

## ORTHOPAEDICS & TRAUMA

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### Scenario 1

You are the FY2 on duty in the Emergency Department when a 22-year-old man arrives by ambulance following a road traffic accident. He has come off his motorbike at an unknown speed and was found at the side of the road by a passing motorist. He has a painful right lower limb that has an obvious overlying wound and you can see a fragment of bone protruding through a tear in his leathers over his shin. His GCS is 15, he is responding appropriately, talking in sentences and is immobilised on a spinal board. It is 0330 in the morning.

### Discuss your initial management of this patient

He has sustained a high-energy injury and is likely to have other, more life threatening injuries. You should immediately call for more senior help. He should be treated and resuscitated following Advanced Trauma Life Support (ATLS®) protocols.

It is fundamental that correct resuscitation procedures are followed in order to efficiently and safely manage victims of trauma. Attention must first be directed to the primary survey, which must be completed in a rapid and timely manner to allow identification and simultaneous treatment of any airway, breathing or circulatory compromise. With regard to safe management of the existing injuries, detection of associated or evolving systemic compromise and identification of associated or distracting disability is covered by the secondary survey. If you are team leader it is important that neither you nor the staff become fixated on the injured limb at the cost of missing more subtle injury or relevant medical complications.

In brief, following rapid assessment of his airway and breathing whilst maintaining cervical spine immobilisation, his clothes should be removed to allow adequate exposure, with appropriate environmental control. Pulse, blood pressure and peripheral oxygen saturations are recorded and his primary survey will be completed with cervical spine, chest and pelvic radiographs. Insert two large bore venous cannulae and take blood for full blood count, baseline biochemistry and group and save. High flow oxygen is administered and morphine is given intravenously, titrated to analgesic effect. He should be transferred from the spinal board as soon as is practical, maintaining in line immobilisation and log-rolled to enable assessment of the soft tissues of the dorsal surface of the body, bony tenderness over the spine and inspection of the perineum and genitalia as well as rectal examination.

*Following transfer and log roll the remainder of the resuscitation proceeds efficiently. The cervical spine imaging and examination reveals no injury and similarly the pelvis and*

*chest are clear on examination and imaging. His observations are unremarkable. Once the primary and secondary surveys are complete you find that the patient has sustained an isolated open fracture to the right tibia and fibula, for which you have requested further imaging. You investigate the wound and find that it is around 10cm x 2cm with protruding bony fragments, minimal bleeding and some surrounding bruising.*

### Discuss the classification and immediate management of this limb injury.

Continuing the immediate management of this injury, pain relief through analgesia and splintage must be addressed. The obviously deformed limb should be splinted to aid both analgesia and to prevent further soft tissue compromise.

Once the limb alignment has been assessed and splinted (Figure 1) and adequate analgesia has been administered, a formal assessment of the limb should be carried out with regard to neurological and vascular insult, soft tissue and bony compromise. Administer cephalosporin antibiotic (Cefuroxime 1.5g) intravenously unless allergic. Check tetanus status and cover the wound with a Betadine swab once a picture of the wound has been taken.



Figure 1. Post immobilisation radiographs demonstrating a comminuted angulated tibial fracture - note the potential for major vessel kinking.

With regard to the neurological and vascular assessment it is key with these injuries that a full, clearly and comprehensively documented examination is performed and repeated if any concern should arise. The foot should be palpated for the dorsalis pedis pulse and also the posterior tibial artery at the ankle should be assessed. As is often the case in the traumatised individual, these pulses may be difficult to palpate and if so they should be further assessed using a hand-held Doppler probe. The general perfusion of the limb with regard to pallor and capillary return should be documented. If there is any concern with regard to the perfusion of the limb the on-call vascular surgery team should be contacted without delay.

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It is important that the sensory and motor modalities of the lower limb are assessed and documented. In particular the deep peroneal nerve (dorsiflexion of the foot, extension of the toes and sensation in the first web space), superficial peroneal nerve (eversion of the foot and sensation over the dorsum of the foot) and the tibial nerve (plantar flexion of the foot and inversion of the foot with sensation on the sole of the foot) are assessed. This is important both in the first instance to identify associated neurological injury but also to subsequently help identify a change in neurological function such as may be the case with an evolving compartment syndrome. X-rays are taken; with all long bone injuries it is essential to assess the whole limb and at a minimum this must include two views (antero-posterior and lateral projections) and the joints above and below the injury.

Once the neuro-vascular status of the limb has been established and x-rays obtained it is important to assess the wound generated by the fracture. In particular with lesions over the tibia, the integrity of the soft tissues is of huge importance to the subsequent management options and prognosis in general. *'An open fracture is a soft tissue wound in which there happens to be a broken bone.'*

Open fractures are commonly graded by the Gustillo & Anderson classification:

**Grade I:** wound less than 1 cm with minimal soft tissue insult, little contamination and an underlying simple bone injury with minimal comminution. These injuries are commonly due to the skin being punctured from within by a bone spike and may be associated with a low energy transfer.

**Grade II:** wound is greater than 1 cm with moderate soft tissue injury and evidence of contamination. Fracture configuration demonstrating moderate comminution and seen with injuries associated with increasing energy transfer.

**Grade III:** Injuries automatically graded as III include high energy transfer fractures such as gunshot wounds, high-speed road traffic accidents and crush injuries. Due to contamination, farmyard open fractures also fall into this category. These injuries are associated with segmental bone loss or severe comminution. Grade III fractures are associated with wounds >10cm but it is important to stress that it is the nature of the wound rather than its strict measurement that is important. Grade III fractures are further subdivided into:

**Grade III A:** Wounds greater than 10cm with crushed tissue and contamination. Bone is not exposed and as such soft tissue coverage procedures are not necessary. This can be remembered as A = Adequate skin coverage.

**Grade III B:** Wounds greater than 10cm with crushed tissue and contamination. Bone is exposed and the soft tissue envelope is inadequate. Soft tissue coverage is required at final reconstruction/closure – a plastic surgery procedure or flap will be required. This is remembered as B = bone exposed.

**Grade III C:** Any fracture with a major vascular injury requiring operative intervention in order to salvage the limb. Remembered as C = circulation compromised.

*As the on-call ward cover for orthopaedics you are called in the early hours of the morning to review this patient. The nurses are concerned about his increasing post-operative pain. The notes state that this man had initial external fixation and subsequent intramedullary nailing and free flap coverage of his tibia fracture 12 hours ago. The nursing staff are concerned that despite administration of substantial opiate analgesia he is in increasing pain and is now becoming distressed. The pain is much greater than following the original fracture and he describes a new area of 'numbness over his toes'. The X-Rays taken in the resuscitation room showing the original injury are available and also those taken following the temporary and definitive procedures are available (Figure 2A-C).*



Figure 2A-C. Postoperative Radiographs following both the temporary (left) and definitive (below) procedures.



## What is the likely diagnosis?

The most likely cause for the evolving clinical picture is acute compartment syndrome. In compartment syndrome the tissues in a muscle compartment bound by fascial planes are compromised by an increased pressure within that compartment. It occurs when the end capillary pressure of perfusion is less than the intra-compartmental pressure. Compartment Syndrome is an initially limb and then potentially life threatening complication of extremity trauma and is generally seen following fractures, crush injuries and burns. Although associated with lower limb trauma, it can occur in any region of the body where fascial compartments exist such as the buttocks, thigh, foot, hand and arm.

## What is the pathophysiology of this condition?

Bone or soft tissue damage may result in an increase in pressure within a defined fascial compartment, which is enclosed by a resisting envelope (deep fascia, skin, casts and dressings all apply). Such insults may be seen to be due to:

**A decrease in compartment size** - from localized external pressure. Plaster casts, over tight dressings and inadvertent compression during positioning in theatre may all contribute.

**An increase in intra-compartmental contents** - A number of factors may contribute either in isolation or in combination to change the nature of the contents of a fascial compartment. These include:

- Bleeding – commonly seen with haematoma formation either as a result of fracture or following vascular insult.
- Increased capillary permeability – post-ischaemia swelling, post-exercise muscle swelling, trauma & burns.
- Increased capillary pressure – following exercise, muscle hypertrophy and venous obstruction.

It is important to note that although the syndrome is most often associated with fractures and in particular complex tibial fractures, it can occur in the absence of a fracture. It has been seen in situations as remote as following Coronary Artery Bypass Surgery and this further reinforces the need for clinical awareness on behalf of all health care staff looking after patients

with swollen or painful limbs. It should also be noted that the condition can also occur in open fractures.

When the pressure within a compartment rises to a point where perfusion is impaired as a result of the factors listed above, there will follow a series of hydrostatic and osmotic pressure changes. Regardless of the mechanism it can be seen that the perfusion of tissues within myofascial compartments is related to the arteriolar pressure, the venous pressure and the resistance afforded by the vessels themselves. This can be described in the equation:

$$\text{TBF} = (\text{PA} - \text{PV}) / \text{R}$$

Where TBF is Tissue Blood Flow, PA is the arteriolar pressure, PV is the draining venous pressure, and R is local vascular resistance. It is therefore easily understood how alterations in tissue microvasculature as discussed above will have an immediate and deteriorating effect on tissue perfusion.

With increasing pressure within a myofascial envelope, the interstitial tissue pressure and venous pressure rise, triggering the mechanisms discussed above which if allowed to continue may lead to compartment syndrome. With capillary collapse and reducing tissue blood flow, ischaemia will occur.

It can be seen that there is a vicious spiral that occurs with the end result not only of muscle necrosis with resultant late contracture formation within the affected compartment but also compromise to those structures transiting the compartment including nerves and blood vessels, leading to sensory and vascular deficit distal to the affected area.

With the establishment of necrosis there is an increase in release of free myoglobin into the circulation. Myoglobin is profoundly nephrotoxic and there is a real risk of consequent renal failure, sepsis and ultimately loss of the limb and death.

## Detail the investigation and management of this condition.

The diagnosis of compartment syndrome is based on clinical findings and attention to the pertinent features of the history from the patient and their notes. The cornerstone of prompt diagnosis of compartment syndrome remains the maintenance of a high degree of suspicion in the clinician presented with a patient who has an acutely swollen or painful limb.

Traditionally the 'five P's' have been described as, albeit late, features of the condition:

**Pain** – often the earliest although sometimes unreliable feature due to the variation in intensity and may be minimal in compartment syndrome complicated by nerve injury or pressure affecting a deep compartment only. Classically pain which is increasing in intensity despite the administration of opiate analgesia, pain which seems to be out of all proportion to the causative insult and pain on gentle passive stretching of the muscles of the limb compartments are key to the diagnosis.

**Paresis** – a decreasing level of muscular function resultant both from pain and increasing neurological dysfunction may be seen.

**Paresthesia** – a decrease or loss of two-point sensory discrimination is a reliable feature of the neurological compromise associated with increasing pressures in the compartments transited by the nerves supplying the limb in question.

**Pallor** – a decrease in perfusion will result in an obvious change in colouring of the limb although this is a very unreliable sign.

**Pulselessness** – a very late and unreliable sign as the arterio-venous gradient may be compromised whilst the pulses remain palpable and reliance on the presence of distal pulses as a marker for perfusion may delay the prompt intervention necessary to salvage the limb and prevent the life-threatening complications of tissue necrosis. It is the 'Motorway syndrome'

– the main arterial trunk with high Mean Arterial Pressure still gets through but there are no 'exits' out of the compartment.

A further P for palpation should be added as the compartment involved may have a noticeable degree of erythema with associated shiny skin and is described as having a 'woody' feel.

It should be clear that the above clinical features are seen in established compartment syndrome – the key is in **early** diagnosis – if you are thinking compartment syndrome, you should be treating compartment syndrome.

Once a suspicion of an evolving compartment syndrome exists, their then comes the question as to what to do next. It should be emphasised at this point that thorough serial examinations of the neurovascular status of the limb, recording of the patient's baseline observations at regular intervals and precise documentation of the above are critical from the moment of admission. These will all combine to aid an early diagnosis prior to the vicious cycle described above. Review should be sought on an urgent basis by senior staff responsible for the patient.

The normal resting pressure within a myofascial compartment is between 0-10 mmHg. 'Normal' capillary perfusion may become compromised at intra-compartmental pressures greater than 20 mmHg with ischaemia and necrosis of muscle tissue said to occur at pressures around 40mmHg. Debate occurs within the orthopaedic community as to the relative importance of either absolute compartment pressure measurement with subsequent fasciotomy in those patients with an intra-compartmental pressure exceeding a pre-determined level of variously reported 30 - 40 mmHg **or** selective fasciotomy in those patients who show a compartment pressure rising to within 30 mmHg of the diastolic blood pressure.

Compartment pressure monitoring may be seen as an adjunct that is of particular use especially in those individuals unable to give a history or respond to examination findings such as the unconscious patient. Compartment Syndrome is essentially a clinical diagnosis.

There are four compartments involved in the lower leg and these may all be affected by compartment syndrome. The compartment most commonly affected is the anterior compartment containing tibialis anterior, extensor digitorum longus, peroneus tertius, extensor hallucis longus, the anterior tibial artery and the deep branch of the peroneal nerve. It is this compartment that is investigated during compartment monitoring. The details of anterior compartment monitoring are beyond the scope of this article although the principle is centred on the use of a handheld syringe, slit catheter and transducer to assess the pressure required to infuse a set volume of fluid into the compartment. The greater the compartment pressure, the greater pressure needed to infuse the fluid which is reflected in the transducer.

Following suspicion of compartment syndrome on clinical grounds or on clinical findings augmented by continual pressure monitoring the patient should proceed for emergent full leg double incision four compartment surgical decompression. Once again, the intricacies of fasciotomy are not for discussion here although the basic principles of full and adequate decompression through skin incisions along the full length of the affected compartment are essential and there is no role for limited or subcutaneous fasciotomy. The commonest error is to mistake the bulging lateral compartment for the anterior compartment and hence fail to adequately decompress the anterior compartment. The resulting skin wounds should be left open and the viability of the tissues assessed at a 'second look' 48 hours later.

This case has demonstrated the need for surveillance,

suspicion and prompt action in order to protect patients from the often-avoidable serious complications of compartment syndrome. This is a very real problem that cannot be overlooked due to the consequences for the patient and the clinicians involved; the latter as highlighted in a recent assessment of the medico-legal impact of compartment syndrome in negligence cases.

## Scenario 2

*A 39-year-old warrant officer attends your sick parade on Monday morning. He is on crutches and has a long leg cast immobilising his right lower limb. A county level player in his youth, he now coaches squash and during a knock around game over the weekend he lunged for a shot and 'heard a snap around his heel and a searing pain spread up his calf'.*

### What is the diagnosis and pathogenesis of the condition?

This patient presents with a classic history of a ruptured Achilles tendon. These injuries are found to occur most commonly in a particular group of individuals – the ageing sports enthusiast. In the population aged 30-50 years, injury to the tendon is associated with activities involving sudden eccentric loading of a dorsiflexed foot – the position in jumping and rapid push off during lunging or sprinting.

Within this group of patients, risk factors, other than the injuring force, that predispose to rupture include recreational sports, changing intensity of training or adoption of a new sport at advancing age. Prior tendon injury or chronic tendon pain also predispose to rupture.

It is valuable when discussing Achilles injury to consider the biomechanics and terminology that is involved in disease and injury to the tendon. The Achilles tendon is formed from an aponeurosis of the tendons of the two bellies of gastrocnemius and soleus. It is between 12-15cm long and is lined by a double-layered sheath of paratenon. The majority of the tendon is composed of type I collagen in healthy individuals and with increasing age and healing, this is seen to be increasingly replaced by scar tissue.

The Achilles tendon is the conjoined tendon for the gastrocnemius-soleus musculotendinous unit. This complex is important in running and jumping as well as stair climbing. Contraction of the gastrocnemius flexes the knee and plantar flexes the foot at the ankle due to its nature of spanning the knee, the ankle and subtalar joints. There is seen to be a large force generated across the tendon – indeed up to ten-times bodyweight during heavy activity. During its path down the posterior aspect of the leg the tendon substance is seen to spiral, with the majority of this phenomenon occurring in the distal aspect prior to insertion. It is thought that this is important in the elastic recoil of the tendon during ambulation. It can be seen therefore that the Achilles tendon is not just a 'rope' attaching the posterior lower leg muscles to the heel, it is essential for normal gait and disease in the tendon may cause significant morbidity.

Blood supply to the Achilles tendon is multi-focal with vessels running from the musculotendinous junction, the paratenon and also from the distal osseous insertion. Debate arises over the so-called 'watershed area' of tendon that is found within 2-6cm from the insertion. Cadaveric studies show a paucity of vessels in cross section of this area although more recent dynamic studies dispute this hypovascular theory and it is unclear as to whether this is indeed cause or effect.

An important area of discussion is the description or nomenclature associated with Achilles tendon disease. Terminology is often confused and interchanged

inappropriately and this may lead to confusion and inappropriate management. The term 'tendonitis' has been described as misleading as light microscopic studies of patients undergoing operation for tendon pain have demonstrated that these cases are indeed tendonosis – their histology show chronic changes and the absence of any acute inflammatory changes. The other acute pain is more reliably described as paratendinitis, of which there are three categories: Paratendinitis, paratendinitis with tendonosis and pure tendonosis. This has obvious implications with treatment modalities including rest and anti-inflammatories, as these are clearly inappropriate in the tendonosis situation. A more proper term for globally describing disease of the Achilles tendon is tendinopathy that leans away from an acute entity and acknowledges the histological evidence of chronic degeneration.

As such it can be seen that the vast majority of individuals have degenerative change (tendonosis) apparent in their ruptured tendons and that only a very small minority had any symptoms prior to damaging their tendon.

*You are the orthopaedic registrar in a busy fracture clinic. You are asked to see this soldier by his medical officer. He is an instructor at the Infantry Training Centre and is due to rejoin his unit to deploy on an operational tour in eight months time. He 'wants it fixing so that he can get back to work and squash coaching'.*

### What are the Management options?

As with the vast majority of surgical consultations, the available treatment options fall loosely into operative and non-operative treatments. In consideration of the best management of patients presenting with Achilles tendon rupture a number of issues need to be addressed:

- Age
- Level of activity
- Desire to return to functional activity
- Time from injury
- Associated co-morbidity
- Patient wishes

A number of studies including several meta-analyses have addressed the question of operative versus non-operative management of Achilles tendon rupture. There is no right answer and there are benefits and risks with either approach. In general in the fit and active population, operative reconstruction is associated with improved function and a decreased re-rupture rate, which is of statistical significance.

Non-operative management is reserved for the elderly and those who are not keen to face the soft tissue related risks of operative repair.

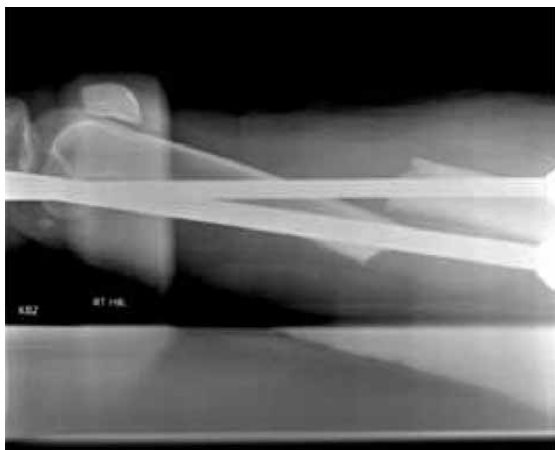
For this soldier's case, he clearly fits into the high demand group with increased functional demands and a desire to return to pre-injury level of activity. He must be counselled that strict compliance with the post operative regime of gradually increasing dorsiflexion in casting from equinus to neutral over a month with protected weight bearing during this time is essential to the success of the repair. He must also be aware that although the risk of re-rupture is less than when compared to conservative management, there is a small risk of repair failure. High level, motivated athletes have successfully returned to sport at eight weeks following final plaster removal.

## Scenario 3.

*A 23-year-old soldier is brought in to your resuscitation facility in a local Ministry of Defence Hospital Unit following a road traffic accident (pedestrian versus car) whilst on exercise and has sustained a closed, isolated right diaphyseal femoral fracture (Figure 3). He is brought in immobilised on a spinal board with*

cervical spine protection and a temporary splint on his leg. He can recall the events surrounding his injury and is talking lucidly in sentences.

Figure 3. Basic Radiographs obtained in the resuscitation department.



### Detail your immediate management of this patient.

This soldier should be initially assessed and resuscitated according to the principles of ATLS®. A thorough primary and secondary survey should be carried out, augmented by appropriate trauma series radiographs, intra-venous access and baseline blood tests with a 4 unit cross match. Only when the secondary survey is complete should the attention become focused on the obvious femoral injury

The temporary splintage should be removed and replaced with a Thomas splint. At this point it is sensible to perform a thorough reassessment of the vascular and neurological status of the limb and also to check for wounds that may be suggestive of an open fracture. Analgesia will be required prior to the application of the splint and to aim for a more smooth application it is advisable to wait until the analgesia or sedation administered has had time to gain maximum benefit prior to manipulation of the limb

Once the patient has been resuscitated and assessed and is comfortable in splintage, it is valuable to obtain further radiographic imaging of the limb with AP and Lateral views if these are not already available and also ensure that the imaging exposes both the knee and hip joints. Subsequent to ensuring adequate imaging it is vital to ensure that a thorough history

has been taken. With the pressure of resuscitation, the routine tasks of enquiring about previous medical problems and concurrent systemic illness and medication etc may be overlooked. It is good practice that once 'the dust has settled' the history and background are re-evaluated.

With the patient stabilised and all imaging and baseline blood tests available, the patient should be referred on to the orthopaedic team for continuing care.

*Following transfer to the orthopaedic ward the patient and staff wish to be informed as to the plan for his subsequent management. He has been told that 'it's going to be nailed...' You are the ST3 on call and you need to consider the following points in order to deal with this patient:*

### What degree of force is required to produce the fracture pattern seen above and what associated injuries need to be considered?

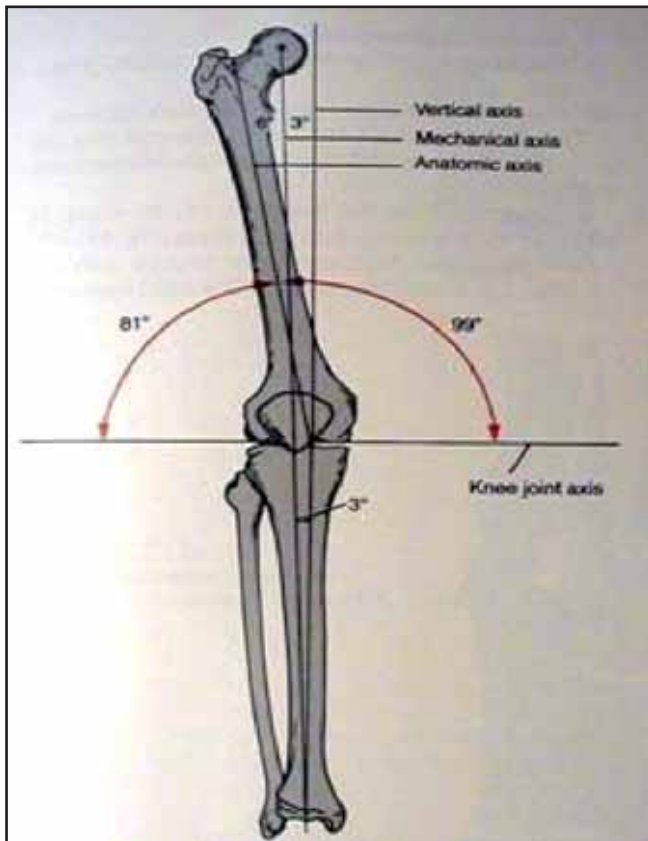
Fractures of the femoral shaft are generally attributable to high-energy insults to the limb. The energy or loading required to enable femoral fracture is considerable. As with all long bones, the femur is strongest in axial compression requiring a huge force applied in this manner to result in fracture. If however this force is applied, as is the case with bending injuries with a combination of axial compression and tension the required force is seen to be far less. This combined force application yields the commonly recognised fracture pattern of transverse or wedge fragment at the mid-shaft. Such fractures may present with associated skeletal injury including ipsilateral femoral neck, pelvic ring and acetabular fractures as well as significant risk of soft tissue damage to the knee.

Distant from the skeleton, there is also an increased risk of organ damage seen with these injuries. As a result, it can be seen that early and comprehensive evaluation of the patient with a femoral fracture is essential and the threshold for investigating associated injuries must be low. Imaging of the femur should include the hip and pelvis as highlighted above and also the ipsilateral knee. In the presence of concern over the integrity of the femoral neck (5% of femoral shaft fractures will have an ipsilateral femoral neck fracture), further imaging options include an AP pelvis radiograph proceeding on to thin slice Computed Tomographic scanning of the femoral neck which if carried out would allow concurrent further assessment of the acetabulum and pelvis.

### How does the osteology of the femur influence the biomechanics of fixation and what impact do the surrounding muscle groups have on the fracture pattern and the reduction of the fragments?

The structure of the femur has obvious impact on its biomechanical properties and hence the selection of implant is dependent on understanding and harnessing these forces present within the architecture of the bone. As well as the impact of the osteology one must also consider the working forces of the vast musculature surrounding the femur as knowledge of the forces applied to fracture fragments will heavily influence reduction of these fragments and hence their suitability to fixation by the chosen device. The osteology and articulation includes the tubular nature of the medullary canal and the relationship between this; the anatomical axis of the femur and the mechanical axis represented by a line drawn between the head of the femur and the middle of the knee (Figure 4). The femoral shaft can be seen to lie in valgus orientation to the mechanical axis described and this varies between the sexes to between 5 and 7 degrees.

Figure 4. The Differing Axes of the lower limb.



The femur also has an anterior bow in the sagittal plane and this is of obvious importance when considering intra-medullary nailing of such fractures. The medullary canal varies in diameter throughout the length of the femur and in general terms is widest at the metaphyseal regions and narrows at the isthmus around its midpoint. The thickness of the cortex is also variable being thickest posteriorly at the linea aspera- the point at which the majority of the vascular supply to the femur is found in the nutrient branches of the perforators from the profunda femoris artery.

The femur is almost completely surrounded by muscle tissue and these muscles along with others distant to, although acting on, fracture fragments are important in understanding the configuration of fracture dynamics and necessary forces required for successful reduction and avoidance of malalignment. Although perhaps not as dramatic as seen in the proximal or more distal fractures, the actions of iliopsoas and the adductors flexing and adducting the proximal fragment respectively along with plantaris and gastrocnemius causing distal fragment to become relatively retroverted must be considered.

### Beginning with non-operative measures, discuss your management options:

Options are available for the non-operative treatment of femoral fractures in skeletal traction and bracing either as a definitive measure or more commonly as a temporising staged pre-cursor to fixation. They are important in regaining length and aiding analgesia. It is important to be aware of these options either as definitive treatments or as adjuncts to operative fixation however it is currently accepted that for the majority of fractures of the femoral shaft that operative intervention through a choice of implants demonstrates improved outcomes. Risks of non-operative management include longer periods of immobility (including the

physiological risks of increased bed rest in terms of respiratory function and thrombo-embolic phenomena); longer time to the achievement of stability and poorer outcomes in terms of increased re-fracture, non-union and malalignment rates.

### Detail the options for operative intervention. What is your rationale in selecting a particular fixation regime?

#### External Fixation

As with all options, the use of external fixators can be considered for either temporary stability or definitive fixation through either mono-lateral or circular constructs. The limitations of definitive external fixation in terms of shortening, deep and superficial infection and limitations on knee movement have been highlighted. The bulky lateral thigh muscle mass is a contributing factor to the multi-factorial problems of long-term treatment by this method. These limitations and the evolution of damage control orthopaedics (DCO) have seen the role of external fixation develop as a temporising, staged procedure prior to definitive fixation via intra-medullary nailing. This use of immediate external fixation in DCO prior to definitive fixation has been shown to be of benefit in the poly-traumatised patient in terms of both favourable outcome and decreased overall physiological impact.

#### Internal Fixation – Plating

Although virtually any fracture configuration of the femoral shaft may be suitable to fixation with a plate in the tension band mode placed on the lateral side of the femur, routine use of this device has been seen to decrease with the availability of locking intramedullary nails. Minimally invasive techniques have evolved to address the obvious functional, infective and periosteal insult associated with plating. Indications for the particular use of plates in these fractures include use in patients with a narrow medullary canal and in those complex fractures involving extension either proximally into the trochanteric region or more distally into the metaphyseal region proximal to the knee.

#### Internal Fixation – Intramedullary nailing

The placement of a load sharing intramedullary nail affording relative stability to femoral shaft fractures with predictable outcomes has become the accepted practice for managing femoral shaft fractures. The nail may be introduced in either an antegrade manner with an entry point into the bone via either the piriform fossa or the greater trochanter proximally (Figure 5) or retrograde with the entry point of the nail into the medullary canal optimally at 1.2cm anterior to the femoral posterior cruciate ligament origin centred in the intercondylar sulcus, providing the optimal balance for fracture reduction and knee joint sparing (Figure 6). Retrograde placement of the femoral nail is indicated in cases involving ipsilateral bony injury such as tibial shaft fractures allowing access through a single exposure or acetabular fracture allowing separation of surgical fields. Retrograde nailing is also indicated in supracondylar and peri-prosthetic femur fractures. The advantages described of treating multiple fractures as well as the relative ease of the procedure in terms of set up and access have to be balanced against the risk of sepsis within the knee joint, especially in open fractures and also the implications for long term knee function including the insult to cruciate ligament perfusion.

Although the use of interlocking intramedullary nails is described as current best practice, the learning curve for successful use of these devices is not to be underestimated.

Intimate awareness of the unique anatomy of the femoral shaft as described earlier and accurate establishment of nail entry point are absolutely fundamental to optimal operative fixation.

Figure 5. Radiograph showing entry point option for antegrade femoral nailing.  
Figure 6. Radiograph showing entry point for retrograde femoral nailing (Lateral).



The patient proceeds to have intramedullary nailing of his femur on the trauma list. Initially he does well and then 48 hours post-operatively you are called to see him as he is complaining that 'his chest feels tight and he doesn't feel too good...cant seem to breathe right...' The nursing staff state that he has become tachycardic and his oxygen saturations have drifted down to 78% on room air. He is sweaty to touch with a temperature of 38.2°C and his respiratory rate is 24 breaths per minute.

## Detail your immediate action:

This patient has a pulmonary embolus until proven otherwise. This should be at the forefront of your approach to the investigation of his respiratory symptoms although other differentials including pulmonary compromise due to ARDS, pneumonia and also acute cardiac events must be borne in mind.

High flow oxygen via facemask should be administered and arterial blood gas measurements and baseline blood tests taken. A request should be made for a portable chest x-ray and a 12 lead ECG. The patient should be thoroughly examined and the observations, wounds and drug charts reviewed.

Whilst the investigations are being carried out the on-call physicians should be contacted. This patient falls into the intermediate to high-risk category for pulmonary embolism according to the Well's Criteria. He should be considered for CT scanning and High-resolution multidetector computed tomographic angiography (MDCTA) is becoming the diagnostic modality of choice, surpassing the ventilation perfusion scans and pulmonary angiography previously in vogue for the diagnosis of embolic disease.

It has been shown that the arterial blood gases, ECG and chest x-ray although useful in ruling out other differential diagnoses, add little of firm consequence to the diagnosis of embolic disease. Clinical judgement especially reliant on dyspnoea, chest pain, anxiety, tachypnoea, tachycardia and fever should alert the clinician to the diagnosis and stimulate the need for rapid investigation and management with the appropriate imaging and rapid anticoagulation using low molecular weight heparin. Imaging will direct further treatment and the need for interventional measures such as vena caval filters etc.

## What other complications may be associated with this fracture and how are they managed?

### Adult Respiratory Distress Syndrome (ARDS)

A prospective, randomized multi-centre trial has shown that there was no increase overall in incidence of ARDS following intramedullary nailing and more importantly no difference between the reamed versus un-reamed group. In animal studies there has been demonstrated increased lung permeability during reaming that was exacerbated by the presence of lung contusion and also this study demonstrated an increase in polymorphonuclear leucocytes activation, again exacerbated by reaming in the presence of pulmonary contusion.

Bearing this in mind, it is essential that clinicians have a high index of suspicion regarding associated chest injuries and a low threshold for securing input from critical care services.

### Compartment Syndrome

As with overt vessel damage, the development of compartment syndrome within the thigh following fixation is similarly low: estimated at around 1 – 2 %. Precipitants particularly associated with an increased risk of compartment problems include those fractures sustained following crush injury, persistence of hypotension and those patients who are coagulopathic. Similar to cases of compartment syndrome elsewhere, the diagnosis is made on the clinical features of increasing pain, severe pain associated with passive stretching of the muscles in the affected compartment and sensory blunting in the nerves traversing the compartment. Pressure monitoring may be seen as an adjunct and a demonstration of an increasing trend is helpful although prompt fasciotomy is required if clinical suspicion is high.

### Associated injuries

As discussed earlier, the clinician must be alert to the identification of associated injuries and these may only become evident once the initial stabilisation has occurred 'in the cold light of day'. This is particularly of importance when considering the integrity of the ligamentous structures of the knee joint and it is fundamental that the joint is examined under anaesthesia as part of the definitive procedure. Of equal importance is a 'tertiary survey' allowing a complete re-evaluation of the patient in a systematic manner to enable identification of occult head, thoracic, abdominal and pelvic injury in particular.

Repeated evaluation of the patient post-operatively is worthwhile and especially in regard to previously missed ipsilateral femoral neck fractures either iatrogenic or occurring at the original injury. It is good practice to screen the hip at completion of femoral nailing.

### Nerve and vessel injury

As described above, the incidence of vessel or nerve injury either at presentation or following fixation is low. An increased suspicion is obviously required with those fractures involving penetrating injury and prompt review with a view to exploration and consultation with the vascular specialists must be considered if there is concern.

### Scenario 4

*An eight year Afghan child presents to your Emergency Department on deployment following a fall off a high wall. He has an obviously deformed upper left limb and is distressed. The radiographers have provided you with the following imaging of his limb:*

*Figure 7. Lateral and AP views of the elbow.*



*You are the Medical Officer in the Emergency department – describe the injury and detail your initial management.*

This child has sustained a supracondylar fracture to the left distal humerus. This injury is the most common fracture around the elbow and overall is the second most common paediatric fracture. Supracondylar fractures are generally seen in the first decade of life with the incidence peaking at 5-8 years of age and they occur more frequently in boys than girls.

There are two types of supracondylar fracture described dependent on the attitude of the distal fragment lying either in extension (95% of fractures) or flexion (5% of supracondylar fractures). For purposes of brevity, the more common extension type fracture will form the basis of the discussion.

In 1959 Gartland classified these fractures according to the degree of displacement and this was later refined by Wilkins and is based on the relative displacement and rotation of the distal fragment with reference to the integrity of the anterior and posterior distal humeral cortices.

**Type 1:** Undisplaced fracture.

**Type 2a:** Intact posterior cortex and angulation only.

**Type 2b:** Intact posterior cortex, angulation and rotation

**Type 3a:** Completely displaced, no cortical contact with posteromedial rotation.

**Type 3b:** Completely displaced, no cortical contact with posterolateral rotation.

Reviewing the radiograph above, this fracture should be classified as a type 3a.

The immediate management of this injury centres not on the bone itself but on the neurovascular structures that may be compromised as a result of the fracture fragments. The limb should be assessed with regards to perfusion and nerve function. The limb should be splinted in an above elbow cast and analgesia administered in order to make the child comfortable. It is important that the neurovascular status of the limb is re-examined and documented after any manipulation, including cast application.

As with all basic emergency management a full history from the patient and relatives is essential and past medical history, medication, allergies and systematic enquiry cannot be allowed to be sidelined by an often anxiety inducing injury. When did the child last eat or drink?

AP and lateral radiographs of the fracture site are requested and these should include the joint above and the joint below. Assess the elbow and wrist both clinically and radiologically.

Further management of this child will take place under the orthopaedic team on-call to whom you now refer.

*As the orthopaedic surgeon, this patient is referred on to you. Describe the biomechanics of this fracture pattern. Discuss the applied anatomy of this injury with regard to nerve and blood vessel injury and detail the examination you would carry out to ascertain the integrity of the most commonly damaged nerve.*

Extension type supracondylar fractures can be seen to represent the end result of similar force vectors that produce dislocations in the adult elbow. Around the age of six, the distal humerus is seen to remodel with a resultant overall decrease in anteroposterior diameter in the supracondylar region, which has an obvious impact on susceptibility to fracture. As well as the dynamic remodelling process, the supracondylar region is biomechanically compromised by the presence of the olecranon fossa, which further reduces its capacity to withstand an applied load.

Other features related to the applied anatomy of the paediatric elbow contributing to this fracture pattern include the level of ligamentous laxity seen in this population, leading to a propensity to hyperextension at the joint. There is a

disparity also in the thickness of the elbow capsule with the anterior aspect being stronger than the posterior component.

Having identified these areas of applied anatomy it is relatively straightforward to work through the biomechanics resulting from the applied load leading to the identified fracture pattern.

When the child falls onto the outstretched hand with the elbow in neutral, particularly from a height such as typically off a wall, out of a tree or more recently off trampolines, the force passes up the forearm and will encourage the already extended elbow to become hyperextended which is easily achieved as discussed above. In the state of hyperextension the anterior aspect of the elbow capsule becomes taught and acts as fulcrum by which the olecranon becomes firmly opposed into the olecranon fossa – an area previously identified as being inherently weak compared to the surrounding bone.

With continued loading of the forearm as would occur with the child's full weight applied, the bone will fail on the tension (anterior) aspect and propagation of the fracture line will pass anteriorly through to the posterior aspect of the bone and this combined with the proximal and posterior pull of the triceps on the distal fragment results in the fracture morphology and the grading systems described above.

With regard to the applied anatomy of the soft tissues and in particular the neurovascular structures around the elbow it can be readily appreciated that collateral damage to these structures both during the index injury and in subsequent manipulation is a significant risk. All of the nerves around the elbow may be injured due to the varying fracture configurations possible. Overall neural injury is seen in around 12-15% of these fractures and the most commonly injured nerve is the anterior interosseous (AIN) branch of the median nerve.

Following its origin from the median nerve the AIN passes distally on the anterior surface of the interosseus membrane between the flexor pollicis longus (FPL) and flexor digitorum profundus (FDP), accompanied by the anterior interosseous artery. It gives motor input to FPL, pronator quadratus and the lateral half of FDP.

With a hurried assessment, which is often the case when examining distressed children, the crucial distinction between injury to the median nerve and the AIN branch can become confused. It is apparent that a child may retain full sensation to the digits whilst having an injury to the AIN. In order to quickly identify a lesion of the AIN the examiner should ask the child to make an 'okay sign' by opposing the distal phalanges of the thumb and index finger. A positive okay sign – in other words indicative of an AIN lesion – is demonstrated by a failure of flexion at the interphalangeal joint of the thumb (paralysis of FPL) and the distal interphalangeal joint of the index finger (paralysis of FDP). As a result, the distal phalanges fail to flex and the volar surfaces of the digits rather than their tips meet. (Figures 8A & B)



Figure 8A. 'Okay sign' with an intact AIN. Figure 8B. 'Okay sign' with an AIN lesion.

With regard to arterial compromise following supracondylar fracture this again is a relatively uncommon but potentially catastrophic early complication associated with this population. Together with the associated risk to the nerve as discussed and before considering the long term complications of mal-union it is no surprise that Gartland remarked upon "the trepidation with which men, otherwise versed in the management of trauma, approach a fresh supracondylar fracture"

As with the nerve lesions, the incidence of reported vascular compromise is variable at 3 -13%. The intricacies surrounding the arguments around the management of the child with presumed vascular compromise both pre-operative and following fixation are outwith the scope of this article. In short, the absence of a pulse in an otherwise warm pink hand is not an indication for either preoperative vascular imaging or formal exploration. The child should proceed for manipulation and stabilisation of the fracture, following which the perfusion of the limb and distal pulses may be reassessed and a decision made at that point to continue with assessment and watchful waiting or proceed to formal exploration of the vascular tree.

### Comment on your proposed management with regard to method and timing of surgical intervention.

Debate continues with regard to the timing of surgical intervention between immediate or delayed surgery. In reality this is often a trade off between the risk of increasing swelling by delaying surgery against approaching this often technically challenging procedure with a well-rested and staffed team.

Management of supracondylar injuries, as with all fractures is dependent primarily on stability. In the undisplaced fracture (Type 1), immobilisation in an above elbow backslab for comfort is appropriate followed by review in fracture clinic. For the displaced fracture with an intact posterior cortex (Type 2) manipulation under anaesthesia may be carried out in order to reduce the fracture and then dependent on achieving a stable configuration, the fracture should be held in an above elbow cast at 90° in pronation. For completely displaced fractures (Type 3) again, all options are available although operative fixation is required to obtain optimum reduction and maintenance of stability.

With regards to the operative management of the fracture, the fragments are first reduced under image intensification by a combination of longitudinal traction and rotation to achieve alignment followed by flexion with pressure over the olecranon to maintain reduction whilst the fracture can be stabilised by Kirshner (K) wire placement (Figure 9). Once again there is debate surrounding optimum fixation with regard to the rigidity of the construct afforded by crossed k wires from medial and lateral wire placement. It has been reported that crossed k wires may provide greater rotational stability in biomechanical studies,



Figure 9. Per-operative Fixation with 2 Kirshner wires.

however a number of articles have demonstrated good results using laterally placed and hence uncrossed wires only with the obvious benefit of decreased risk of iatrogenic ulnar nerve injury.

Post-operatively the limb should be immobilised in an above elbow cast with care taken to not flex the elbow past 90° in order to decrease the risk of compartment syndrome in the volar

compartment and encourage adequate distal perfusion. Observation overnight on the paediatric ward for neurovascular compromise is a sensible course of action with subsequent discharge and follow up at the orthopaedic fracture clinic in one week. The nurses are instructed to check the radial pulse every hour.