

Western Trauma Association Critical Decisions in Trauma: Evaluation and management of peripheral vascular injury, Part II

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ABSTRACT: This is a position article from members of the Western Trauma Association (WTA). Because there are no prospective randomized trials on the evaluation and management of peripheral vascular trauma, the algorithm is based on the expert opinion of the WTA members and published observational studies. It may not be applicable at all hospitals caring for injured patients. The algorithm contains letters that correspond to lettered text that is intentionally concise. This Part II algorithm focuses on operative techniques, while the Part I algorithm (*J Trauma* 2011;70: 1551–1556) emphasized evaluation, diagnosis, and need for operation versus a therapeutic procedure performed in an interventional suite. (*J Trauma Acute Care Surg.* 2013;75: 391–397. Copyright © 2013 by Lippincott Williams & Wilkins)

KEY WORDS: Peripheral vascular injury.

This is a recommended management algorithm from the Western Trauma Association (WTA) addressing the management of peripheral vascular injuries. Because there is a paucity of published prospective randomized clinical trials that have generated Class I data, the recommendations herein are based primarily on published observational studies and the expert opinion of WTA members. The algorithm (Fig. 1) and accompanying comments represent a safe and sensible approach that could be followed at most trauma centers. We recognize that there will be patient, personnel, institutional, and situational factors that may warrant or require deviation from the recommended algorithm and encourage institutions to use this guideline to formulate their own local protocols.

The algorithm contains letters at decision points, and the corresponding paragraphs in the text elaborate on the thought process and cite the pertinent literature. The annotated algorithm is intended to (a) serve as a quick bedside reference for clinicians, (b) foster more detailed patient care protocols that will allow for prospective data collection and analysis to identify best practices, and (c) generate research projects to answer specific questions concerning decision making in the management of peripheral vascular injuries. The Part I

algorithm emphasized evaluation, diagnosis, and need for operation versus a therapeutic procedure performed in an interventional suite, while this Part II algorithm will focus on operative techniques.¹

OPERATIVE INSTRUMENTATION AND ANCILLARY EQUIPMENT

Repair of an injured peripheral vessel is performed with the surgeon and assistants wearing loupe magnification and battery-powered head lamps. Standard vascular instruments including shallow and deep retractors, sharp Metzenbaum scissors, DeBakey forceps, Gerald forceps, jeweler's forceps, fine tipped needle holders, and so on, should be a part of the instrument tray. In addition, vascular adjuncts including vessel loops, Fogarty balloon catheters with stopcocks, intraluminal shunts, unfractionated heparin solution, and a contrast agent for a completion arteriogram should be in the operating room.

- A. As described in Part I, indications for operation in patients with suspected or documented peripheral vascular injuries are hemorrhage, loss of major distal arterial pulse(s), or abnormal imaging results. While uncommon, a peripheral arteriovenous fistula documented on physical examination would be another indication if the insertion of an endovascular stent not be appropriate.^{2–4}
- B. In the field or in the emergency center (EC), hemorrhage from the injured peripheral vessel is controlled by direct pressure on the wound using a finger or pressure dressing or compression of the proximal artery ("pressure point"). Application of a proximal tourniquet on the injured extremity to control hemorrhage is now widely practiced in current military conflicts. Depending on local prejudices, experience, and transit times, it is likely that the use of tourniquets by civilian emergency medical services will increase in the future.^{5–9} Tourniquets should be removed

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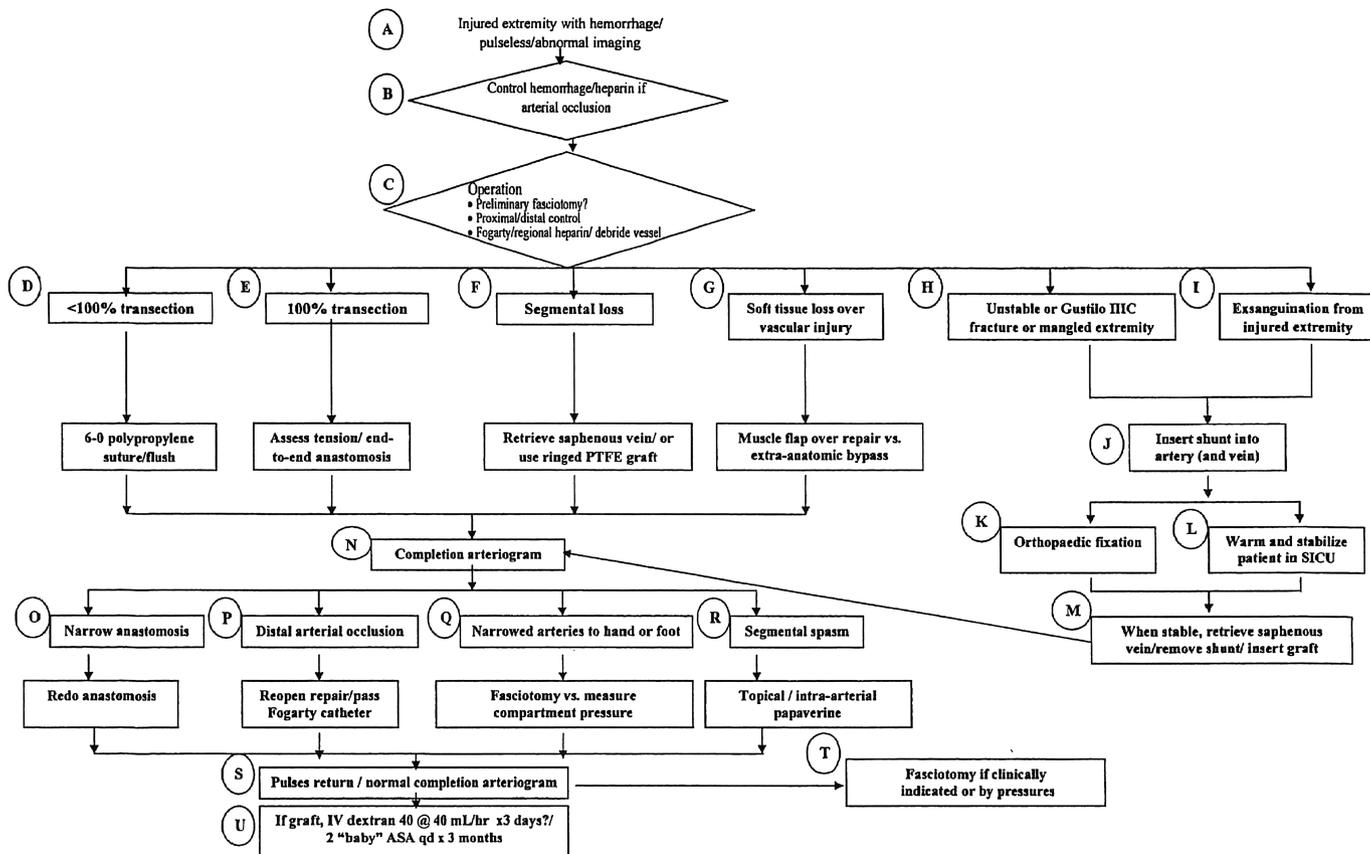


Figure 1. Management algorithm for peripheral vascular injuries.

in the EC as soon as possible by the trauma surgeon, however, as digital control is usually successful and eliminates complete limb ischemia. The intravenous administration of heparin (100 U/kg) to the injured patient in the EC is appropriate when there is a peripheral arterial occlusion resulting in distal “cold ischemia” (inadequate or no collateral flow).¹⁰ Contraindications include near exsanguination (coagulopathy may ensue), a traumatic brain injury, a traumatic false aneurysm of a torso artery, or computed tomographic documentation of an injury that has the potential for cavitory hemorrhage.

C. For all locations of peripheral vascular injuries, preparation of the skin and draping should encompass all potential areas of proximal and distal vascular control, the area where a distal fasciotomy would be performed and one lower extremity from the thigh to the toenails for possible retrieval of the greater or lesser saphenous vein.¹¹ Therefore, preparation and draping for a vascular injury in the proximal upper extremity would be from chin to umbilicus from opposite nipple to ipsilateral fingernails and include one lower extremity to toenails. In a lower extremity, preparation and draping would be from nipples to bilateral toenails. Upon presentation in the EC or operating room, some patients have overt physical evidence of a compartment syndrome in the distal extremity (leg or forearm) beyond a

proximal arterial occlusion or in the musculofascial compartment around the area of the peripheral vascular injury. For example, a patient with an anterior compartment syndrome in the leg would have hypesthesia in the dorsal first web space, weakness of toe extension and foot dorsiflexion, and pain on passive toe flexion and foot plantar flexion.^{12,13} A patient with a volar compartment syndrome in the forearm would present with hypesthesia of the volar aspect of the fingers, weakness of finger and wrist flexion, and pain on finger and wrist extension.^{12,13} Other patients cannot be examined so comprehensively secondary to intoxication, hypovolemic shock, or traumatic brain injury but have significant swelling of the injured extremity or area of injury. Measurement of a compartment pressure can confirm or eliminate the diagnosis of a compartment syndrome. When the diagnosis of a compartment syndrome is made (pressure >30 mm Hg), a preliminary or concurrent (with the arterial repair) fasciotomy is performed. Operative techniques to perform fasciotomies in the leg, forearm, thigh, and arm are well described.^{12,13} A longitudinal incision is made over the area of the peripheral vascular injury. When the area of injury is in proximity to a joint, a gently curved incision to prevent a postoperative scar contracture is appropriate. Examples would be the axillo-brachial “S” over an injury to the distal axillary/proximal brachial vessels or the medial-to-lateral “S” over the

antecubital area of the upper extremity. Proximal and distal control around a peripheral vascular injury is appropriate when arterial occlusion is present or when compression or a proximal tourniquet prevents further bleeding from the area of injury. When hemorrhage cannot be controlled or a large hematoma is present, it is appropriate to enter the area of injury and apply vascular clamps directly around the perforation in the peripheral artery and/or vein. Adequate suction devices and appropriate retractors are mandatory to limit blood loss during this approach. After proximal and distal vascular control has been attained with the use of small DeBakey vascular clamps, bulldog clamps, or vessel loops, the magnitude of the vascular injury (see *D*, *E*, *F* later) is assessed. A laceration encompassing greater than 25% of the circumference of the artery increases the risk of distal embolization of local clot. With this injury or when there has been a delay in treatment, Fogarty balloon catheters are passed proximally and distally through the area of injury. Appropriate sizes of the Fogarty catheters would include the following: #6 for the common and external iliac arteries, #4 to #5 for the common femoral artery, #4 for the superficial femoral artery, #3 to #4 for the popliteal artery, and #3 for the arteries in the leg. Overdistension of the Fogarty balloon should be avoided because this may injure normal intima. The goal is to confirm proximal arterial inflow and have no thrombus on return of two consecutive distal passes of the balloon catheter. It is helpful to remember that passage of a Fogarty balloon catheter into the leg will result in entrance into the peroneal artery approximately 90% of the time.¹⁴ One option to overcome this anatomic issue is to first inflate a Fogarty balloon in the proximal peroneal artery. Then, Fogarty balloon catheters are likely to be passed into the anterior and posterior tibial arteries. In contrast, balloon catheters are never passed into venous injuries because they will disrupt valves. If heparin was not given before this time, it should be administered intravenously at an appropriate dosage. In addition, 20 mL to 25 mL of heparinized saline (50 U/mL) can be injected into the proximal and distal artery (40–50 mL or another 2,000–2,500 U) after passage of a Fogarty catheter. After a passage of Fogarty balloon catheters and administration of heparin, a laceration of an artery from a knife or piece of glass is debrided minimally back to healthy intima. Many arterial injuries from gunshot wounds or blunt trauma, however, have extensive intimal or wall injuries, and segmental resection may be necessary (see *F* later).

D. An injury to a peripheral artery or vein that does not result in complete transection and in which there is minimal loss of tissue can be repaired, depending on luminal diameter, with an interrupted or continuous technique using 6-0 or 7-0 polypropylene suture. No matter which technique is used, the last one or two interrupted sutures are left untied, or the last several loops of a continuous suture are left loose until proximal and distal flushing is performed. With an arterial repair, the proximal clamp is then reapplied, and distal back-flow flushes air out under the repair as the last knot is tied. Excessive tension should be avoided when tying the last knot to avoid constricting the anastomosis. When repairing

a vein, the proximal clamp (toward the heart) is left off to evacuate intraluminal air.

- E. An injury to a peripheral artery or vein that results in complete transection is first managed with minimal debridement back to healthy intima at both ends. The amount of tension necessary to perform an end-to-end anastomosis is then assessed. Should the tension be excessive, a decision must be reached on whether to divide and ligate branches of the vessel on both ends versus inserting an interposition graft. Because of the elasticity of arteries, sacrifice of proximal and distal branches will often gain up to 3-cm total advancement of both ends; however, sacrifice of the geniculate collaterals from the popliteal artery should be performed with caution. This is because they furnish important collateral flow to the leg should atherosclerotic occlusion of the superficial femoral artery occur later in life. Spatulated end-to-end anastomoses using 6-0 or 7-0 polypropylene suture are recommended for arteries that are less than 1 cm in diameter distal to the axillary in the upper extremity and distal to the common femoral in the lower extremity. The ends of a vessel with a diameter greater than 1 cm can be anastomosed using an interrupted or a continuous suture technique with stay sutures 120 degrees or 180 degrees apart.^{15,16} An end-to-end anastomosis performed under tension will result in an “hourglass” narrowing and bleeding from suture holes. When an end-to-end anastomosis cannot be performed, an interposition graft is inserted.
- F. When debridement of an injured vessel or the injury itself results in significant segmental loss, an interposition graft of reversed autogenous saphenous vein or ringed polytetrafluoroethylene (PTFE or Teflon) is inserted.^{17,18} The saphenous vein in the groin or at the ankle is preferred because it is an endothelium-lined conduit, is readily available, is a reasonable size match for most peripheral arteries and some veins, and, especially, has excellent long-term patency.¹⁷ When the greater saphenous vein is absent, is diseased (multiple stenoses), has a small diameter, or is the only venous outflow for an injured lower extremity, other options are available. The lesser saphenous vein on the posterior aspect of the leg is an ideal replacement because it has a muscular wall similar to that of the greater saphenous vein. Another option is to use the cephalic or basilic vein in the upper extremity as an interposition graft in the brachial artery. As these thin-walled veins dilate significantly when placed in the arterial system, ligation of branches during retrieval should be further from the vein than when the greater saphenous vein is retrieved. The time required to create a panel or spiral vein graft is usually excessive in the trauma patient, and these grafts are used rarely to replace injured peripheral vessels. Another option is to insert a PTFE graft, which is readily available off the shelf in appropriate sizes, is easy to sew, has a satisfactory patency when grafts with a diameter greater than 6 mm are used, and is remarkably resistant to infection in the absence of exposure or adjacent osteomyelitis.¹⁸ A newer version of an expanded PTFE graft has heparin molecules bonded directly to the luminal surface

of the graft to reduce thrombosis, but there are not data on the use of these grafts in trauma vascular repairs.¹⁹ The presumptive value of using a ringed PTFE graft is in the support available when the surrounding reaction to the foreign body becomes a scar in the later postoperative period. All of the techniques described for an end-to-end anastomosis in *E* (heparinization, use of small vascular clamps, bulldog clamps, or vessel loops, passage of Fogarty balloon catheters, lack of tension on the anastomoses, a fine suture technique with 6-0 or 7-0 polypropylene, and flushing sequence) are used to complete the two anastomoses. It is helpful to complete the distal anastomosis first in a difficult anatomic location such as the distal tibioperoneal trunk near its bifurcation. This allows for better visualization of the posterior suture line and prevents narrowing of the orifices of the posterior tibial and peroneal arteries. The saphenous vein may not dilate enough to be a satisfactory interposition graft in the popliteal, femoral, common femoral, or axillary veins. With the concerns noted previously for panel or spiral vein grafts, an appropriately sized PTFE graft with external rings should be inserted and will have satisfactory short-term patency.²⁰

- G. A peripheral vascular repair should never be left exposed at the completion of operation. Exposure of a lateral repair, end-to-end anastomosis, or saphenous vein graft will result in contamination leading to infection. In the hemodynamically stable patient, a decision must be made before the arterial repair is performed on whether there is enough healthy muscle available locally to cover the subsequent repair. If there is not, then a decision must be made in conjunction with the plastic surgery service on whether there is healthy muscle close enough to be transposed or rotated to cover the arterial repair.²¹ If neither of these approaches is possible and the arterial repair is likely to require segmental resection and an end-to-end anastomosis or interposition graft, an extra-anatomic bypass graft is inserted in the hemodynamically stable patient.²² The approach separates injuries to the bone and soft tissue from the arterial repair. The operative technique includes the following: (1) debridement of soft tissue/injured artery back to healthy tissue; (2) insertion of an extra-anatomic saphenous vein or PTFE graft with both anastomoses and the graft covered with healthy soft tissue; and (3) open packing or a vacuum-assisted device applied to the defect in soft tissue. In the hemodynamically unstable patient, a lateral arteriorrhaphy is covered with a porcine xenograft placed under mesh gauze soaked in a saline-antibiotic solution.²³ When segmental resection of the arterial injury will be required, a temporary intraluminal shunt is inserted (see *H*), and the porcine xenograft-gauze combination is used to cover the area. Plastic surgery consultation is then obtained to determine which of a large number of options for coverage of the wound would be appropriate at the reoperation for removal of the shunt and insertion of an interposition graft.^{24,25}
- H. Mangled extremities with a combination of injuries to the artery, bone, soft tissue, tendon, and nerve resulted in amputation rates of 42% to 78% in older series.²⁶⁻²⁸ While

amputation rates have decreased in recent years, long-term functional outcomes in patients with either limb salvage or amputation have been disappointing.²⁹ In the absence of absolute criteria for amputation such as disruption of the posterior tibial nerve in the adult or a crush injury with warm ischemia greater than 6 hours, limb salvage may be considered.^{30,31}

- I. In the patient with near exsanguination from an injury to a peripheral artery or vein, there is a temptation to ligate the vessel and potentially sacrifice the limb if the patient survives. Because of advances such as “damage-control resuscitation” and improvements in critical care, this approach is no longer considered to be valid for major arterial injuries.³²
- J. The first step in limb salvage in the patient with a mangled extremity or near exsanguination is to restore arterial inflow and, if needed, venous outflow by the insertion of temporary intraluminal shunts.³³ In addition to intravenous tubing, a number of commercially available carotid artery-type shunts are available, and a rigid 14 Fr size has been the most commonly inserted in recent years.³³ While the Pruitt-Inahara shunt is only 8 Fr in size, the added T-piece will allow for infusion of vasodilators or anticoagulants. The patency of an intraluminal arterial shunt is confirmed by the presence of palpable pulses or Doppler signals at the ankle or wrist. Thoracostomy tubes in the 16 Fr to 24 Fr size range are used as shunts in large peripheral veins such as the popliteal or femoral.
- K. Depending on the patient’s hemodynamic status and presence of other potentially life-threatening injuries, the orthopedic surgery service would then perform some type of fixation to stabilize the mangled extremity.
- L. The patient with near exsanguination and patent shunts is moved to the intensive care unit for damage control transfusion/correction of any coagulopathy and rewarming.
- M. Removal of temporary intraluminal shunts and insertion of vascular interposition grafts are appropriate after orthopedic fixation at the first operation in the hemodynamically stable patient who is normothermic and has no other major injuries requiring immediate diagnostic or therapeutic intervention. In contrast, the patient with previous near exsanguination and insertion of temporary intraluminal shunts is returned to the operating room when hemodynamically stable and normothermic. The longest dwell time for an arterial intraluminal shunt in a recent large civilian series was 52 hours,³³ but there is one report of a patient with a 10-day dwell time in the right axillary artery.³⁴ There has been a recent report of increased infections in PTFE grafts placed at a reoperation after a temporary intraluminal shunt has been removed.³⁵ If these data are noted in other reports, it would be recommended that an extra-anatomic bypass or insertion of an autogenous saphenous vein graft be performed after the shunt is removed.

- N. Completion arteriograms are routinely performed in hemodynamically stable patients after peripheral arterial repairs under the following circumstances: (1) when there has been a delay in diagnosis and/or treatment; (2) when palpable pulses are not present at the ankle or wrist after repair; (3) when there has been a complex repair such as segmental resection and an end-to-end anastomosis or insertion of an interposition graft; or (4) when there is concern about narrowing of an anastomosis.³⁶ After completion of the arterial repair, metal clips are placed on adjacent soft tissue to mark the level of the single or proximal/distal anastomoses. A standard completion arteriogram is then performed.
- O. Narrowing of either anastomosis on the completion arteriogram mandates reheparinization as indicated, reapplication of proximal and distal vascular clamps or vessel loops, and cutting out the polypropylene sutures. Frayed tissue at the end of the vessel is then debrided, especially the adventitia. Should the end(s) of the artery appear to be in spasm, a Garrett coronary artery dilator or Bakes biliary dilator is used to gently dilate the end of the vessel.³⁶ If a continuous suture technique was used on the first anastomosis, an interrupted suture technique is used on the redo.
- P. A distal occlusion of the superficial femoral or popliteal artery or tibioperoneal trunk beyond the arterial repair on the completion arteriogram mandates reheparinization as indicated, reapplication of proximal and distal vascular clamps or vessel loops, and performing a 2-mm to 3-mm transverse arteriotomy distal to the arterial repair. Passage of appropriately sized Fogarty balloon catheters is performed until two successive passes have no return of thrombus. A second arteriogram using the catheter described previously is then performed through the arteriotomy site. If an interposition graft has been inserted, the 2-mm to 3-mm transverse arteriotomy is placed 1 cm proximal to the distal anastomosis. An arteriotomy site in the injured artery or in an interposition graft is closed with interrupted 6-0 or 7-0 polypropylene sutures. When the distal arterial occlusion is present in either the anterior or the posterior tibial artery, it is unlikely that the transfemoral or transpopliteal passage of the Fogarty balloon catheter will enter the desired vessel unless the proximal peroneal artery is occluded with a separate Fogarty balloon as previously described.¹⁴ If one artery in the leg is occluded but the foot has at least one palpable pulse and is clearly viable, it is acceptable to leave the one vessel occluded without further intervention. Occlusion of two vessels mandates transpopliteal or transtibioperoneal embolectomy, especially in patients with significant blunt trauma to the lower extremity (shearing of collaterals). An embolectomy distal to the knee adds 1.5 hours to the operative procedure and is performed through a longitudinal incision 1 cm posterior to the posterior border of the tibia. The crural fascia is incised, the medial head of the gastrocnemius muscle is retracted posteriorly, and the tibial attachments of the soleus muscle are divided.³⁷ Full exposure of the distal popliteal artery and entire tibioperoneal trunk usually mandates division and ligation of the anterior tibial vein. All three vessels of the leg require catheter embolectomy through a distal popliteal transverse arteriotomy, as long as each vessel can be occluded with a bulldog clamp or vessel loop to allow for passage of the catheter into the desired vessel. If only the peroneal and posterior tibial arteries need to have an embolectomy, the transverse arteriotomy is made in the distal tibioperoneal trunk.
- Q. When the completion arteriogram documents narrowing or a “beaded” appearance of the vessels in the leg, either a compartment syndrome or a spasm is present. If the surgeon is convinced that a compartment syndrome is present based on the history (delay in treatment), physical examination (significant swelling of the leg or forearm; neuromuscular findings—see *C*), or operative findings (need for simultaneous arterial and venous clamping, venous ligation), a fasciotomy is performed.¹³ When the presentation is less clear to the surgeon, a compartment pressure is measured. A compartment pressure of 30 mm Hg in the patient with an abnormal postrepair arteriogram would prompt a fasciotomy on most trauma services.
- R. Spasm of vessels distal to an arterial repair is common in young patients but usually does not threaten the viability of the distal extremity. Restoration of a normal hemodynamic state, reversal of hypothermia, and topical warming of the injured extremity will reverse arterial spasm in 6 hours to 8 hours in most patients. In rare patients, severe limb-threatening arterial spasm has been treated with a proximal intra-arterial bolus injection of 60-mg papaverine followed by an infusion of 30 mg/h to 60 mg/h in the past.³⁸ Another option used on rare occasions has been a proximal intra-arterial infusion of a solution of 1,000-mL normal saline, 1,000-U heparin, and 500-mg tolazoline at a rate of 30 mL/h to 60 mL/h.^{39,40} Currently used vasodilators in angiography suites include intra-arterial nitroglycerin (50–100 mg) or nifedipine (10 mg per os or sublingual).
- S. Restoration of normal distal palpable pulses is reassuring after the interventions described in *O*, *P*, *Q*, and *R*, but a completion arteriogram is performed again in these patients to verify that no other abnormalities are present at the suture lines or distally.
- T. In high-risk patients (see *Q*) compartment pressure should be measured distal to the arterial repair. The goal is to avoid the 20% return to the operating room for delayed fasciotomies as noted in the past.⁴¹
- U. When a complex (segmental resection with end-to-end anastomosis or insertion of interposition graft) or complicated (need for postarteriogram intervention) arterial repair has been performed, certain centers will infuse low-molecular-weight dextran at 40 mL/h for the first three postoperative days. There are only modest data to support the use of dextran, and none of it is recent.⁴² All patients with an end-to-end anastomosis, interposition graft, or when there is concern about distal runoff should be started on aspirin 81 mg or 162 mg orally daily at

convenience. This recommendation is based on the long-term results when aspirin is administered after aorto-coronary artery bypass with saphenous vein grafts.^{43,44} Instructions to the patient after arterial repair include a daily walking program and cessation of smoking.

DISCLAIMER

The WTA develops algorithms to provide guidance and recommendations for particular practice areas, but does not establish the standard of care. The WTA develops algorithms based on the evidence available in the literature and the expert opinion of the task force in the recent timeframe of the publication. The WTA considers use of the algorithm to be voluntary. The ultimate determination regarding its application is to be made by the treating physician and health care professionals with full consideration of the individual patient's clinical status as well as available institutional resources. Also, it is not intended to take the place of health care providers' judgment in diagnosing and treating particular patients.

DISCLOSURE

The authors declare no conflicts of interest.

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