Trauma Tips and Tricks: Current Concepts Review of Ballistic Injuries

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Introduction

Gun violence and ballistic injuries are serious public health problems in the United States that are associated with substantial morbidity and often require orthopedic expertise in treatment. The incidence of firearm injuries has increased in recent years. An estimated 134,000 nonfatal firearm injuries occurred nationally in 2017, an increase of over 50% from two years prior according to the Centers for Disease Control and Prevention.[1] The majority of these injuries occur in urban areas, like Philadelphia, which saw 2,266 shooting victims in 2020, nearly double the number from 2015.[2] Firearm injuries continue to rise with 354 shooting victims from Jan 1st–March 3rd 2022.[3] The violence predominantly affects males, those under the age of 35, and racial minorities. In Philadelphia, people of color comprised 95% of gunshot wound (GSW) victims in 2021.[2] Therefore, proper treatment of GSW injuries is an important component of health equity. This article reviews basic management of GSW injuries along with specific insights obtained from working at a high-volume urban Level 1 Trauma Center.

Guns, Ammo, and Ballistic Wounds

Current firearms can be classified in three basic categories: shotguns, rifles, and handguns. Shotguns are smoothbore with limited range, firing either multiple pellets or a single projectile (slug). Wadding is used to separate the propellant from the projectiles. Rifles are long barreled with parallel spiraling grooves along the bore, called rifling, which gives ejected bullets rotational spin. With this stabilization, rifles can fire powerful ammunition with increased range and accuracy. Handguns may also have rifling along their barrels but are typically less than 30 cm in length.[4] Handgun rounds are generally less powerful and less accurate. Exceptions to this rule, however, are increasingly relevant as rifle and handgun distinctions blur.

Bullets are typically lead alloy projectiles (Figure 1). Two key variations on a standard solid design include jacketed and partially jacketed bullets. Jacketed rounds are composed of a soft lead core encased in a harder metal alloy. Partially jacketed bullets, "hollow point," have an exposed tip which allows the projectile to flatten and expand on impact. This transmits more force and leads to more significant and complex injuries.

Ballistic wound character and severity are therefore heavily influenced by mechanism of injury as much as anatomic location. First, the kinetic energy (KE) of a bullet is greatly influenced by the projectiles speed ($KE = \frac{1}{2} * MV^2$). Conventional categorization relies on this characteristic in grouping injuries as either resulting from bullets at low-velocity (< 2,000 ft/s) or high-velocity (> 2,000 ft/s). However, actual energy transfer is an important

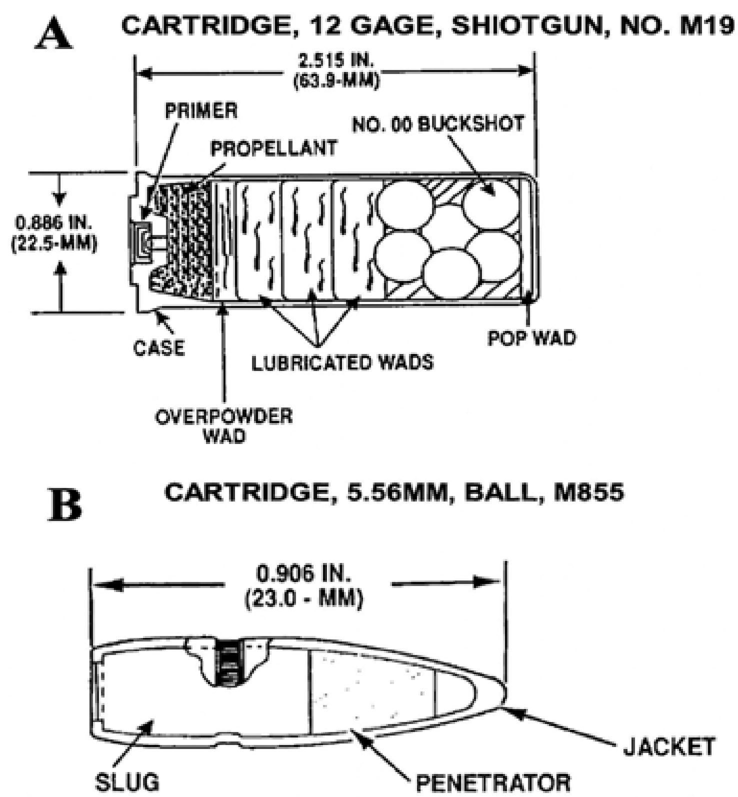

Figure 1.[20] **(A)** Schematic of a 12-gage shotgun round; **(B)** Schematic of a 5.56 millimeter, fully jacketed rifle bullet commonly used in military and civilian rifles

component of the injury. A bullet which comes to rest within the body will transfer its entire KE after impact, compared to the smaller fraction of a bullet which exits. Bullets create a permanent cavity through the tissue though often not in a straight path. Upon impact, the projectile experiences increased yaw, the angle between bullet axis and its initial trajectory, and after 15 degrees will begin to tumble. Bullet trajectory is further altered by fragmentation or striking bone. In high velocity injuries, tissues adjacent to the direction of travel of the projectile will undergo a rapid radial expansion. This expansion forms a temporary cavity with significant damage to small blood vessels and peripheral nerves, and may cause simple fractures.

Acute management

Death prior to arrival of first responders on scene is a major driver of firearm mortality. Philadelphia has sought to reduce prehospital time by allowing police to directly transport to trauma centers.[5] On arrival, patients are stabilized per ATLS protocols. In the trauma bay at Penn Presbyterian, airway, breathing, and circulation are rapidly assessed as the patient is fully exposed. All penetrating wounds are then identified and marked with taped paperclips (closed for anterior and open for posterior) to assist in trajectory identification (Figure 2). The presence of a single wound (or odd number) increases suspicion for a retained bullet. Wounded areas are assessed for pallor, gross contamination, joint effusions, exposed bones, and compartment swelling. Vascular examination using ABI/ABPIs are conducted in cases of poor perfusion or pulsatile bleeding with CT angiography available for continued concern. A neurologic exam documents baseline function. Tetanus prophylaxis is given and, time permitting, wounds are irrigated to remove gross debris, photographed, and dressed. Standard radiographs are taken for assessment of possible fractures, retained bullets, and joint injuries. The fracture is then reduced when necessary and splinted. Skeletal traction is applied for fractures of the acetabulum, femur, or if there are retained materials in the joint (Figure 3).

Treatment Overview

Low velocity GSW fractures can often be treated similar to closed injuries with the goal of restoring function and minimizing complication. Formal debridement is typically not required, and patients are treated with simple wound care and a short course of oral broad-spectrum antibiotics. Stable fractures can be managed conservatively with appropriate wound care. The ulna and tibia remain exceptions, with increased rates of infection stemming from their relatively subcutaneous position. These are treated as open fractures with operative irrigation, debridement, stabilization, and soft tissue coverage as needed.[6] Exploration for soft tissue bullet removal is not recommended due to the risk of damage to surrounding structures. Symptomatic subcutaneous bullets, however, should be removed.

High velocity GSW fractures require more complex treatment emphasizing life and limb saving procedures. Extensive soft tissue injury can include vital end organs which require management by general trauma surgeons. In cases of severe trauma, controlling bleeding is imperative to prevent the lethal triad of hypothermia, coagulopathy, and acidosis. Wound hemorrhage should be managed with direct pressure using a sterile dressing (Figure 3), followed by neurovascular

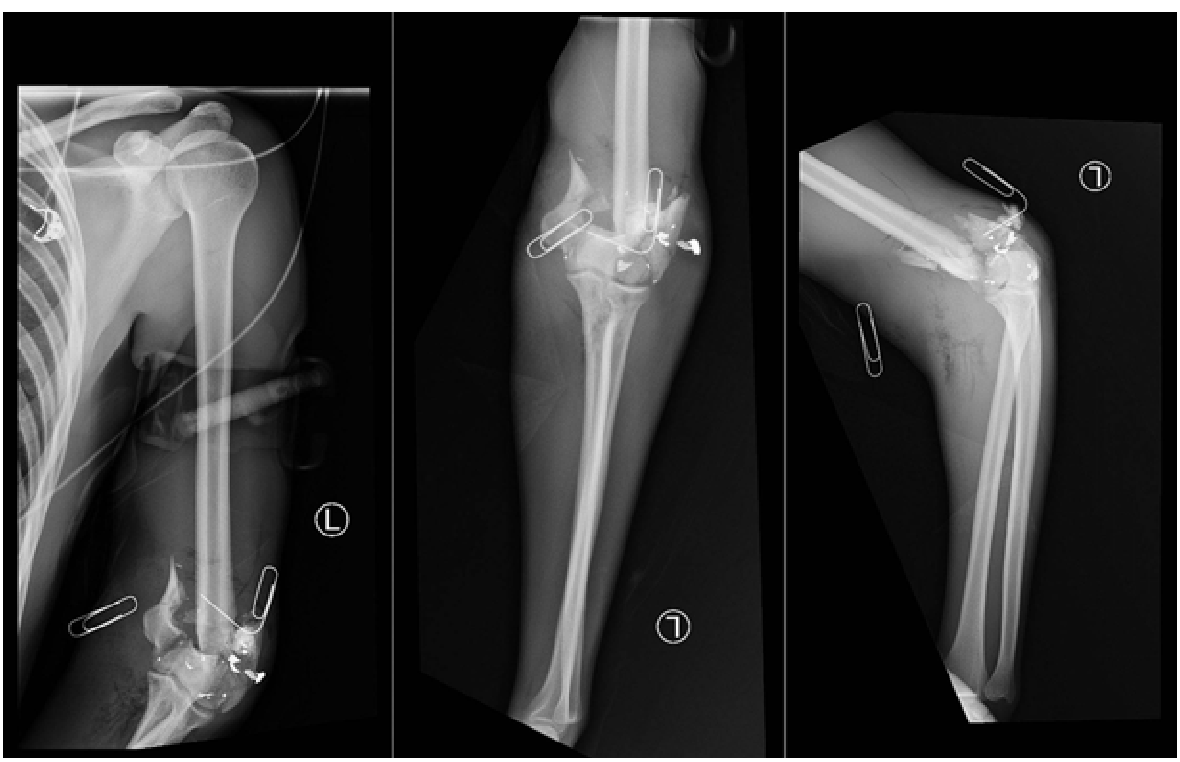

Figure 2. Portable radiographs of 20yo male in trauma bay demonstrating comminuted left distal humerus fracture with retained ballistic fragments.

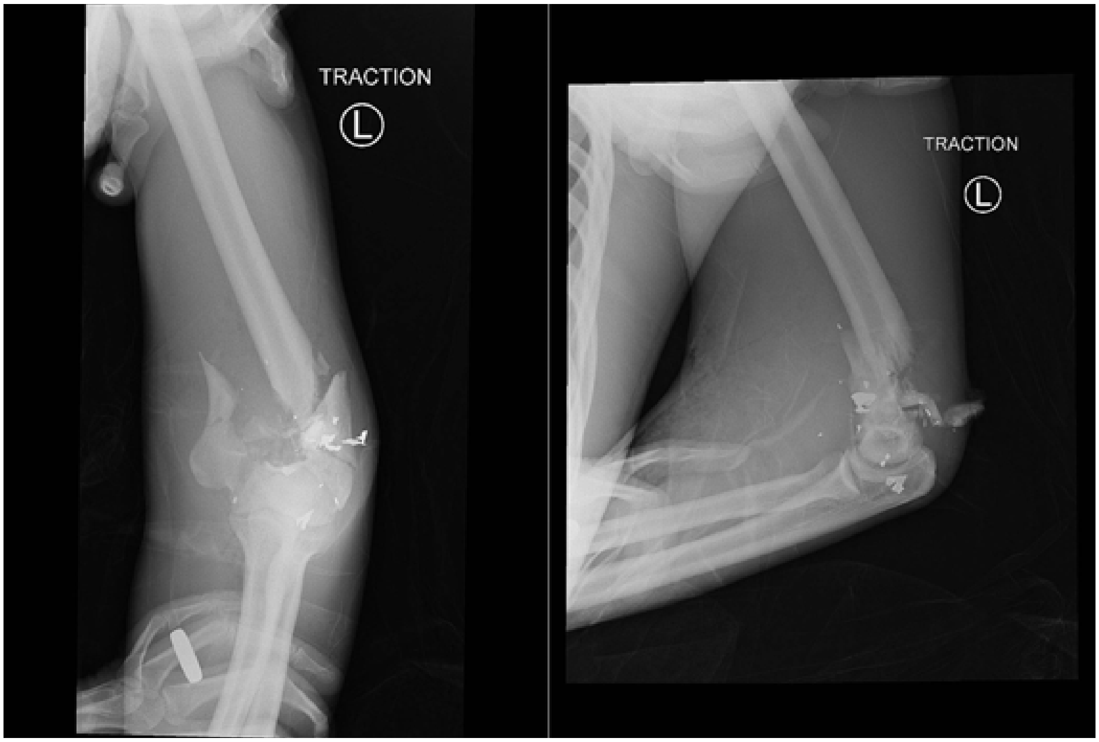

Figure 3. Traction views of comminuted left distal humerus fracture to evaluate for retained fragments

assessment of the limb with fracture reduction if possible. Tranexamic acid is administered to halt fibrinolysis if injury has occurred within three hours of arrival. The patient should be resuscitated as needed with blood products in 1:1:1 (platelets: fresh frozen plasma: packed red blood cells).[7] Serum lactate should be taken regularly to monitor adequate volume resuscitation. Additionally, calcium levels should be monitored and repleted to prevent coagulopathy. Hypothermia is corrected with active warming. Damage control surgery will prioritize hemorrhage control with the duration determined by the physiologic state of patient and definitive surgery deferred to a future date.

Intra-articular Injuries

Bullets retained within the joint space are associated with a high rate of infection, mechanical wear, and lead toxicity.[8] As such, intraarticular injuries with retained bullets should undergo I&D with bullet removal (Figure 4). The bullet or fragment should also be considered for removal if proximal enough to the joint to limit mobility and affecting neurovascular structures. However, cases in which the bullet passes through the joint space with minimal articular damage do not require surgical debridement unless there is high suspicion of contamination within the joint. Arthroscopy can be used for many cases of irrigation and debridement. For example, the arthroscopic debridement of the knee can assess soft tissue injuries while removing fragments of bullets and loose bodies.[9]

Antibiotics/Infection

Low velocity GSW fractures treated operatively are managed with standard perioperative antibiotics. Debate continues around the best antibiotic regiment for non-operatively treated GSW fractures. Not only is there no clear superiority between oral and intravenous antibiotics in recent meta-analysis,[10] but also some studies show no significant difference in infection rates in GSW fractures treated with antibiotics versus those that are not treated with antibiotics.[11] Furthermore, gram negative coverage is not necessary in operative or non-operative treated patients based on similar infection rates between first and third generation cephalosporins.[12,13] At Penn, a single dose of first-generation cephalosporin is employed to reduce the risk of microbial resistance and avoid antibiotic side effects.

High velocity GSW fractures are treated as open fractures and require early administration of antibiotics.[14] First generation cephalosporin are employed for 48–72 hours (potentially longer in cases of serial debridement) with no additional requirement for enhanced gram negative coverage.[15] In situations with significant bone loss, soft tissue injury, or both, antibiotic-impregnated polymethylmethacrylate (PMMA) beads can be added for dead space management and synergy with intravenous antibiotics.

Vascular Injuries

Vascular injury should be identified quickly as these patients are at risk of not only volume depletion but also associated nerve injury and infection. In lower extremity GSW injuries, ankle-brachial indexes should be obtained, where a ratio of < 0.9 necessitates further vascular assessment (e.g., vascular consult, CTA, MRA, angiography). In the event of vascular injury, proximal control should be obtained through either a tourniquet (distal injuries) or surgical vascular control (abdomen or pelvis). Surgical treatment includes shunting to restore blood flow, provisional or definitive bony stabilization,

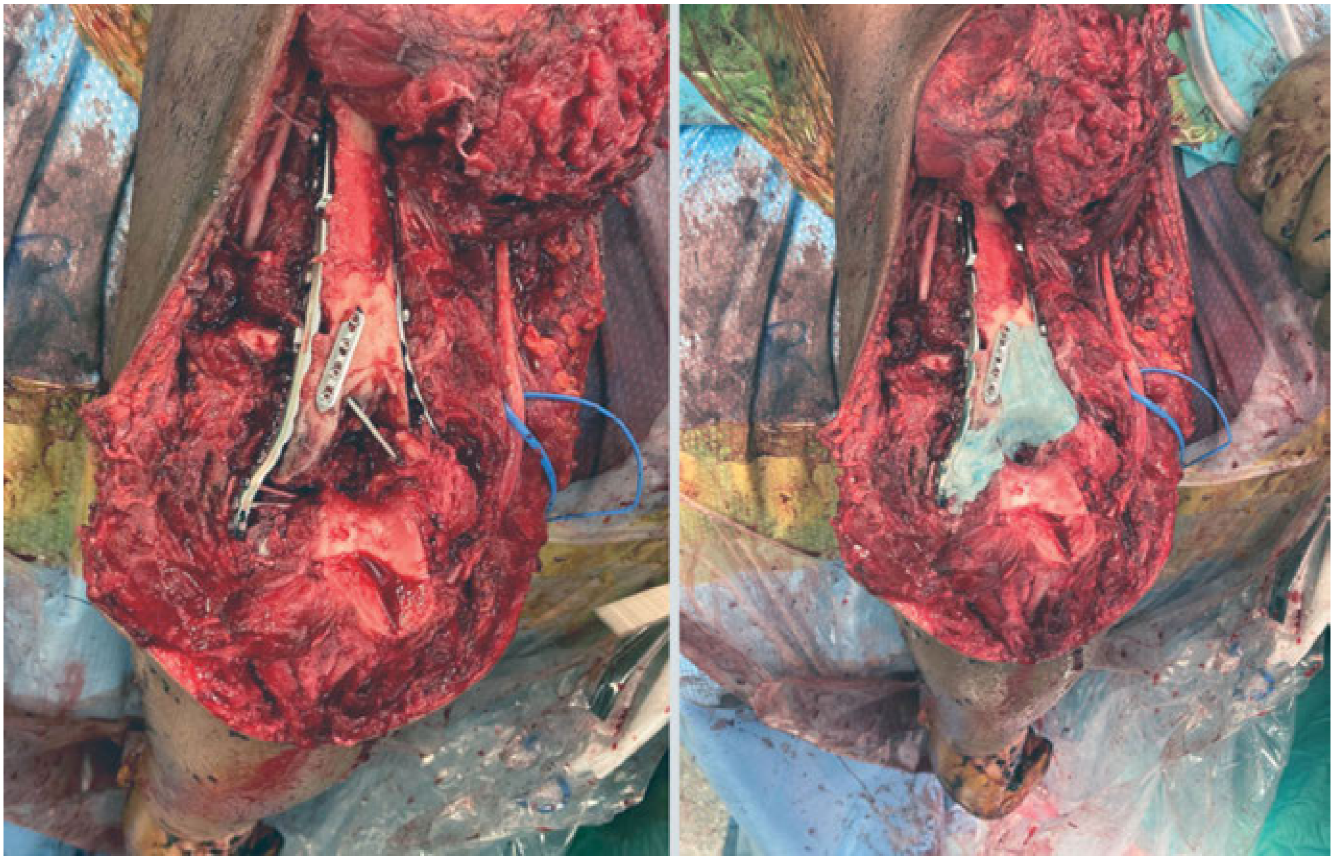

Figure 4. Intraoperative pictures of left distal humerus irrigation and debridement, open reduction internal fixation, and distal humerus reconstruction of cortical defect with cement.

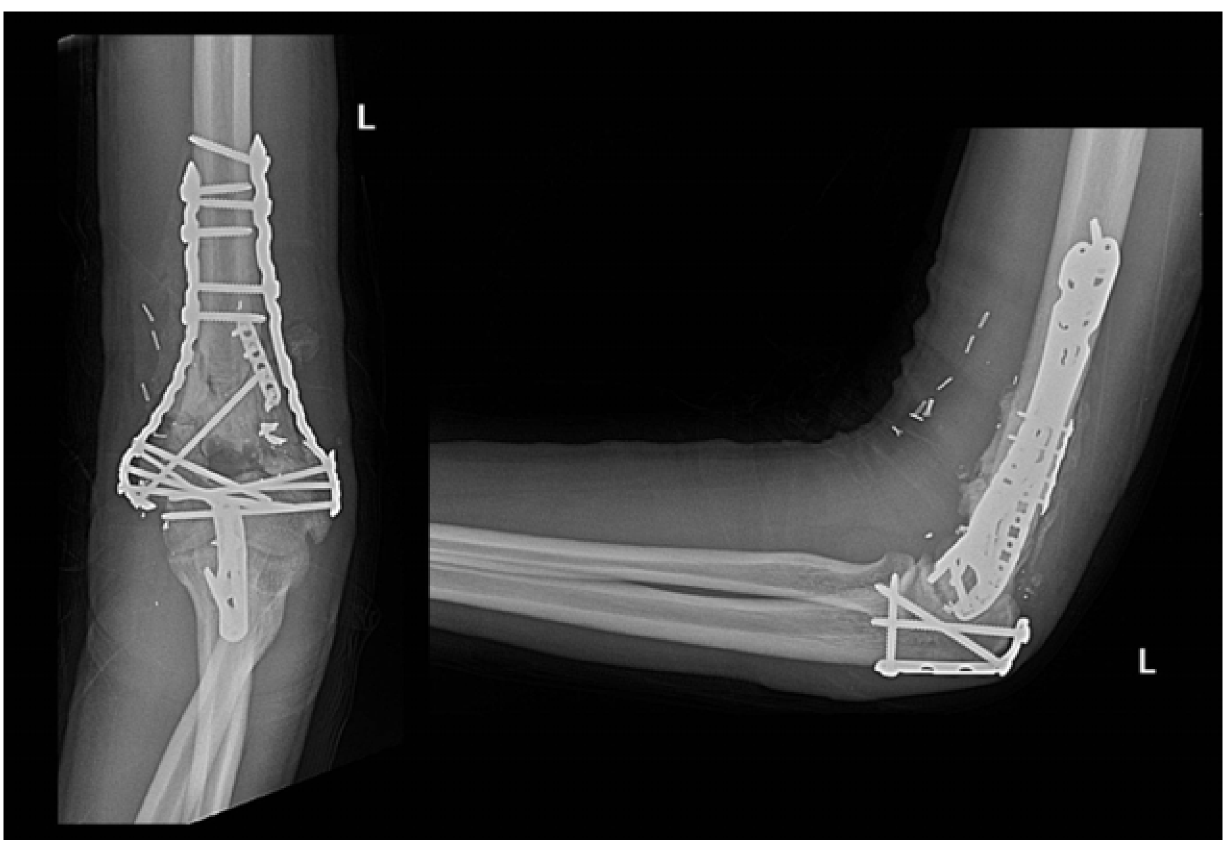

Figure 5. Three month post-operative AP and lateral radiographs with intact hardware. Patient's range of motion full supination/pronation, 45-110° flexion/extension.

vascular repair, and fasciotomies. GSW fractures with associated vascular injuries have a higher rate of infection and should be monitored closely.[16]

Nerve Injuries

Nerve injuries in GSW trauma should be identified early with a neurologic examination of the limb when able. A vascular injury should increase suspicion of a nerve injury because 71% of patients with an arterial injury will also have an associated nerve injury.[17] However, a nerve impairment does not diagnose neurotmesis (laceration). Nerves in the vicinity of a high-velocity GSW may sustain significant intraneural damage, axonotmesis.

In cases of nerve laceration, the ends should be tagged and repaired if the wound is clean. Nerve conduction studies should be conducted only in a delayed fashion (usually three or more weeks from time of injury) to allow for Wallerian degeneration signs to appear.[18] When patients show no signs of improvement three months after initial GSW injury, referral to a peripheral nerve specialist should be considered. Persistent neuropathic pain is often the result of severe scar tissue constricting an otherwise intact nerve. Creation of a healthy tissue bed is essential to nerve recovery which may require soft tissue coverage procedures like local soft tissue rearrangement or fasciocutaneous free tissue flaps. Mixed motor and sensory nerves such as the common peroneal, ulnar, and median nerve tend to have worse outcomes.[19]

Summary

Increasing gun violence in the United States has now brought ballistic injuries once exclusive to warfare to many civilian trauma centers. Management of GSW injuries is related to the amount of energy imparted to the receiving tissue. Life or limb threatening injuries are the priority of treatment which often require a multidisciplinary team effort (Figure 5). Low-velocity GSW fractures can be treated as closed injuries and often managed non-operatively according to standard fracture principles. Exceptions to this include injuries to the subcutaneous bones, like the ulna and tibia, and intra-articular retention. High-velocity GSW fractures require surgical irrigation, debridement, and fixation.

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