Soft-tissue lesions on trauma CT: when the softer side is the hardest part.

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Learning objectives

To review the imaging appearance of soft-tissue lesions on CT performed for orthopedic trauma in the emergency setting.
Background

MDCT is regularly performed for the evaluation of complex or intraarticular orthopaedic trauma in the emergency setting. Associated soft-tissue lesions however are often overlooked or underrated, since emergency radiologists tend to focus on visceral injury and relegate appendicular skeleton trauma to a secondary position, or because of unawareness of their possible existence. Injury to the soft tissues can be of greater clinical relevance than the bone injury itself: it may represent a real emergency, such as vascular lesions or compartment syndrome, may limit treatment options and hinder the prognosis.
Findings and procedure details

A pictorial review of soft-tissue involvement in orthopedic trauma is presented, including: signs of compartment syndrome and predisposing findings, secondary vascular lesions alongside their associated fracture locations and patterns, tendon or ligament injuries which can be commonly inferred, and the appearance of different fluid collections such as Morel-Lavallée lesions. Attention should be paid to open fractures, signs of skin compromise and presence of foreign bodies.

COMPARTMENT SYNDROME

Acute compartment syndrome is a potentially limb-threatening emergency resulting from increased intra-compartmental pressure (ICP) usually requiring urgent decompressive fasciotomy (1-4).

Normal ICP values are 0-10 mmHg (1). Elevated pressure in a limited nonelastic myofascial space causes suppression of microcirculation and capillary perfusion at ICP > 20 mmHg, causing cellular anoxia and muscle ischemia leading to irreversible damage (1, 2, 4, 5). Nerves are the most sensitive structures, followed by muscle (2). Muscle injury and tissue necrosis occur at ICP > 30 mmHg, threshold considered an indication for emergent fasciotomy (1, 3, 4).

Elevated pressures may be caused by hemorrhage as a result of closed or open fractures, crush injuries, soft-tissue trauma, or due to ischemic reperfusion injury, burns or prolonged limb compression (1, 3, 4). Patients with high-risk injuries for vascular lesions (see VASCULAR LESIONS) are also at high risk of compartment syndrome, up to 59% (6). A common mistaken belief is that a compartment syndrome is unlikely to occur in open fractures, on the assumption that ICP will be decompressed through the defect. However, the small transversal fascial tears generally associated with open fractures are not sufficient for compartment decompression (4).

Compartment syndrome is most commonly seen in the leg and forearm (4), but may occur in other locations. The most common location is the lower leg (40%) most secondary to fractures of the tibial shaft, with an incidence of 1-10% (4).

Compartment syndrome is uncommon in the thigh (1, 5), probably due to rich collateral arterial flow which protects this area from a compromising ischemia, more compliant fascia and the possibility of decompression into the hip compartment, and higher threshold pressures for blood flow compromise due to the large volume of the thigh (1, 5). An isolated injury to the thigh with no risk factors has limited risk of compartment syndrome (5). Patients presenting a combination of risk factors such as high-energy blunt
trauma, external compression, systemic hypotension, vascular injury, administration of catecholamines or coagulopathy have higher possibilities of developing a compartment syndrome in the thigh: therefore, multiple trauma patients are especially at risk (5).

Compartment syndrome of the foot occurs in about 6% in patients with foot injuries due to motorcycle accidents (3). In the forearm, apart from trauma, it may be caused by intravenous substance extravasation, including radiologic contrasts, and envenomation due to snake bites.

Diagnosis is based on clinical examination and ICP measurement. Clinical findings include the "5 P's": pain, pallor, pulselessness, paresthesia, paralysis (1-5). Imaging studies are not generally requested, but the diagnosis of compartment syndrome may sometimes be difficult to establish, especially in a polytrauma setting or with unconscious patients (2-4). Full-recovery is time-dependent: the "golden period" for complete revitalization via decompression surgery is less than 6 hours and irreversible tissue damage is unavoidable after 12 hours of clinical presentation (1, 3, 4).

ICP measurement can be helpful in reaching a diagnosis, but is a multifocal, invasive, painful and sometimes unavailable technique (2). Moreover, it cannot establish the severity and extension of the associated soft-tissue damage.

Imaging studies may aid in the diagnosis of this entity. CT will reveal pancompartmental muscular swelling with loss of muscular septations, effacement of fat and fascial planes and fluid laminae, subcutaneous soft-tissue edema and fat stranding (Fig. 1 on page 22, Fig. 2 on page 23, Fig. 3 on page 24, Fig. 15 on page 21). Areas of myonecrosis can be observed on contrast-enhanced CT as patchy areas of non-enhancing muscle tissue with surrounding rim enhancement (1, 2). None of these findings is pathognomonic for compartment syndrome.

Imaging findings are non-specific and have to be correlated with the clinical setting, but the diagnosis should be readily suggested in trauma patients presenting muscular edema and loss of fascial planes on imaging studies. The differential diagnosis includes: inflammatory processes, infectious diseases, trauma, muscle denervation, rhabdomyolysis, diabetic myopathy... all of which can have similar appearances (2), so the clinical context is essential.

MRI is helpful in assessing the extent of compartment syndrome for surgical planning and may be helpful in clinically equivocal cases (2, 4), however, it is generally reserved for chronic compartment syndrome, since in the acute setting it is not routinely available and would be time-consuming therefore risking exceeding the golden period. Also, in acute trauma edema and swelling are present and may not be distinguishable from an acute compartment syndrome (4).

As a rule emergent fasciotomy is required for limb salvage (2-4). Unrecognized compartment syndrome may result in serious complications such as myonecrosis,
infection, neuropathy, contractures, fibrosis, atrophy, disability and deformity (2-5). In severe cases, amputation may be required (3, 4).

**VASCULAR LESIONS**

Vascular injuries secondary to extremity trauma are rare, the incidence varying widely according to the mechanism and type of injury. They occur in < 1% of long bone fractures, in about 9% of open tibial fractures and up to 16% of knee dislocations (6). Vascular damage may be the result of a direct or indirect mechanism. Direct trauma includes stab wounds, projectiles or sharp fracture fragments. Indirect trauma mechanisms with displaced fractures or dislocations are responsible for most vascular lesions, due to tensile or shear strain causing intimal tears (6). Blunt trauma has worse functional outcomes, lower limb salvage rates and higher amputation rates (27%, versus 9% in penetrating trauma) (6-8). The anatomic location also influences the degree of injury (6). The knee has relatively low collateral circulation and is therefore prone to severe lesions.

Initial assessment should begin with physical examination. However, examination may be deceiving or unimpressive, and vascular lesions lacking obvious signs of vascular compromise are frequently missed (6, 9). There should be a high level of suspicion in patients with orthopedic injuries associated with a high risk of vascular lesion, such as: comminuted tibial plateau fractures, severely displaced fractures, open fractures, segmental shaft fractures, blunt trauma, floating joint, crush injury and dislocation (6).

Many surgeons agree that in a high-risk lesion, normal physical examination on presentation warrants only close observation (6). The outcome of these lesions is primarily dependent on their early detection, followed by prompt treatment (6). Delays in diagnosis are associated with an amputation rate as high as 86% (6).

Physical signs of vascular injury are divided into hard and soft signs: hard signs include pallor, pulselessness (doppler), paralysis, paresthesia, pain, rapidly expanding hematoma, massive bleeding and palpable/audible bruit. The so-called soft signs are: history of arterial bleeding, proximity related injuries, neurological deficit diminished distal pulse and hematoma over a named artery. Soft signs are associated to vascular lesion in 3% - 25% (6, 10).

Duplex sonography is a quick and non-invasive technique that may be performed at the bedside (6), however it provides limited evaluation of the extent and cause of the vascular lesions in the complex trauma setting. Angiography has been the standard for diagnosis in the patients with mono-trauma to an extremity (6, 11, 12), but it is not without risk and cannot be performed in the ER. However, the application for CT angiography have considerably increased in the last years, and CT angiography may be considered initially instead of angiography to evaluate multiple vascular regions in the setting of trauma, especially advocated in the polytrauma setting and in patients who do not present hard
signs of vascular lesion, but present a high-risk lesion with soft signs or deterioration of physical examination (6, 10-12). It is quick, cost-effective, sensitive and specific for evaluation of vascular injuries, with reported accuracy of 95% and may be performed in the ER in a whole-body scan (6, 10, 12). As well as offering excellent depiction of the level, type and cause of the vascular injury required for surgical planning, it provides insuperable characterization of orthopedic lesions, in addition to information on the status of the soft tissues. Angiography may be reserved for cases with intention to treat, such as arterial embolization.

Different types of vascular lesions may be observed, such as segmental spasm (Fig. 3 on page 24), occlusion due to thrombosis (Fig. 2 on page 23, Fig. 3 on page 24), dissection, active extravasation implying laceration /transaction (Fig. 2 on page 23), pseudoaneurysm formation (Fig. 4 on page 25) and arteriovenous fistula. Characterization of the type and cause of the vascular lesion is indispensable for surgical planning, but the imaging appearance of these lesions has been readily discussed in the literature (10, 12) and is not the object of this paper.

Lesion to arteries overlying the shaft of the long-bones, both in the upper and lower limbs, are uncommon after blunt trauma but the incidence is increased in high-energy fractures with fragment displacement, and in penetrating trauma. External iliac artery lesion secondary to pelvic ring fractures is extremely uncommon, probably due to its protected retroperitoneal location, and most injuries to the iliac vessels are the result of penetrating trauma (7, 8). Lesion to the popliteal artery following knee dislocation occurs in 4-20%, since the popliteal artery is relatively fixed to the femur in its passage through the adductor canal and to the tibia in the soleus arcade (6, 11). Traumatic popliteal artery lesions are associated with an amputation rate of 14.5% and there is a strong relationship between these lesions and nerve and soft-tissue injury (6, 11). Lesions of the axillary artery following shoulder injuries are uncommon, and are more usually encountered after penetrating or blunt trauma to the axilla (13). When associated to osteoarticular injury to the shoulder it is most often to an anterior dislocation, in which lesion of the axillary artery has been reported to occur in 0.3% of cases (13), but may also occur in fractures of the proximal humerus. Following blunt trauma, lesions tend to occur in the third part of the axillary artery, probably due to the lesser mobility of this segment (13). Pediatric supracondylar humerus fractures are often complicated by arterial compromise.

Time to intervention is the most important factor in the management of these lesions. Irreversible damage occurs after 6 hours due to neurological injury. Delays over 8 hours are associated with an amputation rate of up to 86% (6). Delayed revascularization also increases the risk for compartment syndrome, metabolic acidosis and renal function impairment.

NERVE LESIONS
Peripheral nerve injuries are frequently encountered in orthopedic trauma (14) but are difficult to detect on CT, and mostly the diagnosis of a nerve lesion will be clinical on account of the presence of neurological deficit. Nonetheless, some mechanisms of trauma and determined types of lesions should alert of the possibility of nerve lesion. In some cases, nerve thickening or asymmetry, hypodensity, elongation or perineural fat stranding may be appreciated. Significant soft-tissue damage around a nerve course should also raise suspicion of possible nerve injury that should be transmitted to the clinicians.

The axillary nerve may be injured from glenohumeral dislocation, proximal humerus fractures or direct blow to the deltoid region (15). The reported incidence of nerve injury after anterior dislocation of the shoulder ranges from 5 to 55%, and the axillary nerve is the most frequently injured (15). The so-called "unhappy triad" of the shoulder is a combination of anterior shoulder dislocation, massive rotator cuff tear and neurologic injury (15). The risk of axillary nerve injury increases considerably if there is delayed reduction (15).

Sciatic nerve injury (Fig. 5 on page 13) occurs in 10% of traumatic hip dislocations, and is more frequent in posterior dislocations (16, 17). It may also occur in acetabular fractures with involvement of the posterior column (14). Greater severity of trauma and delay in recognition and reduction has been associated to greater incidence of nerve lesion, among other complications (16). Femoral nerve injury is rarely due to its relatively protected anatomic location (14, 16, 18).

Traumatic injury to the common peroneal nerve (Fig. 6 on page 13) ranges from 1.2-3% in tibial plateau fractures, in 25-40% of cases of knee dislocation, but can be as high as 75% in multi-ligament knee lesions especially in posterolateral knee dislocations (11, 14). It is more frequent in cases associated with popliteal artery lesion, and it is postulated that ischemic injury may play a role in the severity of the nerve injury (11).

**MUSCLE, TENDON & LIGAMENT INJURIES**

**Muscle injury** may go unnoticed on CT and low-grade muscle lesions are not visible on CT. Moderate to high grade muscle lesions will be apparent due to the presence of mass effect, changes in density with areas of low-attenuation corresponding to edema, intramuscular hematoma or surrounding fluid collections, and effacement of fascial planes. However, correct grading of these lesions requires imaging with US or MRI.

**Avulsion injuries** are detachments of the insertion site of a muscular, tendinous, ligamentous or capsular structure, and may or may not involve a small fragment of bone (avulsion fractures). They result from intense and/or eccentric muscular contraction or from tensile forces, occurring more frequently in children and adolescents due to the
relative weakness of their apophyses (18). They may be found in all anatomic regions, the knee joint being particularly susceptible to avulsion lesions due to the numerous insertions, but they are also frequent in the pelvis, ankle/foot, shoulder and elbow (18, 19). It is important to recognize these injuries as they may be associated with severe instability or loss of function. Avulsion injuries may also occur in the midst of complex fractures, and attention must be paid to fragments coinciding with insertions.

In the knee the Segond fracture is a cortical avulsion fracture of lateral capsular ligament insertion, and is associated to anterior cruciate ligament lesions (18, 19). The tibial spine (cruciate ligament insertion) (see Fig. 9 on page 16 ) and fibular head (biceps tendon and lateral collateral ligament) (Fig. 6 on page 13 , Fig. 7 on page 14 ) need to be assessed (18, 19).

In the pelvis, the ischial tuberosity is the most common avulsion injury, at the insertion of the hamstrings (18) followed by the anterior superior iliac spine (sartorius and tensor muscle of the fascia lata), and the anterior inferior iliac spine (rectus femoris, straight head) (18).

In the ankle, malleolar fractures and mortise fractures (posterior malleolus and anterolateral corner tibial fracture) behave like avulsion fractures and have their ligament lesion equivalent: medial malleolus-deltoid ligament, lateral malleolus- lateral collateral ligament, posterior malleolus- posterior tibioperoneal ligament, anterolateral corner of the tibia- anterior tibioperoneal ligament. Avulsion fracture of the superior peroneal retinaculum may be seen associated to ankle sprains. Avulsion fractures of the base of the fifth metatarsal are also common (18).

In the shoulder, avulsion of the greater and lesser tuberosities ( Fig. 8 on page 15 ) are rare (18). Avulsion fractures of the coracoid process are also unusual and may be associated with acromio-clavicular dislocations.

In the elbow, the most common avulsion fracture is the medial epicondyle (118).

**Tendon and ligaments** are readily recognizable on CT , ( Fig. 9 on page 16 ) given the surrounding fat planes are relatively preserved. Orthotopic anatomical tendon location needs to be verified, checking for signs of dislocation ( Fig. 10 on page 18 ) or retraction. Ligament injuries ( Fig. 11 on page 17 ) can be diagnosed when there is thickening, hypodensity or evident disruption of the fascicles, as well as surrounding fat stranding. However, accurate characterization and grading of these lesions generally requires MRI or US.

**FLUID COLLECTIONS**
Soft-tissue hematomas (Fig. 12 on page 19) are common due to blunt trauma and frequently associated to displaced fractures. Hematomas may be located in the subcutaneous fat plane, between muscles or may be intramuscular. Acute hematomas usually contain high-attenuation fluid, fluid-fluid levels may appear in established hematomas and chronic hematomas usually contain low-attenuation fluid reflecting various stages of clot lysis. Rim enhancement may be present after intravenous contrast administration. Most are treated conservatively, although large hematomas may produce important pain and even compartment syndrome, and drainage might be advocated.

Morel-Lavallée lesions are closed soft tissue degloving injuries (20, 21). They occur due shear forces that cause separation of the skin and subcutaneous fat from the underlying deep fascia with disruption of perforating capillaries and lymphatics, creating a potential space that fills with lymph, blood and necrotic fat (20, 21). With time, a peripheral capsule forms due to an inflammatory reaction, accounting in part for the perpetuation and potential growth of the lesion (20, 22).

Morel-Lavallée effusions are most commonly seen in the trochanteric region and proximal thigh, associated with pelvic and acetabular fractures, followed by the lower lumbar area and the scapular region (20-22). Clinically, they present as a large painful fluctuating lesion.

On CT, this lesion appears as a hypodense fluid collection (Fig. 13 on page 19) in the deep subcutaneous plane adjacent to the aponeurotic plane, sometimes with fluid-fluid levels or strands of intralesional fat (20, 22). The capsule is more evident with intravenous contrast administration, but marked capsule enhancement is associated to infection, as are inflammatory signs in the adjacent fatty tissue and fascia. Ultrasound and MRI are better for characterization of the lesion. MRI is the best imaging modality for the evaluation of this injury and for surgical planning, since it allows characterization of the high internal concentration of methemoglobin in the fluid and depicts the capsule, as well as clearly delineating its extension and anatomical relations (20, 23).

The differential diagnosis includes traumatic injuries like fat necrosis and coagulopathy-related hematoma, pseudolipoma, or early-stage myositis ossificans with diffuse subcutaneous edema (20). Neoplastic lesions may be initially suspected due to a painful enlarging mass, but prior history of trauma and the imaging appearance should suggest the correct diagnosis.

Small acute Morel-Lavallée lesions without a definite capsule are amenable to conservative treatment with compression (20, 21). Percutaneous drainage and sclerodesis have also been reported to be successful. Large acute Morel-Lavallée lesions are generally treated surgically to prevent perpetuation, infection or skin necrosis (20, 21). The presence of a capsule is associated to ineffective conservative or percutaneous treatments with recurrence of the effusion, and generally advocates for surgical intervention (20, 22).
Presence of abundant extraarticular fluid laminae near a joint may indicate **capsular injury** (Fig. 14 on page 20). Frequent locations for this finding are the subescapularis region in anterior glenohumeral dislocations and the popliteal fossa in knee lesions. In the shoulder, this sign should raise the suspicion of prior dislocation, especially if accompanied by a greater tuberosity fracture or a more evident Hill-Sachs lesion.

**OPEN FRACTURES**

Open fractures are generally high-energy lesions. The force of trauma alongside the exposure of bone and soft-tissues lead to increased risk of infection, wound complications and non-union (24). However, the different severities entail variable outcomes, prompting the development of grading systems. The most commonly used system in clinical practice is the Gustilo-Anderson classification (24, 25), based on wound size, level of contamination and bone injury: 1. Type I: open fracture with a wound < 1cm and clean; 2. Type II: open fracture with laceration > 1cm without extensive soft-tissue damage, flaps or avulsion; 3. Type III: either open segmental fracture, extensive soft-tissue damage or loss over fracture site or traumatic amputation. Type III is further divided into 3 subcategories: Type III A: open fracture with adequate soft-tissue coverage of the fractured bone despite extensive soft-tissue laceration, flaps or high-energy trauma, regardless the size of the wound; Type III B: open fracture with extensive soft-tissue loss with periosteal stripping and bone exposure; Type III C: open fracture associated with arterial injury requiring repair. Type III C have a 100% rate of complications, many ending in amputation or presenting chronic osteomyelitis (24). The classification of an open fracture is primarily clinical; however, imaging findings may position a lesion in a different category than initially considered.

Skin disruption is observed in CT as a breach in the skin surface (Fig. 1 on page 22, Fig. 2 on page 23, Fig. 3 on page 24). This might be difficult to observe, due to the presence of overlying dressings. Indirect signs of skin compromise such as air in the interstitial planes, muscle or intraarticular location, presence of foreign bodies or severe skin thickening must be investigated. On less subtle cases, evident skin defects may be appreciated, and muscle herniation or bone protrusion may occur through the defect (Fig. 1 on page 22, Fig. 3 on page 24).

CT is an excellent imaging technique for visualization of foreign bodies (26). The appearance of foreign bodies on CT depends on the nature of the material. Metal, glass and stone (Fig. 2 on page 23) all exhibit high-attenuation values (26). Wood however has a low-attenuation (26) and may be difficult to detect if there are air bubbles in the soft tissues due to an open wound. Ultrasound is very useful for detection of superficial foreign bodies (26).
FRACTURE BLISTERS

Fractures complicated by the development of overlying "fracture blisters" are a clinical dilemma in orthopaedics (27, 28). Their true etiology is unknown, but it has been hypothesized that they are secondary to injury to the dermal-epidermal junction resulting from shear forces in the skin during the mechanism of trauma (27, 28). They usually appear within 24-48 hours of trauma, principally in areas with sparse muscle mass or bone prominences with little soft tissue coverage: the ankle, leg, foot, and elbow (28). Fracture blisters are more commonly associated with high-energy trauma, but are rare in open fractures and are not associated with compartment syndrome (28). Moreover, as opposed to representing existence of increased ICP, they tend to represent interstitial pressure release. Fracture blisters do not necessarily imply severe injury to deep tissues, but may delay the surgical management and involve a higher risk of complications, such as infection and scarring (27, 28).

Clinical inspection is of course the standard of diagnosis. Nevertheless, they may be appreciated on CT as a focal elevation in the skin surface (Fig. 15 on page 21 ), with practically unnoticeable skin cover, and contents ranging from water attenuation to soft-tissue attenuation, depending on the presence of hemorrhage within. They will be more difficult to detect if there are tight dressings over the region. 3D reconstructions may aid in their detection.
Fig. 5: 47 year-old male patient involved in a head-on collision car accident. Right acetabular reduced posterior fracture-dislocation follow-up scan after 6 weeks (fracture was not initially addressed due to concomitant injuries). A. 3D VR shows right acetabular fracture without significant displacement. Note heterotopic periarticular ossification (blue arrows in A-C), frequent in patients with head injury, as was the case. B. Coronal image shows acetabular roof fracture with slight protrusion of the femur. A lucent area can be appreciated in the subchondral region of the femoral head, suggesting avascular necrosis without collapse (arrowhead). Note calcified loose bodies in acetabular fossa. C. Axial image shows fracture of the posterior column (arrowhead). The sciatic nerve appears thickened and hypodense, with surrounding fat stranding, in relation to injury (blue square), asymmetric to the contralateral uninjured side (green square). D. Same findings as in C, at a slightly caudal level.

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Fig. 6: 34 year-old man after fall from height and reduced knee dislocation with severe multiligament injury. A-F. Axial images show common peroneal nerve (arrows) with slight thickening and adjacent soft-tissue involvement. The patient presented peroneal nerve palsy. There was contusion-elongation with continuity of the nerve and the patient partially recovered nerve function. Note popliteal artery territory relatively spared. CT angiography ruled out popliteal lesions (not shown). G. Axial PD FS MRI shows extensive soft-tissue swelling in the posterolateral corner lesion (there was avulsion of the lateral collateral ligament, biceps and peroneal tendons) and common peroneal nerve in the midst of the soft-tissue involvement (arrow). Note sparing of popliteal region. H. Coronal CT image shows external tibial plateau displaced flipped fragment (asterisk) and fibular head fracture (arrowhead). I. Markedly displaced fibular head fragments (avulsion fracture) (arrowhead) and adjacent soft-tissue swelling due to extensive posterolateral corner soft-tissue injury. J. Coronal T2 FS MRI shows the same findings as in H, with better depiction of posterolateral corner injury. Note grade III proximal injury of the medial collateral ligament (arrow). K. Sagittal PD MRI shows associated lesion of both cruciate ligaments (arrows).
**Fig. 7:** Polytrauma patient, victim of a hit-and-run motor vehicle accident. A. ICU admittance trauma series shows left tibial and fibular diaphyseal fractures. An avulsion fracture of the right fibular head (red square) was initially missed and the instability was not evident since the patient was bedridden. The fracture was only noticed at follow up CT scan performed after internal fixation of left tibia for persistent pain (notice metallic artifact from intramedullary nail in left tibia in F). B. 3D VR image depicts left tibial shaft fracture and right fibular head multi-fragment fracture including displaced avulsion fracture at the insertion site of the biceps tendon and lateral collateral ligament (arrowhead). The biceps tendon attached to the fragment (arrow) can be seen on this soft window. C. Sagittal CT image shows fibular avulsion and attached retracted biceps tendon. D. Corresponding PD fat-saturated MR image. Note edema in the fibular head. E. Coronal CT depicting the same findings as in C. F. Axial image shows fragment of the fibular head and adjacent soft-tissue edema and loss of delineation of fat planes as an indirect sign of posterolateral corner lesion (arrowhead). G. Axial PD fat-saturated MR image corroborates severe injury to the posterolateral corner which was confirmed at surgery.

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Fig. 8: 49 year-old man after fall from height on outstretched hand. A. 3D VR shows avulsion fracture of the posterior aspect of the greater tuberosity at the insertion site of the teres minor tendon (arrow). B. Sagittal image with soft-tissue window shows bone fragment in the location of teres minor tendon (arrow). C. axial view and D. Coronal view.

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**Fig. 9:** 38 year-old patient, fall from height. A. AP and lateral plain film of the left knee show bicondylar tibial plateau fracture (Schatzker V). B. Coronal image also reveals a type III (complete separation) fracture of anterior tibial spine, at the insertion of the ACL (arrow). C. Sagittal image at the intercondylar region also reveals a type II fracture of the posterior tibial spine at the insertion of the PCL (arrow). D. Soft-tissue window view allows delineation of the PCL, apparently intact, attached to the avulsed fragment (arrowheads). E. 3D VR shows articular surface of tibial plateau with both avulsed fragments (arrows).
Fig. 11: 48 year-old patient with persistent pain 3 weeks after ankle sprain. CT was performed to rule out fractures. A. Coronal image shows no ankle fractures. B. There is soft-tissue swelling around the lateral malleolus and thickening of the anterior talofibular ligament (arrowhead) with no evident disruption, suggestive of grade I lesion. C. There were similar findings in the calcaneofibular ligament (arrow).

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Fig. 10: Preoperative CT in a 50 year-old patient who sustained a calcaneal fracture from a fall from height. A. Axial image shows dislocation of peroneal tendons (arrow). Intraarticular calcaneus fracture partially shown. B. 3D VR clearly shows
anterior dislocation of both peroneal tendons (arrow). Rupture of the superior peroneal retinaculum was found at surgery.

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Fig. 12: Hematomas. A. 3D VR of 35 year-old patient with patellar fracture and marked fragment displacement due to tendon retraction. B. Sagittal image shows soft-tissue hematoma between the displaced bone fragments (asterisk). C. Axial image with ROI measurement of the hematoma demonstrates soft-tissue attenuation. D. 3D VR of complex left acetabular fracture in a 29-year-old patient involved in a car crash. E. Note asymmetric enlargement of left iliac muscle and deep hyperdense area consistent with secondary hematoma (arrows).

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**Fig. 13:** Polytrauma patient involved in a landslide. CT performed after patient transfer for re-evaluation of pelvic ring and left acetabular fracture initially treated conservatively.

A. Scout view shows marked soft-tissue asymmetry in the upper left thigh (arrowheads).

B. 3D VR reconstruction shows non-displanced fracture of all 4 pubic rami with extension to the anterior wall of the left acetabulum. Note suprapubic catheter (arrow) placed due to posterior urethral injury.

C. Deep subcutaneous fluid collection in the upper left thigh; ROI mean attenuation value = 21.3 HU, near water, consistent with Morel-Lavallée lesion.

D. Coronal image partially includes the extensive fluid collection (asterisk), limiting with the fascial plane (green arrowheads). A thin capsule may be seen on its superficial portion (white arrowheads), indicating chronicity and need for surgical intervention.

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Fig. 14: Capsular injuries. A. Axial image of the left shoulder in a 50 year-old man after fall from height on outstretched hand reveals multifragment humeral greater tuberosity impaction fracture (arrow). There was glenohumeral articular congruence. B. Soft-tissue window settings allow visualization of fat stranding and fluid laminae in the axillary and subescapular region (arrowheads) suggesting capsular tear. The findings were suggestive of anterior glenohumeral dislocation mechanism. C. Axial PD FS MRI depicts anterior capsular tear (arrow), joint effusion and edema in the greater tuberosity. Note fluid laminae in the subescapular region (arrowhead). D. Sagittal CT in a patient with comminuted external tibial plateau fracture-subluxation with tibial spine involvement. Note fluid laminae in the popliteal region (arrow) and loss of definition of the capsule, suggesting capsular tear. E. Axial image depicts the same findings (arrows). F. 3D VR of the fracture.

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Fig. 15: Comminuted tibial pilon fracture with metaphysodiaphyseal extension after a fall from height. A. 3D VR image shows fracture and transcalcaneal traction (arrow). B. Axial image shows obliteration of intermuscular fat planes consistent with pancompartmental swelling sparing only the deep posterior compartment. This finding should raise the suspicion of compartment syndrome. C. 3D VR showing the skin surface shows blisters, which can also be appreciated in D. (arrowheads). Fracture blisters do not necessarily imply severe injury to deep tissues, but they involve a higher risk of complications and may delay the surgical management.

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Fig. 1: 32 year-old male involved in a motorcycle crash. A. Scout view shows multifragment displaced tibial open and fibular shaft fractures, Gustilo III B. B. Axial image (at the level of red line in A) demonstrates marked volume increase of the lower leg due to pancompartmental muscle swelling with effacement of fascial planes and fluid lamina (yellow arrow) consistent with compartment syndrome. Note permeability of all three infrapopliteal arteries (red arrows). Gas bubbles are visible in the subcutaneous tissue, fascial planes and even intramuscular. Cutaneous defect in anteromedial region (arrowheads) with slight muscle herniation. C. (At the level of blue line in A) Marked tibial protrusion through large skin defect (arrowhead) with overlying dressings. D. After initial limb salvage attempt (note tubular lucent areas from screw removal in the proximal tibial shaft), the patient eventually underwent amputation for severe soft-tissue infection and osteomyelitis.

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Fig. 2: 28 year-old patient involved in a motorcycle crash. Catastrophic left leg with tibial shaft bifocal Gustilo IIIC open fracture, medial malleolus fracture, fibular shaft fracture and multifragment suprasyndesmotic fibular fracture. A. CT angiography 3D shows active extravasation of contrast from the proximal anterior tibial artery (arrow) and absence of distal opacification, consistent with transection. B. Axial image arterial phase and C. delayed phase show active extravasation of iv contrast in the anterior compartment of the left leg (arrows). Note pooling of the extravasation in the delayed phase with diminished density, indicating active bleeding (as opposed to a contained vascular lesion). There were high-density foreign boids in the subcutaneous tissue and intramuscular (arrowheads) corresponding to stones from the road. Signs of compartment syndrome can also be appreciated. D. Coronal arterial phase and E. delayed phase depict the same findings (arrows). Note foreign bodies in E (arrowhead). E. Coronal image shows occlusion of the distal peroneal artery due to compression by a displaced fibular bone fragment. Thrombosis was observed at surgery. Emergency surgery was performed with direct ligation of anterior tibial artery, excision of devitalized muscle in the anterior compartment and external fixation. However, there was onset of diffuse soft-tissue infection, further massive necrosis and devitalization of bone fragments, and transtibial amputation was finally required.
Fig. 3: Polytrauma patient involved in a motorcycle crash. A3D VR shows "floating joint" in the left knee due to femoral shaft fracture and comminuted Gustilo IIIb open tibial shaft fracture, and fibular shaft fracture. B. Axial image (at the level of blue line in A) shows comparative view of both lower legs. Note increased volume of left lower leg, loss of interfascial planes and pancompartamental muscle swelling consistent with compartment syndrome. The patient underwent lateral and fasciotomy for this cause. Gas bubbles were present in anterior and deep posterior muscle compartments. Note overlapped fibular fracture fragments (arrows). C. Axial image (at the level of blue lines in A) shows anterior skin defect with evident muscle herniation (arrowheads). Note displaced and exposed tibial fragment in anterior location (arrow). D. CT angiography 3D reconstruction shows patent popliteal artery and infrapopliteal trifurcation. MIP reformatted images show E. Patent anterior tibial artery (cross), F. Peroneal artery with focal narrowing (cross) at the level of the fibular fracture, with distal patency, consistent with segmental spasm. G. Posterior tibial artery presented a non-opacified segment (arrow) adjacent to an angulated tibial bone fragment with distal reconstitution. The possibility of a partial lesion (such as non-occlusive dissection, partial transection or thrombosis) was suggested. Non-occlusive thrombosis was confirmed at surgery. The tibial fracture was complicated with osteomyelitis that was managed conservatively and limb salvage was ultimately feasible.
Fig. 4: Patient involved in a motorcycle crash. Following on-site reduction of right anterior glenohumeral dislocation there was enlarging soft-tissue swelling in the right axillary region and weak distal pulses. A. Unenhanced CT shows severe soft tissue asymmetry in the right axillary region due to hematoma, with a central rounded mass (asterisk). B. Delayed contrast-enhanced CT revealed contained extravasation into the rounded mass consistent with pseudoaneurysm (arrow). Distal arterial flow was not detected and laceration of the axillary artery was demonstrated at surgery.

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Conclusion

Limb salvage outcomes are affected by the mechanism of injury, associated injuries and time-to-diagnosis and/or intervention. Although CT is not the modality of choice in the majority of soft-tissue lesions in orthopedic trauma, it does allow a certain degree of assessment of these structures and may reveal indirect signs of injury if not direct demonstration. Radiologists should be aware that these lesions may be present and acquainted with their appearance on MDCT to avoid missing relevant injuries on initial emergency scans that may significantly alter the management or hinder the prognosis.
References