Chapter 14
Orthopaedic Problems in the Critically Injured Patient

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Abstract Polytrauma patients present significant challenges to intensivists and orthopaedic surgeons and benefit from a team approach to management. The challenges of identifying missed injuries, mitigating the risks of spinal injury, and the timing of multiple operations can only be overcome by careful and thorough shared care.

Once a patient is established on a treatment pathway, there are several avoidable and unavoidable complications, which ideally should be spotted early and treated urgently to avoid undesirable outcomes. Compartment syndrome remains one

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of the commonest and most challenging complications to detect, particularly in obtunded patients. Clinicians must maintain a high index of suspicion and be prepared to institute compartment pressure monitoring early. Rhabdomyolysis and fat embolism syndrome can also complicate management of the polytrauma patient.

Keywords Major trauma • Long bone injury • Pelvic injury • Spinal injury • External fixation • Internal fixation • Spinal immobilisation • Compartment syndrome • Fat embolism • Heterotopic calcification

Introduction

Patients admitted to intensive care following trauma may have a spectrum of orthopaedic injuries and complications that must be identified and managed. Significant problems can arise where pitfalls are not anticipated and avoided. The trauma patient may have known issues, have missed injuries, or develop complications during their admission. This chapter therefore provides an overview of the most common and significant conditions that are likely to face intensive care teams when managing patients with orthopaedic injuries.

What Is a Tertiary Survey and When Should It Be Performed?

In the modern trauma system, most patients will have received a thorough assessment before presentation to intensive care. However, a proportion will have been partly assessed before urgent surgery or transfer to the critical care unit and there is always a risk of injuries having been missed. One case series from Australia noted 12 significant missed injuries in 10 out of 65 patients admitted to critical care following trauma [1]. A Dutch series identified missed injuries in 8.2 % of trauma patients in critical care [2]. Such injuries are much easier to miss in critically injured patients with a reduced level of consciousness [2, 3]. As a consequence, patients admitted to critical care following trauma should be assessed with a thorough tertiary survey.

The timing of such a survey is controversial [4]. Generally, a tertiary survey should take place after the initial fast-paced resuscitative and surgical management has settled down. This tertiary survey should include clinical examination alongside radiographs of limbs that may be injured, based on examination or mechanism of injury, and that were not visualised on initial imaging. Where patients remain obtunded or intubated, the threshold for imaging may be lower. Repeat examination is always advisable, especially once a patient has regained consciousness.

Most trauma patients will have had a comprehensive trauma CT series prior to admission to intensive care. Admission imaging studies should be re-assessed in concert with radiologist reports, the findings at surgery and repeat clinical assessment. It has been suggested that almost 20 % of errors in diagnosis and management are caused by mistakes in interpreting initial diagnostic studies which may have been hurried before resuscitative surgery [4].

How Should the Unconscious Patient with Potential Spinal Fractures Be Managed in the Intensive Care Unit?

A substantial number of missed injuries are spinal fractures, which potentially have significant consequences [4]. However, there are risks to taking an over-cautious approach to protecting the spine; cervical collars have their own risks and require a great deal of nursing input [5].

Patients with a diagnosed spinal injury should be managed with advice from a specialist spinal surgeon and with reference to national and local guidelines. Those with a spinal cord injury should be referred to a spinal injuries centre within 24 h of injury and their management should proceed with advice from the specialist centre.

Advanced Trauma Life Support (ATLS) doctrine mandates the assumption that trauma patients have a spinal injury, and in particular a cervical spine injury, until proven otherwise. This doctrine aims to avoid causing complications in the presence of an undiagnosed unstable fracture or ligamentous spinal injury. It is supported by the principle that patients should be kept in a cervical spine collar, kept flat, and log rolled until an injury is excluded; the principle of "spinal clearance". While it is wise to assume that there may be a spinal injury, collars can offer a false sense of security, and thus may not be advisable in all cases. Rigid collars have been shown to increase intracranial pressure [6] and to cause pressure sores [7], which may be exacerbated by spinal injury. In the absence of injury, patients with ankylosing spondylitis and rheumatoid disease are at risk of injury from the application of a collar alone [8]. The effectiveness of cervical spine immobilisation utilising a collar remains controversial at present. Recent guidelines for pre-hospital trauma care increasingly suggest avoiding the use of rigid collars as they are felt to be ineffective, especially in conscious patients, and have significant risks. There is evidence that collars alone do not immobilise the spine [9], and that immobilising with sandbags but no collar is more effective than a rigid collar [10]. One analysis of pre-hospital care practice comparing one nation where cervical spine collars are not used at all with one where they are used routinely found no evidence of a difference in the risk of neurological injury in blunt spinal trauma [11].

Most patients will have had a cervical spine CT scan prior to admission to critical care. This scan has high sensitivity and specificity for an unstable injury. There may be a role for secondary imaging such as MRI, to identify associated cervical disc trauma, and the extent of the cord oedema and contusions. However, this must be weighed against the hazards of moving each individual patient from the critical care unit. For example, placing a head injured patient in the supine position is associated with raised ICP, which may further compromise cerebral perfusion. Each case must be assessed individually to determine the risk of undertaking the scan against the benefit provided by the additional information [12].

The British Orthopaedic Association has published guidelines for spinal clearance in the trauma patient [13]. This policy recommends that spinal immobilisation should not continue for more than 48 h. It acknowledges that there is a risk of ligamentous instability in the neck without fracture, but that CT scanning has high sensitivity and specificity for spinal injuries. It therefore recommends that a fine-slice CT scan is undertaken with the first CT brain scan in head injured patients, and that the thoracic and lumbar spine be imaged with plain films or with reconstructed CT scans from thoracic and abdominal series. MRI is considered the investigation of choice for spinal cord injury.

We suggest that all trauma patients should have CT scans as part of their initial imaging, and that these scans are reviewed to exclude spinal injury. The incidence of unstable injury – defined as failure of the bony and/or ligamentous structures of the spinal complex to withstand normal physiological loads leading to potential deformity, neurological deficit and pain – following blunt trauma is approximately 2 %, and this increases to 34 % in the unconscious patient. Fifty percent of spinal injuries occur in the thoracic spine, and 20 % have 2 levels of injury [13]. While a suspicion of spinal injury remains, the patient should be kept immobilised in an appropriate posture based on their known injuries. Head blocks should provide adequate immobilisation. Patients should be log rolled until the spine is cleared. Rigid collars are not recommended unless advised for a specific injury. Spinal clearance should only be undertaken following the reporting of normal spinal CT images by a senior radiologist. Spinal column and spinal cord injuries, where identified, should be managed by orthopaedic or neurosurgical specialists as appropriate to the institution. Figure 14.1 summarises the advice given in this section.

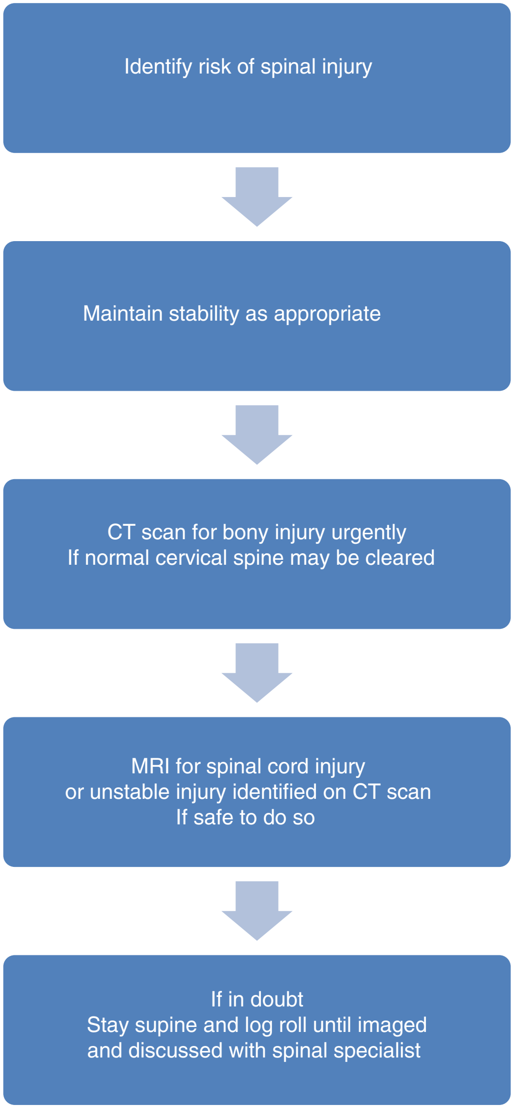

FIGURE 14.1 Suggested process for spinal imaging and clearance

What Are the Treatment Options for Long Bone Fractures in the Critically Injured Patient?

Long bone fractures are associated with haemorrhage, pain and fat embolus. It is desirable to stabilise such injuries early to reduce the incidence of these complications. There are a variety of options for long bone stabilisation which may be used by the orthopaedic team. This section will briefly discuss the options available.

The first decision to make will be whether to definitively stabilise long bone fractures during initial resuscitative surgery, or to perform a stabilisation procedure and delay definitive surgery.

Traditionally, polytrauma victims could expect long primary surgery as all their long bone fractures were stabilised definitively. It was understood that early fracture stabilisation led to a reduced risk of fat embolism and sepsis, and it was believed that ARDS was less likely if all fractures were fixed as soon as possible. It was also believed that these patients were too sick for their surgery to be delayed, as prolonged immobility had been shown to have negative effects [14]. However, a picture began to emerge of a high price for aggressive early surgery with multi-organ failure, ARDS and death. The concept of damage control surgery therefore emerged, with the simplest possible operation to stabilise the patient as fast as possible, reducing the physiological hit from surgery.

As understanding of the inflammatory response to trauma evolved, the concept of the "2 hit phenomenon" arose [15]. It was suggested that the physiological insult of trauma primes the immune system for an inappropriate and exaggerated response, which may lead to ARDS and organ failure when the second hit of surgery is poorly timed or excessive. This led to the concept of damage control orthopaedics, with the primary surgery being made as simple and fast as possible to stabilise long bones and avoid the complications of immobility, but without a stimulating second hit. It eventually became apparent that the second hit phenomenon has significant individual variability and that surgery that would harm some individuals would be safe in others despite a similar injury burden [14].

"Early Appropriate Care" is a recent term described by Nahm et al. [16]. This recognises that there are advantages to early definitive fixation which may outweigh the risks of a more invasive procedure; neither damage control surgery or early total care are necessarily appropriate in any given patient. The timing and extent of individual surgery must be planned with regard to the overall injury burden and physiological status, and the risks and benefits of each surgical modality for each injury. Stable patients may be amenable to early definitive fixation while extremely unstable patients do require damage control surgery. The majority of patients lie in between the extremes, and benefit from a mixture of approaches.

Much of the current literature focuses on the timing of femoral fracture fixation [14]. The femur is not amenable to splinting without the patient being left recumbent, so there are advantages to early fixation. Femoral fractures are commonly definitively fixed with an intramedullary nail. Reamed femoral nailing has been associated with increased lung capillary permeability and increased pulmonary arterial pressures, so femoral nailing may not be suitable in the early stages.

A staged approach to surgery is therefore recommended in most cases. Initial surgery includes stabilising injuries which pose a haemorrhage risk or would otherwise increase immobilisation; these include pelvic and long bone fractures. The initial stabilisation may include internal or external fixation or perhaps simple plaster application depending on the patient's overall condition and the configuration of individual injuries. Once the patient's condition improves, temporary measures may be replaced with definitive fixation.

The resuscitative and metabolic status of the patient are the primary decision tool when selecting temporary or definitive initial fixation. The best way to measure this remains the subject of ongoing research. Simple measures of organ perfusion, such as urine output, make a useful contribution as do measurements of lactate and base deficit. Lactate is currently considered the best measurement of resuscitation to guide surgical decision making [17] with a lactate of 2.5 mmol/l suggested as indicating adequate resuscitation [14, 18]. Interleukin IL-6 is a useful measure and has been shown to be effective [19], but is not available in all units. Where there is doubt over the best approach to take, it is probably safer to tend towards damage control surgery in favour of definitive fixation [20].

Options for stabilising long bone injuries are numerous, and many differing opinions will exist as to the best option. Individual techniques include plaster, external fixation, internal fixation with plates, and intramedullary nails. The benefits of each are beyond the scope of this chapter, as there is great variability in the stability and nature of fractures of any given long bone which may favour a particular technique. However, each method has specific features that merit a brief discussion. In the more austere setting, such as military deployment or humanitarian operations, insertion of metalwork at initial stabilisation is kept to a minimum. This is mainly due to the nature of the operating environment which generally does not have the infection control considerations which we take for granted in a westernised hospital, but also the simple lack of availability of complex operative sets and equipment.

Simple Splints

Simple splints, including the Thomas splint, are satisfactory ways of temporarily and rapidly immobilising a limb. The Thomas splint, and some more modern devices, allow the application of traction to help reduce a femoral fracture into a more anatomical position. However, these devices are bulky, limit patient mobility and positioning, essential in the critically ill patient, and apply traction against part of the patient, thus potentially introducing the risk of pressure sores. They may be used initially, but consideration for further stabilisation should be undertaken in a timely fashion, with splints used for no longer than is necessary.

Plaster Stabilisation

The simplest method of stabilising a fracture is plaster of Paris. The fracture is reduced and the limb stabilised with a plaster splint. This is a quick and simple solution and hence is effective in austere environments; the Red Cross recommends it for most injuries in field hospitals. However, it can be difficult to maintain perfect reduction and the constrictive dressings bring an increased risk of compartment syndrome. In UK practice, plaster is therefore more likely to be a temporary measure in polytrauma depending on the fracture pattern. Patients with a plaster in situ demand monitoring for evidence of compartment syndrome, especially if sedated; if there is a concern of evolving compartment syndrome the plaster must *immediately* be split to the skin.

External Fixation

External fixators use a combination of pins inserted into bone and bars to stabilise an injury. This may be a temporary or definitive treatment. In either case, close attention must be paid to care of the pin sites to prevent infection. The stability of the construct, and therefore what effect the fixator has on patient handling, depends on the fracture configuration so the critical care team must liaise with the surgical team with respect to moving the patient. If an external fixator is a temporary device, it will generally be replaced with definitive fixation within 2 weeks.

Internal Fixation

Internal fixation with plates and screws or nails, is likely to be a definitive treatment modality and may take place at initial or late surgery. Depending on what plates or nails are used, the procedure may be open – with an incision directly to the fracture site and over the hardware – or minimally invasive, with incisions as required to insert hardware and reduce the fracture. In most cases, mobility will be minimally restricted once the fracture is definitively fixed but this is not always the case and operation notes must be reviewed. Whilst this method of fixation appears to provide the definitive answer to fracture management, fracture patterns are not always straightforward and may require the acquisition of particular hardware from differing manufacturers, which is not immediately available within the hospital. Thus a time delay may ensue. A delay of 2–3 weeks will not have a deleterious effect on the overall fracture outcome, but may be deleterious to the physiological status of the patient, particularly if it prevents early mobilisation. Therefore, continuous multidisciplinary discussions between orthopaedic and ICU teams are required.

What Are the Principals of Management for Patients with Pelvic Fractures?

Fractures of the pelvic ring are a common injury following polytrauma. Such patients are at risk of death from haemorrhage, particularly from bleeding sacral veins in certain patterns of fracture. Precautions must be taken to support pelvic injuries in order to reduce bleeding as much as possible, and it is now routine practice to bind the pelvis as early as possible on the assumption that a fracture is present. Open pelvic fractures/disruptions of the pelvic ring demonstrate an overall mortality rate of 50 %.

Pelvic binders have been introduced which can be rapidly applied in the pre hospital environment. They are designed to compress the iliac wings together and reduce the volume within the pelvic cavity, thus reducing the available volume for haemorrhage and providing a tamponade. They have been proven to effectively stabilise certain fracture patterns, but are not entirely without risk. In certain fracture patterns, there is a risk of over-reducing the pelvis if applied too tightly, consequently injuring the structures within. It is easy to place the binder incorrectly, which markedly reduces its efficacy [21]. Binders also apply high pressure to the skin over the greater trochanters, and therefore have a significant risk of skin breakdown and wound complications.

In the presence of a suspected pelvic fracture, it is suggested that the best means of providing stability is to apply a proprietary binder at the correct tension and to obtain imaging as soon as possible. This would normally be undertaken before transfer to critical care. Clinical examination must include assessment of deformity, groin and scrotal swelling and haematoma, urethral bleeding and rectal and vaginal examination to exclude an open fracture. There is no role in any circumstances for "springing the pelvis"; this will destabilise any bleeding vessels around the sacrum and may cause significant blood loss.

Where a pelvic fracture is associated with hypovolaemic shock, it is likely that the bleeding originates from sacral venous plexi. Fractures of the iliac wing and sacrum, and fracture patterns with pubic symphysis diastasis, are more prone to fatal haemorrhage [22]. Some controversy exists regarding the optimal method for controlling haemorrhage, but local resources will likely dictate the best path. Options for haemorrhage control include external fixation and packing, or radiological embolization of bleeding vessels. Embolization is effective in around 85 % of cases [23] but there is a risk of failure to control bleeding and of recurrent haemorrhage. Where a patient is in extremis and interventional radiology is not available, urgent surgery to pack the pelvis is usually effective. If interventional radiology is available and haemorrhage control is successful, this is usually a better option as it is less invasive. Early stabilisation of pelvic fractures by a suitable specialist surgeon will allow easier nursing care. However, this requires sub-specialty care and may therefore require transfer of the patient to a suitably equipped unit, with consequent delay. The development of major trauma networks within the UK, will hopefully reduce the requirement for such transfers, with all suitable sub-specialty management available in one institution.

If a patient is to be transferred to another facility, a pelvic fracture should be stabilised by a suitable means in discussion with the receiving surgeon. Pelvic binders are suitable for transfer provided that their position is checked and re-checked, and that adequate care is taken of the skin. External fixators may be more stable, but are awkward when transferring a patient by ambulance and especially by air.

How Should Hand Injuries Be Managed in the Polytrauma Patient?

Hand fractures are common in polytrauma and may be managed by a combination of orthopaedic and plastic surgeons. Fractures of the hand are commonly missed, with reported incidences of 4–33 % [24], often because they are considered less important than other more dramatic long bone injuries. Poor management of hand injuries is associated with significant loss of function and morbidity, and litigation is not uncommon. Whilst these injuries are clearly not life threatening, patients who develop severe disabilities as a result of polytrauma injuries, require the full use of hands and digits in order to perform activities of daily living. Thus hand and wrist injuries must be identified and appropriate subspecialty management undertaken. Experience has shown that once all the other injuries have recovered it remains the hand injury that causes long term disability and frustration. Therefore, all possible steps must be taken to ensure that the hand is not allowed to become stiff and non-functional and consistent multidisciplinary approach is required.

The spectrum of hand injuries is broad and many can be managed non-operatively. Where surgery is likely to be helpful, it is usually best to operate early, within 14 days – the hand heals quickly and outcomes rapidly worsen if surgery is delayed beyond this.

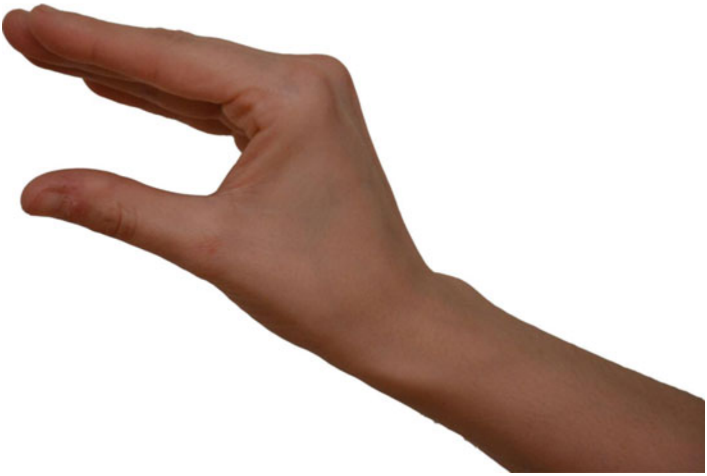

FIGURE 14.2 Position of safe immobilisation for the hand

Where the hand is to be rested immobile, it is essential that it is immobilised in the correct position. The metacarpophalangeal joints have strong collateral ligaments which are tightest when the joint is at 90°. The interphalangeal joint collateral ligaments are tightest when the joint is straight. These ligaments contract rapidly when not allowed to move. If a hand is plastered, it must be immobilised with the collaterals at their tightest – otherwise they will contract, leaving the hand stiff. The hand should therefore be plastered or splinted with the metacarpophalangeal joints at 90° and the fingers straight; this is most comfortable if the wrist is in slight extension. This is known as "position of safe immobilisation" (POSI) splinting or Edinburgh splinting and is shown in Fig. 14.2.

Ideally, the hand should be allowed to move as much as possible. Surgeons will aim to select surgery which allows early movement where possible. If the patient is unconscious, hand therapists should provide daily passive exercises to prevent stiffening.

Which Patients Are at Risk of Limb Compartment Syndrome and How Should They Be Managed?

Compartment syndrome is a condition in which a constricted fascial compartment experiences a rise in pressure, leading to compromised microvascular perfusion and eventual tissue death. It is a difficult condition to diagnose in the obtunded patient, requiring a high index of suspicion [25]. Mortality of critically ill patients with acute limb compartment syndrome is reported to be as high as 67 % [26]. There are many causes, including fractures and soft tissue injury but other causes must be considered including extravascular injection and ischaemic tissue injury. Extracorporeal membrane oxygenation has also been reported as a cause [27]. A full list of causes and incidences is shown in Table 14.1.

After an initial trigger injury, local inflammation and oedema within an enclosed compartment will result in a rise in pressure. Although a significant rise would be needed to cause a loss of arterial circulation, capillary flow will be reduced much faster and this leads to increased local injury, oedema and a vicious cycle of increasing compartment pressures. Eventually, the arterial inflow will fall but, by this stage, the muscular tissue in the compartment may already be dead.

In conscious patients, symptoms of compartment syndrome include pain, pallor, paraesthesia and pulselessness. Other than pain, all of these occur late and if they are present it may be too late to prevent significant tissue death. The most useful early symptom is pain out of proportion to that expected from the injury. The best sign is pain on passive stretch of the involved muscle compartment. Either of these may be absent in sedated or unconscious patients. Affected compartments may be clinically swollen and tense, but this is an unreliable sign to exclude compartment syndrome.

Where there is a risk of compartment syndrome evolving, and clinical signs will be absent, it is possible to monitor the relevant compartments with an indwelling catheter, as shown

TABLE 14.1 Causes and incidence of limb compartment syndrome [28] with permission

Causes of compartment syndrome	**Incidence** %
Closed tibial shaft fractures	33
Radius and ulna fractures	20
Other fractures including tight casts	7
Foot injuries	6
Blunt and crushed soft tissue limb trauma	25
Total other causes	9
Other surgical causes	
Burns	
Blast injury	
High energy gun shot wounds	
Prolonged lithotomy position during surgery	
Arterial and venous injury/revascularisation/ reperfusion injury	
Use of pulsatile lavage	
Use of pneumatic anti-shock garment	
Other accidental causes	
Excessive exercise in athletes	
Non routine/overuse in non athletes	
Non- accidental causes	
Nephrotic syndrome	
Viral myositis	
Hypothyroidism	
Bleeding disorders/anticoagulation	
Malignancies	
Diabetes-associated muscle infarction	
Ruptured bakers cyst	
Snake bite	

FIGURE 14.3 External fixation used to treat a lower limb fracture. A catheter has been inserted in order to measure compartment pressure and provide an early warning of impending compartment syndrome

in Fig. 14.3, or intermittent aspiration. The diagnostic criterion for compartment syndrome is a pressure difference (Delta P) of less than 30 mmHg between diastolic blood pressure and compartment pressure, which indicates a risk of circulation compromise [26].

$$\delta P = Diastolic\ blood\ pressure - Compartment\ Pressure$$

Other measures, such as intra-compartment pH, remain controversial, but may become established in the future. Compartment syndrome should also be considered in the obtunded patient where there is concern of ongoing progressive tissue necrosis or inflammation and no other cause has been found. Other, more subtle, physiological changes can be identified if patients are continually monitored. Even in the unconscious patient, trends in oxygen consumption, increased heart rate and increased sedation requirements may all be indicators of evolving compartment pressure rises, prompting the clinician to be suspicious of this developing condition.

Established compartment syndrome is a surgical emergency. Initial management is to release constrictive dressings and ensure that the limb is not below the level of the heart. The definitive management of compartment syndrome is surgical release along with debridement of any necrotic tissue. This will normally be accompanied by stabilising any underlying fracture to halt the cycle of worsening tissue injury. Male patients aged 15–30 years with a high energy closed tibial fracture are at extremely high risk with 1 in 4 developing compartment syndrome, requiring decompression. Therefore, in the polytraumatised, obtunded patient within this age group and with this injury pattern, consideration may be given to pre-emptively perform surgical decompression as diagnosis of the developing syndrome will be difficult. In addition, patients requiring prolonged transfer to another health care facility, particularly by air, with lower limb fractures, blast injuries or reperfusion/vascular injuries should have decompression performed pre-emptively before transfer.

Which Patients Are at Risk of Rhabdomyolysis and How Should They Be Managed?

Where significant volumes of muscle are injured, as may happen following crush or compartment syndrome, rhabdomyolosis is likely to follow. The release of intracellular muscle components such as myoglobin and creatine kinase (CK) into the circulation may lead to acute renal failure, disseminated intravascular coagulation and significant electrolyte imbalance [29].

Most cases of rhabdomyolysis follow direct trauma, but other causes include infections of muscle tissue, compartment syndrome and ischemia, drugs and toxins. The common denominator of all causes is massive muscle BREAKDOWN. Once muscle cellular breakdown starts, as in compartment syndrome, a self-sustaining cascade of necrosis arises and muscle contents are released to the circulation.

Clinical manifestations of rhabdomyolysis include myalgia, weakness and myoglobinuria but this classical triad is rarely present. The most sensitive laboratory test is elevated serum CK.

Once rhabdomyolysis is suspected, the causative pathology – such as compartment syndrome – must be addressed. The key complication is acute renal failure and fluid management is therefore critical. Aggressive hydration is generally recommended along with alkalinising the urine. However, excessive volume administration in the context of established critical illness can de deleterious and some patients may require early institution of renal replacement therapy.

What Is Fat Embolism Syndrome?

Fat embolus occurs in patients with long bone fractures, although few develop systemic dysfunction. The classical triad of skin, brain and lung dysfunction is uncommon but serious [30].

In fat embolism syndrome, circulating microglobules of fat lead to multisystem dysfunction. It is commonly associated with long bone fractures, especially after intramedullary nailing, but it has also been reported following burns, marrow biopsy and liposuction. Non-traumatic causes are very uncommon and include pancreatitis, fat emulsion infusion and haemoglobinopathies [30].

There are two causative theories. Gossling et al. suggest a mechanical theory in which fat is forced INTO the circulation, perhaps by the force of intramedullary instrumentation causing a rise in pressure within the intramedullary canal, and is deposited in capillary beds [31]. Local tissue inflammation results leading to systemic effects. Alternatively, the response to trauma may lead to systemic release of chylomicrons, which coalesce under the influence of inflammatory mediators leading to the same effects [32].

The key features of fat embolus syndrome are respiratory failure, cerebral dysfunction, and skin petechiae. Manifestations may develop 24–72 h following trauma [30]. The vascular occlusion in fat embolus is often temporary or incomplete as deformable fat globules do not completely obstruct flow.

The skin manifestations include a petechial rash, typically around the chest and axilla. Signs of respiratory and cerebral dysfunction are nonspecific and include tachypnoea and confusion.

Diagnosis is based on excluding other causes in the presence of clinical features of fat embolism [30]. Specific diagnostic criteria have been proposed by Schonfeld [33] and Lindeque [34] and are shown in Table 14.2.

Management is supportive and focuses on maintaining oxygenation and circulating volume. Stabilising long bone fractures early is essential, as delayed stabilisation increases the risk [36], though this must be balanced against the disadvantages of early surgery. Specific medical treatments for fat embolism syndrome have not been shown to be effective.

What Is Heterotopic Ossification and Which Patients Are at Risk?

Heterotopic ossification (HO) is the formation of bone in soft tissues. In patients with traumatic brain injury, the reported incidence of HO is between 10 and 20 % and it can have a significant impact on mobility and function [37].

HO generally forms in neurologically impaired limbs and in these patients is often found in muscle planes surrounding joints, as shown in Fig. 14.4. It may not necessarily occur in an injured limb. In other patients, such as those with traumatic amputations, HO may invade muscle compartments [38].

Unfortunately, there is little evidence to support any effective therapy in preventing or slowing the formation of

TABLE 14.2 Two scoring systems developed to diagnose fat embolism syndrome

Schonfeld et al. [33] **scoring system**	**A score of 5 or more equals a diagnosis of fat embolism syndrome**
Sign/Symptom	Score
Petechial Rash	5
Diffuse infiltrates on CXR	4
Hypoxemia	3
Raised Temperature	1
Tachycardia	1
Confusion	1
Lindeque et al. [34] **specific diagnostic criteria**	
Sustained PaO_2	<60 mmHg/8 Kpa
Sustained $PaCO_2$	>55 mmHg/7.3 Kpa (pH < 7.3)
Respiratory Rate	>35 bpm
Increased work of breathing	Dyspnoea
	Use of accessory muscles of respiration
	Tachycardia
	Anxiety

Although both systems were developed in the early 1980's they are still utilized [35]

HO. Diphosphonates have been shown to have some efficacy. A 6 week course of indomethacin may be effective at reducing HO, but evidence is limited. Radiation therapy may be effective, but the risk of radiation induced sarcoma is significant [37]. Physiotherapy has not been shown to prevent HO.

Once established, the only effective therapy is surgery. However, this may be invasive and carries its own morbidity.

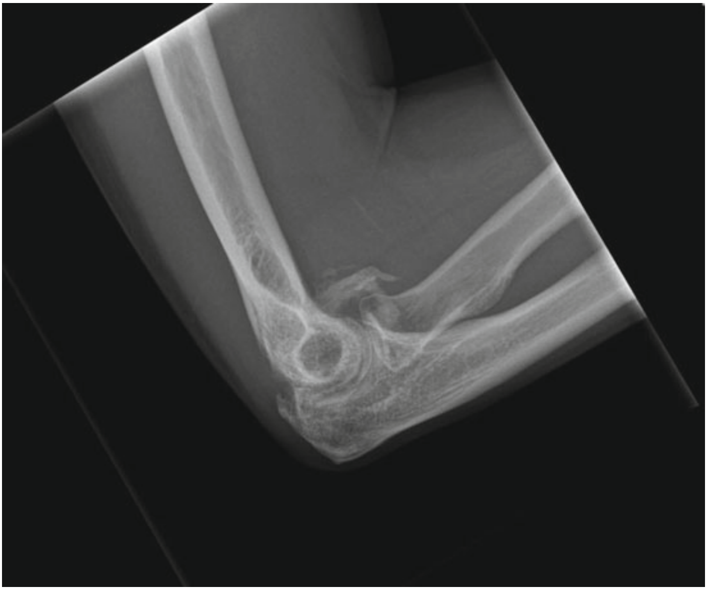

FIGURE 14.4 Radiograph showing heterotopic ossification of the anterior capsule of the elbow joint

References

1. Brooks A, Holroyd B, Riley B. Missed injury in major trauma patients. Injury. 2004;35(4):407–10.
2. Giannakopoulos GF et al. Missed injuries during the initial assessment in a cohort of 1124 level-1 trauma patients. Injury. 2012;43(9):1517–21.
3. Chen C-W et al. Incidence rate and risk factors of missed injuries in major trauma patients. Accid Anal Prev. 2011;43(3):823–8.
4. Thomson CB, Greaves I. Missed injury and the tertiary trauma survey. Injury. 2008;39(1):107–14.
5. Webber-Jones JE, Thomas CA, Bordeaux Jr RE. The management and prevention of rigid cervical collar complications. Orthop Nurs. 2002;21(4):19–25; quiz 25–7.
6. Mobbs RJ, Stoodley MA, Fuller J. Effect of cervical hard collar on intracranial pressure after head injury. ANZ J Surg. 2002;72(6):389–91.

7. Sundstrom T et al. Prehospital use of cervical collars in trauma patients: a critical review. J Neurotrauma. 2014;31(6):531–40.
8. Benger J, Blackham J. Why do we put cervical collars on conscious trauma patients? Scand J Trauma Resusc Emerg Med. 2009;17:44.
9. James CY et al. Comparison of cervical spine motion during application among 4 rigid immobilization collars. J Athl Train. 2004;39(2):138–45.
10. Podolsky S et al. Efficacy of cervical spine immobilization methods. J Trauma. 1983;23(6):461–5.
11. Hauswald M et al. Out-of-hospital spinal immobilization: its effect on neurologic injury. Acad Emerg Med. 1998;5(3):214–9.
12. Dunham CM et al. Risks associated with magnetic resonance imaging and cervical collar in comatose, blunt trauma patients with negative comprehensive cervical spine computed tomography and no apparent spinal deficit. Crit Care. 2008;12(4):R89.
13. BOA, BOAST 2 version 2: Spinal clearance in the trauma patient, in British Orthopaedic Association Standards for Trauma. London: British Orthopaedic Association; 2015.
14. D'Alleyrand J-CG, O'Toole RV. The evolution of damage control orthopedics. Orthop Clin. North Am. 2013;44(4):499–507.
15. Faist E et al. Multiple organ failure in polytrauma patients. J Trauma. 1983;23(9):775–87.
16. Nahm NJ et al. Early appropriate care: definitive stabilization of femoral fractures within 24 hours of injury is safe in most patients with multiple injuries. J Trauma. 2011;71(1):175–85.
17. Giannoudis PV. Surgical priorities in damage control in polytrauma. J Bone Joint Surg Br. 2003;85(4):478–83.
18. O'Toole RV et al. Resuscitation before stabilization of femoral fractures limits acute respiratory distress syndrome in patients with multiple traumatic injuries despite low use of damage control orthopedics. J Trauma. 2009;67(5):1013–21.
19. Pape HC et al. Major secondary surgery in blunt trauma patients and perioperative cytokine liberation: determination of the clinical relevance of biochemical markers. J Trauma. 2001;50(6):989–1000.
20. Tuttle MS et al. Safety and efficacy of damage control external fixation versus early definitive stabilization for femoral shaft fractures in the multiple-injured patient. J Trauma. 2009;67(3):602–5.
21. Bonner TJ et al. Accurate placement of a pelvic binder improves reduction of unstable fractures of the pelvic ring. J Bone Joint Surg Br Vol. 2011;93-B(11):1524–8.

22. Ruatti S et al. Which pelvic ring fractures are potentially lethal? Injury. 2015;46(6):1059–63.
23. Ierardi A, et al. The role of endovascular treatment of pelvic fracture bleeding in emergency settings. Eur Radiol. 2015:1–11.
24. Pfeifer R, Pape H-C. Missed injuries in trauma patients: a literature review. Patient Saf Surg. 2008;2:20.
25. Farrow C, Bodenham A, Troxler M. Acute limb compartment syndromes. Contin Educ Anaesth Crit Care Pain. 2011;11(1):24–8.
26. Kosir R et al. Acute lower extremity compartment syndrome (ALECS) screening protocol in critically ill trauma patients. J Trauma. 2007;63(2):268–75.
27. Wall CJ, Santamaria J. Extracorporeal membrane oxygenation: an unusual cause of acute limb compartment syndrome. Anaesth Intensive Care. 2010;38(3):560–2.
28. Köstler W, Strohm PC, Südkamp NP. Acute compartment syndrome of the limb. Injury. 2005;36(8):992–8.
29. Torres PA et al. Rhabdomyolysis: pathogenesis, diagnosis, and treatment. Ochsner J. 2015;15(1):58–69.
30. Shaikh N. Emergency management of fat embolism syndrome. J Emerg Trauma Shock. 2009;2(1):29–33.
31. Gossling HR, Pellegrini Jr VD. Fat embolism syndrome: a review of the pathophysiology and physiological basis of treatment. Clin Orthop Relat Res. 1982;165:68–82.
32. Baker PL, Pazell JA, Peltier LF. Free fatty acids, catecholamines, and arterial hypoxia in patients with fat embolism. J Trauma. 1971;11(12):1026–30.
33. Schonfeld SA et al. Fat embolism prophylaxis with corticosteroids. A prospective study in high-risk patients. Ann Intern Med. 1983;99(4):438–43.
34. Lindeque BG et al. Fat embolism and the fat embolism syndrome. A double-blind therapeutic study. J Bone Joint Surg Br. 1987;69(1):128–31.
35. Kwiatt ME, Seamon MJ. Fat embolism syndrome. Int J Crit Illness Injury Sci. 2013;3(1):64–8.
36. Behrman SW et al. Improved outcome with femur fractures: early vs. delayed fixation. J Trauma. 1990;30(7):792–7; discussion 797–8.
37. Cipriano CA, Pill SG, Keenan MA. Heterotopic ossification following traumatic brain injury and spinal cord injury. J Am Acad Orthop Surg. 2009;17(11):689–97.
38. Edwards DS, Clasper JC, Patel HD. Heterotopic ossification in victims of the London 7/7 bombings. J R Army Med Corps. 2015;161(4):345–7.