Extremity vascular injury: A Western Trauma Association critical decisions algorithm

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This is a recommended evaluation and management algorithm from the Western Trauma Association (WTA) Algorithms Committee addressing the management of adult patients with extremity vascular injury. Because there is a paucity of published prospective randomized clinical trials that have generated class I data, these recommendations are based primarily on published prospective and retrospective cohort studies and expert opinion of the WTA members. The final algorithm is the result of an iterative process including an initial internal review and revision by the WTA Algorithm Committee members, and then final revisions based on input during and after presentation of the algorithm to the full WTA membership.

Extremity vascular injuries are uncommon but account for more than half of all vascular injuries treated in civilian trauma centers.[1–4] Recent military conflicts have advanced the practice of prehospital tourniquet application and resuscitative techniques that have saved lives and together with modern imaging studies have increased the incidence of diagnosed vascular injuries related to axillobrachial and femoropopliteal wounds.[5,6] Timely diagnosis and prompt treatment are necessary to avoid dreaded ischemic complications where early amputation rates exceed 10% to 15%.[4,7] Improved multidetector row computed tomographic angiography (CTA) and growing acceptance of alternative endovascular therapies have revealed knowledge gaps, variation in practice, and new areas of controversy that prompt an update to the existing algorithm.

The algorithm (Fig. 1) and accompanying comments represent a safe and sensible approach to the evaluation of the patient with an extremity vascular injury. We recognize that there will be multiple factors that may warrant or require deviation from any single recommended algorithm and that no algorithm can completely replace expert bedside clinical judgment. We encourage institutions to use this as a general framework in the approach to these patients and to customize and adapt the algorithm to better suit the specifics of that program or location.

ALGORITHM

The following lettered sections correspond to the letters identifying specific sections of the algorithm shown in Figure 1. In each section, we have provided a brief summary of the important aspects and options that should be considered at that point in the evaluation and management process. This update adopts clinically relevant modern language, such as hemorrhage or ischemia and importance of the physical examination with Doppler-assisted pressure measurements to compute an ankle brachial index as a decision aid to guide the need for diagnostic imaging and surgical treatment. The emergence of endovascular options are also recognized and included in the algorithm.

A. Uncontrolled Bleeding

Active hemorrhage or an expanding hematoma anywhere in an injured extremity requires immediate operative exploration.[1–3] Prehospital tourniquets can mask active bleeding but a history of a penetrating injury with uncontrolled bleeding or the presence of bleeding when a tourniquet is loosened should prompt an immediate surgical exploration. The need to control bleeding and resuscitate the patient is the main concern and the extent of the vascular injury is determined during the exploration.[2]

Operative Exploration

When there is uncontrolled bleeding or an ischemic penetrating injury, operative exploration begins with positioning the patient supine on a table compatible with angiography. The lower abdomen and both legs are circumferentially prepped anticipating the need for harvest of the contralateral saphenous vein. A major instrument set, vessel loops, shunts, heparinized saline, polypropylene sutures and silk ties/sutures, contrast, and a portable fluoroscopy unit should be in the operating room. Special surgical instruments like Gerald forceps, Potts scissors, Adson-Beckman retractors (axillary, popliteal), DeBakey (axillary, femoral) and

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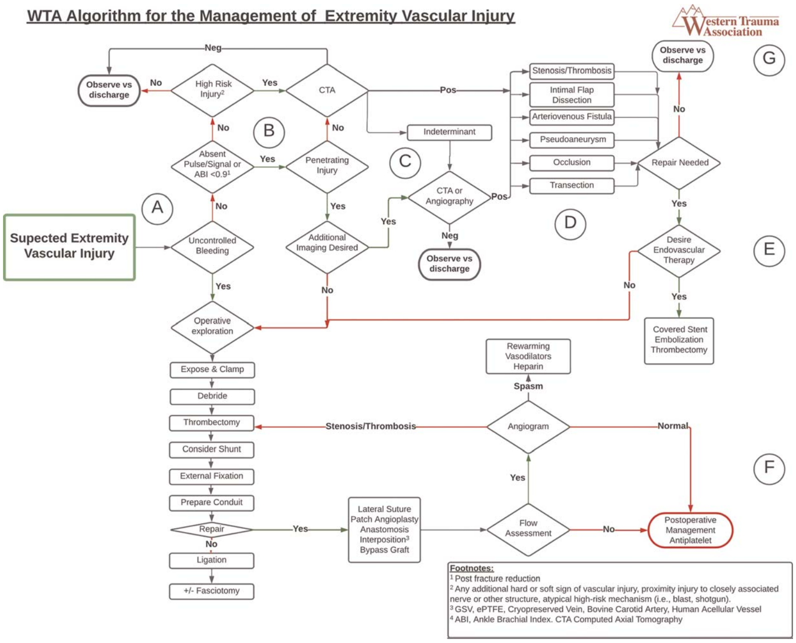

Figure 1. Western Trauma Association algorithm for the evaluation and management of patients with Extremity Vascular Injury. Circled letters correspond to sections in the associated article.

Profunda vascular clamps (femoral, brachial) are necessary. Large incisions will quickly evacuate the hematoma necessary to locate and control the transected ends of injured vessels. For combined orthopedic and vascular injuries, once the bleeding is controlled, the fracture is ideally reduced before the vascular repair unless the time (>4 hours) and degree of ischemia (poor color and contractility) merits other considerations such as temporary vascular shunting and systemic heparinization. The reconstruction begins with sharp debridement of all adventitial and intimal damage, and the vessel is flushed liberally with heparin saline. An appropriately sized Fogarty embolectomy catheter is gently passed when there are concerns about intraluminal thrombus. Selective cannulation will ensure appropriate inflow, and distal arterial back bleeding is reestablished prior to creating the anastomosis. While this step is not a mandatory maneuver, it should be considered and performed delicately to avoid iatrogenic injury. A single pass is usually not enough in the setting of thrombus or trickle bleeding. Prolonged ischemia, patient instability or anticipated transfer should prompt consideration for placing a temporary shunt. The Pruitt F3 (modern Pruitt shunt) or Argyle shunt are two common options that are easily passed and secured without special clamps. The Pruitt F3 is secured in the vessel using occlusion balloons, and the Argyle is secured with suture ties. Shunt flow is confirmed with Doppler and contrast administration through the T-Port of the Pruitt shunt can confirm distal anatomy and shunt patency. Many studies report shunt effectiveness despite occasionally prolonged dwell times.[8–10] When a defect is greater than one third of the vessel circumference, a patch repair is preferable to a lateral suture repair which may result in stenosis or thrombosis. When the defect is greater than 2 cm in length, an interposition graft is preferable to an end-to-end anastomosis done under tension.[4] A second surgeon can help expedite the operation by harvesting vein from the contralateral extremity. The saphenous vein should always be harvested to the saphenofemoral junction to ensure that a branching vein or the smaller anterolateral saphenous tributary is not inadvertently used for the conduit. Cannulation and hydrostatic dilation of the vein by flushing with cold heparinized saline and/or papaverine are important steps to ensure quality. The saphenous vein has the best long-term patency but expanded polytetrafluoroethylene (ePTFE), Dacron, cryopreserved vein, and bovine carotid artery are other commonly utilized nonautologous options. Nonautologous options may be necessary where there is an obvious size mismatch as in iliac or axillary vessels or when the length of the intended bypass exceeds the length of the available venous conduits. The reversed saphenous interposition graft is the most common configuration for reconstruction of a traumatic injury. Marking one side of the vein graft longitudinally with ink helps to maintain orientation and to avoid twists if a particularly long graft is inserted. One exception to a standard interposition graft is in military wounds that have large soft tissue defects. These wounds often require bypass of the conduit around the zone of injury, and this increases the complexity of the revascularization and instruments needed for tunneling the graft. The proximal end of the interposed conduit is prepared for an end-to-end anastomosis and sewn heel-to-toe using a continuous or interrupted technique with 5.0 or 6.0 polypropylene suture. The distal end is then cut to length avoiding both redundancy and tension. Suitable flow through the graft is then determined by the observation of forceful bleeding from the end of the graft prior completion of the distal anastomosis. All intraluminal debris is removed with heparin saline flushes before restoring flow. A completion assessment should include palpation of distal pulses and confirmation of a Doppler signal. When there are concerns for an imperfect repair, digital subtraction angiography can be performed using fixed fluoroscopic units with 6 mL to 10 mL. of Iodixanol-320 (Visipaque) contrast or 30 mL. when using a portable fluoroscopic unit or plain radiographs.[11] The hand injection is performed using an 18-gauge angiocatheter or 4-Fr micropuncture sheath inserted into the native artery proximal to the repair. Technical defects warrant a thrombectomy and revision. It is not uncommon to have delays in the return of tibial, radial, and ulnar signals following prolonged periods of hypothermia, hypovolemia, or Fogarty catheter manipulation. Most of these distal arterial vessels including the profunda femoral, tibial, radial, or ulnar arteries (not both), and all veins can be ligated when they are the source of injury and a Doppler pedal or wrist signal remains present. The popliteal and femoral vein are similarly reconstructed (following arterial repair in concomitant injuries) when the patient condition allows for added operative time. Tibial, brachial, and superficial veins are usually ligated. When there are concerns for a calf compartment syndrome based on history, examination, operative findings or management (ligation of adjacent vein), a prolonged ischemic time (>4 hrs.), or significant swelling, then fasciotomy is performed at the initial operation rather than risking pressure induced ischemia and delayed fasciotomy.[4,10,12] When there is uncertainty about the need for fasciotomy, measurement of a compartment pressure is worthwhile. A pressure >35 mm Hg should mandate consideration for a fasciotomy.

B. Vascular Examination

When there is no obvious external bleeding or expanding hematoma, an accurate vascular examination should identify patients with impaired circulation to reach a decision to either explore the injury or perform additional diagnostic studies. Distinguishing hard and soft signs are less relevant in an era where radiologic studies are quickly done on arrival and patients sorted by bleeding or degrees of ischemia.[13] Since the presence of shock, fractures or limb swelling often impair an accurate pulse assessment, the ankle brachial index (ABI) done after fracture realignment becomes an important component to a complete vascular examination. This requires a Continuous Wave Doppler and sphygmomanometer to assess the injured extremity with an abnormal ABI defined as <0.9.[3,14–16] Pulselessness confirmed by absent Doppler signals has the highest diagnostic probability of a vascular injury and remains a reliable screening modality in the setting of a penetrating or blunt injury.[14,17] Numerous studies have reported that examination alone (pulse, ABI) is highly accurate with a sensitivity and specificity of 92% and 95%, respectively.[2,18] During the era of catheter-based angiography one prospective study evaluated 35 patients with knee dislocations and, despite limited follow-up, concluded that physical examination alone was entirely dependable citing a negative predictive value of 100% and suggested that further imaging was not needed when the examination is normal (i.e., no hard signs, [active hemorrhage, expanding hematoma, absent pulse, distal ischemia, bruit/thrill]).[19] Unless special situations exist like concomitant peripheral arterial disease rendering an examination or ABI inconclusive, diagnostic imaging is unlikely to alter the surgical approach for penetrating trauma.[2,17] Time delays should be prevented to minimize reperfusion injury and maximize chances for successful limb salvage.

C. Diagnostic Imaging

Modern multidetector row computed tomography angiography has emerged as an important and dependable diagnostic tool with a sensitivity and specificity >90% for the detection of vascular injury.[2,16] The advantage of CTA is that it is fast, noninvasive, and can be performed at the time of initial radiological assessment. Computed tomographic angiography uses <100 mL of contrast to image multiple extremities with excellent three-dimensional reformatted resolution even when associated with embedded metallic fragments.[20,21] When there is no bleeding but the examination is abnormal (diminished pulse/signal or ABI <0.9) contrast imaging is indicated for diagnosis, disposition, or preoperative planning in the patient with a blunt mechanism of injury.[2,13] When there is concern for either the detection or knowing the exact location of a vascular injury in patients at high risk (shotgun, blast, multiple GSW, complex fractures, and knee dislocation) postreduction contrast enhanced imaging is recommended even in the setting of a normal exam to avoid a missed injury.[2,16] A CTA can demonstrate fracture patterns, soft tissue wounds, and identify the proximal and distal limits of the vascular injury with excellent resolution in axial, coronal, and sagittal planes.[13,16,21] Computed tomographic angiography has become more widely accepted as studies have cited numerous advantages and prospectively validated 100% sensitivity and specificity of multislice helical technology compared with traditional angiography.[16,21] The preoperative surgical planning derived from CTA is much more valuable when the injury may be ischemic from a blunt impact compared with a straightforward penetrating injury with bleeding.[13] The limitations of CTA include motion or fragment artifacts and poor opacification of distal extremity vessels due to suboptimal dosing of contrast or vasospasm. By comparison, catheter based arteriography may complement an indeterminate CTA and potentially allows for an immediate endovascular intervention. The disadvantages are that traditional angiography can be time-consuming, better accomplished in an endovascular suite, and is associated with a 1% to 4% complication rate.[3,19]

D. Occult Vascular Injury

Occult injuries are those that do not produce either bleeding or ischemia and that lead to late incidental findings discovered on a physical examination (thrill, bruit, mass, ABI <0.9). Modern imaging has increased the overall detection and incidence of traumatic occult vascular injuries, prompting questions regarding repair, observation, and discharge.[6,22] In 1998, Dennis et al. confirmed a prior observation that 89% of 50 occult injuries never required surgery. Their review of 353 prospectively followed clinically occult arterial injuries over 9.1 years (range, 8.6–11.1 years) documented the safety and efficacy of nonoperative management.[18,23] Asymptomatic occlusions of small branches are disregarded, but injury to a named artery in a patient who does not undergo operative or endovascular intervention should prompt outpatient surveillance. Transections of arterial branches are selectively repaired based on location, extent, and concern for rebleeding. When contrast extravasation is present, a transected vessel can be ligated or embolized. If the vessel is very small and asymptomatic, the patient should undergo repeat imaging until resolution. A pseudoaneurysm or arteriovenous fistula not obstructing or limiting distal flow may enlarge over time and should have surveillance imaging or undergo repair depending on the size, location, and body habitus. Intimal tears are minor injuries, but may become larger or evolve into an arterial dissection. These require outpatient follow-up when found in the axillobrachial or femoropopliteal vessels compared with smaller branch vessels of the extremity. Therefore, the baseline pulse examination and ABI are important references for the detection of an abrupt change. Minor injuries are observed and given antiplatelet agents as most will resolve over time.[1,4,18] A change in vessel luminal diameter (stenosis) can occur due to thrombosis or spasm from the surrounding hematoma, inflammation or kinetics of the tissue injury and is a common incidental imaging finding in a young patient.[1] A stenosis can progress to a complete occlusion so diagnostic imaging and close outpatient follow-up examinations are important to ensure resolution or prompt treatment.

E. Endovascular Intervention

Endovascular interventions have increased with the construction of hybrid operating rooms, inclusion of endovascular trained surgeons, and acceptance of a new technology.[24] Decisions to implement endovascular therapies require appropriate resources, and there is no clear consensus for the role or limit of endovascular therapies for surgically accessible vessels. In general, endovascular therapies are preferred for surgically inaccessible vessels or managing occult injuries that need treatment that have a higher risk of surgical morbidity and adverse events with open repair. Investigators for the PROspective Observational Vascular Injury Treatment registry found that patients undergoing CTA for lower extremity injury had higher rates of endovascular repair and observation compared with patients who underwent exploration for diagnosis.[13] Extremity vessels are easily exposed below the junctional areas and, although a percutaneous strategy is possible, endovascular treatment of smaller diameter vessels (tibial, brachial) have yet to establish a clear long-term benefit. When there is uncontrolled bleeding or pulselessness the most expeditious option is still an open surgical approach. Decisions to manage occult injuries with catheters are based on local interest, resources, inventory, and capability. Covered stents for treating an intimal flap or pseudoaneurysm or coil embolization of an arteriovenous fistula can reduce surgical morbidity and hospitalization time. Percutaneous aspiration thrombectomy is an alternative that is gaining wider acceptance among surgeons with advanced endovascular skills.

F. Completion Assessment and Postoperative Management

Immediate postoperative decisions are guided by the success of the repair and return of a palpable pulse and signs of perfusion; however, shock and reperfusion may limit the likelihood of a normal examination until the patient is warm and resuscitated. Volume expansion and the addition of vasodilators like topical papaverine applied to a vessel in spasm or intravenous nitroglycerin are helpful adjuncts to improve flow.[10] When the pulse and Doppler signals are unsatisfactory and the patient is stable, a completion angiogram using digital subtraction is recommended to examine the conduit, anastomosis, and run-off vessels. Completion intraoperative angiography is a low-risk procedure often omitted citing cost, time, and added complexity. [7] A prospective observational multicenter study of 296 arterial repairs reviewed 90 patients (30.4%) who underwent completion angiography following repair. Although most (70.9%) were based on protocol and the patient required no intervention, the authors demonstrated that when a clinical concern prompted completion angiography, 27.7% of the patients underwent immediate revision.[7] A careful postoperative assessment guides the decision to proceed to completion angiography or proceed to medical management. There is not strong evidence for administering systemic anticoagulation during or after an operation to trauma patients to simply to maintain arterial graft patency and improve limb salvage.[25] Several studies have looked at bleeding, mortality, and rates of compartment syndrome with postoperative anticoagulation, and despite mixed results, the rates of thrombosis and amputation were not statistically improved.[25–27] A larger multicenter study by Maher et al.[28] found that systemic intraoperative anticoagulation was associated with better arterial patency rates and no increase in bleeding complications. Despite this lack of consensus, use of intravenous unfractionated heparin is not uncommon in patients without contraindications. If not given routinely, it should be utilized if there are any concerns for clot formation compromising the repair or reconstruction.[13] Antiplatelet therapy postoperatively at 81 mg or 325 mg daily is commonly recommended, and this practice follows the literature and clinical practice guidelines for treatment of peripheral artery disease.[4] The recognition of early graft failure requires diligent postoperative surveillance with hourly neurovascular checks for 24 hours, liberalized over the hospitalization, and a predischarge ultrasound. An ABI before discharge is recommended as a reference for sonography during future graft surveillance.

G. Observation, Discharge, and Surveillance

When a reliable physical examination with ABI is considered to be normal, the work-up is done and the patient can be discharged if there are no other indications for admission. Several authors have demonstrated that a CTA should not be necessary to confirm a normal examination.[3,17] When the examination is not reliable or when there is a high-risk injury mechanism, the patient should be observed until diagnostic imaging is obtained to rule out an occult injury.[2] When there is a minor injury found but no immediate repair is needed, the patient can be discharged with a plan for outpatient follow up for continued reassessment. Following an emergent revascularization, ultrasound surveillance with an ABI is done within 30 days of repair and then semiannually in the first 2 years to 3 years. A decrease in the ABI of >0.15 or an elevated peak systolic or end diastolic velocity should prompt the surgeon to stratify the risk of graft failure and escalate the noninvasive surveillance or schedule diagnostic angiography.[29]

AREAS OF CONTROVERSY AND EXISTING KNOWLEDGE/RESEARCH GAPS

It is also important to note that there are many areas of this algorithm that lack high-quality evidentiary support and where further focused research is required. Table 1 provides a list of the most important specific topics or existing research "gaps"

TABLE 1. Identified Research Gaps in Extremity Vascular Injury

Topic or Research Gap	Algorithm Section
1. Role of CTA when the physical examination is reliable	B
2. Role and utility of an ABI when the pulse examination is normal	B
3. Diagnostic superiority of CTA vs. catheter-based angiography	C
4. The significance of an incidental traumatic stenosis or spasm	D
5. Further investigation of the best candidates for endovascular therapy	E
6. Definition of a completion assessment and indication for immediate postoperative contrast enhanced imaging	F
7. Utility and safety of intraoperative anticoagulation and the impact on postoperative patency and graft complication rates	F
8. Optimal dose, timing and duration of postoperative anticoagulation and antiplatelet therapy	F

related to this topic that were identified by the authors during the development of this algorithm.

SUMMARY AND CONCLUSION

The incidence of extremity vascular injury has increased with penetrating wounds, motor vehicle crashes, pedestrians struck, and falls accounting for a majority of the cases. A thorough physical examination with Doppler assessment including an Ankle Brachial Index will reduce delays for unnecessary imaging in the setting of an injury, which needs operative exploration based on a reliable physical examination. Modern CT scanners offer fast acquisition with high-resolution three-dimensional reformatted images that can lead to catheter-based angiography for select endovascular interventions. Current candidates for endovascular therapy with peripheral vascular injuries remain unclear, and decisions are often extrapolated from other vascular therapies. The key steps for open operative management are described herein with suggestions on temporary shunting, external fixation, and fasciotomy. The definition of a completion assessment is largely subjective, and the threshold to obtain additional imaging is commonly determined by institutional protocols or surgeon preference. The optimal dose, timing, and duration of postoperative anticoagulation and antiplatelet therapy remain controversial with no clear consensus.

AUTHORSHIP

All authors meet authorship criteria for this manuscript as described below. All authors have seen and approved the final manuscript as submitted. The first author (C.J.F.) had full access to all data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. C.J.F., M.J.M. participated in the conception and design. C.J.F. participated in the acquisition of data C.J.F., M.S., S.K., M.dM., L.J.M., C.V.R.B., J.L.H., K.I., E.J.L., N.K., K.A.P., N.G.R., J.A.W., R.C., D.V.F. M.J.M. participated in the analysis and interpretation of data. C.J.F., M.J.M. participated in the drafting of the article. C.J.F., S.K., M.dM., L.J.M., C.V.R.B., J.L.H., K.I., E.J.L., N.K., K.A.P., N.G.R., J.A.W., R.C., D.V.F., M.J.M. participated in the critical revision of the article. M.J.M. participated in the supervision.

DISCLOSURE

All JTACS Disclosure forms have been supplied and are provided as supplemental digital content (http://links.lww.com/TA/D373).
The results and opinions expressed in this article are those of the authors, and do not reflect the opinions or official policy of any of the listed affiliated institutions.

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