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AUTHORS

Matthew M. Gangidine, MD,
Emergency Medicine Resident, Department of Emergency Medicine, Boonshoft School of Medicine, Wright State University, Wright-Patterson Air Force Base, OH

Derek M. Sorensen, MD, FACEP,
Assistant Professor, Departments of Emergency Medicine and Surgery, Boonshoft School of Medicine, Wright State University, Wright-Patterson Air Force Base, OH

PEER REVIEWER

Howard A. Werman, MD, FACEP,
Professor of Clinical Emergency Medicine, Ohio State University, Columbus

STATEMENT OF FINANCIAL DISCLOSURE

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RELIAS MEDIA

Penetrating Extremity Trauma: Part II

Part I of this series discussed etiology, initial field management, and emergency department evaluation of penetrating extremity trauma. This article will cover the mangled extremity, recognizing and managing vascular injuries, imaging approach, and emergency department management of these injuries.

Physical Exam Signs of Vascular Injury

Hard Signs of Vascular Injury

Definitions vary slightly by source, but there is consensus on the hard signs of vascular injury, which indicate the presence of arterial injury. (*See Table 1.*) Hard signs include pulsatile or exsanguinating hemorrhage, expanding or pulsatile hematoma, absent distal pulses, palpable thrill or audible bruit, and signs of ischemia or occlusion.[1-10] The presence of the last finding is indicated by the "six Ps" of acute arterial occlusion: pulselessness, pallor, paresthesias, pain, paralysis, and poikilothermia. The presence of any of these hard signs portends an extremely high probability of vascular injury and mandates expedient operation.[2,4,11] Patients presenting with these hard signs undergo a therapeutic operation 95% to 98% of the time without preoperative diagnostic imaging.[7] Pulse examination is subject to inconsistency and overcalling. If a pulse is anything less than definitively palpable, its presence should be confirmed with the use of handheld continuous wave Doppler examination.[12]

Soft Signs of Vascular Injury

In contrast, soft signs are suggestive of vascular injury but do not imply its presence as definitively as hard signs. (*See Table 1.*) These also have some heterogeneity in their definition, but generally include the following: a history of significant hemorrhage (on scene or in transit); unexplained shock or hypotension in the presence of extremity injury; small, stable, nonexpanding, nonpulsatile hematoma; diminished distal pulses; neurologic deficit; proximity of an injury to major vascular structures; and associated concerning bony injury.[1-10] As an example of the last point, supracondylar fractures of the humerus are particularly concerning for brachial artery injury, as are posterior knee dislocations for the popliteal artery.[1,5,6] Although a "diminished" distal pulse may be appreciated on palpation, it also may be discerned on a handheld Doppler by a change from the normal triphasic pattern heard to a dampened biphasic or monophasic pattern.[5] In the past, the presence of soft signs often led to further imaging evaluation (and some sources still endorse this approach), but the yield of such examinations was low, with positive results in as few as 4% of cases.

EXECUTIVE SUMMARY

- Hard signs of vascular injury include pulsatile or exsanguinating hemorrhage, an expanding or pulsatile hematoma, absent distal pulses, palpable thrill or audible bruit, and signs of ischemia or occlusion. The presence of any of these hard signs portends an extremely high probability of vascular injury and mandates expedient operation.
- A normal ankle-brachial index (ABI) is 1.0 to 1.1. An arterial pressure index (API) < 0.9 represents a positive finding and merits further imaging studies (typically a computed tomography angiography [CTA]). Both sensitivity and specificity have been shown to be > 95% using this 0.9 cutoff.
- In patients with a normal physical exam (i.e., no hard or soft signs) and an ABI ≥ 0.9, peripheral vascular injury may be safely excluded, and the patient may be discharged (in the absence of other reasons for admission).
- Permissive hypotension still approaches resuscitation aggressively but uses a lower blood pressure for the end point (i.e., mean arterial pressure [MAP] > 50 mmHg or systolic blood pressure [SBP] 70-90 mmHg). The theory is to allow adequate tissue perfusion but lessen the chance of increased pressure dislodging fragile clots. A recent meta-analysis suggests this strategy may offer survival benefit, as well as reduce blood loss and blood product use.
- Thromboelastography or thromboelastometry also can be used to monitor the specifics of a given patient's coagulopathy and administer a more tailor-based product replacement later in the resuscitation. There is growing evidence that this can both reduce the need for blood products and improve mortality in bleeding patients.
- Fractures that occur in the setting of penetrating trauma should be considered open. A typical treatment regimen includes gram-positive and gram-negative coverage with cefazolin and gentamycin in most cases.
- Patients with open fractures should receive antibiotics, as should patients with hand injuries, joint or bony involvement, immunocompromised status (including diabetes), vascular compromise, or significant contamination.

Such injuries typically were nonocclusive and managed nonoperatively.[7,11] The presence of a soft sign of vascular injury should prompt further evaluation in the form of arterial pressure indices.[4]

Arterial Pressure Indices

In the absence of hard signs already dictating exploration and the presence of soft signs or any penetrating injury other than the clearly superficial, the existence and degree of distal flow should be addressed in the injured extremity. The nomenclature varies a bit, but the measurements and meanings are the same. These measurements are commonly referred to as the ankle-brachial index (ABI) or brachial-brachial index (BBI) for the detection of lower and upper extremity peripheral arterial disease, respectively. In the setting of trauma, the terminology of arterial pressure index (API) or injured extremity index (IEI) may be used. The technique is executed by using a handheld Doppler to auscultate distal flow. A blood pressure cuff is inflated proximally, and the systolic pressure at which flow is occluded is recorded. The highest pressure is chosen from either the dorsalis pedis or posterior tibial arteries in the leg, or the radial or ulnar arteries in the arm. This value then is divided by the highest pressure obtained in the contralateral or uninjured lower extremity, or, more typically, an uninjured brachial artery. (*See Figure 1.*)

A normal API is 1.0 to 1.1.[5,6] An API < 0.9 represents a positive finding and merits further imaging studies (typically computed tomography angiography [CTA]).[4,11] Both sensitivity and specificity have been shown to be > 95% using this 0.9 cutoff.[4,5] False positives are possible in under-resuscitated patients, and a repeat API should be obtained after a patient receives fluids/ blood, rewarming, and analgesia.[12] In older adults who may have preexisting peripheral arterial disease or known diabetes, the ABI may be falsely elevated because of pathologic vessel wall calcification. Alternative approaches are to use the IEI and compare it to the contralateral side rather than to an arm, or to use a cutoff of an inter-extremity ABI difference of > 0.1.[4] In patients with a normal physical exam (i.e., no hard or soft signs) and an ABI ≥ 0.9, peripheral vascular injury may be safely excluded, and the patient may be discharged (in the absence of other reasons for admission). This approach is supported by guidelines of the Eastern Association for the Surgery of Trauma (EAST), the Western Trauma Association (WTA), and a recent meta-analysis.[4,10,11]

Computed Tomography Angiography

In patients with an abnormal API (< 0.9), further imaging needs to be obtained to discern the presence or absence of vascular injury.[4] *CTA is the imaging modality of choice for penetrating extremity trauma.*[9,10] Modern studies employing 64-row multidetector scanners have found a 100% sensitivity and specificity for clinically important vascular injury.[10,13-15] The advantages of CTA include:

- low risk, noninvasive (vs. traditional angiography);
- fast (a scan can be completed in about two minutes, with no need to assemble an angio team);
- available in most modern EDs;
- detects associated bony and soft tissue injuries; and
- has a lower overall cost.[2,4-6,9,10]

Associated software can produce 3D reconstruction of the vessels and any associated injuries as well.[6,9] If a delayed phase is used, CTA also can assist in the detection of major venous injuries (although such injuries may be missed if the contrast phase is not timed for this).[2,5] Limitations of CTA tend to be inconsequential, but they include

Table 1. Hard and Soft Signs of Vascular Injury

Hard Signs of Vascular Injury	Soft Signs of Vascular Injury
• Pulsatile or exsanguinating hemorrhage • Expanding or pulsatile hematoma • Absent distal pulse • Palpable thrill or audible bruit • Signs of occlusion (pulselessness, pallor, paresthesias, pain, paralysis, poikilothermia)	• History or significant hemorrhage on scene • Stable, nonexpanding, nonpulsatile hematoma • Diminished distal pulse • Neurologic deficit • Proximity of wound to neurovascular bundle or nearby bony injury

artifact from metallic fragments, poorer visualization of tibial vessels, possible contrast nephropathy, and the inability to perform therapeutic interventions.[4,9]

CTA has the potential for overuse because of its ready availability in most EDs. The most recent study examining the use of CTA in penetrating extremity trauma found that without hard signs present, CTA was not required for identification of relevant or operative injuries; serial physical examination alone was sufficient.[16] Although further replication likely is needed before such an approach is adopted, it currently seems reasonable that imaging should not be obtained unless a decrement in the API (< 0.9) is at least demonstrated.[4] However, some sources still advocate for CTA even in the presence of soft signs alone.[6,10,11]

Another approach is to opt for observation and serial examination in the presence of soft signs. Many providers prefer to accomplish the more definitive study at the time of initial evaluation. Clinical judgment always should prevail.

A high index of suspicion for potential false-negative studies should be maintained with low-caliber shotgun injuries because the tiny pellets in these wounds are notorious for creating vessel micropunctures that are not evident on imaging evaluations.[17] If they are still embedded, numerous shotgun pellets (or fragments from a blast injury) may create too much artifact, necessitating the need for angiography in the patient with imaging indications.[2,6]

Magnetic resonance angiography (MRA) also exists but does not really have a place in the routine evaluation of penetrating extremity trauma given the equal or better accuracy, availability, timeliness, and cost of CTA.[5] The presence of ferromagnetic foreign bodies, a frequent occurrence or at least concern, also is a contraindication to MRI.[5]

Duplex Ultrasonography

Duplex ultrasonography is the combination of B (brightness)-mode (i.e., real time 2D or "regular") imaging plus color flow Doppler. The sensitivity of such studies for the identification of arterial injuries has ranged from 50% to 100% across various studies; specificity typically exceeds 95%.[2,4,5,9] Advantages include its noninvasive and inexpensive nature. Disadvantages (apart from sensitivity) include dependence on the availability and skill of ultrasound operators, as well as the time-consuming nature of the study. Because of the variable and sometimes low sensitivity, duplex ultrasonography is not recommended as the primary diagnostic study for the evaluation of penetrating extremity trauma.[2,9,12] It can prove useful when an artifact on CT limits evaluation, in institutions without CTA availability, for the identification of occult venous injuries, or for surveillance of known injuries being managed nonoperatively.[2,11] A recent meta-analysis suggests if ultrasound is used and a positive finding is identified, the post-test probability of arterial injury is 89%. This likelihood exceeds the treatment threshold, and patients should proceed to surgery or vascular intervention without delay for any additional studies.[11]

Angiography

Previously, traditional catheter-based arteriography was the gold standard for the diagnosis of vascular injury.[3,5,10] Now angiography has been replaced by CTA as the primary imaging modality because of the increased availability and accuracy of CTA. Angiography should not be used solely for diagnosis of arterial injury. Its current role is more applicable in combined settings where its use already is necessary for interventional maneuvers.[6] However, one of the distinct disadvantages of angiography is the time required to assemble the personnel and resources necessary for its use.[3] Therefore, even if its use is anticipated, it is still best to obtain a more rapid CTA in the ED for initial diagnosis and planning.[5] There also is an associated complication rate of up to 9%, mostly involving vascular injury for arterial puncture, but contrast nephropathy also is a concern.[11] Fixed fluoroscopic imaging units to allow for real-time angiography and open or endovascular intervention are being incorporated increasingly into trauma surgery suites at modern centers. Such capabilities still generally are limited to vascular suites at most institutions.[12] Therefore, angiography is best reserved for intraoperative use for cases requiring vascular intervention.

Emergency Department Management

Treatment in the ED depends on the nature of the injuries encountered and the capabilities of the hospital facility. For major penetrating extremity trauma, care often consists of identification and stabilization of pathology. Treatment measures will be initiated but will need to continue in the inpatient environment, with additional trauma/surgical consultation as needed. For injuries that are minor, complete care often can be rendered in the ED, with follow-up as needed. The following section highlights essential elements in the ED management of penetrating extremity trauma.

Control Bleeding

For minor bleeding, direct pressure may continue to be used. In the more controlled hospital environment, wounds originally managed with a tourniquet should be reevaluated. If a major arterial injury is suspected, the tourniquet should not be taken down prior to adequate resuscitation, the presence of surgical support, and arrangement of resources for definitive control. If the

Figure 1. Arterial Pressure Index (API) Equation

$$\text{API} = \frac{\text{Highest SBP in distal affected extremity (wrist or ankle)}}{\text{Highest (brachial) OR (contralateral uninjured extremity) SBP}}$$

Measure both dorsalis pedis (DP) and posterior tibial (PT) pressures at the ankle for lower extremity injuries, and both radial and ulnar pressures at the wrist for upper extremity injuries distal to the elbow (brachial pressures at the antecubitum will suffice for injuries proximal to the elbow). Measure the systolic blood pressure (SBP) at the antecubitum in both arms to obtain a brachial pressure to calculate an ankle brachial index (ABI) or brachial brachial index (BBI), or in the contralateral extremity to calculate an injured extremity index (IEI).

tourniquet was placed for an equivocal wound in the field environment for the sake of expediency, and the patient is otherwise stable, the provider may consider tourniquet removal for a complete injury evaluation. If significant bleeding recurs and the source is not easily identified and controlled, replace the tourniquet.

For smaller bleeding vessels, control may be attempted with a figure-of-eight stitch. A well-placed finger is an excellent and effective method of providing temporary, targeted control. Blind clamping or ligation should not be attempted; it is rarely successful and risks injury to concurrent nerves.[9,18] Such techniques are best reserved for the operating room after adequate exposure has been obtained.

Identify Arterial Injury

The approach to arterial injury identification is described earlier. Be sure to alert trauma/vascular consultants immediately regarding such injuries. If such specialists are not available, rapid transport to an appropriate trauma or tertiary care center should be arranged. Further definitive management options are discussed later.

Resuscitate

Basic concepts for resuscitation in the patient with penetrating extremity trauma in hemorrhagic shock will be discussed briefly. These patients almost invariably die from exsanguination, so prompt and aggressive treatment is required for unstable patients. Assess the patient's vitals and presentation for signs of shock (e.g., shock index [heart rate (HR)/systolic blood pressure (SBP)] > 1). Rapidly establish vascular access. In a patient with difficult peripheral access, quickly move on to intraosseous (IO) and/or central venous access. Hemostasis must be established to begin to achieve a net increase in the patient's intravascular volume. In the bleeding trauma patient, infusion of blood products should be the first goal. An initial bolus of crystalloid fluid may be started first if it is the only option readily available, but the immediate preference should be given to blood products. The lethal triad of hypothermia, acidosis, and coagulopathy is well-documented in trauma patients.[19] Room temperature crystalloid will exacerbate all of these. The PROMMTT and PROPPR trials have demonstrated the benefits of administering plasma and platelets in addition to red blood cells, and a 1:1:1 ratio is favored.[20,21] In the combat environment, even warm, fresh whole blood has been used, showing improved survival.[22] The feasibility and effectiveness of whole blood in the civilian trauma setting is just beginning to be studied.

A few additional strategies deserve mention. Permissive hypotension still approaches resuscitation aggressively but uses a lower blood pressure for the end point (i.e., mean arterial pressure [MAP] > 50 mmHg or systolic blood pressure [SBP] 70-90 mmHg). The theory is to allow adequate tissue perfusion but lessen the chance of increased pressure dislodging fragile clots. A recent meta-analysis suggested this strategy may offer survival benefit, as well as reduce blood loss and blood product use.[23] The administration of tranexamic acid (TXA), an antifibrinolytic studied most extensively in the CRASH-2 trial, has demonstrated a small but significant mortality benefit.[24] TXA should be administered within three hours of injury for benefit. Give an initial bolus of 1 g over 10 minutes, followed by an infusion of another 1 g over the next eight hours.[24] Studies in the United Kingdom and Canada have shown there is more limited knowledge of TXA in the civilian practice environment (as opposed to the military), and the majority of patients who are candidates for the drug do not receive it.[25,26] Although the benefit of current mortality data is not necessarily definitive, there are no significant adverse effects reported with the use of TXA, so its increased implementation is an area for potential improvement.[24] Thromboelastography (TEG) or thromboelastometry (ROTEM) also can be used to monitor the specifics of a given patient's coagulopathy and administer a more tailor-based product replacement later in the resuscitation. There is growing evidence that this can both reduce the need for blood products and improve mortality in bleeding patients.[27]

The approach of hemorrhage arrest, limited crystalloid administration, early blood product administration, permissive hypotension, restoration of normal physiology, and early damage control surgery (rather than definitive repair) is known as damage control resuscitation.[28,29] Many goals and interventions are tackled simultaneously, and a strong team approach is needed for optimal patient care.

Finally, caution should be employed when considering tourniquet take-down, especially when the tourniquet has been on for a significant amount of time or the underlying injury is suspected to be severe. The take-down is liable to result in additional blood loss, acidosis, hyperkalemia, and hypotension.[30] This is an endeavor that should be timed carefully; preceded by as much rewarming, resuscitation, and coagulopathy correction as possible; and decided in conjunction with surgical services. In many cases, the more appropriate place for tourniquet take-down and ongoing care is in the operating room in conjunction with the anesthesia team.

Manage Fractures

Concomitant fractures are common in extremity trauma. Although their incidence is much higher with blunt trauma (present in 80-100% of cases with associated arterial injury), the incidence still is significant with penetrating trauma (present in 15-40% of cases with associated vascular injury).[2] Suspicion should be raised in high-energy penetrations, which are encountered more frequently in the military setting. In the patient who is otherwise hemodynamically stable, the most important step is to reduce fractured bones using either splinting or traction fixation.[31] Although managing vascular injuries often takes precedence, reducing fractures in an injured extremity may alleviate vascular kinking and allow for a more accurate examination of distal perfusion.[31] Provide ample analgesia and provide sedation if time and hemodynamics allow. Obvious deformities may be reduced empirically. Plain films should be obtained to identify and characterize additional fractures better.

Fractures that occur in the setting of penetrating trauma should be considered open.[9] Open fractures are described according to the Gustilo classification, which divides these injuries into three types: type I, < 1 cm laceration; type II, > 1 cm laceration; and type III, including > 10 cm laceration, extensive soft tissue injury, traumatic amputation, gunshot wounds, and farm injuries.[32,33] Type I and type II injuries should receive coverage against gram-positive organisms, typically with the first-generation cephalosporin cefazolin, with an initial dose of 2 g IV.[5,9,32,33] Type III injuries should receive extra coverage against gram negatives, typically with the addition of the aminoglycoside gentamycin, with an initial dose of 6 mg/kg IV.[5,9,32,33] The clinician should be aware that there is a tendency to underestimate the severity and grade of an open fracture until the time of operative debridement.[32] Therefore, it is likely good practice at the time of initial evaluation and treatment in the ED to err on the side of dual administration (cefazolin plus gentamycin) for all but the most minor open fracture injuries. De-escalation may be initiated after surgical evaluation if appropriate. Antibiotics should be started as soon as possible after injury and typically continued for at least 24 hours but not longer than 72 hours after adequate tissue coverage.[32]

Manage Joint Injuries

Orthopedic involvement also is necessary in the presence of joint injuries. The goals are threefold: prevention of infection, prevention of traumatic arthritis, and prevention of lead toxicity. Plain films of the affected area should be obtained. Joint injuries commonly receive cefazolin as well, which is effective for infection prevention in these wounds.[34] The decision for operative management will be at the discretion of the orthopedic surgeon. Nonoperative management is not an uncommon strategy, and these wounds do not appear to require surgical debridement for infection prevention unless there is other intra-articular pathology or vascular injury. However, it is common practice to explore injuries in the knee joint regardless.[34] Synovial fluid is an organic acid and can dissolve lead. This can raise concentrations in the blood and cause symptoms of lead poisoning (which can be vague and include malaise, abdominal complaints, and a microcytic anemia). Because of the potential for lead toxicity, bullet fragments should be removed from joints.[34,35]

Irrigate Wounds

All wounds should be irrigated copiously. Provide local anesthesia prior to this process so the patient may tolerate more thorough cleaning. Wounds should be irrigated using high pressure, not just instillation of fluid. At least 500 to 1,000 mL of fluid should be used.[9] Although specialized devices sometimes are helpful, they are not necessarily needed. Pressure from a large syringe connected to an angiocatheter, or a bottle connected to a nozzle or with holes poked into the top, may be squeezed with manual pressure to achieve adequate results. Numerous studies have demonstrated that tap water is just as safe and effective as sterile saline or water, and may be used as an alternative.[36,37] Particularly with an upper extremity injury in an ambulatory patient, the patient may hold the wound under running water for a few minutes. Cleaning and irrigating are the most important steps in preparing a wound for repair, preventing infection, clearing debris, and decreasing the bacterial load.[38]

Close Appropriate Wounds

Appropriate wounds should be closed in the ED. Alternatives to primary closure in the ED are delayed primary closure (DPC) after a period of four to five days, or healing by secondary intention (i.e., leaving the wound open and allowing it to heal by granulation on its own). The decision to initiate primary closure depends mainly on the size and character of the wound, the degree of contamination, and the timing of the injury. Wounds that are extremely large or complicated, involve full or partial amputation, have inadequate coverage, involve damage to underlying structures, contain nonviable tissue, or are otherwise concerning should be left open in the ED, and will require surgical consultation for further debridement and repair. Extensively contaminated wounds should not be closed primarily. Debride any grossly nonviable tissue regardless of closure. Although it was thought that a delay in presentation (often using 12 hours as a cutoff point) increased the risk for infection, newer research has shown this is not the case.[39,40] These wounds also may be closed primarily after proper cleaning and irrigation. Both a high-velocity mechanism and a lower extremity location have demonstrated an increased risk of infection. When opting for DPC, clean, pack, and dress the wound. The patient should follow up in 24 hours for a wound check and packing change, and then in another 72 hours for definitive repair.[39] In general, small, clean wounds can be closed in the ED.

Manage Foreign Bodies

Plain radiographs will detect most relevant foreign bodies in penetrating trauma adequately. CT may be desired for more precise delineation in some cases, and it has the advantage of detecting some radiolucent materials as well. Organic material is more of a concern in contaminated or blast injuries and carries a higher risk of infection.[9] Such material often is not shown with X-rays and can be evaluated alternatively with ultrasound. Most retained foreign bodies are left in place, as the benefit of removal must be weighed against the risk of further damage to surrounding tissue in the process.[9] Bullet fragment removal is indicated for retention in a palm, sole, joint, or location with potential for migration or embolization.[9,41] Chronic infection and persistent pain are potential complications of fragments left in place.[41] In one pediatric series, researchers found a long-term complication rate of 22% and eventual removal rate of 13% for retained bullet fragments.[42] The researchers reasonably concluded that prophylactic bullet removal is not necessary, but close follow-up is required.[42]

Consider Antibiotics for Complicated Wounds

As discussed earlier, patients with open fractures should receive antibiotics. It also is appropriate to provide similar coverage for patients with hand injuries, joint or bony involvement, immunocompromised status (including diabetes), vascular compromise, or significant contamination.[9] However, for uncomplicated extremity gunshot and knife wounds, the occurrence of infection is rare, at only approximately 2% in a large but older study of about 3,400 patients.[43] In a newer but smaller study, a subset of 60 patients with soft tissue, only low-velocity gunshot injuries, researchers found a nonsignificant trend toward lower infection rates with the use of antibiotics, with an infection rate of 6% in those who received antibiotics vs. 26% (7% deep infection) in those who did not.[44] Overall, for small, uncomplicated wounds, there is no convincing evidence that antibiotics are needed or that they provide additional protection.[45]

If coverage is desired for a wound with concerning features, the most common organisms to protect against are *Staphylococcus aureus* and *Streptococcus* species, which are the culprit infectious agents in more than 90% of cases.[45] A common regimen is to provide a first-generation cephalosporin (e.g., cephalexin) in a three- to five-day course. The first dose may be given IV (e.g., cefazolin) if desired or needed, but it is not mandatory or superior.[45] Methicillin-resistant *S. aureus* is increasingly common in the community. The provider may opt to give additional coverage when prescribing antibiotics to include trimethoprim/sulfamethoxazole, clindamycin, or doxycycline.[45]

Update Tetanus

An approach to tetanus prophylaxis involves assessment of the wound and the patient's tetanus status.[33,45] In a patient who is immunocompromised or who has a contaminated or concerning tetanus-prone wound, and either has not completed a primary tetanus series or has an unknown prior immunization status, administer tetanus immune globulin (TIG) in addition to tetanus/diphtheria/acellular pertussis (Tdap) vaccine. For a concerning wound in a patient whose last tetanus booster was more than five years ago, or for any wound in a patient whose last booster was more than 10 years ago (or for incomplete primary vaccination), administer Tdap. For clean, minor wounds with a patient's verified tetanus booster within the past 10 years, no vaccination is needed. For the majority of patients presenting with any significant penetrating extremity trauma, empiric administration of Tdap typically is a reasonable approach.

Assess for Mangled Extremity

By definition, a truly "mangled" extremity involves injury of at least three of the four functional components (soft tissue, bone, nerves, and vessels). This may occur via high-velocity gunshot wounds or the penetrating component of a blast injury. A mangled extremity is encountered more frequently with blunt high-speed motor vehicle accidents. The Mangled Extremity Severity Score (MESS) allows for evaluation and stratification of more severely injured limbs. The MESS grades the injured limb based on four areas: severity of skeletal/soft-tissue injury, degree and time of limb ischemia, severity of shock, and patient age. A total score is tallied and ranges between 2 and 14. The utility of the MESS is somewhat controversial, and its application is changed by the presence of newer operative techniques and options. It is used primarily to assist in the prediction of limb salvage, with a score of 7 or higher correlating with the need for amputation.[1] The original study was completed in 1990, and the author has called for a re-collection of data, speculating that with more modern surgical techniques, the threshold may have increased to 8 or even 9.[46]

Involve Consultants

The presence of any gunshot wound or knife wound other than a minor or superficial injury likely should warrant initiation of the trauma team at any institution where such services are available. Depending on the particulars of the patient and the institution, the trauma team or the ED provider may assume primary care and responsibility for further consultations. The involvement of a vascular surgeon (or possibly interventional radiologist in some situations) is critical in the presence of suspected or confirmed vascular injury. Orthopedic surgery should be involved in the case of associated bone or joint injuries and with associated soft tissue damage (including nerve injury). Subspecialist involvement for hand surgery also should be sought when available and with relevant injuries. Although also within the purview of general and trauma surgery, orthopedic surgery manages and performs fasciotomies at some institutions. For extensive soft tissue damage, plastic surgery services may be required. Burn surgery may be applicable for some wounds as well, especially with blast injury. Surgical critical care services often may be required for the disposition of more severely injured patients. If any such providers are needed but not available at the presenting facility, expedient transfer should be arranged to an institution where appropriate services are available.

Further consultants should be involved at the discretion of the provider. The exact makeup of a patient's ultimate care team often is determined in large part by institution availability and preference, and well as the comfort and experience of surgeons with managing various associated injuries. A multimodal approach is to be expected.

Surgical Evaluation and Management

A detailed account of specific surgical approaches is beyond the scope of this review. However, a few general principles in the operative management of penetrating extremity trauma are worth mentioning and should be familiar to all emergency and trauma clinicians. The Western Trauma Association offers an algorithmic approach to the specifics of surgical management of such injuries for those interested.[47]

Decision to Operate and Timing of Operation

In general, operative management is indicated for patients with identified bleeding or occlusion of any major named peripheral vessel.[7] This may be diagnosed from the presence of hard signs of vascular injury or from positive findings on imaging.[9] The goal time frame for operative intervention and restoration of perfusion generally is less than six hours to avoid irreversible ischemic neuropathy and myonecrosis.[5] Ideally, a surgical suite with fluoroscopic capabilities should be selected. The best place for the resuscitation of an exsanguinating patient is in the operating room (OR).[3] For the patient with anything other than an isolated injury, a two-team surgical approach is recommended, wherein one team may address extremity injury while the other addresses torso trauma, for example.[30]

Advances in damage control surgical techniques have obviated the need for sacrificial vessel ligation in nearly all cases. In patients with a mangled extremity and accompanying unstable fracture, or in those who have suffered significant hemorrhage to the point of near exsanguination, the first step in limb salvage should be the placement of a temporary intraluminal shunt to restore arterial inflow (and venous outflow if necessary).[47] After the patient has been resuscitated in the intensive care unit (including correction of any coagulopathy), he or she may return to the OR for definitive repair when hemodynamically stable and normothermic.[47] Such shunts placed in proximal vessels have been shown to have very high (90%) patency rates and few complications, even in the midst of ongoing care over the course of a day or longer.[2,30]

For elective vascular cases, systemic anticoagulation often is used. In vascular trauma resulting in a pulseless extremity from presumed or confirmed occlusion, anticoagulation with 5,000 units or 100 units/kg of unfractionated heparin may be considered.[3] However, in trauma patients, the risks of such an intervention frequently outweigh the benefits. Obvious contraindications include associated traumatic brain injury, abdominal solid organ injury, retroperitoneal hematoma, or pelvic fracture.[3] Such a decision should be made in conjunction with the operating trauma and/or vascular surgeon. Regional heparinization, instilled intraoperatively, is a potential alternative in those with concomitant injuries. With isolated extremity vascular trauma with resultant pulselessness, anticoagulation likely should be undertaken.

There are competing priorities in a patient who has a mangled extremity with both bony and vascular disruption requiring repair. There is a widespread belief that orthopedic fixation should precede arterial repair because of a concern that traction and manipulation during subsequent fixation would disrupt a prior vascular repair. Conversely, advocates for starting with revascularization worry about increased ischemic time, raising the risk of limb loss and amputation. The authors of a recent meta-analysis found no outcome differences in regard to amputation in patients undergoing fixation prior to revascularization vs. revascularization prior to fixation.[48] Therefore, either approach is reasonable and viable, and individual patient factors and circumstances should allow for surgeons to proceed however is needed, with the decision ultimately at the discretion of the operating surgeons. For patients with a severely mangled extremity or prolonged ischemic time, decisions also need to be made regarding possible limb salvage versus early amputation.

In the OR, the patient should be over-prepped and under-draped. Allow full access for both proximal and distal vessel control, as well as potential contralateral saphenous vein harvesting for autologous graft use.[3] If the patient has to be taken to the OR emergently prior to full imaging characterization of injuries, surgeon-performed angiography may be used for injury localization prior to incision for management.[3] Frequently, completion angiography also is performed following vascular repair, when the patient is stable enough to allow for such evaluation.[48]

Endovascular Management

An increasingly available and preferred option is the use of endovascular management in appropriate cases. Even 10 years ago, a 27-fold increase in the use of endovascular therapy had been observed from the late 1990s to the early 2000s, and with it, decreased morbidity, mortality, and length of hospital stay.[49] More recent analysis shows that the highest utilization of endovascular therapy is for severely injured blunt trauma patients primarily with noncompressible torso hemorrhage.[50] Endovascular techniques were used least often with limb trauma. Penetrating wounds to any region were treated preferentially with open surgery (74%).[50] Currently, the primary role for endovascular therapy in peripheral vascular trauma is for highly selective embolization of injured, noncritical vessels; management of arteriovenous fistulae; and management of junctional injuries (i.e., subclavian and iliac) where open surgery may pose a greater technical challenge.[1,2] Occasionally, interventional radiologists may be involved in the isolated embolization of small distal vessels, but the high incidence of concomitant additional injury and the potential need for adjunctive open techniques usually make management by trauma or vascular surgical services preferable. The main disadvantage of endovascular management is the need for specialized equipment and personnel, which has not yet promulgated throughout most trauma centers. Long-term outcome data currently are sparse, but there is no doubt that treatment options in this realm will continue to be pursued in the future.

Nonoperative Management

Old policies of mandatory operative exploration are long defunct. Nonoperative management is a viable option in appropriately selected injuries at the discretion of managing trauma and vascular surgeons. Generally agreed-upon criteria for eligible injuries include those with no impairment in distal circulation or flow, no active hemorrhage/extravasation, and minimal vessel wall disruption. A low-energy mechanism of injury is another consideration.[2,3,5] Various case studies of such injury patterns have demonstrated a low incidence of progression to requirement of intervention at 0% to 9%.[2] Intimal defects are expected to heal without intervention up to 95% of the time, and in the absence of additional traumatic injuries, such patients may be started on thrombosis prophylaxis, commonly with aspirin or heparin.[4] Patients in the acute phase of injury with high suspicion for progression may be observed in the hospital for development of hard signs of arterial injury on serial exams. However, such injuries may progress over a timeline of multiple weeks to a few months (although the overall progression rate still is quite infrequent). Therefore, follow-up with long-term serial examination (including ABIs) is important for such nonoperative lesions, and repeat imaging with duplex ultrasound or CTA also is recommended to evaluate for progression or resolution of the injury, at least if an abnormality is found on exam.[2,4]

Complications

Compartment Syndrome

Compartment syndrome likely is the most feared and most important complication to be considered for penetrating extremity trauma. Compartment syndrome occurs when there is a mismatch between perfusion pressure and intracompartmental pressure in a given fascia-enclosed space in a limb. The immediate threat is to the viability of muscle and nerve tissue in the compartment, although numerous sequelae also may occur subsequently. In the setting of penetrating extremity trauma, the pathophysiology of compartment syndrome often begins with reperfusion injury, wherein toxic metabolites are created after an area experiencing prolonged ischemia is reoxygenated. A vicious cycle is created, wherein tissue death and capillary leakage create increased edema and microthrombosis and, therefore, a decreased pressure gradient, which then further worsens malperfusion injury, and so on. Fractures are another etiological culprit.

Certain patients present a higher risk for the development of compartment syndrome.[1-3,7,8,47] By history, patients at higher risk are those with previous hypotension or massive hemorrhage, or a delay in treatment/warm ischemic (or tourniquet) time of more than four to six hours. Clinically, those with significant swelling, firmness, pain, paresthesias, or major neurological deficit in the extremity are at increased risk. Additionally, anatomically, those with fractures, multiple arterial injuries, need for proximal venous ligation, or need for simultaneous arterial and venous clamping, especially at the popliteal level, are at higher risk for compartment syndrome. In a recent study, patients with gunshot wounds had a more than nine-fold increased incidence of the need for fasciotomy (at 8.6%) compared to those involved in motor vehicle collisions.[51] Arterial injuries, open fractures, and knee or elbow dislocations also were independent predictors of the need for fasciotomy.[51]

In select patients with compartment syndrome or at high risk for developing it, several diagnostic criteria may be considered. In patients with a significant combination of risk factors, early elective prophylactic fasciotomy may be performed, often occurring along with initial surgical treatment in the OR. In those who do not receive prophylactic fasciotomies, compartment pressures should be measured to aid in decision making. The commonly accepted threshold is compartment pressures > 30-35 mmHg. A delta pressure (i.e., the difference between the diastolic and compartment pressures) < 30 mmHg should be an alternative trigger.

In the military setting, due to the prevalence of high-energy mechanisms and potential for complications during prolonged evacuations, prophylactic fasciotomies are performed routinely in any case in which a risk is present or vascular injury is confirmed, without measurement of compartment pressures.[1,52,53]

If the diagnosis is not definitive and close monitoring with serial exams is available, it may be worth holding off on a prophylactic fasciotomy, since the procedure is not completely benign. Among other issues, closed fractures will be converted to open ones, a significant wound will need to be dealt with, and more than half of patients experience chronic limb pain.[7]

Identified patients with current or high probability for future compartment syndrome should undergo fasciotomy promptly. Early intervention (within eight hours of vascular repair) results in decreased amputation and infection rates, and decreased hospital length of stay.[54]

Other Complications

Missed nerve, tendon, or joint injuries may become apparent later in a patient's course. Infections also may develop. Patients with arterial injury and ensuing intervention may develop stenosis and subsequent thrombosis at repair sites; graft aneurysm or endoleak, in which blood flow is present outside of the graft, is a concern with endovascular repairs. Delayed amputation is a risk for more significant injuries. Functionally, patients may have chronic claudication, edema, or pain. In those requiring amputation, about three-quarters experience phantom limb pain.[1]

Disposition

The following section focuses on the disposition for isolated penetrating extremity trauma. In multi-trauma patients with concomitant injuries, trauma care providers will have to consider the totality of the patient's injuries to determine the most appropriate disposition.

Discharge

Patients with minor wounds only potentially may be discharged from the ED after receiving appropriate care. They should have no hard or soft signs of vascular injury, no abnormal APIs concerning for vascular injury, and no additional bony or soft tissue injuries requiring further attention. Adequate analgesia and wound care should be ensured in such cases.

Observation

Patients with equivocal findings may be observed. Although an API of 0.9

has been proven to be a safe threshold in the absence of additional physical exam findings, some sources suggest 12- to 24-hour observation for patients with an API of 0.90 to 0.99.[5] The presence of soft signs of vascular trauma alone, another concerning injury pattern, or suspected early compartment syndrome also may be reasons for a brief period of observation. The patient should have frequent neurovascular exams, including Doppler pulse examinations and repeat APIs, during this time period.

Admission

Patients with positive findings of injuries requiring additional medical and/or surgical attention should be admitted for ongoing care as indicated.

Transfer

For a patients who present to smaller or outlying facilities with limited resources, transfer likely will need to be considered. If appropriate surgical resources are not available for the management of a suspected vascular injury, transfer to a trauma center should be initiated without delay for imaging, as positive findings could not be acted upon anyway, and may push the patient past the warm ischemic time threshold.[5] For the same reason, providers should be quick to use air rather than ground transport if transfer times will be improved. For a patient with active hemorrhage, a tourniquet should be applied and secured prior to transfer. The emergency medical services crew should have a minimum of one additional tourniquet (or ideally, at least two) in case bleeding is not controlled and an additional tourniquet needs to be applied. It is also prudent to transport the patient with additional blood products available for ongoing transfusion as needed. For patients with no active bleeding but suspected arterial injury, a tourniquet can be placed loosely on the affected extremity in the appropriate position, but not tightened; if bleeding occurs, the windlass can be tightened to achieve control.

Follow-Up

Some traumatic peripheral extremity injuries that otherwise appear manageable in the ED with the patient subsequently discharged home still may carry a risk for occult vascular injury, signs of which are evident only on exam as further time passes. Most missed arterial injuries in the extremities are symptomatic within 10 days of initial injury.[3,8] A suggested follow-up schedule includes re-assessment in an outpatient clinic at one week, two weeks, and two months.[3,8] This visit should include repeat physical examination, noninvasive Doppler examination with APIs, and further imaging (e.g., duplex ultrasound and/or CTA) as dictated by any positive findings.[4] For those discharged following nonoperative management, strict return precautions should be given, with instructions to return immediately for any increasing pain, bleeding from the wound, or pulsatile sensation in the area of injury.[3]

It should be noted that delayed presentation of an undetected injury may occur in 1% to 4% of patients with normal physical examination findings.[10]

Rehabilitation

Victims of major penetrating extremity trauma typically require extensive physical and/or occupational therapy. This is especially true when there is significant soft tissue damage or involvement of bones, nerves, or vessels. Such rehabilitation should be arranged as part of the patient's discharge planning. In the age of remarkable modern prostheses, elective delayed amputation as a management strategy for complicated injuries should be considered as a viable and pragmatic option rather than as a failure. Counterintuitively, this sometimes can lead to better functional outcomes for the patient, both physically and emotionally.[1]

Conclusion

Penetrating extremity trauma is a problem likely to be encountered by the emergency and trauma clinician both at home and on the battlefield. In most cases, these potentially devastating and even lethal injuries are amenable to successful treatment with prompt and proper attention. While consideration should be given to damage sustained by all wounded structures, chief attention should be paid to the evaluation and management of peripheral vascular trauma sustained in such cases. With swift hemorrhage control and resuscitation, careful diagnostics, and coordination of definitive surgical services when needed, penetrating extremity trauma can be managed successfully in a preponderance of cases.

Disclaimer: *The views expressed herein are those of the authors alone, and do not necessarily reflect those of the Department of Defense, United States Air Force, Wright-Patterson Medical Center, or United States Air Force School of Aerospace Medicine.*

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1. When calculating an ankle-brachial index, which lower extremity pressure is used for the calculation?
   a. Dorsalis pedis artery systolic pressure
   b. Posterior tibial artery systolic pressure
   c. The higher of the dorsalis pedis and posterior tibial artery pressures
   d. The average of the dorsalis pedis and posterior tibial artery pressures
2. If duplex ultrasonography is performed and demonstrates positive evidence of arterial injury, what is the next step in management?
   a. Obtain computed tomography angiography to verify injury
   b. Admit for repeat ultrasound examinations
   c. Proceed to angiography to verify injury
   d. Proceed directly to surgical and/or endovascular intervention
3. In a patient with an arterial pressure index < 0.9 in the setting of acute penetrating extremity trauma who is stable for imaging, what is the diagnostic test of choice?
   a. Serial arterial pressure index measurements
   b. Computed tomography angiography
   c. Duplex ultrasonography
   d. Direct catheter-based angiography
4. Which of the following is a soft (rather than hard) sign of arterial injury?
   a. Pulsatile hematoma
   b. Audible bruit
   c. Nonexpanding hematoma
   d. Absent distal pulse
5. In a patient with minor penetrating extremity trauma with no hard or soft signs of arterial injury and a normal arterial pressure index, whose care can otherwise be completed in the ED, what is the most appropriate disposition?
   a. Discharge home with outpatient trauma follow-up
   b. Observe in the ED for 12 hours
   c. Admit for serial examinations and arterial pressure indexes
   d. Admit for observation and further diagnostic imaging
6. In a patient with hard signs of arterial injury, what is the next most appropriate step?
   a. Obtain arterial pressure index measurements
   b. Obtain computed tomography angiography to evaluate for presence of injury
   c. Admit for serial examinations and arterial pressure indexes
   d. Proceed directly to surgical management
7. In a patient with concomitant vascular and long bone injury, in what order should surgical management take place?
   a. Orthopedic fixation should precede arterial repair
   b. Arterial repair should precede arterial fixation
   c. Either approach may be used on a case-by-case basis
   d. Orthopedic fixation first if less than six hours from injury; arterial repair first if more than six hours from injury

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Upon completing this program, the participants will be able to:

- discuss conditions that should increase suspicion for traumatic injuries;
- describe the various modalities used to identify different traumatic conditions;
- cite methods of quickly stabilizing and managing patients; and
- identify possible complications that may occur with traumatic injuries.

8. In a patient with an underlying fracture resulting from a gunshot wound, what antibiotic administration is recommended, if any?
   a. No antibiotics required unless grossly contaminated or significant soft-tissue injury
   b. Gram-positive coverage with cefazolin alone
   c. Gram-negative coverage with gentamycin alone
   d. Gram-positive and gram-negative coverage with cefazolin and gentamycin

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