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PEDIATRIC
Emergency Medicine Practice
Evidence-Based Education • Practical Application

CLINICAL CHALLENGES

- **What are the contraindications for removal of a tourniquet,** and what kind of monitoring is necessary after removal?
- **What physical examination findings** should prompt immediate operative management?
- **What are common secondary complications of extremity firearm injuries,** and how can they be avoided?

Pediatric Firearm Injuries to the Extremity: Management in the Emergency Department

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Prior to beginning this activity, see the "CME Information" on page 2.

Abstract

Firearm injuries are a leading cause of pediatric mortality in the United States. The frequency of pediatric extremity firearm injuries and the high repeat incidence in high-risk patients make it important for emergency clinicians to understand how to manage these injuries. This issue focuses on the acute management of firearm injuries to the extremities of pediatric patients, drawing from the pediatric literature or extrapolated from adult literature where pediatric evidence is scarce. Current trends, novel management, and controversies are also discussed.

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Target Audience: This enduring material is designed for emergency medicine physicians, physician assistants, nurse practitioners, and residents.
Goals: Upon completion of this activity, you should be able to: (1) identify areas in practice that require modification to be consistent with current evidence in order to improve competence and performance; (2) develop strategies to accurately diagnose and treat both common and critical ED presentations; and (3) demonstrate informed medical decision-making based on the strongest clinical evidence.
CME Objectives: Upon completion of this activity, you should be able to: (1) discuss the indications for tourniquet placement and contraindications for tourniquet removal in the management of pediatric firearm injuries to the extremity; (2) describe indications for immediate operative management; (3) calculate and interpret an arterial pressure index; and (4) describe interventions that can be used at the bedside to reduce the risk for firearm injury recurrence.
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Case Presentations

CASE 1

An 8-year-old previously healthy boy presents with a penetrating wound to his left upper extremity…

- Several children were playing with BB guns when the boy sustained the wound.
- Upon arrival, EMS reports an estimated 100 mL of blood loss on scene before a family member placed a makeshift dressing and applied pressure. EMS is unsure about pulsatile bleeding since the dressing was placed prior to their arrival. After noting the dressing soaked in blood, a tourniquet was placed in the field.
- While you are completing your examination, the boy is crying in pain. IV access is obtained, and he is placed on a cardiac monitor. The boy's vital signs are notable for a heart rate of 110 beats/min; blood pressure of 107/60 mm Hg, measured on the right arm; respiratory rate of 20 breaths/min; and oxygen saturation of 100%. The primary survey reveals an absent left radial pulse but no other immediate concerns. The secondary survey demonstrates an appropriately placed left upper extremity tourniquet, and a 0.75-cm linear transverse laceration to the medial left upper arm overlying a small hematoma without active bleeding. No other wounds are appreciated.
- What precautions should you take prior to releasing a tourniquet in the ED? What physical examination findings can help determine the next steps in management? Is advanced imaging indicated? Is emergent surgery required?

Introduction

Pediatric firearm injuries account for a small proportion of visits to the emergency department (ED) but remain a leading cause of pediatric mortality in the United States. In a study using the National Emergency Medical Services Information Systems Database, between 2010 and 2015, pediatric firearm injuries had a mortality rate of 6.1%.[1] A study using the National Trauma Data Bank (NTDB) noted a case fatality rate of 11% for the period of 2010 to 2016.[2] Depending on which database is analyzed, pediatric firearm injury-related mortality rates range from the second to third leading cause of pediatric death in the United States,[3,4] far outpacing rates in similar high-income countries.[5]

When analyzing patterns of injury, the most common location of pediatric firearm injury varies by age. Extremity injuries were the most frequent site of pediatric firearm injury for all ages, but these injuries had the lowest case fatality rate.[2] In terms of lethality, head injuries were the most often fatal, except in children aged 15 to 19 years, in whom truncal injuries proved more deadly.[6] Given the frequency of pediatric extremity firearm injuries and the violent injury recidivism seen in high-risk patients, it is critically important that clinicians understand the management, as well as the social determinants, underlying firearm injuries to the extremities of children.

This issue of *Pediatric Emergency Medicine Practice* reviews the current evidence for initial assessment and management of extremity firearm injuries and examines major pitfalls to avoid while caring for the injured child. It also discusses pertinent ballistic principles and highlights the important role clinicians may have in helping to avoid future pediatric firearm injuries.

Critical Appraisal of the Literature

A literature search was performed using PubMed, Ovid MEDLINE®, the Cochrane Database of Systematic Reviews, Western Trauma Association (WTA) Guidelines, Eastern Association for the Surgery of Trauma (EAST) Guidelines, American College of Emergency Physicians (ACEP), National Association of EMS Physicians (NAEMSP), National Association of Emergency Medical Technicians (NAEMT), and American College of Radiology Appropriateness Criteria®. Searches were limited to publications in English between the years of 1970 and 2021. An initial search was conducted with broad term combinations including *pediatric*, *child*, *children*, *firearm*, *firearm injury*, *gunshot wound*, *penetrating trauma*, and *ballistic injuries*. This search yielded a combined total of 2817 results on PubMed and 2093 results on Ovid MEDLINE®. The abstracts of these articles were reviewed for relevance, and duplicates were eliminated. Additional searches were conducted and refined by the term *extremity*. Bibliographies of relevant articles were reviewed for additional publications. Overall, a total of 202 articles from 1978 to the present were selected for full review.

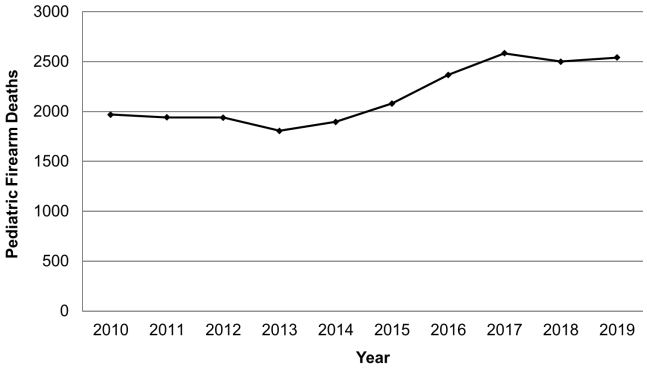
The literature consisted predominantly of retrospective reviews and case studies. Few randomized controlled trials exist. Prospective studies are generally observational and underpowered due to small sample sizes. However, multiple retrospective studies were examined, which included adults as well as pediatric patients aged <18 years but >3 years. The most recent edition (10th) of the Advanced Trauma Life Support® (ATLS®) guidelines was also reviewed.[7]

Epidemiology

In the past decade, there has been a trend of increasing pediatric deaths from firearm injuries. **(See Figure 1.)** When these data are stratified by intent and race **(see Figure 2)**, interpersonal violence is more likely to be experienced by minority males and children aged >12 years.[4,6,8-10] Overall, Black children incur disproportionately higher rates of gun violence and pediatric firearm death.

It is prudent to consider firearm injuries as a sentinel event to be intervened upon during the ED visit. In the United States, pediatric firearm recidivism (recurrent firearm injuries) has been described mainly in males, and disproportionately in minority teenagers living in urban neighborhoods with high rates of poverty, unemployment, and lower educational opportunities.[8,11,12] For at-risk youth who survive the initial episode, there is a >50% risk of a repeat incident within 2 years[11] and increased risk of death from subsequent trauma compared to patients without a prior presentation.[12] This topic will be discussed further in the "Time- and Cost-Effective Strategies" section beginning on page 17.

Figure 1. Ten-Year Trend of United States Pediatric Firearm Deaths



Data source: https://www.gunviolencearchive.org/

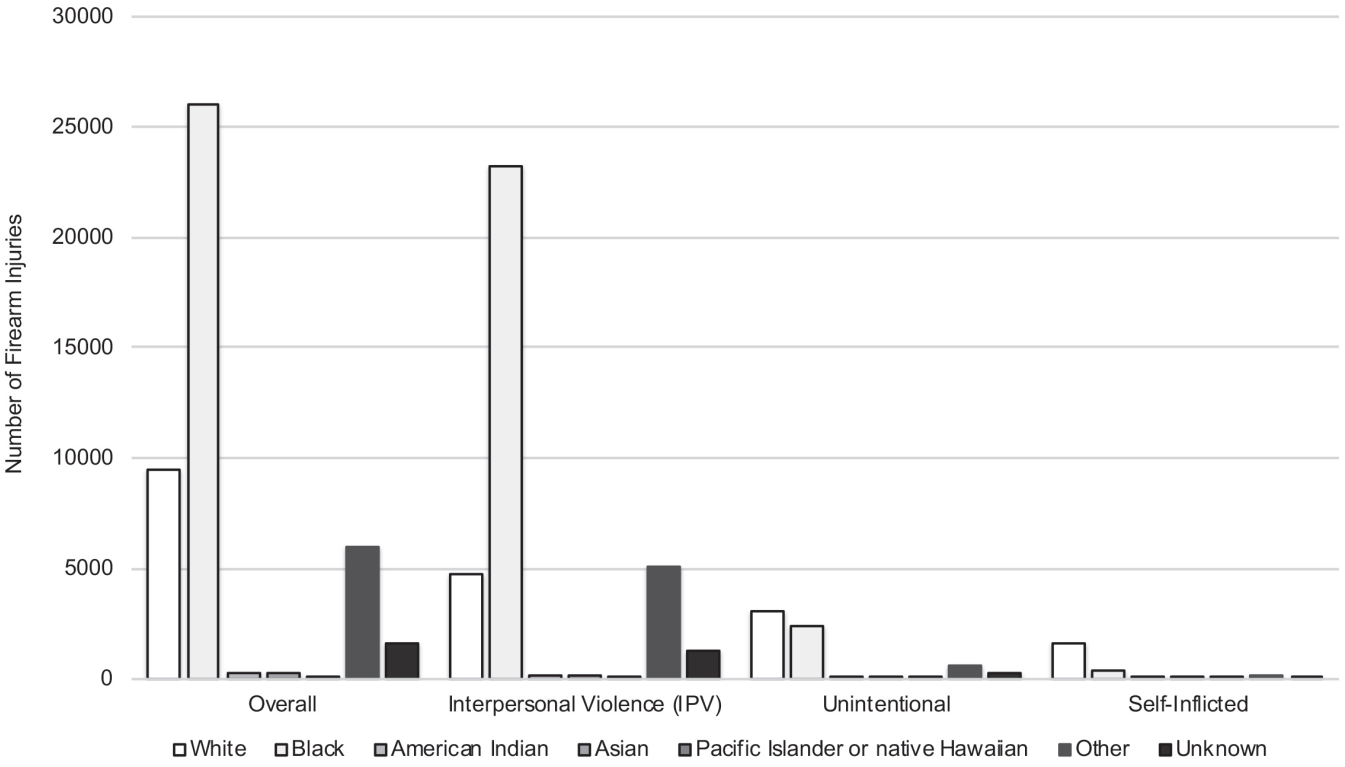
Unintentional Injuries

Unintentional injury occurs more frequently in White males and those aged ≤12 years, usually while playing with a gun.[13] A national survey performed in 2015 revealed that even though the number of gun-owning households had not increased substantially over the prior 15 years, safe-storage practices had decreased dramatically, with close to 5 million children living in homes where at least 1 firearm was stored loaded and unlocked.[14] Unintentional pediatric firearm injury has a low fatality rate, but these injuries predominate in younger children and in rural areas where access to specialized pediatric trauma centers may be more limited.[15]

Suicide

Cases of suicide by firearm tend to have a high fatality rate and more frequently affect older males (aged >12 years). In this age group, suicide is frequently a consequence of impulsive behavior, with children and teenagers deliberating 10 minutes or less before

Figure 2. Pediatric Firearm Injuries From 2010 to 2016, Stratified by Intent and Race[9]



performing the act, underscoring the importance of decreasing the access to highly lethal means.[13,16] Suicidal acts that prove fatal occur most often in households in which a gun is available.[17] While prevention is largely beyond the scope of this issue, gun violence offers many opportunities in which clinicians as well as other ED staff can intervene to improve child safety.

Ballistics

Ballistics is the study of how projectiles travel. This includes travel through the firearm (internal ballistics), through the air (external ballistics), and through the target (terminal ballistics).[18] Understanding the terminology and design of weapons and projectiles may aid clinicians in gathering accurate histories and explaining patterns of injury. A list of relevant terminology can be found in **Table 1**. In the context of emergency medicine and for the purposes of this issue, the term *projectile* most frequently refers to bullets, but can also include other high-energy objects that are propelled in flight (eg, shrapnel, airgun pellets). Notably, although airgun injuries are generally less dangerous than traditional powdered firearm injuries, there have been many case reports documenting severe injuries to sensitive structures (eg, eye, fontanelle) and even fatal injuries (eg, subxiphoid entry into the pericardium).[19-21]

Advancements in internal ballistics have optimized energy transfer between the firearm and projectile, and allowed for designs (eg, rifling) to minimize rotational forces in flight. A bullet does not travel in a straight line, but is acted upon in flight by rotational forces **(see Figure 3, page 6)**, causing variations in flight path en route to the target. These variations affect not only accuracy but also the projectile's terminal ballistics, because a bullet striking at an oblique angle (with greater surface area of impact) will more effectively transfer kinetic energy into energy used to deform tissue. Thus, considering only the velocity of the projectile from a weapon can be a misleading proxy for the degree of tissue damage beneath the skin, as high-velocity projectiles may pass through the target without transferring all kinetic energy, or low-velocity projectiles may be purposefully designed to expand or fragment upon impact, imparting more energy onto the tissue.

In terms of terminal ballistics, there are 3 basic mechanisms of damage: (1) the direct laceration or crushing of tissue in a bullet's path, (2) the cavitation of tissue in the path of a bullet as the force imparted causes it to expand past the diameter of the bullet, and (3) the generation of shock waves that can propagate through the body. These shock waves are not typically clinically significant at low velocities but can cause hollow viscus injuries and, in some cases, dissect nearby blood vessels at higher velocities.

Differential Diagnosis

Table 2, page 6 presents the different injuries that need to be considered when assessing pediatric firearm injuries to the extremity.

Prehospital Care

Prehospital care is an essential step in the treatment of firearm injuries to an extremity. Children have less blood volume compared to adults, increasing the relative importance of the time spent in transit. Death from hemorrhage is more likely to occur within 1 hour of injury, underscoring the importance of optimizing prehospital care and transport.[22]

Transport Destination

Firearm injuries distal to the elbow or knee are appropriate to be treated at any ED; however, injuries involving or proximal to these joints should be transported

Table 1. Terminology for Types of Firearms, Ammunition, and Firearm Settings and Modifications

Type of Firearm	Description
Handgun	Short-barreled firearm that can be held and used with 1 hand.
Rifle	Long-barreled firearm designed to impart higher energy. Named for the rifling along the inside of the barrel, which optimizes accuracy.
Shotgun	Similar basic design as the rifle but without the characteristic rifling. Fires "slugs" or cartridges filled with "shot."
Assault rifle	A type of rifle that can switch between firing settings (eg, may switch from automatic to semi-automatic or burst fire). True assault rifles are rare outside military settings.
Type of Ammunition	**Description**
Round	A single unit of projectile that is fired. Also known as a cartridge.
Slug	A single large, heavy projectile fired by a shotgun.
Shot	Collection of small metal balls or pellets within a shotgun cartridge.
Firearm Settings and Modifications	**Description**
Automatic fire	Pulling the trigger will continuously fire ammunition while automatically reloading. Can repeatedly fire until the entire magazine has been spent.
Semi-automatic fire	Pulling the trigger will fire a single round of ammunition and loads the next round into the chamber.
Burst fire	Pulling the trigger will fire a set number of multiple bullets, typically 2 or 3 rounds per trigger pull.
Bump stock	Modification that can be applied to a semi-automatic fire weapon to make it function automatically.

to the nearest pediatric trauma center whenever possible.[23] A retrospective study compared outcomes of patients aged 15 to 18 years who were treated at adult versus pediatric trauma centers and found adolescents treated at pediatric trauma centers had lower mortality and lower likelihood of surgery.[24] Another retrospective study found children aged ≤5 years had higher odds of death when treated at adult trauma centers.[25] Unfortunately, pediatric trauma centers are not always readily accessible, as they are predominantly located in metropolitan areas. Moreover, regional emergency medical services (EMS) policies differ regarding the transport of an unstable child. Therefore, regardless of the hospital's trauma designation, it is imperative for all clinicians to be familiar with the preliminary stabilization of a pediatric firearm injury.

Prehospital Hemorrhage Control

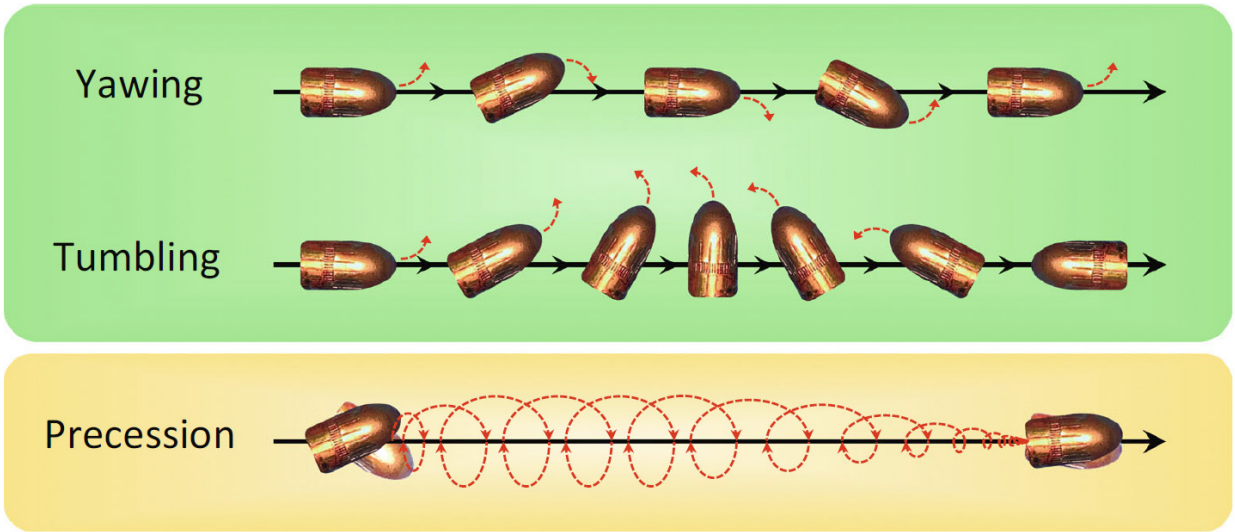
Prehospital personnel must decide what interventions to perform in the field, while minimally delaying transport. Decisions on performing interventions should be based on the location of injury and the expected transport time to the hospital. Mortality is dramatically different between firearm injuries with hemorrhage that is compressible (bleeding controlled by manual pressure or dressing) versus noncompressible, with case fatality rates at 0.1% and 5%, respectively.[1] Therefore, transporting a child with a noncompressible injury as quickly as possible should be the first priority. Conversely, in children with a compressible wound, focus should be placed on prehospital hemorrhage control while minimally delaying transport.

With regard to prehospital hemorrhage control of exsanguinating firearm injuries to the extremity, the evidence supports application of direct pressure with hemostatic gauze, followed by tourniquet use if direct pressure is unsuccessful. Prehospital application of tourniquets in a civilian setting has been shown to increase survival in adults nearly 6-fold.[26] Unfortunately, evidence-based guidelines for tourniquet use in children are lacking. Instead, peer-reviewed guidelines serve as a foundation describing current best practices. The Pediatric Working Group for the 2013 Committee for Tactical Emergency Casualty Care was the first to recommend widespread use of tourniquets for pediatric hemorrhage.[27] It was not until 2017, 2 years after the launch of the American College of

Table 2. Differential Diagnosis of Firearm Injuries to the Extremity

Type of Injury	Differential Diagnosis
Vascular	• Peripheral versus junctional injury • Direct injury versus intimal damage due to shock wave
Osseous/articular	• Open/unstable fracture • Intra-articular involvement • Physeal Injury
Soft tissue	• Isolated soft-tissue injury • Wound contaminated with soil/debris • Compartment syndrome
Retained foreign body	• Proximity of sensitive structures (eg, neurovascular bundle) • Synovitis • Septic arthritis • Lead toxicity
Metabolic	• Rhabdomyolysis • Reperfusion injury

Figure 3. Rotational Forces in Flight: Yawing, Tumbling, and Precession



Source: Yuuki Matsui, Sena Iguchi, Emiri Sato, et al. Atypical gunshot injury traversing the neck with an unexpected nonlinear bullet trajectory: a case report and review of the literature. *SN Comprehensive Clinical Medicine*. 2021;3:765-771. Used under a Creative Commons Attribution 4.0 International License. http://creativecommons.org/licenses/by/4.0/

Surgeons Stop the Bleed® campaign (a civilian emergency training program)[1,28] that the Pediatric Trauma Society released a statement supporting the use of tourniquets.[29] Given the poor quality of evidence, the Pediatric Trauma Society assigned a grade of C/D to their recommendation and encouraged further investigation.[29] A systematic review published in 2021 found only 2 single-arm observational studies[30,31] evaluating the use of windlass tourniquets in children aged 2 to 16 years.[32] Both studies focused on the Combat Application Tourniquet (CAT®), which is used in the Stop the Bleed® campaign and stocked in schools with emergency bleeding response kits.[33] Notably, both observational studies were deemed by the reviewers to have a high risk for bias with a low level of evidence.[32] Despite the shortfalls, the reviewers concluded that CAT® use led to pulse cessation in 100% of upper extremity applications and in 94.5% of lower extremity applications.[32] Further research is needed to assess the effectiveness and safety of tourniquet use in children. The different components of the CAT® are depicted in **Figure 4**, and the steps for its correct application are presented in **Figure 5, page 8**.

Emergency Department Evaluation

Assessment of pediatric patients requires an understanding of pediatric physiology and age-based vital signs. Along with the usual vital signs obtained upon arrival (heart rate, oxygen saturation, respiratory rate, and blood pressure), the pediatric age-adjusted shock index (SIPA) can be used at the onset of resuscitation.[34] *SIPA* is defined as heart rate divided by systolic blood pressure (SBP). A high SIPA has been correlated with adverse outcomes in children sustaining blunt trauma.[34,35] Limited data are available to support its use in penetrating injuries. However, a 2020 retrospective review of children with predominantly penetrating injuries found that a SIPA >1.2 for patients aged 0 to 6 years and >0.9 for patients aged 7 to 17 years had a positive predictive value of 49.2% for blood product transfusion and 22.9% for emergent surgical procedures.[36] Hence, SIPA is an additional data point that can be considered during resuscitation to help guide management and disposition.

MD+CALC

An online tool for the Shock Index, Pediatric Age-Adjusted (SIPA) is available at: https://www.mdcalc.com/shock-index-pediatric-age-adjusted-sipa

Primary Survey

A primary survey should be conducted according to ATLS® guidelines immediately upon patient arrival to the ED.[7] As in any trauma resuscitation, the airway takes priority and must be secured, if necessary. Once the airway has been confirmed to be protected, breath sounds should be auscultated bilaterally, and necessary interventions (eg, thoracostomy tubes) performed.[7] With regard to circulation, normal pediatric blood volume is estimated to be 80 mL/kg.[37] For infants and children, hypotension is a late finding, often not notable until large intravascular volumes (30%-40%) have been lost.[34,38] Given their fixed-stroke volume, infants increase their heart rate to raise their cardiac output, thus tachycardia is the most common presenting examination finding for shock. Both tachycardia and delayed capillary refill time (≥3 seconds) are seen prior to the onset of hypotension with blood volume losses of 15% to 30%, thus an abnormality of either can help the clinician identify compensated shock in a timely manner.[39] Similar to the prehospital setting, active and obvious external bleeding should be controlled immediately with direct pressure or a tourniquet. Hemorrhage control should also include examining the patient for junctional wounds and signs of vascular injuries. *Junctional wounds* are defined as wounds at the point of junction between the trunk and extremities (eg, inguinal regions, axillae). Identification of these wounds is imperative, as these areas contain major vessels with high risk for exsanguination, and

Figure 4. Components of the CAT® Tourniquet

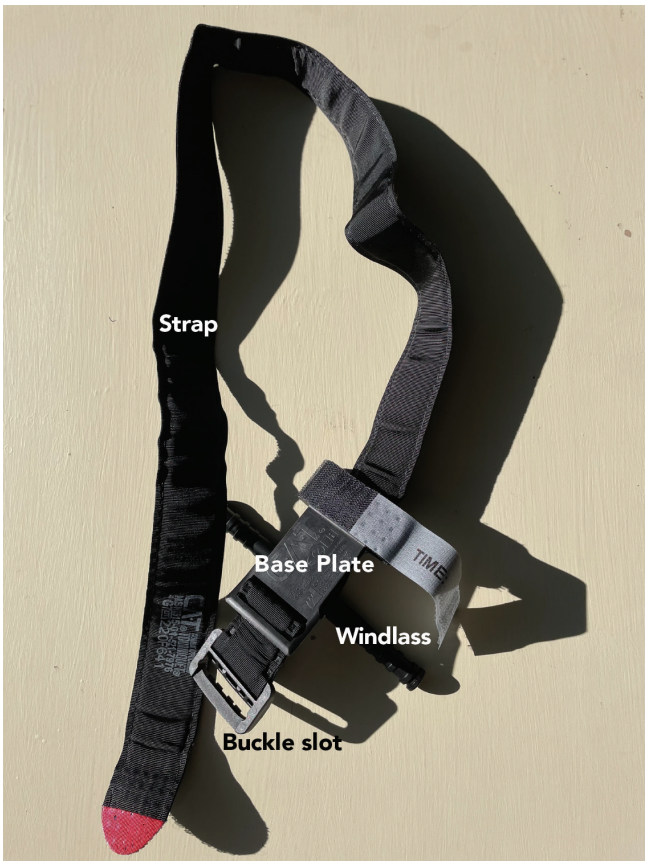


Image courtesy of Eva Tovar Hirashima, MD.

Figure 5. Steps for Correct Application of a Tourniquet

1. Place the tourniquet 2 to 3 inches proximal from the wound over the skin (preferred) or over clothing.

2. Tourniquets are ineffective if used in an area with more than one bone. Wrap the humerus (shown) or femur of the affected extremity with the tourniquet. Flex the base plate into a concave configuration at the time the strap is threaded through the buckle slot.

3. Pull the strap tight enough that fingers cannot be inserted between the band and the child's skin.

4. Twist the windlass to increase tightness until a distal pulse is no longer palpable.

5. Secure the windlass in place.

6. Confirm that the pulse is no longer palpable, and the bleed is controlled.

7. Mark the time the tourniquet was applied on the extremity.

Images courtesy of Eva Tovar Hirashima, MD; Rawad Rayes, MD; and Cathy Dong, MD.

vascular injuries to these areas are more difficult to manage, given the inability to obtain proximal control. These wounds should be managed with direct pressure and hemostatic dressings. If available, specialized junctional tourniquets such as the Abdominal Aortic Junctional Tourniquet®[40] may be utilized, as well as expandable or injectable hemostatic devices (see the "Controversies and Cutting Edge" section, page 16). For a child with suspected hemorrhagic shock, the latest ATLS® guidelines recommend the administration of an IV bolus of 20 mL/kg crystalloid fluids followed by blood product transfusion.[7] Current recommendations on volume repletion are discussed in the "Damage Control Resuscitation and Hemostatic Resuscitation" section on page 10.

Neurologic disability should be assessed next. Commonly used scales are the AVPU (A-alert, V-responds to voice, P-responds to painful stimuli, U-unresponsive) scale, the Pediatric Glasgow Coma Scale (pGCS) score for preverbal children, and the Glasgow Coma Scale (GCS) score for older children.[41] In the case of truncal or extremity injuries, the child's ability to move all extremities should be assessed, and it should be determined whether areas of gross sensory loss are present.

MD+CALC

An online tool for the Pediatric Glasgow Coma Scale (pGCS) is available at: https://www.mdcalc.com/pediatric-glasgow-coma-scale-pgcs

The child should be fully exposed and examined closely to ensure hidden wounds are not missed. Care should be taken to avoid cutting through holes in the child's clothing that may be used as forensic evidence.

Kenefake et al recommend adding F for "family" to the ABCDE mnemonic. The presence of the child's family provides comfort and may assist in obtaining a more accurate evaluation of the child's mental status and injuries.[42]

A change in the patient's clinical status prompts review of their primary survey, troubleshooting each step before moving on. In the event of traumatic cardiac arrest in adults, the WTA recommends time-based criteria for cessation of resuscitation.[43] There are no clear guidelines for pediatric traumatic cardiac arrest in the United States. Vassallo et al published an algorithm by expert consensus for patients aged 0 to 16 years with traumatic cardiac arrest due to penetrating injuries, recommending controlling external hemorrhage, securing the airway, bilateral thoracostomies, fluid and blood product transfusion, and considering thoracotomy. They strongly recommended deprioritizing chest compressions in favor of thoracotomy to relieve possible cardiac tamponade.[44] No specific time was recommended for termination of resuscitation. Other predictors of mortality such as low end-tidal carbon dioxide ($EtCO_2$) and cardiac standstill on ultrasound can be used to guide resuscitative efforts.

Secondary Survey

Upon completion of the primary survey, a secondary survey should be conducted. This includes the focused "AMPLE" history (Allergies, Medications, Past medical history, Last meal, Events surrounding the injury), time of injury, type of bleeding (nonpulsatile vs pulsatile), estimated blood loss, and, if applicable, time of tourniquet placement. EMS personnel, police, bystanders, and the child's family may be able to provide information. As detailed in the "Ballistics" section on page 5, no information about the weapon or ammunition, in isolation, is enough to dictate management; therefore, the clinician must assess and treat based on the clinical picture in front of them. Information to obtain/consider includes:

- *Do the physical examination findings correlate with the reported history?* Objectively document as much information as possible to allow other clinicians and law enforcement personnel to determine whether there is a discrepancy.
- *What is the location, size, and shape of each firearm injury?* These should be documented objectively.
- *What secondary injuries may have occurred?* These include internalized bone or bullet fragments, debris, injury to bowel or bladder from the shockwave, or blunt force injury, in cases in which a projectile was blocked by body armor.
- *Are there other radiolucent foreign bodies that may be retained?*
- *Is the shooter known to the victim?* This information may be useful in removing the child from a dangerous environment, preventing a future injury, or preventing injury to other children in the same environment.

A detailed head-to-toe examination should be conducted while the above questions are answered. Take care to examine the child fully by removing garments and looking under any hemostatic gauze, cervical collar, or blood pressure cuff. Bullets, loose pellets, and wadding should be handled carefully and saved. Note all areas of injury and consider marking wounds with radiopaque clips prior to imaging. Describe the injuries objectively and accurately using standard medical terminology. If the electronic medical record is capable, clinicians may document photographs of wounds in the chart, preferably with a small ruler adjacent to the wound for scale.

Extremity Examination

Look for hard and soft signs of vascular injury. Hard signs include pulsatile external bleeding, expanding hematoma, thrill, bruit, pulselessness, pallor, and/or neurologic deficit.[45] If the presence of a pulse is equivocal

or unable to be felt on palpation, a hand-held vascular Doppler should be used to confirm the presence or absence of a pulse. Soft signs include a history of prehospital arterial bleeding, wounds near known major vessels, and a small nonpulsatile hematoma.

The presence of soft signs should prompt clinicians to obtain an arterial pressure index (API),[45,46] which is analogous to the ankle-brachial index or brachial-brachial index. The API may also be referred to as a Doppler pressure index or an injured extremity index in the context of trauma. Potential pitfalls of this method include improper sizing or placement of the cuff. For the upper extremity, the measurement must be taken distal to the injury site.

To obtain this measurement, lay the patient supine, and using a traditional blood pressure cuff and an 8 mHz vascular Doppler probe placed at a 45° to 60° angle to the artery, inflate the cuff until there is cessation of flow. The cuff should then be allowed to deflate slowly until flow returns. This pressure is the SBP. Repeat this measurement in an uninjured upper extremity. For the lower extremity, the probe should be placed immediately superior to the ankle. Once the measurements are taken, the index is calculated as the SBP of the injured limb divided by the SBP of the uninjured upper limb. Any value <0.9 is concerning for an arterial injury, and computed tomography angiogram (CTA) should be considered.[47] If obtaining this measurement is not feasible or suspicion of injury is high and the patient is hemodynamically stable (without indication for immediate surgical intervention), CTA can be performed instead. Recent literature suggesting performing preprocedural CTA in all hemodynamically stable patients with suspected extremity vascular injury regardless of physical examination findings[48] will be discussed further in the "Controversies and Cutting Edge" section on page 16.

Critical arterial injuries with significantly decreased to absent arterial flow may cause abnormal motor function and sensation. Therefore, a detailed neuromuscular examination should be performed, aimed at distinguishing deficits due to tendon/muscle abnormalities from nerve injuries. **Tables 3 and 4, page 11** present the main extremity arteries and the associated nerves, as well as specific motor and sensory testing for each. In addition, the presence of significant pain on passive extension of the muscles or rigid compartments should prompt immediate compartment pressure measurements (see the "Acute Complications and Secondary Injury" section starting on page 14).

Diagnostic Studies

The choice of diagnostic studies for the evaluation of pediatric extremity firearm injuries depends on final disposition and the child's clinical status. If the patient's injuries require transfer to a pediatric trauma center, diagnostic efforts in the ED should focus on stabilizing the patient for transport. Regarding imaging at nonpediatric trauma centers, ATLS® recommends minimizing testing in favor of expedient transfer to a designated pediatric trauma center.

Laboratory Studies

The priority is to obtain a blood type and crossmatch. Other common studies for severe extremity firearm injuries include complete blood cell count, electrolytes, renal and liver function tests, lactate, international normalized ratio, partial thromboplastin time, fibrinogen, and, if available, viscoelastic hemostatic assays. If there is clinical concern for compartment syndrome or rhabdomyolysis, creatine kinase should be ordered. A toxicology screen and alcohol level may also be considered. In addition, all perimenarchal or postmenarchal females require a urine pregnancy test.

Imaging Studies

When obtaining x-rays for bullet trajectory assessment and location, consider placing a radiopaque bullet-hole marker on the patient's skin and obtain 2 orthogonal views to identify fractures and locate bullet fragments. Suspect damage to structures between the skin markers and any fractures and bullet fragments found on radiograph. Retained foreign bodies may not always need to be removed unless they are close to sensitive structures that may be damaged by migration of the foreign body. If soft signs for vascular injury are present and the API calculation is <0.9, or clinical suspicion for vascular injury is high based on the mechanism of injury, a CTA should be ordered to evaluate for ischemia, vascular injury, or spasm. CTA is the imaging modality of choice for penetrating extremity trauma. When compared to contrast angiography or operative exploration, CTA had a reported sensitivity and specificity of 100% for detection of clinically relevant vascular injuries in adult patients with an API <0.9.[49]

Treatment

Damage Control Resuscitation and Hemostatic Resuscitation

Uncontrolled hemorrhage remains a leading cause of preventable death;[22,50] thus, appropriate resuscitation and management of hemorrhagic shock are the priority in pediatric firearm injuries. Damage control resuscitation targets the metabolic syndrome of acidosis, coagulopathy, and hypothermia often found in severe uncontrolled hemorrhage. In adults with hemorrhagic shock, the 2 key components of damage control resuscitation are permissive hypotension and hemostatic resuscitation, which includes early blood product transfusion. However, there is no evidence to support permissive hypotension strategies in pediatric patients.[51] Children are able to increase their cardiac output by an increase in their heart rate, and blood

Table 3. Main Upper Extremity Arteries and Associated Nerves

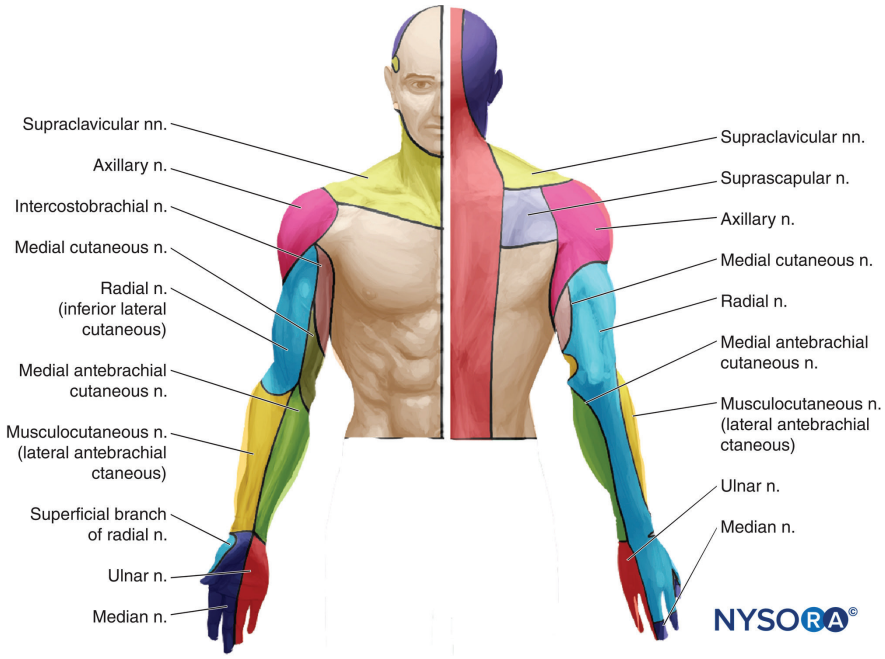
Artery, Associated Nerve, and Testing to Assess Motor Innervation

Brachial artery:
- Median nerve: OK sign
- Ulnar nerve: cross-fingers

Radial artery:
- Radial nerve: wrist extension or thumb interphalangeal joint extension

Ulnar artery:
- Ulnar nerve: cross-fingers

Cutaneous Innervation of Upper Extremities



Source: NYSORA.COM

Table 4. Main Lower Extremity Arteries and Associated Nerves

Artery, Associated Nerve, and Testing to Assess Motor Innervation

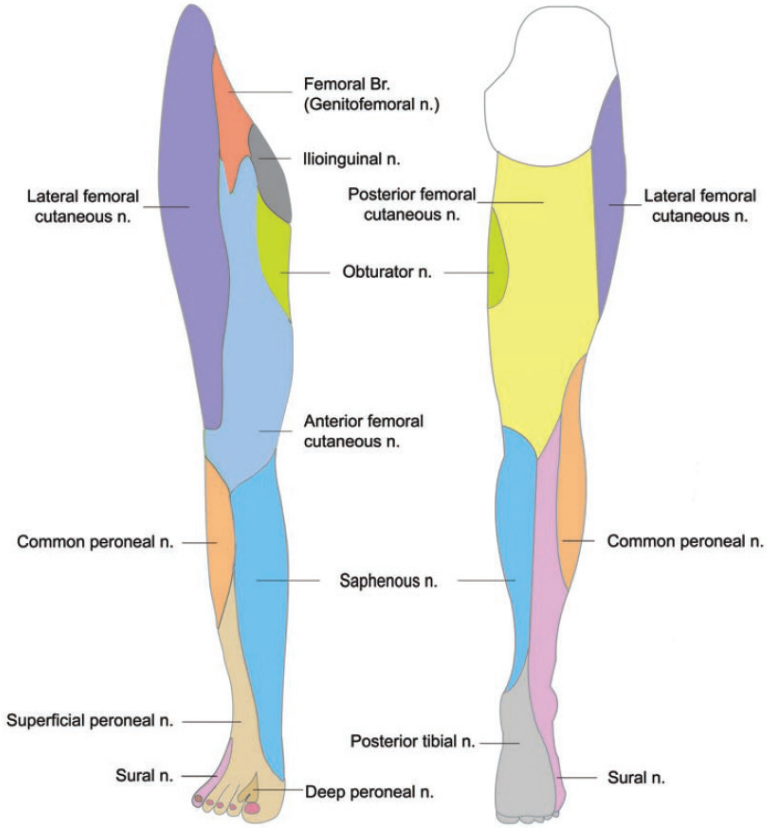
Femoral artery:
- Femoral nerve: knee extension

Popliteal artery:
- Common peroneal nerve: knee
- flexion
- Tibial nerve: ankle plantarflexion

Posterior tibial artery:
- Tibial nerve: ankle plantarflexion

Anterior tibial artery:
- Deep peroneal nerve: ankle dorsiflexion

Cutaneous Innervation of Lower Extremities



Source: NYSORA.COM

pressure is maintained until 30% to 40% blood loss occurs.[38] Hypotension is a late and definitive finding of decompensated shock; thus, permissive hypotension is not applicable in pediatric patients.

Hemostatic resuscitation is the use of fresh frozen plasma, platelets, and packed red blood cells to empirically treat coagulopathy before laboratory values are available to direct management.[51] Many pediatric trauma centers have implemented massive transfusion protocols (MTPs). A systematic review found the definition of MTP to vary between institutions, but the majority agree it is when >40 mL/kg of total blood products are given within 24 hours. The most common target is a ratio of 1:1:1 of fresh frozen plasma:platelets:packed red blood cells.[52] However, the ideal ratio remains controversial, and further research specific to pediatric trauma is needed.[51-53] With regard to balanced component therapy versus whole blood transfusion, Duchesne et al found no difference in survival rates, although they did find that the latter had lower incidences of acute respiratory distress syndrome (ARDS), duration of mechanical ventilation, future MTP activation, and lower transfusion volumes.[54]

Regarding timing of blood products, the current ATLS® guideline allows an initial crystalloid IV bolus of 20 mL/kg prior to blood transfusion for children suspected of having active bleeding.[7] Initial resuscitation with crystalloid fluids is supported by the EAST guidelines, which found no association of mortality with the first bolus.[55] However, further crystalloid IV boluses were associated with increased odds of intensive care unit (ICU) stay, increased hospital days, and extended ventilator use.[55] Presently, more high-powered studies are necessary before conclusions can be made regarding the best timing and ratio of blood product transfusion in pediatric MTPs.[53]

Based on the evidence thus far, for children with impending or current hemorrhagic shock, we recommend 10 mL/kg of packed red blood cells or 20 mL/kg of whole blood after 20 mL/kg of crystalloids have been provided. Individual institutional policy should be followed for activation of an MTP. However, it should be strongly considered when >40 mL/kg of blood product transfusions are required within a 24-hour period. Therapeutic endpoints of resuscitation are restoration of capillary refill time of ≤2 seconds, warm extremities, normal limits of heart rate and blood pressure based on age, urine output >1 mL/kg/hour, and return of baseline mental status.[56]

Tranexamic Acid

CRASH-2 (Clinical Randomization of an Antifibrinolytic in Significant Haemorrhage-2) is a major randomized controlled trial in the adult population that suggested that early use of tranexamic acid, an antifibrinolytic, decreased the risk of death compared to placebo in bleeding trauma patients.[57] The use of tranexamic acid in children has been investigated in a combat setting and has been shown to be independently associated with decreased mortality in all patients with no significant difference in thromboembolic complications or other cardiovascular events. Furthermore, its use was associated with improvements in discharge neurologic status and decreased ventilator dependence.[58] Despite promising findings in military settings, there is a paucity of data in the pediatric civilian setting.

The TIC-TOC study is an ongoing randomized controlled trial evaluating the use of different doses of tranexamic acid versus placebo in children with hemorrhagic injuries to the torso and brain, and data collection is currently in progress.[59] While awaiting the results of the TIC-TOC study, extrapolation from available adult data indicates that tranexamic acid should be considered within 3 hours of injury when overt signs of hemorrhagic shock are present. The recommended dosing for children aged ≥12 years is a loading dose of 1 g IV over 10 minutes given within the first 3 hours post injury, followed by an infusion of 1 g IV over 8 hours. For children aged <12 years, the loading dose is 15 mg/kg IV over 10 minutes (maximum dose 1 g) followed by an infusion of 2 mg/kg/hour over 8 hours or until the bleeding stops.[60]

Management of Vascular Extremity Firearm Injuries

Pediatric firearm injuries to the extremities are managed in accordance with the basic principles of trauma. Significant vascular injury remains uncommon, and children with these injuries tend to have lower mortality rates than adults with comparable injuries.[61] However, it should be noted that they have similar rates of amputation.[61] Known risk factors for amputation include the need for revascularization, limb ischemic time >6 hours, nonreconstructible bony damage, and hemorrhagic shock.[62,63]

Management of pediatric extremity firearm injuries in the ED should prioritize early hemorrhage control. Extrapolation from the adult literature indicates that, for children with a tourniquet placed in the field, it should be removed in <120 minutes if possible. Surgical consults should be placed prior to or upon patient arrival if available, and the patient should be evaluated for contraindications to tourniquet removal. **(See Table 5, page 13.)** If resources or surgical services are necessary but are unavailable at the receiving ED, the patient should be resuscitated appropriately and transferred without unnecessary delay to minimize duration of tourniquet placement and to stay within the 120-minute window. If the tourniquet has been or will be in place for >120 minutes, we recommend consultation with the treating or receiving surgeon and assessment of the individual

patient's circumstances to determine whether benefits of tourniquet removal outweigh risks.[64]

Contraindications to tourniquet removal include traumatic amputation distal to the tourniquet, hemodynamic instability, other life-threatening injuries, and inability to closely monitor the wound for signs of rebleeding.[64] **(See Table 5.)** If no contraindications exist, the tourniquet should be released to evaluate for rebleeding. If no active bleeding is present, application of a dressing, distal neurovascular function evaluation, and serial reassessments for rebleeding for at least 1 hour are recommended. **(See Table 5.)** If non–life-threatening bleeding occurs, it is appropriate to pack the wound with hemostatic gauze and consider tourniquet reapplication if significant bleeding persists. If life-threatening bleeding recurs, immediate tourniquet reapplication and emergency surgery are required. If bleeding continues despite tightening the first tourniquet, placement of a second tourniquet proximal to the first should ensue.[64] Current pediatric guidelines fail to mention ideal transfer and definitive-care times in cases in which a tourniquet has been placed.[27,29] However, extrapolating from the adult literature[64] transfer to a pediatric trauma center should ideally occur within 90 minutes of tourniquet placement, and emergency surgery should follow no later than 120 minutes. If emergency surgery is not available within this time frame, patients should be managed in a critical care setting prior to considering tourniquet removal to address the complications associated with prolonged limb ischemia, which are further detailed in the "Acute Complications and Secondary Injuries" section on page 14.

Table 5. Indications, Contraindications, and Monitoring of Tourniquets in Children With Exsanguinating Extremity Injuries in the Emergency Department

Indications for placement	• Suspected arterial extremity hemorrhage that is unable to be controlled with a pressure dressing
Contraindications for removal in the emergency department	• Tourniquet placed within inches of an amputation site • Hemodynamic instability • Other life-threatening injuries • Inability to closely monitor for rebleeding and other complications Note that patients with tourniquets in place for >120 minutes should be observed in a critical care setting for complications.
Monitoring after tourniquet release in the emergency department	• Conduct distal neurovascular examination • Assess for rebleeding for at least 1 hour • If reapplication is required, consider definitive surgical control

Indications for immediate operative intervention include hard signs of vascular injury, inability to remove a tourniquet given significant bleeding, occlusive injury of a major artery causing impaired perfusion identified on CTA, or development of compartment syndrome. Limb revascularization should be achieved within 6 hours of injury to decrease complications such as compartment syndrome, rhabdomyolysis, and need for amputation. However, in the setting of hemorrhagic shock, expedited revascularization within 60 minutes has been advocated to increase the odds for limb salvage. In a study published in 2019, the amputation rate nearly doubled from 6% in adult patients undergoing revascularization within 60 minutes to 11.7% in those who had repair after 1 to 3 hours.[62] Nonocclusive arterial lesions such as wall injuries, pseudoaneurysm, intimal flaps, and arterial spasm can be observed without immediate operative intervention as long as the limb is not ischemic.[45]

Consultants should be involved as early as possible. Vascular extremity firearm injuries requiring operative repair will frequently benefit from a multidisciplinary approach with contributions from critical care, trauma, vascular, and/or orthopedic surgeons. If surgical and critical care disposition are not immediately available, then the patient should be transferred without delay to a trauma center with these resources.

Bones and Local Wound Care

Once life-threats and limb-threats have been addressed, consider other acute management including:

- Pain relief should be given to conscious children, and analgesia and sedation to intubated children.
- Extremity fractures should be reduced and immobilized followed by repeat neurovascular examination.
- Gross debris should be removed; wound cavities should be irrigated using high-volume, low-pressure tap water or sterile saline/water; and a sterile, saline-soaked dressing should be applied.
- Antibiotic coverage should be considered (see the following section).
- Tetanus prophylaxis should be provided according to Centers for Disease Control and Prevention (CDC) guidelines.
- Projectile removal can be considered in conjunction with the surgical team once a patient reaches a pediatric trauma center.

Antibiotics

Despite commonly held beliefs, bullets are not sterilized by ballistic processes, and wounds may be further contaminated by clothing, debris, and in the case of blast injuries, even soil carried in the projectile's wake. Therefore, antibiotic coverage for most firearm injuries is still prudent.[65-67]

By definition, bony involvement after a firearm injury is an open fracture. The incidence of infection in

open fractures is increased and antibiotics are recommended within 3 hours from injury to reduce infection rates.[68] The Gustilo-Anderson classification is commonly used to describe open fractures, grading these into 3 main categories. Type I fractures are clean and low-energy, with minimal soft-tissue damage and a wound size of <1 cm. Type II fractures have moderate soft-tissue damage, moderate contamination, and a wound size of 1 to 10 cm. Type III fractures are high-energy fractures with extensive soft-tissue injury or traumatic amputation. Traditionally, types I and II fractures are treated with first-generation cephalosporins, and an aminoglycoside is added for type III fractures. More recent evidence focused on improved antimicrobial stewardship advocates for the use of a third-generation cephalosporin alone for type III fractures.[69] High-level research or guidelines are lacking for antibiotic regimens for pediatric firearm injuries. Based on limited evidence derived from the adult literature, **Table 6** lists antibiotic regimens for firearm injuries to the extremity of pediatric patients.

Joint Involvement

Orthopedic surgery should be consulted when joint capsule violation is noted, and antibiotic coverage should be provided while in the ED. **(See Table 6.)** Given the lack of set guidelines, the decision for operative management is at the discretion of the orthopedic surgeon. However, there are 2 instances in which this is likely: (1) a retained bullet within the joint, and (2) a transarticular injury with the bullet passing through the large bowel prior to entering the capsule. With regard to the presence of a bullet within a joint, synovial fluid is an organic acid and can dissolve lead, with potential for toxicity. Also, it may cause synovitis, secondary arthritis, and septic arthritis; thus, removal of the bullet is indicated.[71] In the latter scenario, the joint must be considered contaminated, appropriate antibiotic coverage should be provided **(see Table 6)**, and immediate washout should be performed.[72,73]

Acute Complications and Secondary Injuries

Whenever possible, care should be taken to minimize secondary injuries caused by medical interventions or sequelae of the original insult. These secondary injuries may be caused by systemic effects of the initial wound such as rhabdomyolysis leading to renal damage, post-traumatic edema causing compartment syndrome, or prolonged tourniquet use, which may cause reperfusion-related complications as well as the aforementioned complications. These are imperative to recognize and act upon urgently, as failure to do so can cause threats to life, loss of limb, and decreased functional ability (eg, decreased range of motion, sensation, or strength).

Compartment Syndrome

Clinicians should maintain high suspicion for development of acute compartment syndrome, with the anterior compartment of the lower leg and volar forearm being the highest-risk sites.[74] In addition to gunshot wounds, other pertinent risk factors include hypotension in the field, prolonged ischemia (>4-6 hours), crush injury, significant extremity swelling, pain out of proportion to examination, increasing age, and male sex.[75,76] Acute compartment syndrome in pediatric patients is important to be aware of, since there is evidence that pediatric patients take longer than adults to reach peak compartment pressures, which

Table 6. Recommended Intravenous Antibiotic Regimens for Pediatric Extremity Injuries from Firearms[66,67,69,70]

Indication	Antibiotic Choice and Dosing[a]	Duration After Initial Injury
Gustilo-Anderson classification of open fracture type I-II, low-risk transarticular wound	Cefazolin 25 mg/kg IV q8 hr; max dose 6 g/day **Or if penicillin allergy:** Clindamycin 10 mg/kg IV q8 hr; max dose 4.8 g/day	48 hr
Gustilo-Anderson classification of open fracture type III, other high-risk orthopedic injury (eg, intra-articular, transarticular with prior bowel perforation,[b] hand)	Ceftriaxone 25-50 mg/kg IV q12 hr; max dose 4 g/day **Or** Cefazolin 25 mg/kg IV q8 hr; max dose 6 g/day **PLUS** Gentamicin 2 mg/kg q8 hr; max dose ≤10 years 320 mg/day, max dose >10 years 560 mg/day **Or if penicillin allergy:** Clindamycin 10 mg/kg IV q8 hr, max dose 4.8 g/day **PLUS** Gentamicin 2 mg/kg q8 hr; max dose ≤10 years 320 mg/day, max dose >10 years 560 mg/day	72 hr

[a]Dosing intervals are based on normal renal function.
[b]Consider adding anaerobic coverage.
Abbreviations: IV, intravenous; q, every.

may lead to delayed diagnosis.[77] A 2020 meta-analysis found that, when reported, the mean time from injury to diagnosis was 22 hours, and of this subset, the mean time from injury to fasciotomy was 23.8 hours.[77] The classic teaching of clinical signs of compartment syndrome in adults emphasizes the 6 Ps (pain out of proportion, pallor, paresthesia, paralysis, pulselessness, poikilothermia), with pain out of proportion being the most sensitive sign. However, these signs are not quite as sensitive in pediatric patients, with some pediatric orthopedic literature suggesting the "3 As" of increasing anxiety, agitation, and analgesic requirement[78] as being more sensitive clinical signs. When in doubt, compartment pressure measurements may provide additional data, with a compartment pressure >30 mm Hg or within 30 mm Hg of diastolic blood pressure being highly concerning for acute compartment syndrome.[77] Comparatively, pediatric patients with compartment syndrome have better outcomes than adults even when there is a prolonged interval between injury and fasciotomy, leading researchers to advocate for fasciotomy even when intervention is late (>24 hours).[77]

Rhabdomyolysis

Another complication to assess for after extremity trauma is rhabdomyolysis. The most common presenting complaints of patients experiencing rhabdomyolysis are myalgias, weakness, and dark urine,[79] which can be easily overlooked in a trauma patient. Mainstays of treatment include aggressive hydration to minimize the likelihood of developing acute kidney injury. Though this protocol is generally supported by literature, there are no specific widely accepted guidelines for treatment of pediatric rhabdomyolysis.[80] Normal saline is the most-used crystalloid, though lactated Ringer's solution may also be appropriate, as studies have found no difference in outcomes when comparing it with normal saline. Animal studies have shown a potential benefit to adding sodium bicarbonate, with resultant decrease in renal cast formation; however, data in humans are lacking at this time. Typically, 3 amps of sodium bicarbonate are added to 5% dextrose in water, and this fluid is infused in at rates above maintenance. Regarding rate of fluid infusion, again, there is no set guideline; however, it is appropriate to administer a 20-mL/kg IV bolus in the acute setting, double maintenance-rate fluids, and adjust as needed over the next several days while monitoring creatine kinase, urine output, and for clinical signs of abnormal fluid balance. Long-term renal damage or chronic kidney disease is a rare complication of rhabdomyolysis in pediatric populations.[80]

Secondary Ischemic Injury

Prolonged limb ischemia, whether from the primary injury, compartment syndrome, or use of a tourniquet, increases the risk of amputation or development of reperfusion injury if blood flow is successfully restored. There is, once again, a paucity of data in pediatric patients, and the data that do exist are primarily from transplant, adult, and military literature. Limbs have been shown to be potentially salvageable for up to 6 hours; however, the timeline for meaningful recovery is generally accepted to be shorter and may be as short as 1 hour if hemorrhagic shock is present.[81,82] During the ischemic period, anaerobic metabolism leads to an inappropriate buildup of proinflammatory cytokines and electrolytes (eg, calcium, potassium), edema, and decreased enzyme and ribosomal function. Once blood flow is restored, there can be secondary injury to local tissues from the development of reactive oxygen species and circulating immune cells. Aside from local damage, reperfusion can also cause remote organ injury from systemic circulation of the aforementioned inflammatory cytokines, renal failure from circulation of myocyte contents (eg, creatine kinase, myoglobin), and potentially lethal arrhythmias from sudden influx of high levels of potassium. The risk for developing ischemia-reperfusion injury is directly related to the duration of ischemia as well as the muscle mass involved; thus, ischemic injury to the lower extremities or multiple extremities increases risk, and treatment is based on emergent controlled revascularization, if possible, or amputation if revascularization poses too high a risk to the patient's life.[83-85] At the time of this publication, there are efforts being made to improve limb salvage, including the use of biomarkers to predict development of post-reperfusion syndrome,[86] optimization of the perfusate used, and promising animal studies using extracorporeal membrane oxygenation (ECMO) to prolong limb viability while the patient is being stabilized.[87]

Other Complications

It should be noted that there are pediatric-specific complications of extremity trauma (eg, physeal injuries), with resultant limb-length discrepancies.[65] Interestingly, the physes may be injured even if they did not come directly in contact with the projectile, as there have been case reports of the shock wave created by a high-velocity projectile causing premature closure.[65]

Evidence appears to support the association between retained bullet fragments and increased blood lead levels,[88] and though complications from this are generally rare, clinicians should be aware of the potential for lead toxicity. One meta-analysis recommends blood lead level monitoring every 3 months for the first year after the wound occurred, with operative intervention to remove the fragment if blood lead levels rise above 5 mcg/dL.[88] For more information on managing pediatric lead poisoning, see the April 2022 issue of *Pediatric Emergency Medicine Practice*, "Lead Poisoning in Children: Emergency Department Recognition and Management," available at: www.ebmedicine.net/peds-lead-poisoning

Special Considerations

Once hemodynamic stabilization has been achieved, the clinician must go beyond terminal ballistics and acknowledge the root cause that led to the bullet in the first place. Firearm-related deaths and nonfatal injuries among teenagers and young adults in the United States are at the highest rates in more than 25 years.[3,89] The ED is a critical access point for identifying and intervening with at-risk youth, and the initial ED visit represents a timely and unique opportunity to change the predicted trajectory. An understanding of the evidence-informed strategies that can be performed or initiated in the ED targeting interpersonal violence, unintentional injury, and attempted suicide as detailed in the "Time- and Cost-Effective Strategies" section, beginning on page 17, could have a profound impact on these populations.

Controversies and Cutting Edge

Change in Paradigm: "Hard Signs Gone Soft"

Since the 1980s the terms *hard signs* and *soft signs* of vascular injury have been taught to vascular surgeons. In 1992, Frykberg clearly defined hard signs and stated that their presence should prompt immediate surgical intervention.[90] However, their value in guiding diagnosis and management has been challenged recently in a study in which 1910 limbs with an extremity arterial injury were analyzed. Based on the findings, the authors proposed assessing for hemorrhagic signs (hemorrhage or expanding hematoma) and ischemic signs (absent or diminished pulses) instead. Furthermore, they recommend preprocedural CTA for all cases if the patient is hemodynamically stable, stating that it allows for identification of sites for endovascular intervention in the former and helps plan vascular reconstruction in the latter. They also argue for the use of preoperative systemic anticoagulation in cases of isolated extremity injuries with low soft-tissue injury burden and ischemic signs.[48] Although further prospective studies are needed to validate the proposed algorithm both in adults and pediatric patients, in the era of readily-available CTA imaging, this approach may soon be embraced.

Hemostatic Devices

Preventable hemorrhagic deaths are frequently due to injuries located in regions found to be noncompressible and/or from wounds having narrow entrance sites, complicating the use of hemostatic dressings.[50,91-93] XSTAT® is an United States Food and Drug Administration-approved hemostatic sponge device developed for temporarily controlling hemorrhage in junctional wounds in adults and adolescents.[94] It is a temporary device that can be used for up to 4 hours until surgical care is available, and has been approved for both military and civilian settings. The contents of the device are injected into the wound cavity, and upon contact with blood, it will expand 12 to 15 times the original volume, exerting pressure from within the cavity without need for manual compression.[91] In 2019, Warriner et al published the first reported clinical application of XSTAT® in penetrating civilian trauma at a high-volume, level I trauma center.[95] Their case series included 10 patients, one as young as 16-years-old. The device was noted to be lightweight and portable, and deployment was found to be rapid and straightforward, without the need to locate the injured blood vessel. Temporary hemorrhage control was achieved with the initial deployment in 90% of cases.[95] Although all patients survived and underwent definitive hemostasis in either the operating room or the angiography suite, 1 patient developed rhabdomyolysis, and 2 patients were noted to have a retained sponge following initial wound exploration. Although further evaluation of the product is necessary, XSTAT® seems to be a promising adjunct in the management of uncontrolled bleeding both in the prehospital setting as well as in the ED.

Disposition

Disposition will be based on injury and intent as summarized in **Table 7**.

Table 7. Final Disposition of Pediatric Patients With an Extremity Firearm Injury, Based on Injury and Intent

Injury/Intent	Disposition
Extremity injury	*Emergent Surgical Intervention (within 6 hr)* • Hard signs or evidence of vascular injury • Compartment syndrome *Urgent Surgical Intervention (within 24 hr)* • Open/unstable fracture • Joint involvement *Admission for Observation* • Retained foreign body close to sensitive areas • Soft-tissue injury requiring serial compartment checks • Soft signs with unremarkable advanced imaging *Discharge from Emergency Department* • Without evidence of the above or concomitant injury
Suicidal ideation	Manage acute injuries. If medically cleared and true or imminent threat to self or others is present, place on a psychiatric hold while awaiting psychiatric evaluation and/or hospitalization.
Nonaccidental trauma	If nonaccidental trauma is suspected and/or there is concern for an unsafe environment, call Child Protective Services. Admission may be required even without significant injuries.

Case Conclusions

CASE 1

For the 8-year-old previously healthy boy who presented with a penetrating wound to his left upper extremity…

After confirming with EMS that the tourniquet had been in place <120 minutes and noting no other life-threatening injuries, you released the tourniquet, without signs of rebleeding. Upon reassessment of the left upper extremity, you noted a nonpulsatile hematoma with a faint but present radial pulse. There were only soft signs of an arterial injury, so you calculated an API. You noted a left upper extremity SBP of 96 mm Hg, and a right upper extremity SBP of 107 mm Hg, leading to an API <0.9. Given that the API was nonreassuring, you ordered a CTA to decide whether operative intervention would be required. The CTA was negative for arterial injury, though a superficial, circular 5 mm foreign body was noted in the left arm, without an acute fracture. The wound was explored at bedside, and the pellet was safely removed. The child's immunization status was up-to-date. He was treated with simple wound dressing and discharged home to his parents after a period of observation did not reveal rebleeding and serial neurovascular examinations remained unremarkable. Prior to discharge, the parents denied having other firearms and were informed about safe-storage practices as well as the risks of airguns. They agreed to remove the airgun from the child's environment.

Summary

Firearm injuries are a leading cause of pediatric mortality. Extremities are the most frequent injury location. Prehospital personnel should focus on external hemorrhage control with direct pressure and tourniquets, if indicated. In the ED, hemorrhage control and hemostatic resuscitation are the priorities. Vascular hard signs, evidence of vascular injury on advanced imaging, and open or unstable fractures necessitate emergent operative intervention. Special care should be taken to monitor for and prevent complications including rhabdomyolysis, compartment syndrome, and reperfusion injury. Given the complexity of firearm injuries, clinicians should involve consultants early or expediently transfer the patient to a pediatric trauma center. In addition, clinicians should acknowledge the root causes of pediatric firearm injuries and initiate evidence-based interventions in the ED to try to prevent future pediatric firearm injuries.

Time- and Cost-Effective Strategies

All but 5 jurisdictions (Alabama, New Mexico, Wyoming, American Samoa, and Guam) have laws mandating that healthcare providers report specific injuries to law enforcement.[96] With regard to firearm injuries, some states and territories require only nonaccidental wounds be reported, while others require all to be reported, regardless of intent. Reviewing individual state and territory laws regarding circumstance, timing, and reporting method (telephone or writing) is recommended. If the child is deemed to be in danger of abuse or neglect, Child Protective Services should also be notified separately.

Concise, unbiased bedside counseling to gun-owner parents or guardians and teenage patients should include the suggestion to remove the gun from the house, particularly if acute suicidal ideation is present. If removing the gun is not an acceptable option, then recommend the following:

- Guns should be stored locked in a lockbox, gun cabinet, or with cable locks.
- Guns should be stored unloaded.
- Ammunition should be stored in a separate lockbox.

An innovative strategy that has shown promising results in office-based, primary care settings is to distribute free safe-storage devices to gun-owner parents or guardians.[97] Because the ED reaches at-risk children and adolescents who lack a primary care physician, extending this practice to the bedside could be even more impactful.

With regard to interpersonal violence, it has been 30 years since trauma has been recognized as a chronic recurrent disease.[98] Encountering a child or adolescent who survived a firearm injury should be viewed by the clinician as a sentinel event. Retrospective studies have shown that, for at-risk youth who survive an initial episode, there is a >50% risk of a repeat incident within 2 years[11] and increased risk of death from subsequent trauma compared to patients without a prior presentation.[12] It is important for clinicians to recognize the ED visit as a "teachable opportunity" and strive to initiate interventions to reduce firearm injury recurrence.[12] This is particularly relevant for patients whose injuries are deemed not severe enough to require hospitalization and who will be discharged immediately back into the circumstances that led to the initial injury. Keep in mind that the most cost-effective strategy is to prevent a second injury, while the most unfortunate risk management caveat is to focus solely on the ABCDE of trauma resuscitation.

Regardless of the reported intent, all patients

should be screened for firearm access, mental health concerns, and substance abuse.[89] Clinicians and/or other ED staff (eg, nurses, social workers, case managers) should receive appropriate training to be ready to counsel on safe-storage practices and firearm safety and be aware of hospital-based and community-specific resources available for firearm-injury survivors in the communities they serve. Given that exposure to violence can lead to trauma, efforts to refer the patient to trauma-focused mental health services are imperative to "promote healing and to mitigate the disproportionate impact of youth in marginalized communities."[89] Ideally, a counselor trained in trauma-informed care can address issues such as retaliation and gun access, and introduce the patient to a hospital-based violence intervention program. Violence intervention programs that embrace a trauma-informed approach and incorporate culturally sensitive wraparound case management have been shown to reduce recidivism.[8,99] These programs can be cost-effective, given that they lead to a substantial decrease in hospital readmissions and incarceration rates.[100]

References

Evidence-based medicine requires a critical appraisal of the literature based upon study methodology and number of subjects. Not all references are equally robust. The findings of a large, prospective, randomized, and blinded trial should carry more weight than a case report.

To help the reader judge the strength of each reference, pertinent information about the study, such as the type of study and the number of patients in the study is included in bold type following the references, where available. The most informative references cited in this paper, as determined by the authors, are noted by an asterisk (*) next to the number of the reference.

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5 Things That Will Change Your Practice

1. Pediatric firearm injuries are sentinel events and provide an opportunity for emergency clinicians to initiate evidence-based interventions to help reduce recidivism.
2. For pediatric patients, the 3 As (increasing anxiety, agitation, and analgesic requirement) may be more sensitive clinical signs for compartment syndrome than the classically taught 6 Ps (pain out of proportion, pallor, paresthesia, paralysis, pulselessness, poikilothermia).
3. In children, blood pressure is maintained until 30% to 40% blood loss. Hypotension is a late finding and definitive of decompensated shock.
4. Clinicians must be aware of the potential for injuries resulting from not only the bullet trajectory but also the shock-wave and cavitation that can occur.
5. Bullets are not sterilized by the ballistic processes they undergo. Antibiotic coverage for most firearm injuries is still prudent.

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Risk Management Pitfalls for Pediatric Firearm Injuries to the Extremity

1. **"He had no vascular injury, full range of motion of his knee, and a normal sensory evaluation. I did not know that a bullet in the knee joint had to be removed!"** Bullets that violate the joint space can lead to a septic joint, mechanical arthritis, and even lead poisoning. Because of this, regardless of the presence of other indications for operative management, removal should be the norm.

2. **"A 9-year-old boy presented after an airgun injury to his leg. I removed the pellet under sterile technique and discharged the boy. I assumed he was vaccinated and did not provide tetanus prophylaxis."** Projectiles are not sterile, and wounds may be further contaminated by clothing or debris. Tetanus prophylaxis should follow CDC guidelines. In unvaccinated children, both the tetanus immune globin as well as the tetanus vaccine need to be administered. The patient should receive the next dose per age-appropriate schedule.

3. **"A 17-year-old boy presented with a through-and-through GSW to the forearm. I didn't think it would lead to compartment syndrome!"** A gunshot wound to an extremity can cause fractures or significant soft-tissue damage, leading to increased compartment pressures, regardless of the presence of a through-and-through wound. Diligent and serial clinical examinations should be performed, and if compartment syndrome is suspected, compartment pressures should be measured.

4. **"We were experiencing delays with transport to an institution with surgical capabilities, and we were concerned the patient was losing limb viability, as the tourniquet had been on his leg for several hours. We applied pressure dressings and tried to release the tourniquet. Now he's developing arrhythmias, and we're fighting to keep him hemodynamically stable."** Remember that muscle mass and increasing duration of ischemia are risk factors for reperfusion injuries, which can include remote organ injury and systemic effects. If there has been prolonged ischemia, tourniquet release should be performed in a location where the development of reperfusion injury can be promptly identified and effectively managed.

5. **"The child's blood pressure was appropriate for age. How could I have realized he was in shock!"** In children, blood pressure is maintained until 30% to 40% blood loss. Persistent tachycardia should alert the clinician to the presence of compensated shock. Hypotension is a late and ominous finding and definitive of decompensated shock.

6. **"We were so focused on the hemorrhaging leg that we didn't see the GSW to the left axilla until he began to decompensate."** Beware of distracting injuries that may prevent you from finding other less apparent but equally lethal injuries such as tension pneumothorax, hemothorax, hemoperitoneum, and/or cardiac tamponade.

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7. **"The child presented with a single GSW to his left thigh. EMS placed a tourniquet in the field and transported him immediately to our ED. I didn't want to take the tourniquet off because he was being transferred to a pediatric trauma center. The transfer got delayed. A CTA done at the pediatric trauma center did not reveal vascular injury, but because the tourniquet was on so long, they had to amputate his leg."** To prevent complications such as limb ischemia, the clinician should attempt to remove the tourniquet in the ED if no contraindications are present. Contraindications for removal in the ED are hemodynamic instability, life-threatening injuries that take precedence over limb salvage, amputation distal to tourniquet placement, and inability to closely monitor for rebleeding or reperfusion injury. Once released, if no significant bleeding is noted, the tourniquet can be removed, a dressing placed, and the patient monitored for significant bleeding for at least an hour.

8. **"He was brought in by police 4 weeks ago for a superficial GSW to his left calf. I discharged him after a complete trauma assessment did not reveal any significant injuries. He was brought in again today in traumatic cardiac arrest. I don't think he will make it."** Trauma has been recognized as a chronic recurrent disease. Children and teenagers who are victims of interpersonal violence have a high rate of recidivism and death from subsequent trauma. It is important for clinicians to recognize the ED visit as a "teachable opportunity" and strive to initiate interventions such as a hospital-based violence intervention program.

9. **"A 6-year-old girl presented with a GSW to her right upper extremity. She was accidently shot by her 9-year-old brother who was playing with their father's gun. The wound was a tangential graze without any concerning findings. I did not think I needed to report this."** In most states, clinicians are mandated reporters of firearm injuries. Clinicians should be familiar with state laws, and the ED should have systems in place for timely reporting as required by law. In this case, the child has experienced a threat to life and limb due to unsafe firearm storage practices or supervision. Depending on the state in which the incident occurred, reporting this incident to local law enforcement may be mandated. In addition, if the child's environment is deemed to be unsafe, notifying Child Protective Services may prevent this child and other children from sustaining future injuries.

10. **"The child we treated at the beginning of the shift with the GSW to the shin is getting more and more fussy even though we're treating his pain appropriately."** Remember to perform serial examinations to ensure compartment syndrome is not developing. The lower leg and volar forearm are high-risk areas, and children can take longer than adults to begin developing compartment syndrome. Furthermore, their presenting signs may be more subtle than in adults. Thus, in children, keep in mind the 3 As (agitation, anxiety, and increased analgesic requirements) rather than the 6 Ps when considering acute compartment syndrome.

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CME Questions

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1. **A 17-year-old boy is brought into the ED after sustaining a gunshot wound to the right upper extremity. He has stable vital signs. Upon removal of the tourniquet placed by EMS, you note an expanding hematoma. Pressure is applied, and after the wound is packed with hemostatic gauze, bleeding is controlled. What is the best next course of action?**
   a. Perform local wound exploration and stop the bleeding.
   b. Perform computed tomography angiography (CTA).
   c. Initiate fluid resuscitation and massive transfusion protocol.
   d. Measure the arterial pressure index (API).

2. **A 15-year-old girl is shot multiple times in the left lower extremity. CTA imaging shows damage to the anterior tibial artery, with a retained bullet fragment noted in the distal thigh near the femoral artery; however, the artery itself remains intact. In addition to interventional radiology consultation for the damaged anterior tibial artery, what management is indicated?**
   a. Consider removal of shrapnel to prevent infection.
   b. Consider removal of shrapnel to prevent damage to nearby critical structures.
   c. Administer a prolonged antibiotic course to cover for bacteria present on retained shrapnel.
   d. No further intervention is needed.

3. **An 11-year-old boy is brought into the ED with a gunshot wound to the shoulder. En route, he was found to be tachycardic for his age and was given 2 IV boluses of 20 mL/kg crystalloid fluids. Upon arrival, he continues to be tachycardic with a heart rate of 153 beats/min, is diaphoretic, pale, and appears obtunded. He has a patent airway and equal breath sounds bilaterally. There are several layers of gauze over his right shoulder wound, which appear soaked with blood. An extended focused assessment with sonography in trauma (EFAST) is unremarkable. What should be the next step in the patient's resuscitation?**
   a. Initiate a 10-mL/kg bolus of packed red blood cells.
   b. Perform local wound exploration and debridement.
   c. Give an IV bolus of 20 mL/kg normal saline.
   d. Perform an in-depth neurological examination of the right arm.

4. **A 13-year-old boy presents as a transfer from a critical-access hospital after suffering a shotgun injury to the right upper extremity. The transferring hospital staff were unable to stop his bleeding and had applied a tourniquet at 9:30 AM. It is 11:00 AM as he arrives at your pediatric trauma center. An attempt to remove the tourniquet showed the patient has pulsatile bleeding that cannot be controlled with direct pressure. The tourniquet is replaced, but the bleeding does not resolve. What is the immediate next step?**
   a. Place another tourniquet over the adjacent joint.
   b. Consult general surgery.
   c. Place another tourniquet distal to the first tourniquet.
   d. Place another tourniquet proximal to the first tourniquet.

5. **A 12-year-old boy presents to the ED after a hunting accident in which he suffered a shotgun blast to the right upper extremity. He has multiple injuries to the extremity and was noted by EMS to have pulsatile bleeding. No other injuries are noted. The patient underwent initial stabilization in the trauma bay, with pulsatile bleeding once again noted, but temporarily controlled with hemostatic dressings. What is the next step in the management of this patient?**
   a. Proceed directly to the operating room for intervention to salvage the limb.
   b. Measure API.
   c. Apply a tourniquet.
   d. Measure compartment pressures.

6. **While re-evaluating a 5-year-old child with a gunshot wound to the left forearm, the clinician notes increased agitation, anxiety, and pain despite high doses of parenteral opioids. What is the best next step?**
   a. Administer an anxiolytic.
   b. Repeat a CTA to assess for delayed bleeding.
   c. Perform local wound exploration.
   d. Measure compartment pressure.

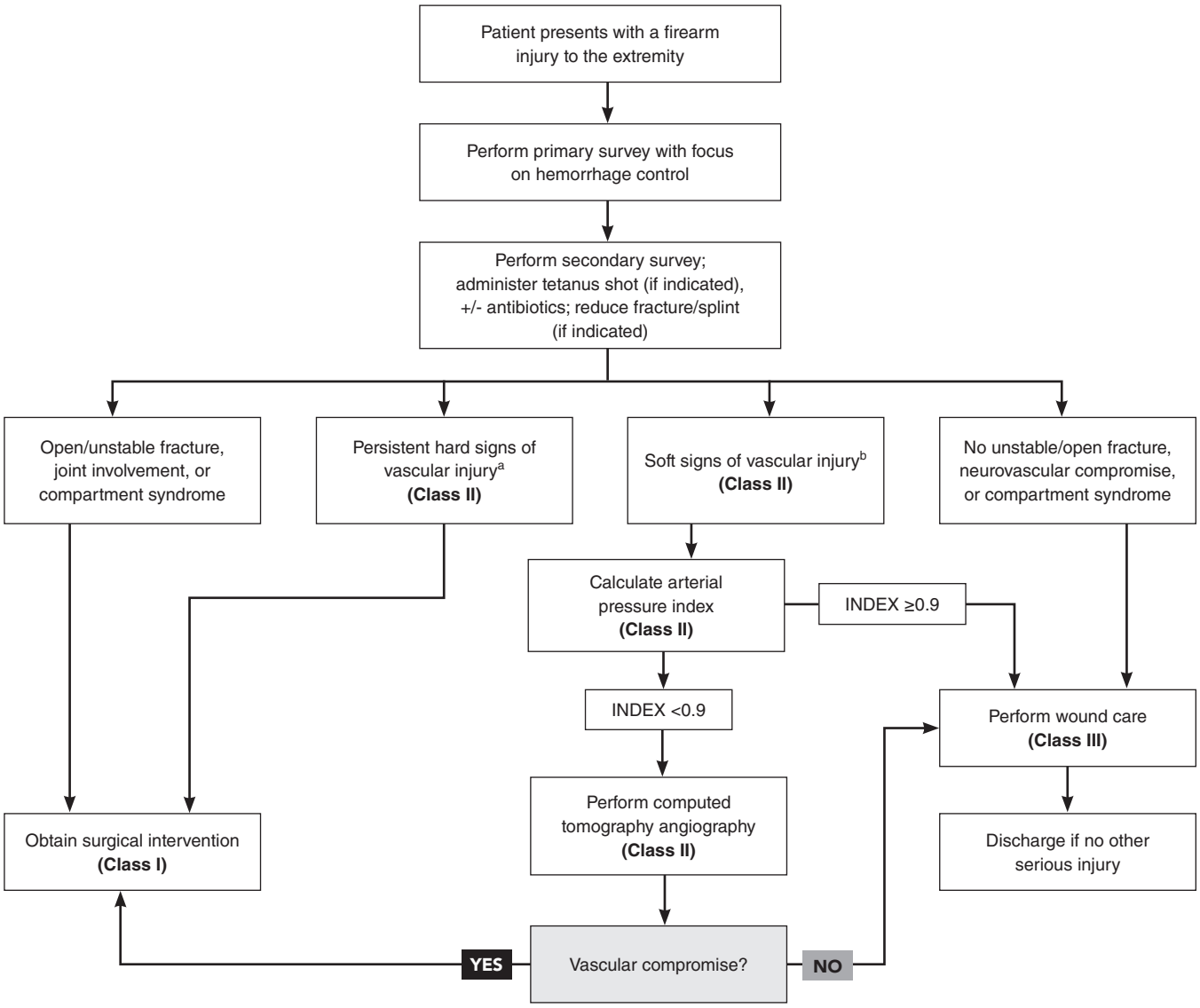
7. **While waiting for transfer of a patient to a pediatric trauma center, you note dark-colored urine in the Foley catheter of a child who sustained a shotgun injury to his left thigh. What is the best next step?**
   a. Start a norepinephrine drip.
   b. Administer calcium gluconate and other potassium-lowering strategies.
   c. Administer a 20-mL/kg IV bolus of crystalloid fluid and start double maintenance fluids.
   d. Replace the Foley catheter and start the patient on antibiotics.

8. **A 17-year-old girl presents to a pediatric trauma center after being transferred from another ED for a gunshot wound to the left thigh. A tourniquet was placed 6 hours ago for bleeding control. After removal of the tourniquet, you note hypotension and a sine-wave rhythm on the monitor. The girl is experiencing:**
   a. Hemorrhagic shock
   b. Reperfusion injury
   c. Acute compartment syndrome
   d. Septic shock

9. **A 6-year-old girl presents by EMS after sustaining a gunshot wound to the left lower extremity while playing with a family member's handgun. ED workup is completed, and no fractures or neurovascular injuries are identified on examination or plain radiographs. Trauma surgery recommends no surgical intervention. What is the next step in the management of this patient?**
   a. Obtain a CTA of the injured extremity to evaluate for occult vascular injury/dissection.
   b. Consult orthopedic surgery emergently over concern for an occult physeal injury.
   c. Discharge home with simple wound dressing.
   d. Call Child Protective Services.

10. **A 14-year-old girl is brought to the ED by her father for "an evaluation," given that a schoolmate recently died by suicide. The patient denies suicidal ideation, depression, or hopelessness. She denies substance abuse or prior mental health disorders. During your assessment, you are made aware that there is a handgun at the home. The father states that it has sentimental value and is not willing to remove it from home. The next step in management is to:**
   a. Inform the police and call Child Protective Services.
   b. Refer them to their pediatrician for counseling.
   c. Discuss safe-storage practices with the father.
   d. Admit the patient, given the unsafe environment.

Clinical Pathway for Managing Pediatric Extremity Injuries from Firearms



[a]Hard signs of vascular injury: pulsatile bleeding, expanding hematoma, thrill, bruit, pulselessness, pallor, neurologic deficit.
[b]Soft signs of vascular injury: history of prehospital arterial bleed, wound in proximity to major vessels, small nonpulsatile hematoma.

Class of Evidence Definitions

Each action in the clinical pathways section of *Pediatric Emergency Medicine Practice* receives a score based on the following definitions.

Class I
- Always acceptable, safe
- Definitely useful
- Proven in both efficacy and effectiveness

Level of Evidence:
- One or more large prospective studies are present (with rare exceptions)
- High-quality meta-analyses
- Study results consistently positive and compelling

Class II
- Safe, acceptable
- Probably useful

Level of Evidence:
- Generally higher levels of evidence
- Nonrandomized or retrospective studies: historic, cohort, or case control studies
- Less robust randomized controlled trials
- Results consistently positive

Class III
- May be acceptable
- Possibly useful
- Considered optional or alternative treatments

Level of Evidence:
- Generally lower or intermediate levels of evidence
- Case series, animal studies, consensus panels
- Occasionally positive results

Indeterminate
- Continuing area of research
- No recommendations until further research

Level of Evidence:
- Evidence not available
- Higher studies in progress
- Results inconsistent, contradictory
- Results not compelling

The *Pediatric Emergency Medicine Practice* Editorial Board

QUICK READ

Points & Pearls

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Pediatric Firearm Injuries to the Extremity: Management in the Emergency Department

Points

- Exsanguinating pediatric firearm injuries to the extremity in which bleeding is not controlled with hemostatic gauze should prompt immediate application of a tourniquet.
- If possible, the tourniquet should be removed within 120 minutes. Contraindications to removal include distal traumatic amputation, hemodynamic instability, other life-threatening injuries, and inability to monitor the wound for signs of rebleeding.[64] **(See Table 5, page 12.)**
- If the tourniquet has been in place for >120 minutes, be prepared to monitor and manage complications such as rhabdomyolysis and/or compartment syndrome.
- Hard signs of extremity injury include pulsatile external bleeding, expanding hematoma, thrill, bruit, pulselessness, pallor, and/or neurologic deficit.[45]
- If hard signs are absent, calculate an arterial pressure index (API) by comparing the systolic blood pressure obtained through Doppler evaluation of the injured extremity over the systolic blood pressure of the uninjured extremity.
- Obtain a computed tomography angiogram if the API is <0.9 or if there is any concern for a vascular injury.[47]
- Gunshot wounds that violate the joint capsule and open fractures likely benefit from early (<3 hours) antibiotic coverage. The Gustilo-Anderson classification for open fractures can help guide antimicrobial management.[66,67,69,70] **(See Table 6, page 13.)** Recently, the use of ceftriaxone alone without the use of an aminoglycoside has been advocated for type III open fractures, without an increase in soft-tissue infections.[69]
- Involve consultants early, as these injuries require a multidisciplinary approach with contributions from trauma, vascular, and/or orthopedic surgeons.
- Indications for immediate operative intervention include hard signs of vascular injury, inability to remove a tourniquet given significant bleeding, occlusive injury of a major artery causing impaired perfusion, or development of compartment syndrome.
- To decrease complications (eg, compartment syndrome, rhabdomyolysis, or limb ischemia), revascularization should be achieved as soon as possible, despite classic teaching of limb viability for up to 6 hours.
- For retained bullet fragments, discuss the potential need for serial blood lead level monitoring and possible removal if blood lead level exceeds the recommended value.[88]
- Inform parents and patients about the potential for physeal injuries leading to limb-length discrepancies that may result from the shock wave created by high-velocity projectiles.[65]
- Regardless of the intent, pediatric firearm injuries are sentinel events and provide an opportunity to discuss safe-storage practices and to screen for mental health concerns and substance abuse.[89]
- Review the state or territory laws regarding mandated firearm injury reporting to law enforcement.
- Child Protective Services should be notified separately if the child is deemed to be in danger of abuse or neglect.

Pearls

- Tachycardia and delayed capillary refill are early signs of compensated shock.
- CAT® tourniquets can be used in children as young as 2 years of age. Tourniquets should be placed proximal to the wound. Once the strap is tightened around the humerus or femur, twist the windlass until the distal pulse is no longer palpable. **(See Figure 5, page 7.)**
- Clearly document on the tourniquet and/or the chart the exact time of application.
- Beware of the "3 As" (increasing anxiety, agitation, and analgesic requirement) seen in pediatric compartment syndrome.[78]
- Safe-storage practices that should be discussed with patients and guardians are: guns should be stored unloaded and locked in a lockbox, and ammunition should be stored in a separate lockbox.