the guidelines recommend parenteral anticoagulant therapy while awaiting confirmation of the diagnosis with imaging. If clinical suspicion of deep venous thrombosis is intermediate, the guidelines suggest (based on weaker evidence) that anticoagulation can be withheld if imaging will be completed within four hours. In patients with a low suspicion for thrombosis based on clinical evaluation, anticoagulants may be withheld if imaging will be completed in 24 hours or less.

The updated guidelines suggest that the newer antithrombin or anti-factor XA anticoagulant agents are as effective as low-molecular-weight heparin and vitamin K antagonists for initial therapy of DVT. The newer anticoagulant agents are associated with low rates of bleeding during therapy. According to the guidelines and a review article by Galanis and Merli101 in Cardiology Clinics, 2015, the newer agents are excreted primarily by the kidney, and because of this, clinicians will need to be cautious regarding use of these agents in patients with renal insufficiency. The newer agents have the advantage of not requiring blood test monitoring. The disadvantage? There are no specific agents that can reverse the anticoagulant effect. A summary of the mechanisms of action, dosing, pharmacokinetics, and renal elimination characteristics of the newer anticoagulant drugs was presented in an article by Mookadam and coauthors102 in Annals of Cardiac Anes-
The guidelines document and the review article recognized that some clinicians prefer to use unfractionated heparin. The guidelines view intravenous unfractionated heparin as an acceptable alternative to low-molecular-weight heparin. The suggestion of low-molecular-weight heparin or fondaparinux rather than unfractionated heparin was made because of significant evidence of effectiveness, with a lower risk of significant bleeding, of these two drugs compared with unfractionated heparin. The fact that monitoring of coagulation status is not needed with low-molecular-weight heparin and fondaparinux is another advantage.

When treatment with unfractionated heparin or low-molecular-weight heparin is chosen, the guidelines recommend that warfarin therapy be instituted simultaneous with parenteral anticoagulant therapy in patients with acute symptomatic deep venous thrombosis of the leg. Parenteral anticoagulant therapy is continued for five days or longer until therapeutic anticoagulation with warfarin is achieved (International Normalized Ratio [INR] of 2.0 or above). Additional recommendations are that patients may be treated at home rather than in the hospital if home circumstances are adequate. The guidelines recommend that patients be encouraged to ambulate after beginning therapy. If swelling and pain are severe, compression therapy is used and ambulation is delayed until symptoms improve. The guidelines state that symptomatic deep venous thrombosis is not an indication for systemic thrombolysis, catheter-directed thrombolysis, or surgical thrombectomy. Inferior vena cava filter placement is recommended for patients with a contraindication to anticoagulant therapy.

The practice guidelines recommend treatment of deep venous thrombosis brought on by a transient or surgical risk factor with three months of warfarin therapy. Therapy duration may be adjusted according to patient risk factors (malignancy and chemotherapy) and estimated risk of bleeding. The review article by Galanis and Merli provided a useful illustration of indications for anticoagulant therapy and duration of therapy (Figure 12).

**Ileofemoral Venous Thrombosis & Obstruction**

Proximal iliac vein thrombosis or obstruction (May-Thurner syndrome, or MTS) is a source of significant patient disability. Progression to venous gangrene is a life- and limb-threatening event. When iliac vein thrombosis or obstruction occurs, aggressive efforts to reestablish venous drainage using thrombolysis, stenting, or surgical interventions are indicated. Additional reviews will be provided in the section of this review that deals with chronic venous disease.
Practice guidelines for managing patients with the extension of deep venous thrombosis into the iliac veins and inferior vena cava have been produced by a joint committee of the Society for Vascular Surgery and the American Venous Forum. The guidelines document was by Meissner and coauthors in the Journal of Vascular Surgery, 2012. The guidelines recommend that the location and extent of venous thrombosis be precisely determined using CT venography. The authors further recommend that the terms “proximal” and “distal” thrombosis be replaced by a precise description of the vein or veins involved as documented with imaging. The guidelines recommend catheter-directed thrombolysis or pharmacomechanical clot removal for patients with acute iliofemoral thrombosis who have good pre-illness functional capacity and a normal life expectancy with acceptable bleeding risk. The choice between pharmacologic catheter-directed thrombolysis and pharmacomechanical clot removal can be made depending on local availability of and expertise with these techniques. The guidelines went on to recommend standard anticoagulant therapy for patients who undergo catheter-directed interventions. Open surgical thrombectomy is indicated in patients who are candidates for anticoagulation but who have a contraindication to thrombolytic therapy. The guidelines advise against the routine use of vena cava filters in this patient group. They also discouraged the use of catheter-directed interventions in patients with femoral-popliteal venous thrombosis.

Casey and coauthors provided a systematic review of current literature dealing with management approaches for iliofemoral thrombosis in the Journal of Vascular Surgery, 2012. The authors reviewed 15 studies that were gauged as acceptable. The overall strength of the evidence was judged as low. The available evidence suggested that catheter-directed thrombolysis and pharmacomechanical clot removal interventions are associated with a lower risk of PTS and venous reflux compared with anticoagulation alone in patients with iliofemoral thrombosis. These conclusions were supported by a recent Norwegian randomized controlled trial reported in an article by Enden and...
coauthors\textsuperscript{55} in \textit{Lancet}, 2012. The authors randomized 108 patients with ileofemoral thrombosis to be treated with anticoagulation plus catheter-directed thrombolysis or anticoagulation alone. At 24 months of follow-up, patients treated with catheter-directed thrombolysis had a 14.4% reduction in risk of PTS and a statistically significant increased frequency of ileofemoral venous patency.

**Deep Venous Thrombosis in Pregnancy**

Venous thromboembolism is a potentially life-threatening complication of pregnancy. Sequelae of venous thromboembolism represent the third most common cause of pregnancy-associated mortality. Because warfarin compounds cross the placenta, these cannot be used to treat venous thromboembolism during pregnancy. Heparin remains the first-line therapy for pregnant patients, although data on newer anticoagulant agents is being generated that may support these agents as an alternative to heparin. In selected high-risk patients, vena cava filter placement, preferably using a retrievable device, might be indicated. Deep vein thrombosis during pregnancy or during the use of birth-control medications may represent the first manifestation of a hypercoagulable condition.

A recent article presenting recommended practices for pregnant patients at risk for venous thromboembolism was by James\textsuperscript{106} in \textit{Obstetrics and Gynecology}, 2011. James stressed that venous thromboembolism is the cause of 9% of maternal deaths in American patients and the risk is higher in developing countries. Patients with a personal or family history of venous thromboembolism may have a diagnosable thrombophilic state and confirmation of the diagnosis with laboratory studies is indicated in these patients. Patients with symptoms of deep venous thrombosis are initially evaluated with compression ultrasound imaging and this is supplemented with additional imaging on a selective basis. Treatment of venous thrombosis in the antepartum period is achieved with low-molecular-weight heparin (again, because warfarin crosses the placenta and can damage the fetus). Anticoagulation is continued in the postpartum period based on patient risk assessment.

**Venous Thromboembolism in Children**

Venous thrombosis and pulmonary embolus are uncommon clinical problems in children, but can be encountered in children undergoing active treatment for cancer and in children with serious infections. The latter topic was discussed in an article by Hollmig and coauthors\textsuperscript{107} in the \textit{Journal of Bone and Joint Surgery}, 2007. The authors reported on a series of 212 children with deep skeletal infections. Eleven of these patients developed deep venous thrombosis. Nine of the 11 patients had an infection in the lower extremity or pelvis and the infection was adjacent to the thrombosed vein or on the side ipsilateral to the thrombosed vein in all nine patients. The patients with deep vein thrombosis were older (mean age of 10 vs. 7 years) than the patients who did not develop deep vein thrombosis. More than three-fourths of the patients with deep vein thrombosis had infections caused by methicillin-resistant \textit{staphylococcus aureus}. Furthermore, patients who developed deep vein thrombosis had signs of ongoing inflammation, evidenced by elevated C-reactive protein levels. The authors concluded that deep vein thrombosis is a significant complication occurring in children with osteomyelitis; they suggested that osteomyelitis caused by methicillin-resistant \textit{staphylococcus aureus} plus an elevated C-reactive protein level makes screening for deep vein thrombosis an appropriate step.

Children and adults with sickle cell disease are also at risk for deep vein thrombosis. This topic was discussed in an article by Austin and coauthors\textsuperscript{108} in \textit{Blood}, 2007. The authors conducted a case control study of 515 hospitalized patients diagnosed with deep vein thrombosis. This group was compared with an outpatient sample of 550 patients without deep vein thrombosis. All patients were screened for sickle cell disease. The data analysis revealed that the presence of sickle cell disease or trait doubles the risk of deep vein thrombosis. The most common predisposing conditions for the development of spontaneous deep vein thrombosis in Americans of European descent are the Factor V Leiden and prothrombin gene c20210 mutation. While both these conditions are rare in African-American patients, African Americans have an equivalent risk of spontaneous deep vein thrombosis as Caucasian patients. The authors concluded that the equivalence in risk may be partially explained by the risk increase associated with sickle cell disease and trait.
Calf Vein Thrombosis

Assigning risk and determining the best management strategy for calf vein thrombosis is challenging because most of the available published articles do not differentiate between thrombotic events involving the veins of the calf muscles as opposed to thromboses of the main draining veins of the calf. It is likely that the risks of extension into the popliteal and more proximal veins, and thus the risks of pulmonary embolus and thrombosis-related disability, are different for these two entities.

The updated practice guidelines document recommends anticoagulation for patients with calf vein thrombosis if risk factors for proximal extension are present. These include elevated D-dimer levels, concomitant active cancer, involvement of multiple calf veins, clot close to proximal veins, history of prior DVT episodes, and inpatient status. Patients without these risk factors can be managed without anticoagulation with serial imaging. Additional perspective on the management of calf vein thrombosis was supplied in an article by Keeling and co-authors in Blood Reviews, 2016. The authors emphasized that anticoagulation or serial imaging are both acceptable alternatives in patients without risk factors for progression who are at low risk for bleeding.

Masuda and coauthors offered a systematic review of the available literature relevant to calf vein thrombosis in the Journal of Vascular Surgery, 2012. The authors found 31 studies of acceptable quality. Only two randomized trials were available for review. On the basis of the available evidence, the authors concluded that the risk of progression of calf vein thrombosis into proximal veins is 6%–8%. The risk of pulmonary embolus could not be quantified from the available evidence. Two treatment options are available: anticoagulation according to practice guideline recommendations for femoral-popliteal deep venous thrombosis or compression and sequential ultrasound imaging with anticoagulant therapy for documented thrombus propagation. These options were discussed in the article by Masuda and in a retrospective case series by Singh and coauthors in the Journal of Vascular Surgery, 2012. Both articles confirmed that the choice of treatment will depend on an assessment of risk factors, surgeon judgment, and patient preferences.

Upper Extremity Deep Venous Thrombosis

Upper extremity venous thrombosis is increasingly diagnosed as central venous catheterization, placement of percutaneous peripheral venous catheters, and placement of transvenous pacemaker wires have become more commonplace.

Updated practice guidelines by Kearon and coauthors recommend anticoagulant therapy for upper extremity thrombotic events involving the axillary vein and/or proximal veins, confirmed by imaging. Thrombosis extension into the proximal axillary and subclavian vein warrants consideration of catheter-directed interventions based on patient preferences (e.g., desire to minimize PTS risk, expertise, and the availability of facilities for catheter-based interventions). The guidelines suggest that upper extremity venous thrombosis in the presence of an indwelling venous catheter is not an indication for catheter removal as long as the catheter is functional and there is a documented clinical need for the catheter. Anticoagulant therapy is continued for three months or for as long as the catheter is in place.

The risk of upper extremity deep vein thrombosis and pulmonary embolus in patients with peripherally inserted central venous catheters (PICC) was the focus of a retrospective case review involving more than 400 PICC lines in critically ill patients with neurologic disease by Fletcher and coauthors in Neurocritical Care, 2011. The authors were able to confirm symptomatic pulmonary embolus occurrence in 1.3% of PICC lines (15% of patients with symptomatic deep vein thrombosis). Most of the lines were removed when deep vein thrombosis was diagnosed and the authors questioned the wisdom of removal, as this meant that a significant number of patients would require a second line and be exposed to a second episode of venous thrombosis. The risk of anticoagulation in this neurologic illness population prompted placement of superior vena cava filters in a significant number of patients. The authors recommended careful risk assessment when determining treatment for PICC line-associated upper extremity venous thrombosis. The authors further suggested that needed lines that are functional be left in place during treatment.
Alternative Therapies for Deep Venous Thrombosis

Other therapies for venous thrombosis have been evaluated. Elevated levels of homocysteine are observed in some patients with deep vein thrombosis. Efforts to lower homocysteine levels have been evaluated. An article by Ray and coauthors\textsuperscript{112} provided one example in *Annals of Internal Medicine*, 2007. The report concluded that lowering homocysteine levels with folic acid do not offer measurable benefit in managing patients with deep vein thrombosis. Aspirin therapy has also been evaluated and one example of this effort was presented in an article by Glynn and coauthors\textsuperscript{113} in *Annals of Internal Medicine*, 2007. This analysis concluded that there is no measurable benefit from aspirin therapy in patients with deep vein thrombosis.

Pulmonary Embolus

Pulmonary embolus is usually suspected when patients present with dyspnea, hypoxia in the face, or hypocapnia. Hypotension may be present and laboratory testing will frequently disclose elevated levels of d-dimer in the blood, indicating an ongoing thrombotic process. D-dimer levels within normal limits in patients with a low probability of venous thromboembolism can be managed without additional imaging studies. This recommendation does not pertain to surgical patients who usually have a number of reasons for nonspecific elevations of d-dimer levels. Furthermore, venous thromboembolism has been documented in injured patients who have normal d-dimer levels. When there is suspicion of pulmonary embolus, confirmatory imaging is indicated. Duplex ultrasound of lower extremity veins is the first step and this test is complemented by CT angiography of the chest and, in selected patients, CT venography of pelvic and lower extremity veins. CT angiography has strong negative predictive value.

The value of CT pulmonary angiography for diagnosis of pulmonary embolus was reviewed in a report by Le Gal and coauthors\textsuperscript{114} in *JAMA*, 2015. The authors cited data confirming sensitivity of 100% and specificity of 90% for this diagnostic approach. They recommended that CT pulmonary angiography be used in all patients where pulmonary embolus is strongly suspected.

Stawicki and coauthors\textsuperscript{115} analyzed the value of transesophageal echocardiography (TEE) for diagnosis of pulmonary embolus in the *Journal of the American College of Surgeons*, 2008. The authors found that TEE evidence of right ventricular dilation, and tricuspid insufficiency were the most dependable findings confirming the presence of hemodynamically significant pulmonary embolus.

According to updated practice guidelines sponsored by the American College of Chest Physicians,\textsuperscript{100} anticoagulation with heparin and warfarin, along with supportive critical care, are the first lines of therapy for pulmonary embolus. Therapeutic approaches are determined based on the hemodynamic status of the patient. Patients with persistent signs of right heart failure and hypotension will require escalation of therapy. The clinical practice guidelines recommend catheter-directed thrombolysis and embolectomy for hemodynamically unstable patients with massive pulmonary embolus. Formal surgical removal of the embolus is indicated when hemodynamic instability persists despite catheter interventions or if such interventions are not available.

Stein and Matta\textsuperscript{116} analyzed data from a national administrative database that focused on the use and outcomes of catheter-directed therapies for pulmonary embolus with hemodynamic instability in the *American Journal of Medicine*, 2012. The authors queried the National Inpatient Sample for the years 1999 to 2008 and identified more than 21,000 patients who were hemodynamically unstable following a documented pulmonary embolus. Catheter-directed therapy (mostly thrombolysis) was undertaken in 30% of the patients. Analysis of the data showed that all-cause mortality and mortality attributable to the pulmonary embolus were significantly reduced in patients undergoing thrombolysis. Additional reduction in mortality risk was realized if vena cava filter placement was added to catheter-directed therapy. The authors concluded that thrombolysis and vena cava filter placement are effective therapies that are underutilized in this patient group.
Vena cava filters have been available for more than three decades. The currently available filters are easy to insert and position; filter tilt is the most common problem with placement. Modern vena cava filters are retrievable and can be removed when no longer needed. Determining which patients are ideal candidates for filter placement is a clinical challenge. The practice guidelines by Kearon and coauthors\(^{100}\) for managing venous thromboembolism recommend placement of vena cava filters in patients who have documented deep venous thrombosis and cannot be treated with anticoagulants. The guidelines also recommend vena cava filter placement for patients who have had a pulmonary embolus and cannot be treated with anticoagulants. Practice guidelines for the prevention of venous thromboembolism in nonorthopedic surgery patients by Gould and coauthors\(^{83}\) discourage the use of vena cava filters for primary prevention of pulmonary embolus in surgical patients and injured patients.

Despite these recommendations, the use of vena cava filters for prevention of pulmonary embolus is increasing. An article on this topic was by Stein and coauthors\(^{117}\) in the *American Journal of Medicine*, 2011. According to the authors, there is high-quality evidence that vena cava filter placement reduces the risk of pulmonary embolus, but increases the risk of associated deep venous thrombosis after filter insertion. The data indicate that overall, long-term mortality risk is not changed for patients who have filters inserted. Additional data cited by the authors suggest a reduction in all-cause short-term mortality risk in patients with documented pulmonary embolism who have undergone vena cava filter placement. There is considerable variation in practice patterns for insertion of vena cava filters in patients who are perceived to be at a high risk for pulmonary embolism (trauma patients, patients undergoing knee and hip replacement, patients with malignancy, and patients with recurrent pulmonary embolus). Data analysis of an administrative database reported in this article showed that vena cava filter insertion has increased threefold in the years 2001 to 2006 in patients without documented deep venous thrombosis or pulmonary embolus. The authors concluded that differing clinical opinions and perceptions of benefit of vena cava filters have driven this increased use.

Dossett and coauthors\(^{118}\) presented additional data on variation in use of vena cava filters in the *Journal of Trauma*, 2011. The authors queried the National Trauma Data Bank. According to the authors, practice guidelines offer differing recommendations for the use of vena cava filters in injured patients. Recommendations from the guidelines of the American College of Chest Physicians have been discussed previously. The 1998 guidelines of the Eastern Association for the Surgery of Trauma (EAST)\(^ {119}\) recommend consideration of vena cava filter placement in patients deemed to be at high risk for venous thromboembolism who cannot be treated with anticoagulants. In the analysis by Dossett and colleagues,\(^ {118}\) up to a tenfold variation in vena cava filter use was observed. While 1.8% of patients having vena cava filter placement fit the EAST guidelines recommendations, 24% of patients having filter placement did not. The editorial comment accompanying this article stressed that increased discussion and education could lead to a more evidence-based approach to vena cava filter placement. This, in turn, could lead to reduced variability.

Kidane and coauthors\(^ {120}\) provided a systematic review of available literature on the indications for placement of prophylactic vena cava filters in injured patients. The article was published in *Injury*, 2012. The authors found 24 studies of acceptable quality. The data analysis supported the conclusion that high-quality data do not exist that confirm mortality reduction after placement of prophylactic vena cava filters except in patients with contraindications to anticoagulation and a high-risk injury pattern. These data suggested that the recommendations of the EAST should be applied to this high-risk patient group and that data should be gathered to document a benefit for this intervention.

Use of prophylactic vena cava filters in high-risk patients undergoing bariatric surgery was examined in an article by Li and coauthors\(^ {121}\) in the *Journal of Vascular Surgery*, 2012. The authors examined patient characteristics and outcomes data from a large national database. The data analysis disclosed that patients receiving vena cava filters at the time of the bariatric operation were significantly more likely to have a history of prior abdominal surgery and/or past history of deep venous thrombosis. BMI was significantly higher in patients receiving filters and the patients receiving filters were more likely
to have severe complications of morbid obesity such as sleep apnea, hypoventilation syndrome, and refractory leg edema. Examination of outcomes data showed that overall short-term mortality was significantly higher in patients receiving filters.

The availability of retrievable vena cava filters potentially offers an opportunity to achieve benefit without the risk of long-term complications of permanent filters. A systematic review of the use of retrievable filters was by Angel and coauthors in the *Journal of Vascular Interventional Radiology*, 2011. The authors included 37 studies involving nearly 7,000 patients. There were no randomized controlled trials. The data analysis showed that the filters were effective in preventing pulmonary embolus (postplacement pulmonary embolus rate of 1.7%), but only 34% of the filters were retrieved.

Small, single-center studies showing improved retrieval rates for vena cava filters have been published in the past 2–3 years. Studies in specific patient groups such as children and pregnant patients have demonstrated retrieval rates >80%. One single-center study demonstrated improved retrieval (from 18% to 86%) after implementation of a protocol to improve long-term follow-up and filter retrieval.

**Editorial Comment**

Data showing large increases in the use of vena cava filters with wide variability in usage in medical centers in the same geographic area suggest that evidence-based approaches to vena cava filter use are not being followed. Available data are inconsistent about a mortality benefit for these devices. Furthermore, data on retrievable filters disclose very low retrieval rates. Surgeons need to lead additional efforts to refine guidelines and document adherence to the guidelines in practice.

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**General Aspects of Chronic Venous Disease**

Chronic venous diseases represent a spectrum of problems that are common in adults. These conditions include non-life threatening skin changes such as telangiectasis and venous lakes at one end of the clinical spectrum. More severe, potentially disabling chronic venous conditions include varicose veins, venous edema, and venous ulceration. Deep venous obstruction from thrombosis (PTS) is the most common form of chronic venous disease encountered by surgeons; articles relevant to this topic will be reviewed in this section.

**Primary Chronic Venous Disease**

A detailed review of clinical features of primary chronic venous disease was reported by Meissner and coauthors in a supplement to the *Journal of Vascular Surgery*, 2007. The authors began by providing data on the prevalence and health burden of chronic venous disease. Estimates they cited from several studies report that 10%–35% of the adult population has some degree of chronic venous disease, with the largest proportion having saphenous vein varicosities. An estimated 500,000 Americans suffer from venous stasis ulceration, creating significant problems in quality of life and health care costs. Symptoms generally increase with increasing age and additional risk factors include obesity, family history of chronic venous disease in a primary relative, and pregnancy.

Additional data from a population-based study from Italy added clarification about the frequency and population distribution of chronic venous disease. These data were reported by Chiesa and coauthors in the *Journal of Vascular Surgery*, 2007. The authors conducted clinical evaluations including interviews, physical examinations, and Doppler ultrasound imaging on a group of nearly 14,000 patients from 53 locations in Italy. The patients were recruited through television and print advertisements. Vascular surgeons familiar with ultrasound imaging did clinical evaluations. Clinical status of patients was classified according to the CEAP classification sys-
tem that provides information concerning clinical stage (C), etiology (E), anatomic location of disease (A), and pathophysiology (P). This clinical classification system is contained in the recent clinical practice guidelines promulgated by the Society for Vascular Surgery and the American Venous Forum. The guidelines were published in an article by Gloviczki and coauthors\textsuperscript{128} in the Journal of Vascular Surgery, 2011. Clinical staging using the CEAP scale ranges from C0 to C6. Stage zero indicates no clinical evidence of venous disease and stage 6 indicates active venous ulceration. Treatment can be indicated at any clinical stage higher than zero, but most interventions are used in stages 3–6. The CEAP classification system is presented in table form in the guidelines document (Figure 13).

In the study by Chiesa and coauthors\textsuperscript{127} Doppler imaging was performed with patients in the standing position and abnormal vein valve function was documented. The authors defined abnormal vein valve reflux as reflux flow $>$500 milliseconds. Overall, 20% of the study group was free of symptoms and signs of venous disease. Men were twice as likely as women to be free of evidence of disease. Telangiectasia was common in women; men had more evidence of varicose veins. The frequency of trophic changes and ulceration was equivalent in both genders and there was a linear increase in disease evidence and severity with increasing age. Signs of venous disease were more frequent in patients who had a primary relative with a history of venous disease. Obesity, as evidenced by increasing BMI, was associated with increased frequency and severity of clinical venous disease. Doppler evidence of reflux increased with increasing C score. Reflux was documented in nearly 80% of patients with C scores of 4–6. The authors were not able to correlate symptoms such as leg pain, heaviness, skin irritation, and sensations of swelling with the severity of venous disease ascertained by objective testing.

Careful questioning of patients with primary chronic venous disease, especially patients with varicose veins, will frequently document symptoms that impact quality of life. These include sensations of leg heaviness, swelling, and pruritus. According to the practice guidelines document by Gloviczki and coauthors,\textsuperscript{128} 23% of Americans have varicose vein disease and approximately 6% have more advanced vein disease, including active and healed venous ulcers. The authors stressed that varicose vein disease is more than a cosmetic problem. The guidelines document cited data confirming the presence of symptoms that reduce quality of life in the majority of patients with CEAP scores of 3 and above. The authors went on to stress that progression of primary venous disease from varicose veins to a more disabling form of venous insufficiency is not uncommon. They cited several data sources confirming that evidence of deep venous thrombosis, nonthrombotic iliac vein occlusion (MTS), or other causes provoking chronic venous disease, is absent in the majority of patients who progress to more severe CEAP scores over time.

### The CEAP classification

<table>
<thead>
<tr>
<th>CEAP</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0</td>
<td>No visible or palpable signs of venous disease</td>
</tr>
<tr>
<td>C1</td>
<td>Telangiectases or reticular veins</td>
</tr>
<tr>
<td>C2</td>
<td>Varicose veins</td>
</tr>
<tr>
<td>C3</td>
<td>Edema</td>
</tr>
<tr>
<td>C4</td>
<td>Pigmentation and/or eczema</td>
</tr>
<tr>
<td>C5</td>
<td>Lipodermatosclerosis and/or atrophic blanche</td>
</tr>
<tr>
<td>C6</td>
<td>Healed venous ulcer</td>
</tr>
<tr>
<td>Cx</td>
<td>Active venous ulcer</td>
</tr>
<tr>
<td>Cx</td>
<td>Symptoms, including ache, pain, tightness, skin irritation, heaviness, muscle cramps, as well as other complaints attributable to venous dysfunction</td>
</tr>
<tr>
<td>CA</td>
<td>Asymptomatic</td>
</tr>
</tbody>
</table>

2. Etiologic classification

| Ee   | Congenital |
| Ee   | Primary |
| Ee   | Secondary (postthrombotic) |
| Ee   | No venous etiology identified |

3. Anatomic classification

| Ae   | Superficial veins |
| Ae   | Perforator veins |
| Ad   | Deep veins |
| Ae   | No venous location identified |

4. Pathophysiologic classification

| Pe   | Reflux |
| Pe   | Obstruction |
| Pe   | Reflux and obstruction |
| Pe   | No venous pathophysiology identifiable |

Figure 13  
The CEAP classification of chronic venous disease. Reproduced from Eklöf and coauthors\textsuperscript{172} as modified by Gloviczki and coauthors\textsuperscript{128} with permission.
Pathophysiology of Primary Chronic Venous Disease

Traditional understanding of the pathophysiology of primary chronic venous disease has been based upon the tenet of abnormal venous valve function resulting in reflux and venous hypertension. Expanded knowledge has shown that there are major shortcomings in this explanation. For example, Meissner and coauthors found that saphenous varicosities occur frequently in veins where valve function is normal. Normally functioning valves are also observed in segments of dilated and tortuous veins. Veins showing signs of varicose vein changes may have normally functioning valves interspersed with valves that demonstrate reflux.

Vein valve function serves to facilitate the return of blood from the leg to the heart while the person is standing and walking. This function is assisted by the action of the muscles of the leg (muscular pump). The action of the veins, the valves, and the muscular pump are best understood as combining a hydrostatic function, where elevated venous pressure caused by the column of blood extending from the right atrium to the foot during standing, is counterbalanced by normal valve function that prevents a rise in pressure with standing that may exceed 90 mm Hg. The muscle functions of the foot and calf serve to propel blood toward the heart and this reduces venous pressure in the limb. Prolonged immobility, obesity, and muscle atrophy from disease all diminish the function of the muscular pump. The resulting exposure of the venous valves to increased pressure leads, over time, to valvular dysfunction.

Experimental models of venous hypertension, such as the mouse mesenteric vein model, have shown that valve dysfunction is observed after the induction of venous hypertension but that these changes are not seen for several days after the experiment begins; valve dysfunction may not appear and progress for days or weeks after the induction of venous hypertension. This experimental model is discussed in detail by Bergan and coauthors in the Journal of Vascular Surgery, 2008. The processes of vein valve changes leading to valve dysfunction have been clarified by the experimental models. These have shown that venous hypertension disrupts the normal pattern of blood flow in the area of the venous valves. Normally, this flow pattern consists of a linear flow in the main blood stream and a “vortex” flow that serves to remove blood from the valve cusps. These flow patterns ensure that the endothelial surfaces of the venous valves are exposed to a constant pattern of shear stress. A disruption of these flow patterns with the induction of venous hypertension induces an inflammatory response in the valve leaflets that, over time, leads to valve dysfunction and reflux. Bergan and coauthors explained that multiple components of the inflammatory response including cytokines, leucocytes, and products of oxidative stress contribute to the damage leading to valve incompetency.

Meissner and coauthors emphasized that changes in the vein wall that occur over time may also contribute to the development of signs of chronic vascular disease, especially varicose veins. They cited several experimental and clinical analyses that have shown changes in the vein wall leading to disorganization of the smooth muscle layers of the vein and induction of fibrosis as a consequence of abnormal collagen metabolism in the vein wall. The strong relationship of a family history of chronic venous disease in a first-degree relative to the development of significant venous disease suggests a genetic influence. Naoum and coauthors discussed this topic in the Journal of Surgical Research in 2007. The authors reviewed research advances that have assisted clinician understanding of the underlying mechanisms of chronic venous disease. The report confirmed findings reviewed in the previous articles and also devoted a special section to possible genetic influences that would help explain the role of family history in chronic venous disease. They cited data from a study of 2,000 twins that disclosed a functional variant of the FOXC2 gene in patients with chronic venous disease. This gene has been associated with the development of varicose veins in patients with lymphedema distichiasis. It has also been identified as having a role in the development of venous valves. The authors cited research identifying three candidate cDNAs that influenced the development of chronic venous disease. They closed their discussion with data linking altered expression of vascular endothelial growth factors and their receptors in the saphenous veins of patients with saphenofemoral valve reflux. This alteration was not observed in patients with competent saphenofemoral venous valves.
Skin changes and ulceration result from inflammatory processes also. Bergan and coauthors\textsuperscript{129} pointed out that experimental models of venous hypertension produce forces that cause the transport of macromolecules and erythrocytes into the perivascular spaces where the erythrocytes break down, leaving ferritin debris. Fibrin “cuffs” form around the vessels of the skin microcirculation in an attempt to preserve microcirculatory architecture, but this fails in time as a result of recruitment of inflammatory cells into the interstitium, a process mediated by the leucocyte adhesion and recruitment factor ICAM-1. The bulk of the experimental and clinical evidence supports the hypothesis that the development of signs of chronic vascular disease is a multifactorial process depending on the development of venous hypertension, the induction of an inflammatory response in the vein valves, changes in the cutaneous microcirculation, and altered smooth muscle and collagen metabolism in the vein wall.

**General Treatment Approaches to Mild Primary Venous Disease**

Exercise may play a role in treating chronic venous disease. At least, approaches designed to improve the function of the muscular pump deserve attention. Additional data on the role of muscular activity in maintaining venous function was presented in a report by Eifell and coauthors\textsuperscript{131} in the *Journal of Vascular Surgery* in 2006. This article presented data from 60 patients with chronic venous disease and compared them with 15 controls. An electronic device that measured intervals spent standing, sitting, walking, and walking intensity was supplied to each patient. Patients with chronic venous disease were assigned to groups based on their CEAP scores. Patients with scores in the C2 to C3 range were classified as having mild disease; patients in the C4 category were classed as moderate. Patients in classes C5 and C6 were assigned to the severe disease group. The authors found that healthy control patients spent significantly more time upright and walking than patients with venous disease did. Furthermore, the intensity of walking was higher in healthy patients. Time spent sitting was longer and lower walking intensities were observed in patients with worse CEAP scores. It was not clear from the study whether these factors were causative or whether the symptoms caused by increasing disease severity were responsible for the observed differences.

**Varicose Vein Disease**

Varicosity of the saphenous vein system of the lower extremities is the most common form of primary chronic venous disease encountered and treated by surgeons. This condition can occur with normal or abnormal venous valve function in the veins of the greater and lesser saphenous system. The greater saphenous and lesser saphenous systems are illustrated as Figure 14 and Figure 15.

**Evaluating Patients with Varicose Veins**

An important part of the initial evaluation is the clinical history: this step should focus on the presence of venous disease symptoms, the association of symptoms of concomitant arterial disease, and a history of cutaneous bacterial infection (a potentially important contributor to disabling venous obstructive disease, per Raju and colleagues\textsuperscript{132}). An assessment of the effect of chronic venous disease and the associated symptoms on the patient’s quality of life is also an important part of the history.

The practice guidelines document by Gloviczki and coauthors\textsuperscript{128} stress that the initial evaluation of patients with venous disease should have enough data to complete a CEAP score for the patient. The guidelines recommend questioning the patient about symptoms of prior deep venous thrombosis. A family history of varicose veins or other types of venous disease is also important as well as a history of birth control pill use. In addition, premenopausal women with saphenous varicosities should be questioned regarding symptoms of pelvic congestion syndrome.

The physical examination of the patient includes assessment of the various types of superficial venous changes such as telangiectasis, varicose veins, edema, skin changes, and ulceration. Palpation of varicose veins is important for detecting pulsatility. The veins should be auscultated for...
the presence of bruits and the mobility of the ankle joint should be assessed. Additionally, the presence of “ankle flare” should be ascertained: this fan-shaped pattern of cutaneous veins at the ankle is considered an early sign of progressive venous disease.

The practice guidelines document recommends a Doppler imaging examination as the initial diagnostic test in patients with venous disease. The examination assesses anatomic areas extending from the calf to the inferior vena cava. The objective of the Doppler imaging study is to establish the anatomic locations of the contributing venous abnormalities within the superficial, perforating, and deep systems and to document whether the principle contributing mechanism is pure valvular reflux, reflux with obstruction, or dominant obstruction.

Plethysmography may be useful for establishing the venous filling time that provides a quantitative estimate of vein function and may be useful in following patients postoperatively as a means of detecting early recurrence of venous disease. The authors emphasize, however, that this test has been largely supplanted by Doppler imaging, and is used selectively.

CT imaging as a diagnostic approach is gaining popularity. CT venography has been evaluated as a way to provide images of the entire abnormal venous system in patients with chronic venous disease. Lee and coauthors discussed this topic in the American Journal of Radiology in 2008. The authors analyzed images from 100 consecutive patients who underwent CT venography for the evaluation of chronic venous disease. Concomitant Doppler

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**Figure 14** Anatomy of the greater saphenous venous system. Reproduced with permission from the Mayo Foundation for Medical Education and Research.

**Figure 15** Anatomy of the lesser saphenous vein system. Reproduced with permission from the Mayo Foundation for Medical Education and Research.
ultrasound imaging was available for each of the patients. The quality of the images and the types of information furnished to the clinician from each method were assessed. The data disclosed that excellent CT images were obtained in 76% of patients. Twenty-one percent of the images were classed as fair, and 3% were deemed unsatisfactory. The entire saphenous system was satisfactorily imaged in 99% of patients.

The main strength of the CT images was the ability to document the presence of deep vein thrombosis. The CT images were accurate for the diagnosis of calf vein thrombosis and for proximal deep vein thrombosis. One significant limitation of CT venography is the lack of functional information. CT venography could provide images of perforating veins, but no information could be gained about whether these were incompetent or competent veins. Valve function in the saphenous trunk and branches could not be assessed. There was no area of the vein disease assessment in which the CT venogram was superior to the Doppler examination. Another possible advantage of CT venography is that the patient does not have to stand for the duration of the study. In patients with associated diseases such as osteoarthritis with joint pain, this factor might be helpful. Lee and coauthors concluded that CT venography should be considered as a complementary study to Doppler imaging.

Nonoperative Management of Varicose Veins

On completion of the clinical evaluation described above, patients can be assigned to treatment categories. The choice of treatment for patients with CEAP classification of 1 is based on patient desire for improved cosmesis, because venous disease in this category is usually not a significant contributor to diminished quality of life.

Most of the well-studied treatments for patients with chronic venous disease focus on therapies used in patients in clinical categories 2–6. Patients in CEAP categories 2 and 3 represent a heterogeneous group that might comprise patients with small- to medium-sized varicose veins with or without significant edema. Patients in categories 3–6 usually have significant morbidity and diminished quality of life. In all groups, however, the most frequently used therapies are various invasive procedures. The practice guidelines document by Gloviczki and coauthors recommend against nonoperative therapy for patients with symptomatic varicose veins who are candidates for venous ablation (see later discussion). The guidelines suggest, based on weak evidence, compression therapy at an ankle pressure of 20–30 mmHg for symptomatic varicose veins in patients who are not candidates for ablative therapy.

Operative Management of Varicose Veins

Meissner and coauthors discussed each of the surgical approaches to the management of varicose vein disease. The traditional method of dealing with saphenous varicosities has been to ligate the vein at the saphenofemoral junction along with the other branches in the area of the junction. Removal of all of the branches of the saphenofemoral junction has been thought to be a main feature of the operative technique responsible for reducing the recurrence rate of varices. This notion is currently being challenged because data are now available that suggest that meticulous ligation of all branches might actually contribute to recurrence because of the collateral channels that form from pressure from venous drainage beds in the lower abdomen and perineum.

The saphenous vein is then stripped from the ankle upward. This effectively removes the vein with the dysfunctional venous valves and disrupts the potentially incompetent perforating veins. Limitations of this technique are the potential for damage to the saphenous nerve, postoperative pain, ecchymosis from subcutaneous hemorrhages, and, in the long term, recurrence of varicosities that can be observed in up to 40% of patients at five years of follow-up. The need for general anesthesia, the potential for wound complications, and postoperative pain have been the main reasons that drive preferences for endovenous ablative procedures over traditional open operations.
Venous Ablation Therapy for Varicose Veins

Venous ablation therapy using thermal or laser devices offers patients an option for saphenous varicosity treatment that can be performed on an outpatient basis under local anesthesia. Available data analyzed in the practice guidelines by Gloviczki and coauthors documented the effectiveness and low morbidity of this approach. The guidelines recommend laser or radiofrequency thermal ablation as the first-line therapy for varicose veins.

Darwood and coauthors reported a randomized clinical trial of endovenous laser ablation compared with open saphenous ligation and stripping in the British Journal of Surgery, 2008. Three groups are reported: 42 limbs were treated with endovenous laser ablation applied with stepwise removal of the catheter and 29 limbs were treated with continuous removal of the laser catheter. Thirty-two patients were treated with conventional saphenous vein ligation and stripping with avulsion of individual varicosity clusters. Endpoints of the study were elimination of reflux documented by Doppler imaging and change in the venous symptom score. Patients were followed for three months. At the end of the follow-up interval, equivalent improvement of reflux and venous symptoms were observed in all groups. Return to normal activity occurred significantly sooner with laser ablation than with open surgery. The authors concluded that laser ablation may offer a more cost-effective means of treating saphenous varicose veins because of the earlier return to normal activity observed in these patients.

Gale and coauthors presented a randomized, controlled trial comparing radiofrequency ablation with laser ablation therapy in the Journal of Vascular Surgery, 2010. The authors enrolled a total of 118 patients with 141 treated limbs. Patients with bilateral disease had one technique on the first limb and the other on the second limb. Outcomes were assessed with standard quality-of-life assessment instruments designed for use in patients with venous disease. Doppler ultrasound examination to determine saphenous vein patency was performed at one month and one year postoperatively. The data analysis disclosed that CEAP scores decreased by 50% in all patients. Endovascular laser ablation was associated with more bruising but had a higher rate of permanent saphenous vein closure compared with radiofrequency ablation.

A second randomized, controlled trial comparing radiofrequency and laser ablation was by Nordon and coauthors in Annals of Surgery, 2011. The authors found similar rates of symptom relief with both interventions and equal saphenous occlusion rates; but, in this study, Doppler examinations were done one time at one month postoperatively. The authors also discovered that radiofrequency ablation was associated with less bruising compared with laser ablation.

Theivacumar and coauthors conducted a study comparing above knee with full saphenous ablation in patients with above-knee and below-knee venous reflux; this article was published in the Journal of Vascular Surgery, 2008. Persistent varicosities are observed in a significant proportion of patients who have above-knee saphenous ablation. The authors hypothesized that full saphenous ablation in patients with documented above-knee and below-knee venous reflux would yield improved results. They randomized 68 limbs in 65 patients to undergo full saphenous laser ablation or above-knee ablation with saphenous foam sclerotherapy for residual varices. The data analysis disclosed that 61% of patients with only above-knee ablation required sclerotherapy for residual varices compared with 17% of patients with full saphenous ablation.

Additional data have shown that laser ablation of both limbs of patients with bilateral disease in one session is safe and feasible. In addition, laser ablation of saphenous varicosities is effective in patients with documented deep venous insufficiency. The authors provided data indicating that clinical success of the procedure occurs because connecting venous channels between the superficial and deep systems are apparently occluded after ablation of the saphenous vein.

Meissner and coauthors discussed using sclerotherapy to treat superficial primary venous disease. The conventional indications for sclerotherapy include the treatment of telangiectasis and venous lakes of less than 1 mm diameter and superficial varicose vein clusters between 1 and 3 mm diameter without connection to an
incompetent main saphenous trunk. The authors emphasized that the types of sclerosant agents used include hypertonic saline, hypertonic glucose, and sodium salicylate. Detergent agents include sodium tetradeyl sulfate, polidocanol, ethanolamine olate, and sodium morrhuate; these are the only sclerosants approved by the Food and Drug Administration for use in the United States. Additional agents are used in other countries. The available agents cause irreversible venous endosclerosis. Major side effects have not been reported, although local side effects such as hyperpigmentation can be observed. Concentrations of sclerosing solutions vary depending on the lesion to be treated.

The authors briefly reviewed the technique of ultrasound-guided foam sclerotherapy. This treatment is performed by injecting a column of sclerosant foam, which is created by mixing one of the detergent sclerosing solutions with carbon dioxide, oxygen, or room air; this is currently an investigational technique in the United States, and it is important to note that embolic events such as ischemic stroke have been reported with the use of these agents.

Complications of Primary Chronic Venous Disease

The complications of chronic venous disease include superficial vein thrombosis and progression of disease to chronic edema and venous ulceration. The latter two complications are managed according to similar principles whether the venous disease is primary or secondary; these techniques will be reviewed in the next section of this review.

Superficial venous thrombosis was the focus of an article by Karathanos and coauthors in the European Journal of Vascular and Endovascular Surgery, 2012. Superficial venous thrombosis complicates varicose vein disease in up to 60% of patients. Recently, the potential for extension of the thrombotic process into the saphenous vein, and occasionally into the deep vein system, has renewed interest in this condition and drawn attention to the fact that superficial venous thrombosis is not always a benign condition. Observations from several reports cited by the authors suggested that associated risk factors may determine why some patients develop superficial venous thrombosis and others do not.

The authors conducted a prospective analysis of risk factors in 128 patients with varicose veins who developed or had a history of superficial venous thrombosis. This group was compared with 102 patients with varicose veins who had no history of superficial venous thrombosis. Data analysis discovered three main risk factors, including obesity, older age, and the presence of an inherited thrombophilic state. Thrombophilia was documented in 59% of patients. The largest proportion of patients had protein S deficiency. The authors concluded that definite risk factors exist for developing superficial venous thrombosis. The authors recommended that low-dose, low-molecular-weight heparin be used for thrombosis confined to saphenous tributaries and that therapeutic low-molecular-weight heparin be used for thrombosis episodes that extend into the saphenous vein. They also suggested that chronic low-molecular-weight heparin therapy might be useful in patients with evidence of a thrombophilic state.

Secondary Chronic Venous Disorders

Meissner and coauthors’ article in the Journal of Vascular Surgery, 2007, defined secondary chronic venous disease. This is a process that results in complications similar to those seen in patients with primary venous disease—but in this disease, there is a history of venous obstruction. Most of the instances of secondary venous disease are the result of an episode of deep vein thrombosis that has destroyed the valves in the deep system of the involved limb. This phenomenon was demonstrated by the scientist Gunnar Bauer using descending contrast venography; per Bauer, most veins recanalize after deep vein thrombosis, but deep venous valves are destroyed during this process.

Additional research has demonstrated that fibrosis and stenosis of deep veins can occur, as can residual adherent thrombi with vein lumens. These events can result in sustained outflow restriction that can accelerate compli-
cations such as pain, chronic edema, skin changes, and ulceration. The pain associated with this process can be accentuated by walking and is termed venous claudication. The combination of symptoms including pain, edema, skin changes, and ulceration is called post-thrombotic syndrome (PTS).

Meissner and colleagues stressed that diagnosing secondary chronic venous disease requires clinical evidence of PTS combined with Doppler imaging evidence of deep venous valve dysfunction, thrombosis, or obstruction. Superficial venous valve dysfunction will frequently accompany deep venous disease. Deep venous obstruction can occur without thrombosis from vascular compression of the left iliac vein by the right iliac artery (May-Thurner syndrome), by compression from pelvic tumors, and by obstruction from primary venous tumors. Plethysmography and venography may be helpful diagnostic tools if operation or endovascular treatment of venous obstruction is contemplated. Meissner and associates stressed that reviews of secondary venous disease have shown that up to 40% of patients with secondary venous disease resulting in ulceration will have a documentable thrombophilic disorder—laboratory investigation of this is an important part of the diagnostic evaluation.

Meissner’s review pointed out that many deep vein thromboses do not recanalize. Furthermore, severe symptoms of acute venous occlusion may occur; the most severe of these being phlegmasia cerulea dolens. In this extreme circumstance, arterial circulation is threatened by the intense swelling resulting from venous outflow obstruction. Mainstays of treatment for phlegmasia have been venous thrombectomy and fasciotomy. Although heparin has been the traditional method of treating deep venous thrombosis, patients with severe symptoms may benefit from direct thrombolytic approaches.

Clinical practice guidelines sponsored by the American Heart Association review current approaches for the prevention, diagnosis, and management of PTS. The guidelines were published in an article by Jain and Cifulli in JAMA, 2016. The main recommendations of the guidelines are that long-term therapy with warfarin should be carefully monitored to avoid subtherapeutic INR, especially in the first few months of treatment. The guidelines recommend consideration of catheter-directed thrombolysis in acute (significant venous obstructive symptoms for 14 days or less) thrombotic events in patients with good functional capacity and life expectancy of more than one year. Evidence was deemed insufficient to make a strong recommendation for using newer anticoagulant drugs for PTS. Evidence was insufficient to make a recommendation to use compression stockings for PTS prevention. Instead, the guidelines recommend considering compression stocking use for reducing symptomatic swelling in patients with proximal deep venous thrombosis; compression stockings are also recommended for managing venous ulceration rather than dressings alone. To manage venous ulcers, using pentoxifylline alone or in combination with compression was recommended.

Endovascular approaches for clot lysis and for stenting of chronically obstructed veins have shown promise for patients with acute, limb-threatening symptoms from venous thrombosis, for good-risk patients with significant symptomatic venous obstruction, and for patients with severe chronic venous obstructive symptoms. Data on approaches and outcomes of these therapies were reviewed in an article by Sista and coauthors in Radiology, 2015. The authors emphasized the need to determine risk for major bleeding prior to use of endovascular approaches. Patients at low risk for bleeding can benefit from thrombolyis for acute limb-threatening symptoms, extensive inferior vena cava thrombosis, and for progression of symptoms or extension of clot despite anticoagulation. Lysis may also be helpful for PTS prevention in patients with iliofemoral and femoropopliteal thrombosis. The authors cited data that support a reduction in PTS risk of 26% in patients who had thrombolysis.

Chronic iliofemoral venous obstruction can be caused by thrombosis, external compression, and MTS. Approximately 25% of patients have venous obstruction of unknown cause. The placement of endovenous stents offers the opportunity to restore venous patency and reduce disability for this patient group. Titus and coauthors reported a retrospective case series of 36 patients in whom 40 stents were placed; this article appeared in the Journal of Vascular Surgery, 2011. According to the authors, 75% of the patients were women and venous obstruction was due to acute thrombotic events in 38% of patients. All of the thrombotic patients received thrombolysis. Stent
patency at 24 months was 100%. Symptom relief was better for patients with idiopathic venous obstruction and MTS.

Ye and coauthors present long-term follow-up data for iliofemoral venous stenting for nonthrombotic iliofemoral venous obstruction in the *Journal of Vascular Interventional Radiology*, 2012. The authors reported data on more than 200 stented patients followed for a mean interval of more than four years. Overall, patency was 100% and relief from edema was observed in 89% of patients. Pain levels and quality-of-life scores improved significantly in stented patients.

Keeling and coauthors reviewed available evidence relevant to the use of compression stockings for PTS prevention in *Blood Reviews*, 2016. The authors concluded that no strong evidence is available that supports the value of compression to prevent PTS.

Meissner and coauthors also discussed the use of compression therapy for established PTS with edema and ulceration. They stressed the importance of CEAP classification of patients because the compression devices used and the pressures applied to the extremity will vary with CEAP classification. Compression stockings applying pressures of 10–20 mmHg at the ankle are used as first-line treatments of patients in class 1 and 2. Compression stockings applying pressures of 20–30 mmHg are used for classes 3 and 4, with higher-pressure stockings for more severe disease. These authors provided data documenting the effectiveness of below-knee compression stockings in providing support, resulting in ulcer healing in patients with both primary and secondary venous ulceration. Meissner and colleagues emphasized that compliance with the compression program is problematic because of discomfort associated with stocking use, especially in warm, humid climates. The authors suggested starting at a low pressure and working up toward the optimum indicated pressure level to minimize discomfort. They also stressed the effectiveness of a dedicated team of caregivers due, in part, to improved compliance.

Physical therapy approaches for managing patients with PTS were reviewed in an article by Yim and coauthors in *JAMA-Dermatology*, 2015. Decreased range of motion and muscle strength are common findings in patients with PTS. Compression dressings may further reduce range of motion and cause the patient to avoid movement. The authors reviewed 10 studies that presented data supporting the benefit of physical therapy combined with compression for patients with PTS and venous ulceration. Data on quality-of-life improvements were not available from the studies reviewed. In an editorial by McCulloch and coauthors that accompanied the Yim et al article, the authors stressed the importance of involving physical therapists in the care of these patients and coordinating exercise programs with compression therapy interventions to make sure that exercise capacity and range of motion are not reduced by the compression devices. They also emphasized the need for research to determine the best strategies for combining compression therapy with exercise programs to improve the quality of life for patients with PTS.

**Venous Ulceration Management**

Meissner’s report outlined the available therapies for venous ulceration. These include debridement and local wound care, specialized wound dressings, applying skin substitutes, and pharmacologic agents such as pentoxifylline and micronized purified flavonoid fraction. The benefits of using prostaglandin analogues have been documented in several reports; the principle obstacle to their widespread use is the need for intravenous infusion.

According to the authors’ discussion of direct wound care approaches, research has documented the need for warmth, moisture, and effective management of wound drainage as important principles leading to successful ulcer healing. Several types of dressings are available. Use of any dressing should be preceded by wound debridement and cleansing. Film dressings, foam dressings, and skin substitutes are all available. Film dressings have the advantage that the inner layers of the dressing can assist with debridement. Foam dressings offer improved management of wound drainage. Skin substitutes may provide important growth factors to the wound. The authors stressed that strong evidence supporting the superiority of one dressing over another is not available. Ultimately, the treating surgeon will need to choose an approach that is cost efficient and associated with maximum compliance. A time-tested approach is to combine compression with moisture and medication, such as the Unna Boot. This device is inexpensive but must be changed weekly.
or more often (especially during the early phases of ulcer treatment). All approaches require the consistent use of compression therapy.

**Surgical Approaches to Venous Ulceration**

Direct surgical approaches to the venous ulcer may be helpful. We previously mentioned the importance of ulcer debridement and cleansing before wound dressing and compression. In long-standing venous ulcers, excision of the ulcer and the underlying, often fibrotic, fascia with skin grafting may accelerate the rate of healing. This procedure also gives an opportunity to obliterate any incompetent perforating veins that might underlie the ulcerated area.

Surgical approaches to superficial varicosities with incompetent valves might also improve prospects of ulcer healing. Meissner’s review described the results of the ESCHAR trial that demonstrated no change in the rate of ulcer healing after ligation and stripping of saphenous varicosities but did show a 50% reduction in the rates of ulcer recurrence in a study of 500 patients. Howard and coauthors presented a systematic review of available data on using superficial vein procedures to treat venous ulceration in the *European Journal of Vascular and Endovascular Surgery*, 2008. The authors reviewed 61 surgical literature articles to evaluate the evidence for or against the role of superficial saphenous ligation and stripping in managing venous ulceration. The authors concluded, after their extensive literature review, that superficial vein procedures for treatment of venous ulcers improve the rates of recurrence but not the rates of ulcer healing. Overall, the results of ulcer treatment are not as good when deep venous valve dysfunction or venous outflow obstruction exists in conjunction with the ulcer. This observation raises the question whether direct interventions to improve venous outflow are indicated to improve the rates of venous ulcer healing.

Meissner and coauthors stated that improvements in venous outflow can be achieved in patients with stenoses of proximal deep veins of greater than 50%. Endovascular stents, repair of deep venous valves in the popliteal vein and more proximally, and vein bypass of stenoses are measures discussed by Meissner and colleagues. The authors stressed that careful diagnostic evaluation using intravascular ultrasound and contrast venography are important parts of the evaluation before any of the mentioned procedures. Their report also emphasized that patency rates are generally in the 90% range at three and five years after stenting, and bypass and mortality rates are less than 1%. Patients with PTS fare worse than patients with nonthrombotic occlusive disease. In addition, Meissner cited several studies of the various interventions indicating improvements in venous severity scores and quality of life in the majority of patients after successful interventions.

Seager and coauthors reviewed endovascular stenting for chronic venous obstruction in the *European Journal of Vascular and Endovascular Surgery*, 2016. Data from 16 studies involving nearly 5,000 patients were analyzed. There was significant heterogeneity of the studies, but the data suggested that improved ulcer healing and improved quality of life were frequently cited in the available studies. While the authors affirmed the need for prospective randomized trials, they also stressed that endovascular stenting should be considered for patients with symptomatic chronic venous obstruction.

Delis and coauthors presented additional data confirming the utility of deep venous procedures to improve venous outflow in *Annals of Surgery*, 2007. This analysis evaluated venous outflow and muscle pump function as well as intensity of venous claudication in 16 patients with documented venous outflow obstruction in one limb. The contralateral normal limb served as the control. All outflow veins were successfully stented and the authors observed improvements in muscle pump function and venous outflow. Reflux increased in all patients, but this did not prevent a significant improvement in the intensity of venous claudication. The authors concluded that symptomatic improvement, coupled with improved venous outflow and muscle pump function, make stenting to improve venous outflow an attractive alternative in these highly-selected patients.

Meissner and associates confirmed that there have been encouraging results with the use of vein bypass of deep venous obstructions. Readers are encouraged to read this article for details of this procedure that might be helpful for carefully selected patients.
Editorial Comment

It is clear that a diverse array of approaches is possible for managing venous ulcers from primary or secondary chronic venous disease. Clinical success depends on a stepwise approach in which compression is a mainstay of therapy. Careful diagnosis supported by Doppler imaging leads to improved therapeutic choices and improved outcomes. Additional strong clinical data is necessary to help guide the choices of direct ulcer treatment with dressings or skin substitutes.

Dialysis Access

Successful management of patients requiring hemodialysis depends on acquiring and maintaining vascular access. Rose and coauthors152 supplied an important perspective on the approaches that can yield the best results in Surgical Clinics of North America, 2013. This article is supplied as a full-text reprint accompanying some formats of SRGS. The article provided information on the need for dialysis access. More than 100,000 patients began hemodialysis in one recent year (2009). In that same year, approximately 600,000 patients required end-stage renal disease (ESRD) management. This need for ESRD management is highest among African-American and Native-American populations. The financial burden of this disease is significant, accounting for 6% of the Medicare budget in 2009. Much of this cost is devoted to managing ESRD complications. As the population of the United States ages, ESRD costs of care and management complications are likely to increase.

Hoggard and coauthors next reviewed the mechanisms of venous injury resulting from venipuncture and venous catheter placement. They recognized that ESRD patients are chronically ill and will require repeated hospitalizations, blood sampling, and intravenous therapy for diagnosis and treatment of the renal disease as well as the frequent comorbid conditions common to this patient group (diabetes, cardiovascular disease, and malignancy). Venous injury can occur at the time of venipuncture or it may develop gradually over the interval that an indwelling device is present. The authors cited data from an analysis of venous specimens obtained at autopsy. Short-term intravenous catheter use was characterized by areas of endothelial denudation in the vein where the catheter was residing. Longer-term use led to vein wall thickening, increased numbers of smooth muscle cells at the site of vein wall puncture, and multiple areas of catheter adherence to the vein wall. At these attachment sites, thrombus formation and collagen deposition were observed. Another autopsy study disclosed thrombus formation in nearly one-third of cannulated veins at two weeks following catheter insertion. Peripherally inserted central catheters (PICC) have been studied and the data are cited by Hoggard and colleagues. Twenty-three percent of PICC lines had demonstrable thrombosis on removal. If multiple lines had been placed, the frequency of thrombosis rose to 38%. The analysis of PICC lines disclosed that the chronic dialysis access (the preferred access type) depends on venous drainage that is open and undamaged. The authors also emphasized the savings in both morbidity and cost associated with the creation of functioning autogenous arteriovenous fistula access for chronic hemodialysis. Important national groups such as the National Kidney Foundation–Kidney Disease Outcomes Quality Initiative, the Center for Medicare and Medicaid Services, and the End-Stage Renal Disease Networks have joined together to create the National Vascular Access Improvement Initiative (Fistula-First Breakthrough Initiative) to promote guidelines leading to autogenous fistula creation for patients requiring first-time entry into chronic hemodialysis—this initiative has set a goal for autogenous fistula creation as first-time dialysis access in 67% of ESRD patients. For this goal to be achieved, aggressive efforts to prevent venous outflow injury are required. Their guidelines document is available for download at kidney.org.
cephalic vein (the preferable venous drainage channel for upper-extremity dialysis fistulas) was thrombosed in more than half of the patients when this vein was used for PICC insertion. The authors cited several other data sources that confirmed the high rate of vein injury associated with PICC insertion. Subclavian catheters are also associated with a significant risk of vein injury that may contribute to ipsilateral upper-extremity dialysis-access failure. In one study, vein stenosis or occlusion was found in 57% of patients having subclavian catheters removed. When subclavian catheters were compared with internal jugular catheters, stenosis and thrombosis rates were 4–8 times lower in internal jugular catheter placements and the time to develop thrombosis was nearly four times longer for internal jugular catheters.

Hoggard and associates next discussed identifying patients who should enter a clinical pathway for vein protection. Severity grading for patients with chronic renal disease is achieved with a four-level grading system based on estimated glomerular filtration rate. Glomerular filtration rate is usually determined using a four-variable, abbreviated Modification of Diet in Renal Disease Study equation formula. The authors emphasized that a cascade of clinical events leading to ESRD and chronic hemodialysis usually begins when a patient reaches Grade III renal insufficiency. Although this cascade proceeds at different rates in individual patients, the authors recommended that patients enter a vein protective pathway upon reaching Grade III. This recommendation is consistent with the consensus of the organizations participating in the National Vascular Access Improvement Initiative. The article stressed that patients who have functional dialysis accesses and/or functioning renal transplants are not protected from access failure or failure of the transplanted organ. These patient groups should remain in the vein protective pathway. Peritoneal dialysis becomes untenable in 20%–30% of patients each year and that failure of a transplanted kidney is the most common reason leading to chronic hemodialysis in many centers. The recommendations made in this article are that dorsal hand veins be used for temporary venous access in patients with Grade III or higher renal dysfunction. The dominant hand is used first and vein access is facilitated by warming the hand. For central venous access, tunneled catheters placed in the internal jugular position are preferred because of the higher infection rates observed with percutaneously placed internal jugular catheters. With ultrasound guidance and adequate operator expertise, these catheters can be placed and maintained at high levels of safety. Ideally, the tunneled catheter should be placed on the opposite side from the location of a functioning dialysis access fistula or the arm where creation of an access is planned. The authors concluded by emphasizing the value of a multispecialty team devoted to identifying patients who are progressing toward dialysis and selecting access types and sites for these patients using input from nephrologists, surgeons, and dialysis nurses. A policy and procedure for the vein protective pathway is a valuable way for all caregivers to recognize the patient who is enrolled in the vein protective pathway (for example, a MedicAlert® bracelet).

Ideally, the surgical procedure that is needed to establish dialysis access exposes the patient to minimal morbidity, can be done under local or regional anesthesia, and provides a dependable and durable means of performing efficient hemodialysis within 4–6 weeks of the procedure. Constructing acceptable dialysis access has depended on autogenous arteriovenous fistula or prosthetic interposition conduits between the arterial and venous circulation of the upper extremity. Rose and colleagues cited data supporting the conclusion that autogenous arteriovenous fistula construction meets these requirements. This approach has a record of fewer complications and reinterventions. Additional data have confirmed that patients managed with autogenous fistulas have a lower mortality risk. National and international consensus groups have identified direct arteriovenous anastomoses or prosthetic interposition conduits between the arterial and venous circulation of the upper extremity. Rose and colleagues cited data supporting the conclusion that autogenous arteriovenous fistula construction meets these requirements. This approach has a record of fewer complications and reinterventions. Additional data have confirmed that patients managed with autogenous fistulas have a lower mortality risk. National and international consensus groups have identified direct arteriovenous anastomoses or prosthetic interposition conduits between the arterial and venous circulation of the upper extremity. Rose and colleagues cited data supporting the conclusion that autogenous arteriovenous fistula construction meets these requirements. This approach has a record of fewer complications and reinterventions. Additional data have confirmed that patients managed with autogenous fistulas have a lower mortality risk.
Drainage systems can be protected from injury due to the frequent need for intravenous catheterization and venipuncture in patients with renal insufficiency. Since autogenous arteriovenous fistulas require 4–6 weeks to mature sufficiently to support dialysis, the patient would ideally have the fistula constructed at a point significantly in advance of the anticipated dialysis start date so that the time on dialysis accomplished via tunneled central venous catheters can be kept to a minimum. After the nephrologist identifies the patient, the surgeon can perform a focused history and physical examination supported by ultrasound imaging to determine the optimum access procedure for the patient. Important elements of the history include documentation of a history of diabetes and/or vascular disease. In addition, the number and location(s) of previous access procedures, including tunneled catheters and surgical accesses, are observed. The presence of other intravenous devices such as cardiac pacemakers is also noted. The authors stressed that the nondominant upper extremity is usually chosen for the access site, but the main objective is the location of a satisfactory arterial input and venous outflow channel. Bilateral upper extremity arterial pressures as well as the presence and characteristics of lower-extremity pulses are recorded. This is an important step because many patients will ultimately require lower-extremity dialysis-access sites. Upper extremity veins are examined with a tourniquet in place and areas of thickening and potential stenosis are documented. The physical examination is supplemented by duplex ultrasound mapping of the venous system. The optimal diameter of outflow veins is 2.5–4 mm. The duplex ultrasound can identify veins for use as outflow channels that are not detectable on physical examination. Patients with a history of prior venous catheter placement may require contrast venography to determine the presence and locations of stenoses or occlusions. Contrast angiography may also be needed in patients with a history of arterial disease; contrast use in patients with renal failure carries a risk of worsening already impaired renal function. Limiting the amount of contrast and supplementing contrast with N-acetylcysteine or bicarbonate may afford some protection. Duplex ultrasound and using MRI without gadolinium are also options for reducing the risk of additional renal function impairment.

Rose and coauthors next reviewed various aspects of perioperative care and surgical techniques relevant to dialysis-access procedures. They recommended that patients who are candidates for autogenous tissue access be referred for the access procedure at least six months prior to the anticipated need for beginning hemodialysis. Patients who will require prosthetic placement can undergo their procedure just prior to beginning hemodialysis. Important principles of perioperative management include using autogenous arteriovenous fistula whenever possible, access placement in the distal upper extremity if possible, and preferential use of the upper extremity for access sites.

Rose and coauthors also reviewed options for hemodialysis access placement that contribute to successful hemodialysis. The authors’ recommendations regarding this topic were published in the clinical practice guidelines for hemodialysis access promulgated by the Society for Vascular Surgery. Forearm placement can be achieved using radial artery to cephalic vein wrist fistula creation (snuffbox AV fistula). Alternative placements include the brachial/proximal radial artery anastomosis to the transposed cephalic vein (cephalic vein loop fistula), and the radial artery or ulnar artery to basilic vein AV fistula. Upper arm options include the direct or transposed anastomoses between the brachial artery and the cephalic or basilic veins. Rose and coauthors recommended using the cephalic vein because of its superficial location in the upper arm. The second recommended choice is a basilic AV fistula. The basilic vein in the upper arm is located deep to the fascia of the upper arm; because of this, damage to the vein from prior cannulations is less likely. Lower extremity autogenous AV fistulas can be constructed using anastomoses between the transposed saphenous vein and superficial femoral artery and the femoral artery to the looped femoral vein.

Extremity AV fistulas can be created using intravenous sedation, regional anesthesia, or general anesthesia. Aitken and coauthors reported a randomized prospective trial comparing regional with local anesthesia for AV fistula creation in The Lancet, 2016. Local, regional, and general anesthesia approaches have all been considered acceptable for patients requiring dialysis-access creation. General anesthesia has the disadvantage of being associated with increased risk for pulmonary complications in patients with renal insufficiency. Also, brachial plexus
block has the potential benefit of producing arterial and venous dilation that can facilitate AV fistula construction. The study consisted of 163 patients assessed in three medical centers located in Glasgow, Scotland. Of these, 126 patients were randomized to receive either subcutaneous 0.5% L-bupivacaine and 1% lidocaine or a brachial plexus block using 0.5% L-bupivacaine plus 1.5% lidocaine with epinephrine. The study groups consisted of 63 patients each. The data analysis showed that patients receiving the brachial plexus block had significantly better three-month AV fistula patency rates (84% vs. 62%). Radial artery to cephalic vein fistulas were associated with higher patency rates compared to other fistula configurations (77% vs. 48%). In the discussion section of the article, the authors stressed that successful brachial plexus block anesthesia is operator-dependent. Two experienced anesthesiologists performed ultrasound-guided brachial plexus blocks in the study patients. Operative times were longer in patients who had brachial plexus blocks. One potential benefit of the brachial plexus block is the ability to create AV fistulas in more distal locations because of the arterial and venous dilation that results from this anesthetic approach.

Rose and coauthors emphasized the importance of handling tissues gently, using magnification when creating the anastomosis, carefully creating subcutaneous tunnels where indicated, gently dilating the chosen vein with heparin-saline injection, and conducting a clinical assessment of the patency after anastomosis creation. Other recommended technical features include repeating the ultrasound examination of the vein prior to beginning the dissection to assess the artery and vein after anesthesia-related dilation has occurred, using single or skip incisions for exposure, preserving nerves that are often adjacent to chosen arteries and veins, and ligation of side branches of the chosen vein. The authors recommended using 6-0 or 7-0 nonabsorbable monofilament suture for the anastomosis; anastomosis diameter of 4 mm to 6 mm is recommended to minimize the risk of steal syndrome. The most dependable predictor of a successful anastomosis is the presence of a continuous thrill on completion of the anastomosis. The presence of a pulsatile fistula should prompt a search for outflow obstruction. Flow rates <600 ml/min are predictive of significant outflow vessel stenosis. The authors concluded their discussion of perioperative management of dialysis access procedures by noting that failures due to venous stenosis or poor arterial inflow are relatively common and failure of the access to mature is an additional factor that prevents success. Data cited by the authors suggest that successful long-term access without postoperative intervention may only be observed in 40% of procedures.

Smith and coauthors presented data on factors affecting the patency of dialysis-access AV fistulas, as well as a review of current literature relevant to this topic, in the *Journal of Vascular Surgery*, 2012. With regard to patient factors that may impact patency, the authors cited data that suggest lower primary patency rates in elderly patients. They cautioned, however, that the available data dealt mainly with wrist fistulas and that the definition of “elderly” varied widely among the sources reviewed. No convincing evidence was presented to support an effect of gender or obesity on dialysis-access patency. In the setting of optimal preoperative evaluation and preparation, there was no discernable effect of diabetes on outcomes of dialysis-fistula creation. Smoking was associated with reduced patency rates. Studies of adjuvant drug therapy to improve AV fistula patency were reviewed by the authors. Available data supports the use of antiplatelet therapy for six weeks postoperatively. Perioperative heparin therapy increased bleeding episodes but did not improve long-term outcomes according to the data reviewed. Available studies of topical vasodilators such as glyceryl trinitrate have shown increased early flow rates, but a benefit in terms of long-term patency has not been confirmed. The only postoperative management factor that has been proven to reduce patency rates is cannulation prior to 14 days after fistula creation. The authors could not confirm the superiority of one needle-entry technique over another for improvement of overall outcome and reduction of complications such as AV fistula infection.

Rose and coauthors opined that the reason AV fistulas fail to mature despite adequate preoperative arterial and venous diameters and postoperative Doppler blood flow measurements may be due to the access being placed too deeply in the tissue, inadequate ligation of venous side branches, venous stenosis, or insufficient arterial inflow. Data cited by the authors supported using aggressive measures to correct venous stenosis with balloon-assisted or...
patch angioplasty. Balloon-assisted angioplasty may be accompanied by nitinol stenting, which has shown improved outcomes according to data cited in the review article.

A review article by Saad\textsuperscript{157} in \textit{Vascular}, 2010, provided useful information on the pathophysiology, diagnosis, and management of dialysis AV fistulas that fail to mature. The recommendations from the National Kidney Foundation state that AV fistulas used for dialysis access should meet the “rule of sixes” to ensure the successful management of renal insufficiency in the individual patient. This rule states that by six weeks following construction, the fistula should measure 6 mm in diameter and be located 6 mm or less deep to the skin surface and have a 600 mL/min or greater blood flow. Saad emphasized that a functional measure of the AV fistula can be determined using the urea kinetic model that estimates the urea clearance associated with each dialysis session; a minimum clearance of 65% of predialysis urea is the target for adequate fistula performance in support of dialysis. Achieving the target level of urea clearance requires a clearance of 175 ml per minute for a 240-minute dialysis session. An AV fistula with adequate size, location, and flow can accomplish this goal using punctures made with small needles.

Saad next reviewed the hemodynamic, cellular, and humoral processes that contribute to fistula maturation. Endothelial cell production of nitric oxide and prostanoids occurs because of shear stress applied to the cells after construction of the AV fistula. This produces vasodilation and hypertrophy of the vessel wall that leads to the formation of a satisfactory dialysis-access fistula. Unfortunately, outcomes data cited by Saad show that primary failure rates of access construction are in the 15% range. Primary one-year fistula patency was 36% and secondary patency was 66%, according to one report. The author recommended imaging for AV fistulas that fail to mature so that anatomic factors contributing to failure of maturation can be documented. The author stressed that maturation failure at four weeks after AV fistula construction is a sign that the fistula will not be successful and that “watchful waiting” for longer intervals was unlikely to be successful.

Options for managing arterial or venous stenoses include balloon dilation with or without stenting. Patent branch veins can be occluded with endovascular coils. Outcomes data for interventions to manage maturation failure cited by the author show that a one-year patency in the 60%–65% range can be achieved.

An article by Roy-Chaudhury and coauthors\textsuperscript{158} provided data on success rates of balloon dilation of AV fistulas that fail to mature in \textit{Seminars in Nephrology}, 2012. The authors cited data confirming that several balloon angioplasty interventions are frequently necessary to achieve maturation of the AV fistula. Additional cited data showed that an average of 2–3 interventions were necessary to achieve fistula maturation using balloon dilation techniques and that the mean time for maturation was 4–7 weeks. Primary patency rates at one year ranged from 15% to 53% in the reviewed clinical series. Secondary patency rates ranged from 72% to 90%. The cost of the primary and repeat balloon-assisted maturation interventions ranged from $3,000 to $4,000 per intervention. The authors concluded that additional studies were desirable to identify means of reducing the rates for reintervention and improving patency rates while reducing costs. They concluded that conversion to prosthetic-dialysis access should also be considered.

Several clinical series have provided valuable data on the success of autogenous arteriovenous fistula creation for chronic dialysis access. These series also offered insights into the influence of patient type and pattern of comorbidities on results. An example is the clinical series reported by Papanikolaou and coauthors\textsuperscript{159} in \textit{Surgery}, 2009. The data provided in this report came from a retrospective review of a single group of surgeons in Greece. The data were gathered during the 20-year interval beginning in January 1986 and ending in December 2005. A total of 3,685 dialysis accesses were created in this patient group during the study interval. More than half of the patients were women and the mean patient age was 61. Interestingly, only 8.3% of the patients were diabetic. The authors did not, by protocol, use Doppler ultrasound imaging to map available arteries and veins. The procedures were performed under local anesthesia and the technical details of each procedure were described in the report. Nearly three-fourths of the procedures were either radial-cephalic arteriovenous anastomoses or brachial-cephalic fistulas. End-to-end or end-to-side anastomoses were created using, usually, 6-0 polypropylene suture. Sixteen
percent of patients chosen for radial-cephalic fistula had this procedure abandoned and another 25% required a second access to achieve successful dialysis. The mean patency rate for autogenous fistulas was more than three years; for prosthetic grafts, it was one year. The authors stressed that their experience demonstrates the superiority of autogenous fistulas over prosthetic conduits in terms of longevity and the reduced risk of needing secondary interventions to maintain adequate access. The authors observed lower patency rates in diabetic patients and they recommended prosthetic-fistula creation in older diabetic patients with limited life expectancies. For younger diabetic patients, they continued to recommend autogenous fistulas. Papanikalou and coauthors did not regularly use ultrasound vascular mapping and they cited reviews of this technique showing mixed results. From their standpoint, ultrasound mapping is not a key component of their approach to dialysis access creation. Recent results support using MRI to select appropriate venous drainage for upper-extremity fistulas. In the near future, MRI improvements may make this approach valuable for preoperative venous assessment. The authors concluded that autogenous AV fistula formation was the preferred option for dialysis access.

Although autogenous AV fistula formation may be the preferred option for dialysis access, a significant proportion of patients are referred for dialysis access that require short intervals between access placement and the beginning of dialysis because catheter-based hemodialysis has already begun or because vascular anatomy and function are suboptimal for autogenous fistula construction. Disbrow and coauthors presented data at the December 2012 meeting of the Southern Surgical Association; this information provided a useful perspective on outcomes of arteriovenous fistula vs. arterial-to-venous graft placement in patients who are receiving catheter-based dialysis at the time of dialysis access placement. In this study, only patients with acceptable anatomy for fistula creation were included in the comparison. The analysis disclosed that outcomes were similar for both types of access in terms of patency at two years. The interval from access placement to usage for dialysis was significantly shorter for interposition graft access patients. The risk of repeat interventions was equivalent in both groups. The authors concluded that the shorter time from access placement to usage is an advantage for this higher risk patient group and earlier removal of venous catheters may reduce the risk of catheter-related infection in these patients. These data lend support for the protocol-driven selection process for arteriovenous fistula (described earlier) that seeks to identify patients for fistula creation before the need for dialysis institution. The discussion that occurred during the presentation of this work was included in the journal publication. In the discussion, the article’s authors stated that patients were often chosen for graft placement because of inadequate superficial venous sites for access construction. The authors stressed the importance of ultrasound vein mapping as a means of determining whether patients might be better suited for autogenous fistula formation vs. graft placement. The authors concluded that prosthetic graft access is a useful option for many patients requiring hemodialysis.

Rose and coauthors provided information on other complications of dialysis-access placement. Access infection occurs in 0.5%–5% of AV fistulas annually and prosthetic graft infection is observed in 4%–20% of patients each year. Causative organisms are mainly Staphylococcus sp. Polymicrobial infections due to gram-negative organisms are also observed, primarily in immunosuppressed patients and patients with impaired neutrophil function and reduced lymphocyte-mediated immunity. Autogenous AV fistula infections may be treated with 4–6 weeks of systemic antibiotics unless the infection is para-anastomotic in location or associated with bleeding from the access. In these latter cases, sacrifice of the access will be necessary. Total or near-total prosthetic graft removal will be necessary when infection involves a prosthetic graft access.

Vascular access site infection was the focus of an article by Lafrance and coauthors in the American Journal of Kidney Disease, 2008. The authors conducted a systematic review of articles related to the topic of dialysis access-related infection. The article discussed the results of the review. The authors first cited data relating to the magnitude of this clinical problem. Chronic dialysis patients are hospitalized, on average, twice yearly and 20% of these hospital admissions are related to infections. Infection in ESRD patients is associated with significant mortality risk. Mortality rates for septicemia in this patient population exceed 40%. The authors emphasized...
that the most common site of infection in dialysis access is an indwelling central venous catheter. Positive blood cultures are relatively unusual, even in patients with overt clinical evidence of bacteremia. Also, the pathogenesis of infection associated with indwelling venous catheters includes the immunosuppressed nature of renal failure patients along with skin colonization with pathogenic organisms that then migrate from the skin exit site to colonize the catheter; *Staphylococcus aureus* and MRSA were frequent pathogens. The frequency of dialysis-access infection is, as stated, highest for indwelling venous catheters, followed by prosthetic accesses. Autogenous arteriovenous accesses have the lowest infection risks. Some protection against dialysis-access infection may be aspirin use as an antithrombotic agent following access creation. Preservation of access functionality will depend on infection prevention. No clearly superior preventive protocol has emerged from available research. The use of strict sterile barrier techniques and meticulous access care are characteristics of successful prevention protocols.

Rose and coauthors\(^\text{152}\) affirmed that diffuse aneurysmal dilation occurs in long-standing autogenous AV fistulas and rarely requires any intervention. Pseudoaneurysm formation is observed in 2%–10% of prosthetic graft accesses. Small puncture site pseudoaneurysms can be managed with observation and intervention if aneurysm growth occurs. Large pseudoaneurysms resulting from repeated punctures with graft material deterioration will require revision of the access.

Approaches to true and false aneurysm formation in dialysis access fistulas vary depending on the presence of infection, skin erosion, or threatened aneurysm rupture. Other considerations include the availability of sites distant from the site of aneurysm formation for dialysis access, and whether the aneurysm location is close to one of the anastomotic sites. The management of these complications was the subject of an article by Georgiadis and coauthors\(^\text{162}\) in the *Journal of Vascular Surgery*, 2008, and the various technical approaches were described in this article. Maintenance of early dialysis effectiveness was observed in more than 90% of patients, with functioning fistulas persisting in 32% of patients at two years following an operation for the aneurysm.

For patients with thrombosed accesses, percutaneous techniques have been increasingly offered. These techniques and their results were reviewed in two articles.\(^\text{163, 164}\) Thrombolyis may be useful for managing thrombosed accesses. Angioplasty with or without stenting can be used to reestablish adequate access function to support dialysis. Stents may be most useful for patients with multiple access failures where options for revision or new-access creation are limited.

Hand ischemia can occur because of arterial steal syndrome. Clinically, arterial steal syndrome presents with unilateral neurologic symptoms and signs of distal ischemia. Risk factors include female gender, diabetes, and the use of brachial artery inflow. Hand ischemia is observed in 0.25%–2% of autogenous AV fistulas and occurs in 4%–9% of AV fistulas when brachial artery inflow is used. Simple ligation of the access is the most expeditious means of managing hand ischemia.

Hand ischemia and heart failure are complications that result secondary to high arteriovenous flow rates in elbow-level dialysis-access fistulas. Banding of the fistula is used to decrease flow, but these procedures lack sufficient precision to be consistently effective. Another approach to increasing venous resistance while maintaining adequate outflow is plication of the dilated vein. This approach was recently described in a small group of seven patients where success was achieved initially in all patients, but one patient required another plication at a later date.\(^\text{165}\) The extent of plication was determined by monitoring Doppler pressures in the inflow artery to the ischemic hand.

Bourquelot and coauthors\(^\text{166}\) described an alternate approach in the *Journal of Vascular Surgery*, 2009: the distal radial artery is disconnected and transposed between the brachial artery and basilic vein. The authors reported results in 47 patients who developed hand ischemia or heart failure following creation of an elbow-level dialysis fistula. All of the patients operated on for hand ischemia were cured. Persistent cardiac failure necessitated fistula ligation in three patients. Satisfactory dialysis access was maintained in 70% of patients at three years of follow-up.
In the final section of this review, we will focus on four conditions that affect the vascular system and which, in some patients, cause aneurysmal disease and occlusive vascular symptoms. These are unusual diseases and will not be encountered often in the practice of general surgeons.

A recent article that reviewed the pathogenesis, diagnosis, and management of Raynaud phenomenon was by Wigley and Flavahan\textsuperscript{167} in the New England Journal of Medicine, 2016. This article is supplied as a full-text reprint accompanying some formats of SRGS. The article opened with an excerpt from the original publication by Raynaud, in which the clinical features of Raynaud phenomenon were described as they appeared in a 26-year-old female patient. Symptoms of pallor and numbness of the fingers (often occurring in response to exposure to mild-moderate cold) followed by a return of the circulation to normal, along with pain in the digits and hand occurring over a variable recovery period, was known as “Raynaud disease” until Hutchinson, in a 1901 publication, emphasized that these symptoms could be documented in a number of different disease settings. These findings led to the use of the term “Raynaud phenomenon” to describe the typical symptoms. Wigley and Flavahan cited data indicating that the symptoms can be documented in 3%–5% of the general population and that patients are classified as having primary or secondary Raynaud phenomenon. Primary Raynaud phenomenon is diagnosed when the symptoms appear with no associated disease and secondary Raynaud phenomenon diagnosed when a concurrent disease process is identified as the condition precipitating the symptoms.

Raynaud phenomenon is primarily diagnosed based on history and physical findings. Most important is the observation of biphasic (white-blue) skin color change. Patients with primary Raynaud phenomenon are usually younger (15–30 years of age at symptom onset) and symptoms do not involve the thumb. A positive family history is observed in 30%–50% of patients with primary Raynaud phenomenon. Diseases that are associated with secondary Raynaud phenomenon include connective tissue disorders (scleroderma), hypothyroidism, obstructive vascular disease, carpal tunnel syndrome, prior episode of frostbite, and drug-associated conditions (ergotamine, chemotherapeutic agents).

The pathogenesis of Raynaud phenomenon involves abnormal responses to cold-induced sympathetic vasoconstrictor impulses. The capillary beds in the skin in areas such as the digits and the tip of the nose are normally resistant to vasoconstrictor impulses and this resistance is lost in patients with Raynaud phenomenon, leading to pronounced vasoconstrictor responses that produce the phenomenon’s symptoms. Patients with secondary Raynaud phenomenon commonly have more severe vasoconstriction, probably due to endothelial dysfunction associated with the associated disease process.

Treating Raynaud phenomenon relies primarily on avoiding sudden cold exposure. Pharmacotherapy with calcium channel blockers is effective for patients with resistant symptoms. For severe ischemic changes (resistant ulceration), topical nitrates and intravenous prostacyclin analogs are recommended. Digital sympathectomy may be considered in patients with severe, resistant disease, but strong evidence to support the value of this option is not available. Correction of vascular obstructing lesions may also be considered, but this approach has not been consistently effective.

Higgins and McClinton\textsuperscript{168} discussed surgical approaches to complications of upper extremity vasospastic disorders in the Journal of Hand Surgery, 2010. The authors recommended surgical exploration, thrombectomy, and vascular reconstruction for the rare instance when proximal vessel thrombosis occurs as a result of severe ischemia that is caused by secondary Raynaud phenomenon and is resistant to pharmacotherapy. In the authors’ experience, past efforts to use sympathectomy or sympathetic block have not been effective. Irreversible ischemic damage may require digital amputation.
Nonarteriosclerotic Occlusive Vascular Diseases

Wu and Chaer\textsuperscript{169} provided perspective on the various forms of nonatherosclerotic occlusive vascular diseases in \textit{Surgical Clinics of North America}, 2013. The diseases included in their discussion were thromboangiitis obliterans (TAO) or Buerger disease, Takayasu arteritis, giant cell arteritis, Polyarteritis nodosa, Kawasaki disease, small vessel vasculitis, and radiation arteritis. Brief reviews of each of these will be provided in this section.

**Thromboangiitis Obliterans**

TAO was first described in 1879 by Felix Winiwarter, a student of Theodor Billroth. The disease was named for Leo Buerger, a pathologist from New York City who, in 1908, reported detailed histologic findings on 11 amputated limbs and confirmed the observations of Winiwarter. Data cited in the article confirmed that the most important pathogenesis feature of the disease is an immune-mediated vessel injury resulting from tobacco exposure. Research has confirmed that deposition within endothelial cells of circulating immune complexes and antibody-mediated endothelial injury occurs in patients with TAO. Occlusion of distal small vessels occurs, causing gangrene. Amputation of digits and distal extremity tissues is frequently required. Of interest is that the main histologic findings documented by Buerger were fibrous agglutination of arteries, veins, and nerves of the distal extremity vessels—without involvement of the proximal vasculature. In involved vessels, cellular infiltration of the vascular wall with preservation of the internal elastic lamina was characteristic of the disease. Recent research has suggested a genetic component to TAO because of the increased frequency of the disease in patients with certain HLA haplotypes.

The most common clinical presentation of TAO is distal limb ischemia, usually with digital gangrene in a male smoker in the 30–40 age range. The proportion of women with TAO is increased in populations with increased numbers of women who smoke. Most patients will have clinical distal ischemia of the extremities with palpable proximal pulses. Involvelement of cerebral, visceral, coronary, and pulmonary vessels has been reported. Superficial venous thrombophlebitis and secondary Raynaud phenomenon is observed in up to 50% of patients with TAO. Digital plethysmography is recommended by Wu and Chaer. Contrast angiography can provide evidence of segmental obstruction of small arteries with corkscrew configuration of collateral vessels. International diagnostic classification systems cited by the authors emphasize the presence of five factors: smoking history, onset age prior to 50, infrapopliteal occlusive lesions, upper limb involvement or phlebitis migrans, and absence of atherosclerotic risk factors other than smoking. Additional studies recommended by the authors include assessing blood count, liver function, and lipid profile as well as studies to exclude connective tissue, autoimmune, and hereditary hypercoagulation syndromes. Exclusion of intravenous drug use history is also recommended.

Risk factor reduction is the mainstay of nonoperative management of TAO. Pharmacologic management with prostacyclin analogues may be helpful as well. Surgical management of TAO with sympathectomy and bypass procedures has resulted in limb salvage rates at five years exceeding 95% (if satisfactory distal runoff vessels are available) according to data cited in the article. Recent experience with endovascular techniques has shown similar limb salvage rates at two years.

Another article that reviewed current knowledge of TAO was by Piazza and Creager\textsuperscript{170} in \textit{Circulation}, 2010. As suggested previously, this disorder involves the small arteries, veins, and nerves of the extremities and symptoms are caused by tobacco exposure. The incidence of TAO in the United States is 12.6 per 100,000 population. The disease is more prevalent in the Middle East and Asia. The symptoms occur in conjunction with the formation of an intense inflammatory thrombus in the small arteries; while the process is thought to be inflammatory and immune-mediated, most of the common inflammatory mediators, such as C-reactive protein, are not abnormal. Autoantibodies, when present, are predictive of a more severe symptom complex.
Cessation of tobacco use is essential to controlling the disease and prognosis is determined by success or failure of cessation efforts. In addition to smoking cessation therapy, vasodilator prostanoid therapy with Iloprost has been successful. Other vasodilator drugs have not been extensively studied. Surgical revascularization is infrequently possible although this can be considered if suitable target vessels are identified.

**Takayasu Arteritis**

Takayasu arteritis is a rare inflammatory disease involving the aortic arch and aortic branch vessels as well as the pulmonary vessels. Available data support the conclusion that the disease is an autoimmune disorder primarily caused by abnormal cell-mediated immunity with infiltration of macrophages and T-cells into the vascular wall. Involvement of the adaptive and innate immune systems has been recently reported. The disease begins with vague constitutional symptoms (myalgia, fevers) followed by an acute inflammatory phase that progresses to occlusion of cerebral, upper extremity, coronary, or mesenteric arteries. Patients in Japan usually present with occlusion of aortic arch vessels. Renovascular occlusive disease is a variant of the disease observed more frequently in Korean patients and in patients from other Asian regions. Recent classification systems have subdivided the disease into four categories: the most common clinical type observed is type III, characterized by the involvement of the aortic arch, descending aorta, and branches; type I disease involves the aortic arch and branches; type II involves the descending aorta and branches; and type IV involves the pulmonary circulation.

Immune suppression with corticosteroids is the mainstay of Takayasu arteritis treatment. Other immune-suppression agents may also be helpful. According to data presented in the review article by Wu and Chaer\(^1^6^9\), successful treatment without corticosteroids was only possible in one-fourth of patients. Surgical management is chosen based on whether the disease manifests as vascular stenosis/occlusion or aneurysm formation. Disease management using open surgical procedures has been more successful than endovascular approaches, according to data presented by Wu and Chaer.

Additional perspective on Takayasu arteritis was presented by Mason\(^1^7^1\) in *Nature Reviews Rheumatology*, 2010. Severe granulomatous arteritis involving the full thickness of the vascular wall of the aorta and its branches is the characteristic pathological finding. The disease usually has its onset prior to age 40. Although the entire aortic system may be involved, inflammatory stenosis and aneurysm formation is most common in the subclavian and carotid arteries. Stenosis is present in more than 90% of patients and aneurysm formation is observed in 25%. In rare instances, the pulmonary arteries may be involved.

Suspicion of the diagnosis should be aroused when there are symptoms of neck pain or claudication (usually of the upper extremity) in a young person. Important physical findings include bruits and pulse deficits when the extremities are compared. Signs of inflammation, including increased C-reactive protein levels, are frequently observed. Imaging is used to determine the anatomy of the vascular abnormalities: ultrasound, CT angiography, and MRI may all be useful. Encouraging results have been recently obtained in trials using anti-TNF-α agents such as infliximab. Endovascular or open surgical intervention is indicated for severe symptoms, cardiac valve dysfunction, and aneurysm formation.

**Giant Cell Arteritis**

Giant cell arteritis (GCA) is a relatively common form of vasculitis that usually involves the extracranial branches of the carotid artery, especially the temporal artery, and is characterized by symptoms of pain and occlusion of the involved vessels. Temporal artery biopsy has been recommended, but the findings do not often change the course of disease management. Stroke and loss of vision are potential complications of the disease. In patients where GCA is being considered, screening of the extracranial vessels is indicated. Imaging of involved vessels using MR techniques have demonstrated ongoing inflammation of the artery walls.

Other cardiovascular complications of GCA include aortic dissection, aneurysm formation, and coronary artery stenosis with resulting symptomatic coronary artery disease. Corticosteroid therapy is the first-line treatment approach for GCA. Promising results have been obtained
in therapeutic trials using monoclonal antibodies to tumor necrosis factor α. Surgical repair of aneurysm formation and bypass operations for ischemic symptoms are occasionally required.

**Other Forms of Arteritis**

Several additional forms of nonarteriosclerotic occlusive vascular disease will rarely be encountered by general surgeons. These conditions include polyarteritis nodosa, Kawasaki disease, Wegener's granulomatosis, microscopic polyangiitis, Churg-Strauss syndrome, and arteritis due to radiation injury. The review by Wu and Chaer provides clear descriptions of these conditions and readers are encouraged to review this information as needed.
We hope that you have found this three-part series on Vascular Surgery to be useful to your practice. Please join us next month as we begin our two-part series on Critical Care of Surgical Patients.

Thanks for reading SRGS!

Lewis Flint, MD, FACS
Editor in Chief


References | VASCULAR SURGERY, PART III


60. de Virgilio C, Kim JJ. More Evidence That the Use of Venous Thromboembolism Rates as Hospital Quality Measures May Be Off the Mark. JAMA Surg. 2015;150(8):721.


References | VASCULAR SURGERY, PART III
1. The most common vessel injured in adult patients is?
   a) Popliteal artery  
   b) Carotid artery  
   c) Abdominal aorta  
   d) Iliac artery  
   e) Femoral artery

2. Experience with vascular injuries in recent military experience indicates that the mortality for patients with actively bleeding extremity wounds and who had tourniquets applied after developing signs of hemorrhagic shock is 24%. The mortality for patients who had tourniquets applied before signs of shock is which of the following?
   a) 10%  
   b) 2%  
   c) 16%  
   d) 27%  
   e) 19%

3. All of the following statements are true concerning vascular injuries in elderly patients except which one?
   a) Elderly patients account for 25% of patients admitted with vascular injuries  
   b) Compared with all patients with vascular injuries, elderly patients incur more injuries to thoracic vessels  
   c) Thoracic aortic injuries occur in 33% of elderly patients with vascular injuries  
   d) Mortality risk for injured elderly patients increases fourfold if a vascular injury is diagnosed  
   e) Blunt trauma is the main cause of injury in elderly patients with vascular injuries

4. Each of the following is a “hard sign” of vascular injury except which one?
   a) Active arterial bleeding from entry and/or exit wounds  
   b) Absence of pulses distal to the injury  
   c) Pallor of the extremity distal to the wound  
   d) Paralysis of the extremity distal to the wound  
   e) Signs of adjacent nerve injury

5. A 36-year-old female is involved in a motor vehicle crash. She was not wearing a seat belt and there was a history of alcohol intake prior to the crash. Paramedics report that the left lower extremity was angulated because of a femur fracture and the initial blood pressure at the scene was 85/50 with a pulse rate of 92. In the emergency department, the patient is conscious with a blood pressure of 109/77 and a heart rate of 88. There is an obvious left femoral fracture with a 5.5 cm stable hematoma. After alignment and splinting of the fracture, weak pulses are noted with an ankle-brachial index (ABI) of 0.8. Which of the following is indicated?
   a) Immediate exploration of the femoral artery  
   b) Open reduction and internal fixation of the fracture  
   c) Intravenous fluid therapy until the systolic blood pressure is >130 mm Hg  
   d) Contrast-enhanced CT angiography  
   e) Observation in the emergency department for 12 hours

6. What percentage of annual motor vehicle crash deaths are the result of injury to the thoracic aorta?
   a) 24%  
   b) 16%  
   c) 39%  
   d) 1%  
   e) 62%
7. Each of the following vehicle crash factors increase the risk of thoracic aortic injuries except which one?
   a) Driver of vehicle
   b) Front-seat passenger
   c) Frontal- or driver-side impact
   d) Deceleration of >20 km/h
   e) Small vehicle size

8. Side-impact motor vehicle crashes cause what percentage of thoracic aortic injuries?
   a) 5%
   b) 42%
   c) 78%
   d) 95%
   e) 21%

9. What percentage of patients with blunt thoracic aortic injuries who are transported from the crash scene to a nontrauma center survive the injury?
   a) 10%
   b) 65%
   c) 27%
   d) 88%
   e) 43%

10. All of the following are signs of increased risk for blunt injuries to the carotid and vertebral arteries except which one?
    a) Le Fort III facial fracture
    b) Cervical spine fracture
    c) Cervical contusion
    d) Scalp laceration
    e) Basilar skull fracture

11. All of the following patient groups are at a high risk for postinjury venous thromboembolism except which one?
    a) Patients with isolated humerus fracture
    b) Patients with a spinal cord injury
    c) Patients with a traumatic brain injury
    d) Patients with a pelvic and/or acetabular fracture
    e) Patients with multiple lower extremity fractures

12. In multiple injury patients treated with aggressive venous thromboembolism prophylaxis, the incidence of pulmonary embolus is which of the following?
    a) 7.5%
    b) 3.1%
    c) 2.2%
    d) 4%
    e) 0.7%

13. Which of the following is a major causative factor increasing the risk of venous thromboembolism in patients with cancer?
    a) Thrombocytosis
    b) Weight loss
    c) Leucocyte activation
    d) Production of tissue factor by cancer cells and tumor stromal cells
    e) Anemia

14. A 62-year-old woman is found to have a suspicious lesion on screening mammography. Ultrasound-guided core needle biopsy shows invasive ductal carcinoma. She is scheduled to undergo excision of the lesion and sentinel node biopsy under general anesthesia. She is otherwise in good health. Appropriate venous thromboembolism prophylaxis in this patient would be which of the following?
    a) Low-molecular-weight heparin
    b) Antiplatelet therapy
    c) Intermittent lower-extremity compression and early ambulation
    d) Unfractionated heparin
    e) Fondaparinux

15. The Caprini risk score is used to estimate the risk of venous thromboembolism in surgical patients. Which score defines “moderate” risk?
    a) 1
    b) 0–1
    c) 2
    d) 3–4
    e) ≥5
16. All of the following are markers of increased risk for venous thromboembolism in elective surgery patients except which one?

a) ASA score >3  
b) Elevated creatinine  
c) Laparoscopic operation  
d) Weight loss of >10% of body weight  
e) Preoperative transfusion

17. Practice guidelines recommend catheter-directed therapy for ileofemoral thrombosis for which of the following patient groups?

a) Patients older than 70 years of age with metastatic cancer  
b) Patients with good functional capacity and normal life expectancy  
c) Patients with a history of previous deep vein thrombosis  
d) Female patients  
e) Patients with a known thrombophilic condition

18. Which of the following choices is suspected to produce vein-valve damage leading to the development of varicose veins?

a) Female gender  
b) Pregnancy  
c) Prolonged standing  
d) Increased production of tissue factor  
e) Inflammation induced by abnormal blood flow patterns

19. A 42-year-old woman presents with varicose veins of the right lower extremity. There is a positive family history of varicose vein disease. The patient complains of sensations of heaviness and leg fatigue. The calculated CEAP score is 4. Appropriate therapy for this patient would be which of the following?

a) Supervised exercise  
b) Endovenous laser ablation of the right saphenous vein  
c) Open stripping of the right saphenous vein below the knee  
d) Compression stockings with ankle pressure of 20–30 mm Hg  
e) Sclerotherapy of perforating veins

20. Stent placement for chronic iliac vein obstruction is associated with a two-year patency of which of the following?

a) 100%  
b) 21%  
c) 11%  
d) 36%  
e) 55%

21. This issue met the stated learning objectives.

a) Strongly agree  
b) Agree  
c) Neutral  
d) Disagree  
e) Strongly disagree

22. The content was relevant to my educational needs and practice environment.

a) Strongly agree  
b) Agree  
c) Neutral  
d) Disagree  
e) Strongly disagree

23. There are potential barriers to incorporating what I have learned from this issue into my practice.

a) Strongly agree  
b) Agree  
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d) Disagree  
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e) Strongly disagree

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   Feliciano DV, Moore FA, Moore EE, et al.
   This article is the first of a two-part series of articles dealing with the management of vascular injuries of the extremities.

2. Western Trauma Association critical decisions in trauma: evaluation and management of peripheral vascular injury, Part II…90-96
   Feliciano DV, Moore EE, West MA, et al.
   This article is the second of a two-part series of articles dealing with the management of arterial and venous injuries of the extremities.

3. Western Trauma Association Critical Decisions in Trauma: Management of abdominal vascular trauma …97-106
   Feliciano DV, Moore EE, Biffl WL.
   This article provides data and a consensus opinion relevant to the management of abdominal vascular injuries.

4. Western Trauma Association Critical Decisions in Trauma: Penetrating neck trauma…107-111
   Sperry JL, Moore EE, Coimbra R, et al.
   This article provides data and a consensus opinion for managing patients with penetrating injuries of the neck. Criteria for nonoperative management are presented as well as diagnostic and treatment options for patients with vascular and visceral injuries.

5. Hemodialysis access…112-127
   Rose DA, Sonaike E, Hughes K.
   This is a clear and thorough review of the management of patients in need of hemodialysis access.

6. Raynaud’s Phenomenon…128-137
   Wigley FM, Flavahan NA.
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