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Authors
Covey, Cpt DC
Schwartz, Alexandra K

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CURRENT CONCEPTS REVIEW

Orthopaedic Junctional Injuries

CPT D.C. Covey, MD, MC, USN(Ret.), and Alexandra K. Schwartz, MD

Investigation performed at the Department of Orthopaedic Surgery, University of California San Diego, San Diego, California

- Junctional injuries are those spanning the root of an extremity and the adjacent torso to include the shoulder region (shoulder and thoracic outlet) or pelvic region (pelvis, lower part of the abdomen, and proximal part of the thigh).
- These anatomic regions are traversed by major neurovascular structures where proximal and distal hemorrhage control is necessary in the torso and involved extremity.
- Nineteen percent of battlefield deaths from potentially survivable hemorrhage in Iraq and Afghanistan occurred in junctional anatomic regions.
- Patients with junctional injuries who present in extremis benefit from a resuscitation protocol that prioritizes control of life-threatening bleeding.
- A coordinated effort with general and orthopaedic surgeons working together can maximize chances for survival.
- Intermingling of new developments in the mitigation and treatment of junctional injuries will hopefully decrease their associated morbidity and mortality.

Orthopaedic junctional injuries span the root of an extremity and the adjacent torso to include the shoulder and thoracic outlet or the pelvis, lower part of the abdomen, and proximal part of the thigh[1]. Infrequently mentioned in the orthopaedic literature, they pose great surgical challenges. Junctional zones are traversed by major neurovascular structures where proximal and distal hemorrhage control is necessary in the torso and extremity. The injuries are often due to explosive trauma that causes bleeding in the pelvic region proximal to the inguinal ligament, the perineum, or the gluteal region or causes bleeding in the shoulder from the subclavian or axillary vessels. Junctional injuries analogous to those seen on the battlefield can be encountered in civilian casualties from terrorist or other attacks[2-6]. Examples include gunshot wounds, stabbings, and bombings affecting the pelvis, groin, proximal part of the thigh, or axilla. Pelvic fractures with vascular injury may result in uncontrolled hemorrhage refractory to external compression and requiring direct vessel control.

There may also be profound hemorrhage with orthopaedic junctional injuries caused by blunt or open trauma, such as from motor vehicle collisions, in the civilian setting. Principles of vascular control apply in these instances. One example is scapulothoracic dissociation—a traumatic, usually closed, disruption of the articulation between the scapula and thorax—which often includes severe injuries of the subclavian or axillary arteries combined with neurologic injury, resulting in a mortality rate of 10%[7]. Traumatic hemipelvectomy, a junctional-type injury, involves wide separation of the innominate bone from the pubic symphysis and sacrum. Avulsion of the external iliac vessels and severe injury of the femoral and sciatic nerves can occur. The majority of traumatic hemipelvectomies are open fractures with extensive soft-tissue disruption of the inguinal and perineal regions. The leading cause of death is acute blood loss; therefore, junctional hemorrhage control is paramount[8].

It is important to meld knowledge from military and civilian experiences to appreciate the spectrum of junctional injuries and optimize treatment. The purpose of this review is to increase awareness of junctional trauma by highlighting the epidemiology, anatomy, diagnosis, and treatment of these life-threatening injuries.

Epidemiology

The prevalence of junctional trauma is not always apparent as stand-alone data in the literature but may be gleaned from

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TABLE I Junctional Vascular Injuries of the Shoulder Region

Study	Region	Level of Evidence	No. of Junctional/Total Arterial Injuries	No. of Junctional/Total Venous Injuries	Main Finding
Fox et al.[9] (2005)	Iraq & Afghanistan	IV	2/53 (3.8%)	2/11 (18%)	Vascular injuries were sustained by 107 (7%) of battle casualties; majority were from IEDs
Clouse et al.[10] (2007)	Iraq	IV	11/301 (3.7%)	9/107 (8.4%)	Nearly 5% of those evaluated for battle-related wounds had vascular injury; 75% of vascular injuries involved extremities
Markov et al.[12] (2012)	Iraq & Afghanistan; U.S. civilian	IV	35/380 (9.2%) for Iraq & Afghanistan; 772/7,020 (11%) for U.S. civilian	Not recorded	Mortality of injured service personnel who reached medical treatment facility after major arterial injury was 8%, which compared favorably with a matched civilian standard

subsets of larger studies. Fox and coworkers[9] reviewed known or suspected combat-related vascular injuries from 2001 to 2004 (Table I). In a subgroup of arterial injuries, 3.8% were shoulder/upper-extremity (axillary) junctional injuries and 28% were pelvic/lower extremity junctional injuries involving the common, superficial, or deep femoral arteries (Table II). Clouse et al.[10] noted that 4.8% (324) of 6,801 patients treated for combat-related trauma had a junctional wound. Injuries of the subclavian or axillary arteries accounted for 3.7% of the vascular injuries (Table I). Together, 26% of the vascular injuries were of the external iliac artery and common, superficial, and deep femoral arteries (Table II). McDonald et al.[11] found that, of 198 pelvic vascular injuries in 143 patients, 42% were arterial and 57% were venous injuries in the pelvic junctional region (Table II).

Markov et al.[12] compared the anatomic distribution of and mortality from arterial injury between the military and civilian environments using the Joint Trauma Theater Registry (JTTR) and the National Trauma Data Bank (NTDB), respectively. Shoulder region arterial injuries were less frequent than arterial injuries of the pelvis and proximal part of the thigh in both the military and the civilian setting (Tables I and II). The prevalence of noncompressible arterial injuries (injuries in an anatomic location not conducive to compression or tourniquet application) did not significantly differ, but the civilian group had a significantly higher prevalence of compressible arterial injuries ($p = 0.005$).

Eastridge et al.[13] studied died-of-wounds deaths (i.e., those occurring after reaching a medical treatment facility) from 287 potentially survivable battle injuries in Iraq and Afghanistan. Evaluation of autopsy and other records showed that 21% of the deaths were due to junctional injuries. In an analogous follow-on study of killed-in-action deaths (i.e., before reaching a medical treatment facility), Eastridge and colleagues[14] identified 976 casualties from potentially

TABLE II Junctional Vascular Injuries of the Pelvic and Proximal Thigh Regions

Study	Region	Level of Evidence	No. of Junctional/Total Arterial Injuries	No. of Junctional/Total Venous Injuries	Main Finding
Fox et al.[9] (2005)	Iraq & Afghanistan	IV	15/53 (28%)	2/11 (18%)	Vascular injuries were sustained by 107 (7%) of battle casualties; majority of junctional injuries were pelvic and in proximal part of thigh
Clouse et al.[10] (2007)	Iraq	IV	77/301 (26%)	46/107 (43%)	Nearly 5% of those evaluated for battle-related wounds had vascular injury; 75% of vascular injuries involved extremities
McDonald et al.[11] (2016)	Afghanistan	IV	84/198 (42%)	112/198 (57%)	Most frequent arterial injury involved common iliac artery
Markov et al.[12] (2012)	Iraq & Afghanistan; U.S. civilian	IV	148/380 (39%) for Iraq & Afghanistan; 1,895/7,020 (27%) for U.S. civilian	Not recorded	Mortality of injured service personnel who reached a medical treatment facility after major arterial injury was 8%, which compared favorably with a matched civilian standard

survivable wounds. Hemorrhage accounted for 91.0% of the battlefield deaths, and 19.3% of the cases of fatal hemorrhage were junctional (Fig. 1). Singleton and coworkers[15] found that, of 230 British personnel who were fatally injured while on foot patrol in Afghanistan, 22.2% (51) sustained junctional trauma. Pannell and colleagues[16] reported that, of 63 Canadian Forces personnel killed in Afghanistan over a 2-year period, 2 died from junctional trauma. In a report encompassing the first decade of the Iraq and Afghanistan wars, 833 nonfatal junctional injuries were identified, a rate that increased from 0% in 2001 to 5% in 2010[17]. Jacobs et al.[18] documented increasing wound severity from improvised explosive devices (IEDs) with increases in proximal lower-extremity amputations and severe pelvic and perineal injuries, a finding noted by others[19].

Junctional Anatomy (see Appendix)

Shoulder and Axillary Region

Vascular Anatomy

Vessels at risk from junctional trauma include the subclavian and axillary arteries and veins, and their branches. Once the subclavian artery passes the lateral border of the first rib, it becomes the axillary artery[20]. This artery has several branches. Some of the larger ones, especially the subscapular and occasionally the circumflex humeral branches, are approachable through an axillary incision[20].

Nerve Anatomy

The brachial plexus formed by the anterior rami of C5 through C8 and T1 supplies sensation and motor function to the upper limbs. It begins in the root of the neck, passes through the axilla, and continues through the entire extremity. The divisions exit the posterior triangle and pass into the axilla, forming the 3 cords of the brachial plexus, named by their position relative to the axillary artery: lateral, posterior, and medial cords. These cords give rise to the musculocutaneous, axillary, median, radial, and ulnar nerves.

Pelvis, Torso, and Proximal Part of the Thigh

Vascular Anatomy

This region is more prone to junctional trauma than the upper extremity[10,21], and understanding vessel anatomy is critical to gaining control of vascular injury. The abdominal aorta branches into the left and right common iliac arteries at the L4 vertebral level, which then branch into the external and internal iliac arteries at the L5-S1 vertebral level. The external iliac artery continues distally to become the common femoral artery, which then branches into the deep and superficial femoral arteries[22].

Nerve Anatomy

The lumbosacral plexus comprises the ventral rami from T12 through S3. The femoral triangle bordered superiorly by the inguinal ligament, laterally by the medial border of the sartorius, and medially by the adductor longus contains the femoral nerve, artery, vein, and lymphatics. Complex pelviperineal trauma can include scrotal, penile, testicular, and anorectal injuries, with mortality rates upwards of 70%[23].

Junctional Injury Classification

Tai and Dickson[1] classified junctional injuries into 2 categories depending on the zone of vascular control. Type-1 injuries involve a junctional region and are too proximal for a tourniquet, but surgical hemorrhage control does not require entrance into the adjacent body cavity. For Type-2 injuries, the peritoneal or thoracic cavity must be entered via laparotomy, thoracotomy, or sternotomy to achieve vascular control. Although this classification system addresses only the location of vascular injury, other variables that would be relevant to orthopaedics include the presence of open pelvic, hip, or

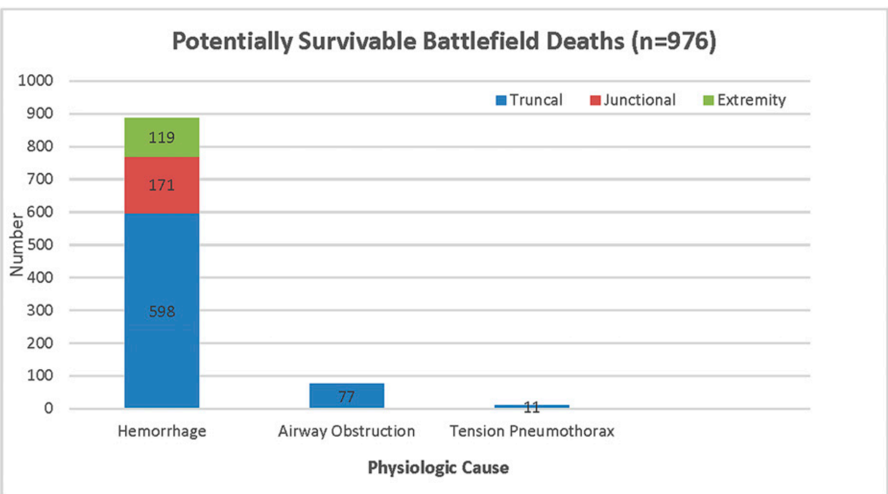

Fig. 1
Acute mortality data from Iraq and Afghanistan showing 976 deaths from potentially survivable injuries in a cohort of 4,596 battlefield fatalities, as reported by Eastridge et al.[14]. Junctional injuries accounted for 19.3% of the deaths from potentially survivable hemorrhage.

shoulder region fractures; the presence or absence of distal pulses; and the neurologic status of the limb.

Prehospital Treatment

Preventing exsanguination from severe junctional trauma requires immediate action before the patient's arrival at a field treatment facility or hospital[24]. Because these proximal injuries often preclude effective tourniquet application but may be compressible, direct manual pressure, ideally combined with hemostatic gauze, can be an effective temporary means to control bleeding[25-28]. However, on the battlefield, during medical evacuation, or in a dangerous or chaotic civilian environment, it may not be feasible for medical personnel to maintain adequate manual pressure to control bleeding[29].

The Iraq and Afghanistan wars gave rise to several devices for situations in which manual pressure cannot be maintained or proves inadequate to control hemorrhage. Devices approved by the U.S. Food and Drug Administration for treatment of junctional injury include the Abdominal Aortic Tourniquet, Combat Ready Clamp, Junctional Emergency Treatment Tool, and SAM Junctional Tourniquet[30]. To our knowledge, there have been no prospective trials to support the use of one device over another, only anecdotal and case reports[31-34]. However, Walker et al.[35] surmised that decreasing hemorrhage via a groin junctional tourniquet might be ineffective because of collateral circulation bypassing the pressure application point.

In Afghanistan, amputations have become increasingly more proximal and mutilating because of more powerful IEDs[18]. Service members who encounter IEDs on foot patrols are most at risk for receiving devastating lower-extremity and pelvic injuries. Patients with lower-extremity amputations that are too proximal for tourniquet placement should be considered to have an unstable pelvic fracture until proven otherwise. In a recent series of 67 patients who sustained traumatic lower-extremity amputation from IEDs in Afghanistan, Cross et al.[36] found the prevalence of associated pelvic fracture to be 14% in 28 patients with a single amputation but 31% in 39 with an above-the-knee double amputation. Given the substantial risk of pelvic fractures in patients with traumatic bilateral lower-limb amputation, these authors recommended that a pelvic binder be applied at the earliest opportunity.

It is also essential to obtain prompt access for delivery of crystalloid, blood and blood products, and medications. Establishing intravenous access in patients with severe junctional injury, massive blood loss, and flat veins is challenging in the best of environments, but much more so during evacuation from the battlefield. This has led to use of intraosseous needles (proximal humeral, tibial, sternal, or iliac crest) to provide a faster, more reliable, and mechanically secure route to the vascular system (Fig. 2)[37,38].

Hospital Treatment

Diagnosis

History and Physical Examination

Management of patients with junctional trauma is challenging and begins with an adequate history if feasible. This includes medically relevant information and the mechanism of injury[39].

Fig. 2
Intraosseous access via the sternum and proximal part of the left humerus in a service member wounded by an IED in Afghanistan.

It is crucial to maintain an index of suspicion for possible junctional injury given an appropriate history and suggestive physical findings.

When a patient is hemodynamically stable, dressings may be removed in the casualty receiving area or emergency department to determine wound characteristics, including location, extent, and depth. This involves identification of entry and exit wounds that suggest the path taken by bullets or fragments, including through the abdomen or thorax. If profuse bleeding occurs during wound examination, compression dressings should be applied along with manual pressure. However, vascular injury is not always associated with visible bleeding, and assessment for major junctional hemorrhage, and by extension limb viability, should begin with careful physical examination[28]. More than 90% of extremity vascular injuries can be diagnosed on the basis of the history and physical examination findings[40]. In the acute setting, "hard" signs of a major vascular injury of an extremity, although not pathognomonic, include pulsatile bleeding, an expanding hematoma, a cool pulseless extremity, and a palpable thrill or audible bruit[41]. However, these signs are unhelpful if the hemorrhage is within the thorax or pelvis. Absent hard signs, soft signs of penetrating injury including proximity to major vessels, a stable hematoma, and unexplained hypotension may aid in diagnosis[42]. A handheld vascular Doppler probe can be an important adjunct to physical examination through measurement of the ankle-brachial index (ABI) in hemodynamically stable patients. If the ABI is <0.9, further diagnostic evaluation can be done with computed tomographic angiography (CTA)[40,43], which has the advantage of necessitating only intravenous contrast medium. When CTA is inconclusive, conventional catheter angiography may be performed[43].

Imaging

Physical examination findings should determine which patients warrant further imaging. Chest, abdominal, and pelvic radiographs should be prioritized over those of the extremities; however, radiographs and advanced imaging should follow control of major or catastrophic bleeding[44]. If the patient's condition allows, CTA can identify large and medium-vessel injury, active bleeding, occlusion, or thrombosis[1].

Resuscitation

General Principles

Some patients with junctional injuries arrive at a treatment facility at the limit of physiological survival after massive blood loss; thus, physical examination often occurs simultaneously with the Catastrophic Hemorrhage, Airway, Breathing, Circulation (<C>ABC) resuscitation protocol[45]. The aim of this approach is to prioritize rapid control of life-threatening bleeding over the more traditional ABC paradigm in a hemodynamically unstable patient. This can be combined with what some have termed “right-turn resuscitation,” in which critically injured casualties are received by the trauma team in the operating room rather than the emergency department[46]. In this setting, there is urgent and aggressive resuscitation to correct critical physiological instability, with restoration of physiology, rather than repair or fixation of anatomy, determining the schedule of initial intervention[46]. If there is heavy bleeding, radiographs should be delayed in favor of controlling hemorrhage. Concomitantly, airway control and large-bore venous access should be obtained to institute damage control resuscitation, often using a massive transfusion protocol[47-49].

Damage Control Resuscitation

This consists of essentially 2 parts[49]. First, resuscitation is controlled to keep systolic blood pressure at approximately 90 mm Hg to help prevent renewed bleeding from recently clotted vessels. Second, crystalloid use is limited, and intravascular volume restoration is performed with plasma as a primary resuscitation fluid in at least a 1:1 ratio with packed red blood cells. Patients who require massive transfusion are at risk of early death from hemorrhage (within 6 hours after admission), and rapid treatment of coagulopathy can help prevent early mortality[50]. The massive transfusion protocol is accomplished by administration of plasma, packed red blood cells, and platelets in a 1:1:1 ratio along with cryoprecipitate[49,51]. Use of tranexamic acid (TXA) helps treat coagulopathy[52]. Fresh whole blood from prescreened donors can be used by employing a walking blood bank[49,53]. The immediate aim is restoration of vital physiology in critically unstable patients, for whom any delay in achieving hemorrhage control can adversely affect the outcome.

Surgical Treatment

General Principles

A coordinated effort with general and orthopaedic surgeons working together can maximize survival[52,54,55]. Calm and efficient communication between members of the surgical team is imperative (Fig. 3). Surgeons must frequently update the anesthesiologist regarding the status of vascular control and the extent of any continuing hemorrhage. If required, surgical dissection should stop and occlusive pressure be applied to allow the anesthesiologist to catch up with ongoing blood loss by administering whole blood, or packed red blood cells and blood products, before surgery is continued.

Fig. 3
U.S. Marine Corps forward surgical team in Afghanistan treating a battlefield casualty. Each member of the team has an assigned task to enable efficient patient care during resuscitation and surgery.

Controlling Hemorrhage

Proximal control is a basic principle of vascular surgery, and for surgeons unaccustomed to performing a vascular surgical procedure, remote proximal control offers the best opportunity for success when treating a severely injured military or civilian patient with a junctional injury[52]. The surgeon must identify the likely injured vessel and whether it is inside or outside the adjacent trunk. Bleeding from smaller wounds may be controlled with digital pressure, while larger wounds are packed with gauze with manual pressure applied. If manual pressure is ineffective, a Foley catheter may be considered for tamponade by inserting it into the wound cavity and inflating the balloon with saline solution[56,57]. The catheter is advanced and intermittently inflated until the appropriate location is achieved as evidenced by hemorrhage tamponade. This procedure can be used for either upper or lower-extremity junctional injuries. Although the catheter may reduce external bleeding, it may not decrease internal hemorrhage if the wound track includes an adjacent body cavity. If these measures are inadequate, efforts should be directed toward proximal control of bleeding.

Proximal Control for Upper-Extremity Injuries

For shoulder region injuries, proximal control may be obtained by exposing the subclavian artery through a supraclavicular or a less hazardous infraclavicular incision depending on the comfort level of the surgeon (Figs. 4-A and 4-B)[40]. The axillary vessels can be exposed through an infraclavicular incision beginning at the midpart of the clavicle and extending laterally to the deltopectoral groove. The pectoralis major is split in line with its fibers, and the pectoralis minor is divided to expose the clavipectoral fascia, which when incised will reveal the neurovascular bundle[57].

Proximal Control for Lower-Extremity Injuries

In some junctional injuries of the lower limbs, proximal control of the common femoral artery via a midinguinal vertical incision midway between the anterior superior iliac spine and the pubic tubercle allows for dissection of a more distal injured vessel (Figs. 5-A and 5-B). Junctional injury directly to the femoral triangle requires a lower abdominal oblique incision with division of all 3

Fig. 4-A

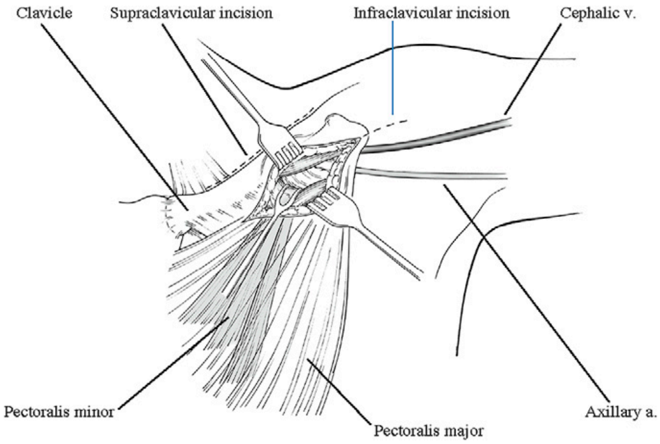

Fig. 4-B

Figs. 4-A and 4-B Junctional injury in the right shoulder region. **Fig. 4-A** U.S. Marine injured by fragments from an exploding rocket-propelled grenade. **Fig. 4-B** An infraclavicular approach may be used for vascular control in this type of injury since it allows access to the distal subclavian/proximal axillary vessels by splitting the pectoralis major and dividing or retracting the pectoralis minor. (Reprinted by permission from Springer Nature: Springer. Du Toit DF. Penetrating trauma to the subclavian vessels. In: Velmahos GC, Degiannis E, Doll D, editors. Penetrating trauma. A practical guide on operative technique and peri-operative management. New York: Springer; 2012. © Springer Berlin Heidelberg 2012.)

abdominal muscular layers and dissection within the preperitoneal space to expose the external iliac artery, which can be controlled using digital compression against the iliac fossa[40]. If the injury is unilateral and involves the proximal part of the thigh, a suprainguinal extraperitoneal approach, with control at the external iliac level, should be considered. If the injury is bilateral and very proximal, immediate laparotomy and control at the level of the distal aorta or iliac system can be achieved more rapidly and limits blood loss from bilateral amputation and pelvic and perineal injuries[52].

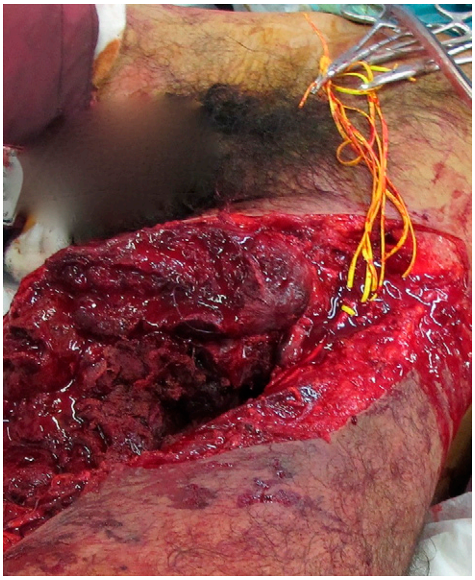

Fig. 5-A

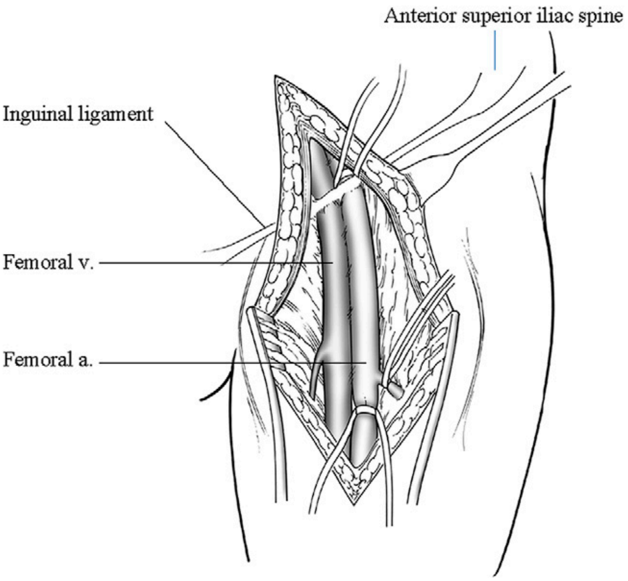

Fig. 5-B

Figs. 5-A and 5-B Junctional injury in the left hip region. **Fig. 5-A** Left-thigh proximal hemorrhage control through exposure of femoral vessels in a service member injured by an IED blast in Afghanistan. **Fig. 5-B** Surgical approach for vascular injury of the proximal part of the thigh. A vertical incision is made over the femoral pulsation and extended several centimeters above the inguinal crease. If there is no palpable pulsation, the incision is placed equidistant between the anterior superior iliac spine and the pubic tubercle and dissection is performed through the hematoma to the injury site. If the injury is in the superior part of the groin, the inguinal ligament is divided to expose the external iliac vessels for proximal control. (Reprinted by permission from Springer Nature: Springer. Du Toit DF. Penetrating trauma to the subclavian vessels. In: Velmahos GC, Degiannis E, Doll D, editors. Penetrating trauma. A practical guide on operative technique and peri-operative management. New York: Springer; 2012. © Springer Berlin Heidelberg 2012.)

Fig. 6
Service member with a junctional injury including right above-the-knee and left below-the-knee amputations from an IED blast in Afghanistan. The wounds have been dressed with absorbent cotton and covered with an Ioban drape (3M).

Vascular Shunts

Temporary intraluminal shunts allow rapid restoration of blood flow to an ischemic limb while other procedures can be accomplished[58,59]. In a damage-control or far-forward battlefield setting, an appropriately placed shunt can provide enough distal blood flow to perfuse a severely injured extremity until definitive repair can be performed[40,60]. Use of a temporary vascular shunt rather than vessel ligation depends on the potential for limb viability. A major vascular injury in a blast-mangled extremity with a low potential for salvage is usually treated with ligation. Alternatively, if the injured vessel supplies an otherwise potentially viable limb, temporary vascular shunting is appropriate until definitive vessel repair.

Orthopaedic Treatment

In conjunction with general surgery procedures, orthopaedic intervention is directed at pelvic ring and long-bone stabilization as well as debridement of osseous and soft-tissue injuries according to basic principles of extremity war surgery[61,62]. The more massive the junctional trauma, the more extensive and complex the debridement. Primary amputation may be required if massive bleeding cannot be otherwise controlled or the limb is not salvageable because of more distal injury.

Muscle tissue can be assessed by its appearance, consistency, contractility, and ability to bleed; if necrotic, it should be transected at its most distal viable point. A large, dark blood clot encountered during debridement indicates major vessel injury, and caution must be exercised before proceeding further without a plan for proximal control. Contamination is often driven up intermuscular planes and neurovascular structures beyond what is externally visible and must be specifically sought. Bone ends should be debrided of contaminants, and nonviable fragments should be removed. Definitive muscle flaps are not formed at this initial surgery, and skin is excised only if it is nonviable. Removal of metallic fragments is not the specific goal of the initial debridement unless they are intra-articular or compromising neurovascular structures[63,64]. Proximal vascular control is maintained until debridement is complete, rather than released immediately after vessel ligation, because small-vessel bleeding obscures the surgical field and worsens coagulopathy[52].

A thorough understanding of extremity fasciotomy is important because an acutely injured extremity with vascular involvement will need fasciotomy to avoid or treat compartment syndrome[40]. There are 4 compartments in the leg, 3 in the thigh, 2 in the arm, and 3 in the forearm, any of which could be subject to compromise after junctional trauma and vascular injury.

Traumatic amputations caused by explosions are usually associated with extensive soft-tissue injury and a proximal zone of injury[65]. Serial debridements are usually required at least every 24 to 48 hours to remove devitalized tissue and reduce contamination and infection[63,66,67]. Amputations should not be closed primarily but should be dressed open (Fig. 6)[28,64] or treated with negative-pressure wound therapy[37,68].

Contemporary Developments in Prevention and Treatment

Decreasing Risk of Junctional Injury

To decrease the morbidity and mortality from perineal and junctional region trauma, service members have been issued a recently developed 2-tiered pelvic protection system. The system consists of a protective undergarment (tier 1) and a more robust protective overgarment (tier 2). In a recent study on the effectiveness of this system, Oh et al.[69] found that the proportion of patients with an Abbreviated Injury Scale[70] score of ≥3 for the extremity and pelvic regions was significantly higher when the pelvic protection system had not been worn than

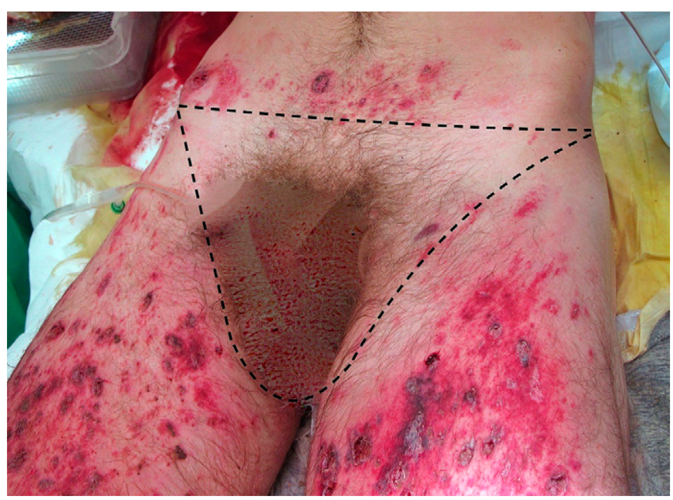

Fig. 7
Injured by an IED blast while wearing a pelvic protection system, this service member had relative sparing of the lower-extremity perineal and junctional regions as shown by the area within the dashed lines.

when it had been worn (95.1% versus 56.9%; p = 0.001). They concluded that use of body armor that specifically protects the perineal and groin areas has the potential to reduce morbidity (Fig. 7).

Battlefield Use of TXA

TXA is a synthetic lysine analogue antifibrinolytic agent that is a competitive inhibitor of plasminogen[71]. Morrison et al.[72] evaluated 896 patients who had sustained a combat injury in Afghanistan, 293 of whom had been administered TXA. The group who received TXA, despite being more severely injured, had a lower unadjusted mortality rate than the group who did not (17.4% and 23.9%; p = 0.03). This benefit was greatest in the group who received massive transfusions, in which TXA was also independently associated with greater survival and less coagulopathy (p = 0.003). The use of TXA with blood-component-based resuscitation following major combat injury had improved measures of coagulopathy and survival.

Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA)

REBOA has been proposed for treatment of junctional injuries. In this endovascular technique, a balloon occlusion catheter is inserted into the aorta via the common femoral artery to temporarily control hemorrhage; this is a less invasive approach than open surgery[73]. As REBOA has become more refined, it has also been evaluated for use in the battlefield environment to temporize noncompressible and junctional hemorrhage[74]. Manley et al.[75] reported on 4 patients who presented to a forward surgical team with torso gunshot or fragmentation wounds, hemoperitoneum, and class-IV shock (blood loss of >2,000 mL). Each underwent REBOA without radiography and this immediately normalized blood pressure, facilitating resuscitation and surgical hemostasis in all cases.

Conclusions

Junctional trauma caused 1 in 5 deaths from potentially survivable battlefield injuries in Iraq and Afghanistan. Whether junctional injuries will occur similarly in future conflicts is unknown. Terrorist attacks on civilians have increased the potential for these injuries to occur off the battlefield. Success in treating junctional trauma depends on early recognition, control of exsanguinating hemorrhage, and prioritization of damage control resuscitation to aggressively correct physiological instability. There is a paucity of outcome data on junctional injuries regarding reconstruction, rehabilitation, and residual physical and emotional disabilities.

Appendix

eA Supporting material provided by the authors is posted with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJS/F476). ■

CPT D.C. Covey, MD, MC, USN(Ret.)[1]
Alexandra K. Schwartz, MD[1]

[1]Department of Orthopaedic Surgery, University of California San Diego, San Diego, California

Email address for D.C. Covey: dcovey@ucsd.edu

ORCID iD for D.C. Covey: 0000-0002-4023-6304
ORCID iD for A.K. Schwartz: 0000-0001-7465-972X

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