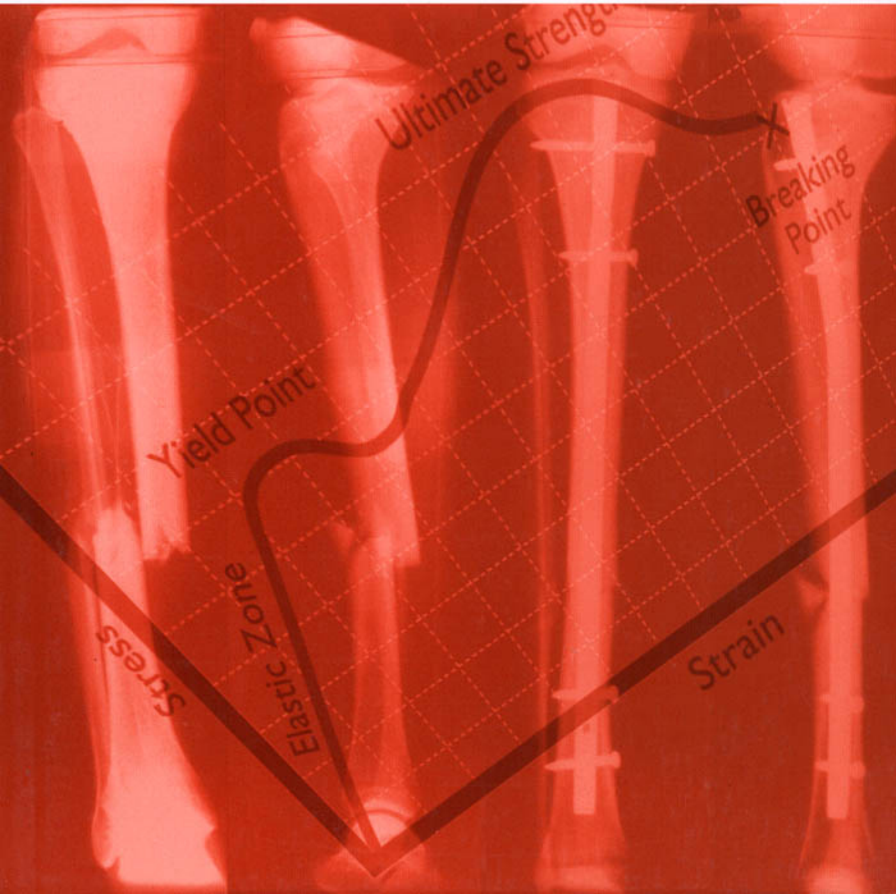
KEY TOPICS IN

# ORTHOPAEDIC TRAUMA SURGERY

G S KEENE · A H N ROBINSON · M G BOWDITCH · D J EDWARDS



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# ORTHOPAEDIC TRAUMA SURGERY

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nd a 2 cm heel raise is used for 6 weeks. Calf muscle
rgical repair, with a calf strength greater than 85% of
or conservative treatment. Jogging should not be
ter the rupture and more vigorous sport gradually
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l range of movement, with faster recovery and return
cal repair using a mobile cast or brace, allowing early

# AMPUTATION AND REPLANTATION

This chapter considers amputation and replantation. Should the severely mangled limb be salvaged and should an already amputated limb be replanted?

## Amputation

Traumatic amputation accounts for 11% of all amputations, and in the under 50s the figure approaches 50%. The decision to amputate is difficult. The limb must be considered both in the context of the patient's acute condition and long-term health. Economic, social and psychological factors should be assessed, ideally involving the patient in the decision-making process. Independent orthopaedic and plastic surgical opinions on the feasibility of limb salvage are helpful. Prognostic factors include:

1. ***Local factors.*** The following are linked to a poor outcome:

- Vascular injury, especially if the warm ischaemia time exceeds 6 hours.
- Gustilo IIIc injury, in which the amputation rate is 40–88%.
- Infrapopliteal vascular injury of all three vessels – these have amputation rates around 100%.
- Neurological injury – the restoration of protective sensation is critical to successful outcome.
- Soft tissue crush injury – as opposed to sharp cutting injury.
- Loss of bone length in the lower limb.
- Compartment syndrome.
- Pre-existing limb disease – atherosclerosis.

2. ***Systemic factors.*** The following are linked to a poor outcome:

- Age.
- Smoking.
- Pre-existing conditions – diabetes mellitus.
- Associated polytrauma. The Hanover group advocate amputation in Gustilo III fractures, when the Injury Severity Score (ISS) exceeds 40. This reduces the risk from systemic release of breakdown products, reducing the threat to renal and pulmonary function, therefore putting life before limb.
- Systemic hypotension.

3. ***Absolute and relative indications.*** Lange suggested the following indications for amputation in Gustilo IIIc tibial injuries:

(a) Absolute
- Warm ischaemia time exceeding 6 hours.
- Complete posterior tibial nerve disruption.

(b) Relative
- Associated polytrauma.
- Severe ipsilateral foot trauma.
- Fracture with major soft tissue injury and bony reconstruction anticipated.

4. ***Scoring systems.*** To aid the decision-making process, various scoring systems have been devised, the Mangled Extremity Severity Score (MESS) being the most

commonly used (*Table 1*). This score was developed retrospectively by assessing the outcome in patients with Gustilo IIIc tibial fractures. A score of >7 was predictive of amputation in 100% of cases. Subsequent studies have been less convincing, with a reported sensitivity of 22% and specificity of 53%. Interobserver variability is a problem.

The MESS has been modified to the NISSA (nerve injury, ischaemia, soft tissue contamination, skeletal, shock and age score). Despite the usefulness of scores, no method is fail-safe and clinical judgement remains paramount.

***5. Other indications for amputation.*** Entrapment of the patient by the limb and attempting to prevent the development of 'crush' syndrome.

***6. Late indications for amputation.*** These are an infected or functionless limb.

***7. Prognosis.*** The outcome after reconstruction can be good, but late amputation rates of 12–61% are reported. In the amputation group, the best results reported in young patients demonstrated 96% return to work with a prosthesis. Only 16% considered themselves disabled at 2-year follow-up.

## Replantation

'Replantation' is the reattachment of a part that has been completely separated, as opposed to 'revascularization' of a partially amputated limb or digit. Generally, revascularization is easier and more successful, as some of the venous and lymphatic drainage remains in continuity.

Table 1. The Mangled Extremity Severity Score (MESS)

| Factor | Points |
|---|---|
| A–Energy | |
| Low energy (closed fracture, stab, low-velocity gunshot) | 1 |
| Medium energy (open, multiple fractures, dislocation) | 2 |
| High energy (close-range gunshot, high-velocity gunshot, crush) | 3 |
| Massive crush (contamination, avulsion of soft tissues) | 4 |
| B–Limb ischaemia | |
| Diminished pulse, no ischaemia | 1* |
| No pulse, paraesthesiae, slow capillary refill | 2* |
| No pulse, cool, paralysed, anaesthetic, no capillary refill | 3* |
| C–Shock | |
| Stable BP | 0 |
| Hypotensive, responds to i.v. fluids | 1 |
| Persistent systolic BP <90 mmHg | 2 |
| D–Age | |
| <30 years | 0 |
| 30–50 years | 1 |
| >50 years | 2 |

*Double score if ischaemia time is >6 hours.

*1.* ***Indications.*** The ideal part for replantation should have been sharply severed at a single level. There should be a short warm ischaemia time: <6 hours if muscle is present and <12 hours with digits. These figures are doubled for cold ischaemia. Replantation requires prolonged operating times and is inappropriate in the polytraumatized patient or those in poor general health. Replantation is most important in the upper limb. Lower limb replants are less common as the initial mechanism of injury tends to make the limb less suitable for replantation, and good function can be achieved with modern lower limb orthoses. An attempt at replantation should usually be made in children, whatever the injury.

*2.* ***Transport.*** The amputated part is either transported wrapped in a swab moistened with isotonic saline, or immersed in isotonic saline within a plastic bag. The swab is then placed on, or the bag in, ice. Care must be taken to avoid frostbite by direct contact with ice.

*3.* ***Surgery.*** The surgical technique includes achieving bone stability, tendon repair, and microsurgical nerve, arterial and venous anastomoses. If the amputated part contains muscle, arterial circulation should be re-established as early as possible, possibly using a temporary shunt. It may be necessary to shorten the bones to prevent tension in the repaired soft tissues.

*4.* ***Prognosis.*** Replantation survival exceeding 80% is achievable. The best results are with replantation of the thumb, finger distal to the flexor digitorum superficialis (FDS) insertion, wrist and forearm. The expected range of movement is approximately 50% of normal. Cold insensitivity lasts 2 years. With proximal and lower limb replantation, recovery takes 3–5 years.

## Further reading


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## Related topics of interest


Hand – neurovascular and soft tissue injuries, p. 85; Principles of soft tissue management, p. 223

# ANKLE FRACTURES

Ankle fractures are the commonest lower limb fractures. The prevalence and age of presentation are increasing.

## Mechanism and classifications

Mechanisms of injury include both high-energy injuries (e.g. road traffic accidents (RTA), falls from a height and sports injuries), and low-energy injuries (e.g. falls, twists or slips). The most common age groups are young sportsmen and late-middle-age obese females.

Three classifications are popular:

- Simple descriptive (Henderson, 1932).
- Lauge–Hansen, 1950.
- Weber, 1972 (expanded by AO, 1979).

***1. Descriptive classification.*** This is based on the number of malleoli involved (bi/tri-malleolar) and the displacement.

***2. Lauge–Hansen classification.*** This is based on the position of the foot (supinated or pronated) and the direction of the deforming force (abduction, adduction or external rotation) at the time of injury. Ninety five per cent of fractures are classified into one of five groups, with up to four stages of injury severity and damaged structures for each group (*Figure 1*). While not easily remembered, these fracture patterns are invaluable for closed reduction techniques.

- Supination – adduction.
  I. Transverse distal fibula fracture or lateral ligament rupture.
  II. Vertical medial malleolus fracture.
- Supination – external rotation (of talus in mortice).
  I. Anterior talo-fibular ligament rupture +/– avulsion fracture of antero-lateral tibia (Tillaux).
  II. Spiral/oblique fibula fracture (anterior distal) at syndesmosis.
  III. Posterior malleolus fracture or posterior tibio-fibular ligament rupture.
  IV. Low medial malleolus fracture or ligament rupture.
- Pronation – abduction.
  I. Transverse medial malleolus fracture or medial ligament rupture.
  II. Syndesmosis disruption.
  III. Short transverse or oblique fibula fracture above joint.
- Pronation – external rotation.
  I. Transverse medial malleolus fracture or medial ligament rupture.
  II. Anterior tibio-fibular ligament rupture +/– avulsion fracture.
  III. Oblique fibula fracture (antero-superior) at/above syndesmosis (proximal fibula = Maisonneuve fracture).
  IV. Posterior malleolus fracture or posterior tibio-fibular ligament rupture.
- Pronation – axial compression (pilon).

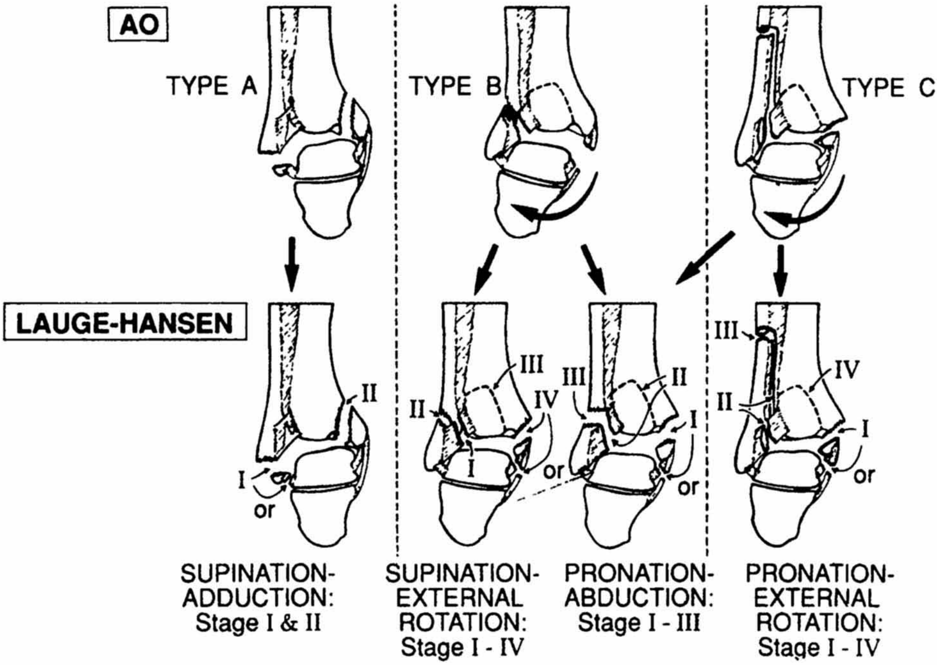


**Figure 1.** The AO (Danis–Weber) and Lauge–Hansen classification of ankle fractures. Reprinted from Sangeorzan BJ and Hansen ST (1990) *Orthopaedic Knowledge Update III*, p. 615. With permission from American Academy of Orthopaedic Surgeons.

[redacted]

# BIOMATERIALS – BONE

Bone consists of the mineral calcium hydroxyapatite [$Ca_{10}(PO_4)_6(OH)_2$], collagen and glycosaminoglycans which bind collagen. Hydroxyapatite is strong in compression, whereas collagen gives bone flexibility and tensile strength. The weakest area is the cement line between osteons. Bone is 3× as light, 10× as flexible, but has approximately the same tensile strength as cast iron. Any material deforms under load, yet to act as a skeleton the deformations must be small. Bone tested in the laboratory is dead, but the data obtained are important and form the basis of the stress/strain curve – the formal expression of strength and stiffness.

## Stress/strain curves

1. ***Stress.*** This is the intensity of a force, expressed as force per unit area ($Nm^{-2}$ or Pascal).

2. ***Strain.*** Linear strain is defined as the deformation, or change in length of an object, as a result of loading. Angular (shear) strain is the rotational equivalent. Strain is a proportion and has no units.

3. ***Stress (Y axis) plotted against strain (X axis) (Figure 1).*** The resulting curve consists of two lines, with an almost vertical element and an almost horizontal element. The vertical element is the elastic portion where deformation is temporary, and if the deforming force is removed, the structure returns to its original length (like an elastic band). In this elastic range stress is proportional to strain and the stress/strain ratio is known as *Young's modulus of elasticity* – '*E*'. The horizontal element is the plastic portion where increasing the stress on the subject leads to permanent deformity. The point of change from vertical to horizontal is known as the *yield point* or *proportional limit.*

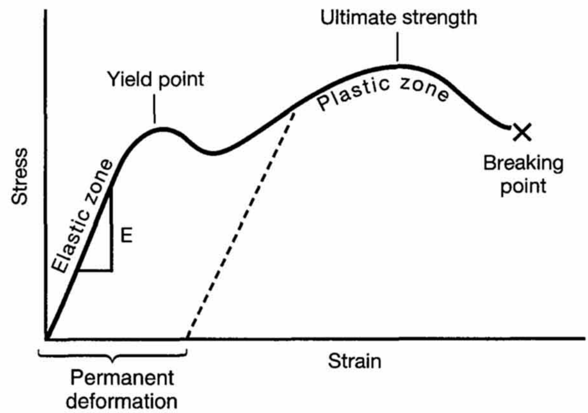


**Figure 1.** The stress–strain curve. E = Young's modulus. The area under the curve is the energy stored.

**4. *Ultimate strength.*** Stress/strain curves are plotted by testing material to destruction. The point at which the material fractures, at the end of the plastic portion of the curve, is the ultimate strength. The area under the curve is the total energy stored – this is released at the time of fracture.

**5. *Materials are either brittle or ductile.*** Brittle materials have no plasticity and ultimate failure occurs at, or soon after, the yield point (e.g. glass). Ductile

## Related topics of interest

Biomaterials – implants in trauma, p. 15; Biomechanics of fracture implants and implant removal, p. 19; Bone structure, p. 34

# BIOMATERIALS – IMPLANTS IN TRAUMA

Implants have traditionally been made of metal, but recently bioresorbable implants have been introduced. The 'ideal' implant should fulfil the following criteria:

- Biocompatibility – inert, non-immunogenic, non-toxic, non-carcinogenic.
- Strength – sufficient tensile, compressive and torsional strength, stiffness and fatigue resistance, for early resumption of function.
- Workability – easy to manufacture and implant.
- Corrosion free.
- Inexpensive.
- No affect on subsequent radiological imaging.
- Avoidance of prominence, sparing the need for removal.

## Metal implants

### Types of metal implant

Stainless steel and titanium are the principal metals used in trauma. Cobalt–chromium is used for joint replacement implants.

***1. Stainless steel,*** as 316L stainless steel, is a chromium (13–15.5%) and nickel (17–19%) alloy, low (L) in carbon (0.03%). Nickel provides corrosion resistance and stabilizes the crystalline structure, while chromium provides an oxidized surface, reducing corrosion.

***2. Titanium*** is used in one of four pure forms, or as an alloy. Adding oxygen, making the implant stronger and more brittle, modifies the form. Type 4 has the highest oxygen content. Titanium superalloys (e.g. Ti-6Al-4V) are also used.

***3. Cobalt–chromium*** alloys (e.g. cobalt–chromium–molybdenum, vitallium) are used in replacement implants, but seldom in trauma devices.

### Processing

Changing the atomic and crystalline structure of the metal during processing can alter the properties of metals:

- Casting – liquid metal is poured into a mould.
- Wrought – cast metal is modified by rolling or extruding.
- Forging – metal is heated and then subjected to a force, increasing strength and hardness, but decreasing ductility.
- Cold working – metal is repeatedly loaded with loads greater than the yield point.
- Annealing – metal is heated and cooled to toughen it.
- Passivation – creates an oxide covering over the surface of a metal, generally by placing the implant in nitric acid, improving biocompatibility and reducing corrosion. In 316L stainless steel, chromium and nickel form an oxide coat that reforms in air when scratched.

*Table 1* quantifies some of the alterations in properties achieved by processing metals.

**Table 1.** Comparison of yield and tensile strength in different materials

| Metal | Yield strength (MPa) | Ultimate tensile strength (MPa) |
|---|---|---|
| Cortical bone | 130 | 150 |
| 316L SS hot-forged | 250 | 600 |
| 316L SS cold-worked | 690 | 860 |
| 316L SS cold-forged | 1200 | 1350 |
| Titanium | 485 | 550 |
| Ti-6Al-4V | 795 | 860 |

L, low.
SS, stainless steel.

## Properties

1. ***Corrosion*** can be caused by electrochemical currents which arise when two dissimilar metals are in contact – known as *galvanic corrosion*. However, currents can also arise between two areas of the same metal, due to variations in tension, leading to *crevice corrosion*. Areas of high-stress gradients lead to stress corrosion and micromovement abrading two surfaces leads to *fretting corrosion*.

2. ***Fatigue failure*** is the result of cyclical or repetitive loading below the ultimate stress, causing a fracture. A fracture occurs after a few repetitions of a high load, or many repetitions of a lower load. The *endurance limit* is the stress at which the material under load will not have failed after 10 million cycles. It is considered that failure will never occur after this many cycles and assumed that orthopaedic implants are stressed 2 million cycles per year. The endurance limit is 900 MPa for cold-forged 316L stainless steel and 520 MPa for Ti-6Al-4V.

3. ***Creep*** is the progressive deformation of a material over time, under constant load.

## Choice of materials

316L stainless steel is commonly used and is cheap, with adequate ductility, yield and ultimate strength. A small number of people are hypersensitive to nickel and chromium. Steel is not perfect and for this reason titanium is used in some situations. The advantages of titanium are:

- Less fatigable after large numbers of cycles.
- Greater modulus of elasticity, 6× that of bone (cf 12× for steel), and there is less stress shielding with titanium implants.
- More biocompatible, forming a direct interface with the bone, promoting bony ingrowth.
- Less interference with MRI or CT.
- Less interference with radiotherapy, for example following pathological fractures.

The disadvantages of titanium are:

- Expense.
- Sensitivity to stress risers (scratches).

- Pure titanium has a low tensile strength, making it less suitable for use in the lower limb.

## Bioresorbable implants

### Types of bioresorbable implants

Organic molecules can be polymerized and formed into filaments, rods and screws. The production process is complex and closely regulated. The principal bioresorbable polymers are:

- Polyglycolic acid (PGA).
- Polylactic acid (PLA).
- Poly-p-dioxanone (PDS).
- Poly-β-hydroxybutyric acid (PHBA).

***1. Bioresorbable implants*** are low in strength, but this can be increased using reinforcing techniques, such as sintering under pressure. The reinforced products are prefixed with the letters 'SR'. Sterilization is by irradiation or ethylene oxide.

***2. Non-reinforced implants*** have a tensile strength of 30–70 MPa, increasing to 450 MPa for SR-PLA (cf *Table 1*).

***3. Degradation is by hydrolysis,*** until the molecular weight is reduced to 5000 Da, when a foreign body reaction supersedes. Complete loss of strength of the implant occurs between 1 month (SR-PGA), and 1 year (SR-PLA) depending on the polymer. Complete resorption takes between 3 months (SR-PGA) and 6 years (SR-PLA).

***4. The use of bioresorbable implants is controversial***

Advantages are:

- No removal of hardware, with cost and morbidity savings.
- Less stress shielding and weakening of bone.
- Absence of metal toxicity.

The disadvantages are:

- The initial implant is expensive, with a finite shelf-life.
- The strength of the implant is low.
- Foreign body reactions occur, with reports of osteolysis, sinus formation and implant extrusion.
- Synovitis has been reported with PLA and PGA.

### Clinical experience

Bioresorbable implants have been used in paediatric, hip, ankle, elbow and wrist fractures. Initial reports of 15% redisplacement and 8% sinus formation after the fixation of ankle fractures with PGA rods have lead to scepticism. Lower rates of sinus formation are seen with PLA, which resorbs more slowly.

In summary, until the mechanical properties can be improved, it will not be possible to use these implants for fixation and allow early mobilization with weight-bearing.

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## Related topics of interest

Biomaterials – implants in trauma, p. 15; Principles of operative fracture management, p. 220

# BIRTH INJURIES

The incidence of birth injuries in the Western World is <2 per 1000 live births and decreasing with advances in obstetric care. Injuries are associated with breech presentation, shoulder dystocia and birth weight over 4 kg. Injuries are also seen in premature and very small neonates. The two most common injuries are fractures of the clavicle and brachial plexus lesions.

## Specific injuries

1. ***Fractures of the clavicle*** are the most common birth injury, accounting for 40% of the total. Particular risk factors include high birth weight and shoulder dystocia. The fracture – usually in the middle third – is recognized by pain on handling and pseudoparalysis of the limb. Five per cent are associated with a brachial plexus injury and neonates should be reassessed to exclude a neurological deficit at 2 weeks. Parental reassurance, cautious handling and occasionally support for the arm in a sling is the only treatment required.

2. ***Brachial plexus injuries (obstetric palsies)*** are seen in 0.8 per 1000 live births following traction on the arm or head, and comprise around 40% of all birth injuries. There may be an associated fracture of the clavicle in 10–15% of cases. The diagnosis is either obvious after birth with a flail limb, or made by a high index of suspicion following a difficult delivery. Shoulder X-rays should be obtained to exclude a fracture. Three types of palsy are recognized:

- *Erb's palsy* affects the upper trunk and occurs when the head is abducted from the shoulders during delivery, stretching the C5/6 nerve root. The arm lies in a position of internal rotation, with the forearm in pronation. There is no active shoulder abduction or elbow flexion, but there is active flexion of the digits. Erb's palsy carries the best prognosis with spontaneous recovery in 90% of cases.
- *Klumpke's palsy* affects the lower trunk and more commonly follows breech presentation, with severe abduction of the arms or extension of the neck during delivery. There may be a Horner's sign, which is a bad prognostic factor. Bilateral injuries are reported.
- *Total plexus palsy* is occasionally seen, often with a Horner's sign, and has a very poor prognosis as spontaneous recovery is rare.

Within a few days of birth, the pattern of injury becomes more obvious. The principle of treatment is to maintain passive movement and close observation for signs of recovery, as 80–90% recover spontaneously. Early recovery of biceps and deltoid function, within a couple of months, are good prognostic signs. Physiotherapy should be maintained to prevent contractures. Absent biceps function at 3 months is the primary indication for surgical exploration. Reconstruction by nerve grafting or neurotization is usually required as end to end repair is rarely feasible. The outcome is proportional to the extent of the lesion.

3. ***Fractures of the humerus*** are generally transverse, middle-third fractures. The humerus is treated by support for about 2 weeks – shortening and angulation of up

to 50° rapidly correct. There are occasional instances of separation of the physis from the metaphysis in the humerus and rare reports of dislocations around the elbow.

*4. Fractures of the femur* are again most commonly middle third and transverse. Treatment is by cautious vertical gallows traction, or strapping the lower limb to the chest with the hip and knee flexed, or in a hip spica. The proximal fragment tends to stay in flexion, if the injury followed an extended breech presentation, and should therefore be treated with the hip flexed. Angular malunion remodels well. Fracture separation of the proximal or distal physis is rare.

*5. Cervical injuries* occasionally follow breech presentation and where the neonate survives, cause cord injury. Damage to the cord can sometimes be confused or attributed to a neuromuscular condition.

### Late reconstruction of the neglected obstetric palsy

The untreated brachial plexus palsy results in deformity and loss of function due to paralysis and contracture.

- The shoulder assumes a position of internal rotation and a progressive contracture of subscapularis may need to be released to restore external rotation. Isolated weakness of abduction and external rotation may be addressed by transfer of latissimus dorsi and teres major. A rotation humeral osteotomy may be required.
- Hand deformities are often severe and results of surgery are poor in the neglected palsy. Wrist-drop can sometimes be improved by transfer of flexor carpi ulnaris (FCU) to extensor carpi radialis brevis (ECRB), although tenodesis in extension improves the grasp more reliably.

## Further reading

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## Related topic of interest

Shoulder – brachial plexus injuries, p. 243

# BONE DEFECTS, TRANSPORT AND LATE RECONSTRUCTION

Reconstituting bone defects by transport of bone was developed by Ilizarov in Russia in the 1960s, capitalizing on the production of callus with distraction. The technique has been widely developed to address established non-union, infected non-union and for the primary management of some complex fractures. In trauma situations, defects of 3–12 cm can be reconstructed by bone transport. Defects of 7–10 cm have a 95% healing rate after transport and docking.

## Principles and techniques

Extensive counselling of the patient and family is essential before surgery. Careful pre-operative planning is mandatory.

The three phases of treatment are:

- Latency.
- Distraction.
- Consolidation.

Deformities can be corrected in a single or multiple planes, restoring the mechanical axis. Construction of the frame generally requires four-point fixation to maintain a mechanical advantage for segment lengthening and correction of angular deformity.

6. *Multifocal treatment* is the transport of bone in two directions, which allow more rapid closure of an intercalary gap, or treatment of a wider gap.

7. *To reduce the healing time* the docking site can be grafted, or an intra medullary nail inserted.

8. *Complications,* to which this technique is frequently prone, include:

- Neurological injury.
- Inadequate soft tissue cover.
- Joint subluxation.
- Joint stiffness.
- Loss of alignment.
- Pin-tract infections.
- Delayed consolidation.
- Non-union.

## Further reading

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## Related topics of interest

Bone grafting, p. 28; Bone healing, p. 31; Non-union – infected, p. 150; Non-union and delayed union, p. 153

# BONE GRAFTING

Bone graft is used to assist new bone formation and hence bone healing, and to replace bone lost through trauma or a chronic process. Graft takes the form of autograft, with or without a blood supply, allograft or xenograft. Autograft is most commonly used and the incorporation process should be understood.

The mechanism of graft incorporation, enveloping graft bone with viable new bone, depends upon revascularization by the host, but the precise bio-histological process is ill understood. However, the incorporation of bone graft has very similar features to fracture healing. Osteoblasts play a vital role and lay down bone mineral in an identical manner to that seen in fracture healing. The fundamental requirement is a good blood supply for vascular ingrowth.

## Types of graft

- Autograft – non-vascularized, cancellous or cortical, morsellized, block or bulk.
- Autograft – vascularized, cortical strut.
- Allograft – cancellous or cortical, morsellized or strut.
- Xenograft (experimental/research tool).
- Bone substitutes.

## Graft incorporation

1. ***When autograft is harvested, the blood supply is sacrificed;*** however, some osteogenic cells survive transplantation and promote new bone formation. In

2. ***To promote osteogenic cell survival,*** graft should not be lef
before implantation, but stored in chilled blood or a saline soake

## Vascularized autografts

***Autograft on a vascularized pedicle or as a free graft*** is suita
defects. Microsurgical transfer of rib, iliac crest, radius or prefe
used. In the leg, the fibula may be transferred to create a tibio
in established tibial non-union. Vascularized grafts lose some
potential, but healing and union are similar to the process o
without creeping substitution.

## Allografts

1. ***Morsellized cancellous chips,*** cortical struts, or in some c
tural allografts are used to reconstruct defects, although se
trauma surgery. The osteogenic potential of allograft is subst
autograft, leading to slower revascularization and incorporatio
stitution. The risk of infection in the post-trauma setting wit
substantial.

2. ***Union*** is initially by callus formation and partial bridging at the margins of the host–allograft interface, with some rounding off of the allograft strut. There is bone resorption and associated loss of strength, followed by gradual revascularization, creeping substitution and incorporation. With cortical allograft, this is a slow process over many years and seldom complete.

### Xenograft

Bone harvested from other animals is used only for experimental purposes. The development of bovine spongiform encephalitis and Creutzfeld–Jakob disease may prohibit the future use of xenografts.

### Ceramics and bone substitutes

Tricalcium phosphate and hydroxyapatite have a pore size of 100–400 μm, which is effective for bone ingrowth by osteoconduction, in the presence of marrow cells. These substitutes may be effective for filling metaphyseal bone defects, but the rate of ingrowth and remodelling are slow and the biomechanical properties are poor.

## Further reading

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## Related topics of interest

Bone defects, transport and late reconstruction, p. 25; Bone healing, p. 31

# BONE HEALING

Fracture healing is a specialized form of tissue healing and similar to other histopathological repair processes. An understanding of normal bone formation and structure is essential. Bone consists of mesenchymal cells embedded in a mineralized extracellular matrix for strength and stiffness, with type I collagen predominating. The periosteum, with an inner cambium or vascular layer and outer fibrous layer, plays a vital role in fracture healing.

The process of fracture healing is similar to the process occurring at an active growth plate. Woven (immature) bone formed within callus after a fracture, with rapid turnover and irregular mineralization giving it a blurred radiographic appearance, is replaced by lamellar (mature) bone. Fracture healing consists of three distinct phases: inflammation, repair and remodelling. The formation of callus, in response to fracture movement, is a vital part of healing called indirect healing and is followed by a process of remodelling. Rigid internal fixation interferes with this natural process, leading to direct or primary healing without abundant callus formation.

## Phases of fracture healing

***1. Acute inflammation.*** This is the first phase of healing in response to haematoma formation at a fracture site. The haematoma provides a source of haematopoietic cells secreting growth factors (cytokines) to promote healing. A classical inflammatory response secondary to mediators is evoked, leading to vascular ingrowth and cell proliferation, with an influx of polymorphonuclear leucocytes, macrophages and lymphocytes. Exudate and necrotic tissue are removed by demolition. From osteogenic precursors, pluripotent mesenchymal stem cells (MSC), osteoblasts and fibroblasts proliferate, producing a new matrix.

***2. Repair process.*** The process starts with organization of the haematoma into granulation tissue and a change of environment from slightly acidic (the acidic tide), to neutral and subsequently slightly alkaline (the alkaline tide), promoting alkaline phosphatase activity. Periosteal vessels are stimulated by angiogenic fibroblast growth factors to produce capillary buds. Osteoclasts, derived from monocytes and monocytic progenitors, resorb non-viable bone, possibly under stimulus from prostaglandins. Proliferation of the MSCs leads to formation of a matrix of fibrous tissue and cartilage. After mineralization this forms woven bone, described as fracture callus. Hard callus is formed at the periphery by intramembranous bone formation, and soft callus is formed in the central region, with a higher cartilage content, by endochondral ossification. Eventually a mass of callus bridges the fracture margins and clinical union has occurred.

Initially the matrix consists of types I, III and V collagen, glucosaminoglycans, proteoglycans and other non-collagenous proteins acting as enzymes, growth factors and mediators. Some of this collagen is converted to types II and IX collagen and then type I collagen predominates during osteogenesis, mineralization and remodelling.

Local oxygen tension, pH, electrical charge and numerous growth factor mediators (cytokines) which are non-collagenous proteins, mostly released from platelets and cells, promote the repair process of cartilage and bone formation. These factor mediators include fibroblast growth factor (FGF), platelet-derived growth factor (PDGF) and the progression factor transforming growth factor beta (TGF-β). These mediators and others, such as IGF-I, IGF-II and epidermal growth factor (EGF) encourage mitoses. BMP and TGF-ß stimulate the differentiation of MSCs

tourniquet or PASG and fluid extravasation during kn
the same and where the diagnosis is suspected, th
released. Plasters and bandages should be split, open
limb reassessed.

## Late sequelae

Fibrosis of necrotic muscle occurs when surgical dec
cessful, too late, or the diagnosis overlooked. Fibro
ineffective muscle function. There may be a mild co
clawing of the toes, or a florid Volkmann's ischaemic c
may occasionally be indicated to improve function.

## Related topics of interest

Paediatric humeral supracondylar fractures, p. 172; Tibial shaft fr

# ELBOW DISLOCATION

Dislocation of the elbow is second only in frequency to dislocation of the shoulder. Simple dislocation carries a good prognosis. There are two theories for the mechanism of injury: firstly hyperextension causing the olecranon to impinge in the olecranon fossa 'levering' out the joint, and secondly axial loading of the slightly flexed joint causing dislocation.

## Classification

Elbow dislocation is classified according to the direction of forearm displacement. Posterior dislocation is commonest, with anterior, medial and lateral being rarer. Divergent dislocation, where the radius and ulna dissociate to either side of the humerus may occur, either antero-posterior with the radius anterior and the ulna posterior, or medio-lateral. Ulnar and radial dislocation may occur in isolation.

## Clinical presentation

1. ***Typically acute*** and if delayed beyond 7 days constitutes a 'neglected' case, seldom reducible by closed means.

2. ***Clinically*** the equilateral triangle formed by the olecranon, medial and lateral epicondyles is disrupted, differentiating dislocation from supracondylar fracture.

3. ***Careful neuro-vascular assessment*** should be documented at presentation and repeated after reduction.

## Associated injuries

1. ***Vascular injury.*** If arterial injury is suspected, an arteriogram should be obtained after reduction. The presence of distal pulses does not exclude significant arterial injury. Historically, good results have been reported with simple ligation of the brachial artery; however, modern standards of care advocate vascular reconstruction.

2. ***Neurological injury.*** The median, ulnar, anterior interosseous and radial nerves can all be injured. The radial is the least often involved and anterior interosseous palsy the most difficult to diagnose, because of the lack of sensory involvement. The median and ulnar nerves can be trapped within the joint during reduction and the development of post-reduction palsy requires surgical exploration. For palsy present before reduction it is customary to wait 3 months, obtain electromyelogram (EMG) studies and if recovery does not occur spontaneously, undertake surgical exploration.

3. ***Fracture dislocation.*** The incidence of associated fractures varies from 16% to 62%, reflecting the unreliable detection of osteochondral fragments. Fracture dislocation is associated with a poorer outcome.

4. ***Medial epicondyle avulsion.*** Occurs in adults or children and requires early recognition, as retained joint fragments lead to articular surface damage. ORIF is usually required, although success with closed reduction is reported.

**5. *Muscular injury.*** Avulsion of the triceps is associated with anterior dislocation, possibly with an associated bony fragment. Following reduction of anterior dislocation, triceps function should be assessed and reattachment performed if required.

## Treatment

**1. *Closed reduction is favoured.*** Posterior dislocation can usually be reduced under sedation, by one of two methods. Firstly, extension of the elbow to 'unlock' it, which may predispose to nerve entrapment; or secondly, application of longitudinal forearm traction, with digital pressure over the olecranon. The elbow is immobilized in 100° flexion in a plaster slab for 7–10 days, before commencing mobilization. Physiotherapy may be helpful but is seldom required, and forced passive mobilization should be avoided. In the presence of a significant fracture, for example an unfixed coronoid process fracture, immobilization may be increased to 3 weeks.

**2. *Other patterns of dislocation.*** These are rare and closed reduction is usually successful.

**3. *Indications for open surgery.*** These include:

- Open dislocation.
- Significant fracture requiring fixation.
- Entrapped soft tissue, blocking reduction.
- Vascular injury requiring surgery.
- Ligamentous repair (seldom improving the result).
- Irreducible neglected dislocation.

**4. *With persistent instability,*** despite fixation of fractures, there are three options:

- Ligamentous repair (usually lateral).
- A hinged external fixator, or brace.
- Passing a Steinman pin across the joint – while this prevents dislocation, stiffness, heterotopic ossification and pin breakage may follow.

## Complications

**1. *Ectopic calcification and heterotopic ossification (HO).*** Ectopic ossification is mineralization of normal anatomical structures (such as collateral ligaments) and is usually associated with minimal symptoms. HO is the laying down of heterotopic bone in a previous haematoma, which leads to stiffness. HO occurs more frequently after head injury, burns, massive trauma and prolonged immobilization. The role of ill-timed surgery (after 3 days) and forceful passive mobilization are debated. Treatment is excision once the ossification is mature (trabeculated with a rim), typically around 6–8 months, and should include prophylactic indomethacin for 6 weeks post-operatively.

**2. *Chronic instability.*** While frank recurrent dislocation is rare, there is increasing awareness of 'elbow instability' as a long-term sequel, with patients complaining of clunking or snapping in the elbow. The critical lesion is damage to the lateral collateral ligament (LCL), specifically the ulnar part.

## Prognosis

The prognosis is good in the simple dislocation. Recovery takes 3–6 months and many patients are left with 10–15° flexion contracture.

## Paediatrics

The peak age of dislocation is 10–13 years, against 5 years for supracondylar fractures. Intra-articular entrapment of the medial epicondyle must be considered. In common with adults, posterior dislocation is commonest and early active flexion at 5 days is advised to avoid stiffness.

# Further reading


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# Related topics of interest


Humeral fractures – distal, p. 107; Radius and ulna – diaphyseal fractures, p. 230; Radius and ulna – fractures around the elbow, p. 236

# FEMORAL FRACTURES – DISTAL

Distal or supracondylar femoral fractures are difficult to treat. Sir Reginald Watson-Jones stated in 1957 that 'few injuries present more difficult problems than supracondylar fractures of the femur'.

## Epidemiology

Distal femoral fractures represent 7% of all femoral fractures. Fifty per cent are extra-articular supracondylar fractures and 50% have an intra-articular extension. Of the intra-articular group, 80% are intercondylar and 20% involve the condyles. Twenty five per cent of all fractures are open. Associated neurovascular or ligamentous injuries are relatively rare and present in <15% of cases.

There is a bimodal age distribution for supracondylar fractures. A younger, predominantly male, group is affected following high-energy polytrauma. An elderly, predominantly female, osteoporotic group is affected following minimal trauma.

## Anatomy and mechanism of injury

The distal femoral metaphysis is a 9 cm transitional zone from the thick cortical region of the shaft to the broad condylar region. There is a thin cortex and a wide cancellous area. There are numerous muscle and ligamentous attachments, which cause deforming forces. Gastrocnemius rotates the distal fragment posteriorly, while the strong adductors cause varus angulation. Intercondylar fractures are splayed open by discordant muscle action.

In most cases, axial loading with a varus or valgus force leads to a distal femoral fracture. In the young this is usually a high-energy injury, typically an RTA, with considerable comminution, displacement and soft tissue trauma. In the elderly with osteoporotic bone, a fall on a flexed knee is the most common mechanism of injury. A long spiral supracondylar fracture is the result, sometimes complicated by a femoral prosthesis above or below the fracture. Rarely, a fracture occurs without obvious trauma in the immobile, as a result of severe osteoporosis.

## Fracture classification

Various classifications have been described, from simple extra- and intra-articular classifications, to the detailed AO classification (33-A, 33-B and 33-C, depending on site, intra-articular involvement and extent of comminution).

## Non-operative management

Non-operative management of these fractures, in a long leg cast or skeletal traction, has proved difficult. The deforming force of the gastrocnemius muscle attachment causes a hyperextension deformity of the distal segment, making accurate reduction difficult. Reduction can be achieved by 90/90 traction, but this is difficult to maintain over a protracted period and subsequent knee stiffness is a problem. Malunion and non-union are common.

Non-operative management is therefore reserved for the minimally displaced fracture, or the elderly, low-mobility patient, particularly if unfit for anaesthesia.

Conservative treatment in the 1960s was reported to give a satisfactory outcome in 67–84% of cases.

## Operative management

Operative management is appropriate for open and most displaced fractures. The aims are anatomical reduction of the articular surface, stable fixation and early mobilization, achieved with minimal disruption to the soft tissue envelope and blood supply to the bone. Several techniques are available and all have an application:

- Plate and screws.
- IM nails – rigid and flexible.
- External fixation – monolateral, circular and hybrid.

As there is a wide range of injury patterns, it is important to appreciate that one particular technique is not applicable to all fractures.

***1. Screw fixation*** alone may be appropriate for partial articular or unicondylar fractures (33-B1-3), followed by early mobilization in a cast brace.

***2. Plate fixation*** takes the form of a blade plate, a dynamic condylar screw (DCS), or a condylar buttress plate, after lag screw fixation of any intercondylar extension. Plate fixation is usually through a lateral approach. Bone grafting is advisable for comminuted fractures, especially in the elderly, or when the comminution is on the medial side.

The disadvantages of this technique include the wide exposure necessary to insert the plate, the extensive soft tissue damage and resultant damage to the blood supply, as well as load sparing, or stress shielding by the plate itself. A DCS is preferable to a blade plate, as it allows more flexibility in plate positioning on the femur.

***3. Intramedullary devices*** inserted in a retrograde fashion are becoming increasingly popular. In the past, Zickel supracondylar nails, Rush pins, and Ender's nails have been used. These are inserted through the epicondylar region and are suitable for distal fractures. Unfortunately there is little control of rotation of the distal fragment.

Newer intramedullary devices, inserted through the roof of the intercondylar notch adjacent to the posterior cruciate ligament (PCL) attachment, have significant advantages. This type of device allows load sharing by virtue of the intramedullary placement, as well as controlling length and rotation by interlocking screw fixation. Supplementary screw fixation to stabilize condylar fractures is possible anterior or posterior to the nail. The advantage of this technique is the relative ease of insertion, together with minimal soft tissue damage. Infection rates are low and union rates approaching 100% have been reported. Implant failure is relatively rare. The lack of periosteal stripping and soft tissue damage allows early knee movement to be regained. These devices, however, do not hold the bone fragments rigidly and therefore cautious mobilization is encouraged with, or without, a cast brace post-operatively.

In the elderly, fixation is often tenuous, and therefore cast brace support and partial or non-weight-bearing is advised for 3 months.

IM nails are ideal for 33-A1 to A3 and C1 and C2 fractures, particularly in the younger group with good bone quality, but are rather unsatisfactory for C3 type fractures where there is significant articular comminution. Open fixation and reconstruction is required.

***4. External fixation*** is usually reserved for more severe injuries, 33-C3 type fractures, and open fractures. An anterior bridging fixator is used to stabilize the limb for soft tissue and vascular reconstruction. Minimal open reduction and percutaneous screw or wire fixation may be supported by circular frame stabilization. These techniques minimize soft tissue stripping, yet give adequate fixation for early movement.

### Special cases

Some fractures in the elderly may extend down from the tip of a proximal femoral prosthesis. In such cases, fixation can be difficult. Dual plating, cable plating, and modified 'interlock' nailing are the options available. The latter involves engaging the proximal tip within the end of the retrograde nail. Fractures above a total knee replacement may be treated by any of the above methods or revision arthroplasty. If possible, the best technique is an IM nail through the condylar notch, which needs to be a minimum of 12 mm wide.

### Complications

***1. Early.*** Vascular compromise, infection, malreduction and fixation failure.

***2. Late.*** Malunion, non-union (particularly with a fracture above a stiff knee), implant failure and knee stiffness.

## Further reading

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## Related topics of interest

Intramedullary nailing techniques, p. 128; Peri-prosthetic fractures (hip and knee), p. 167; Principles of external fixation, p. 214

# FEMORAL FRACTURES – SHAFT

Fractures of the shaft of the femur are relatively common and frequently associated with major

should be employed and with the advent of excellent intramedullary techniques, the only real indication in the adult for DCP fixation is an associated ipsilateral pelvic or acetabular fracture. Early surgical stabilization of a pelvic fracture may be prevented if there is a recent wound around the hip joint.

5. ***Paediatric femoral fractures*** are commonly treated by skin or skeletal traction in a Thomas splint to allow fracture union, before mobilization in a suitable cast. For the young infant, and in some centres children up to the age of 10, early immobilization in a hip spica is favoured, obviating the need for prolonged hospital treatment. In the polytraumatized child, plate fixation is indicated, or an external fixator can be used with less disturbance of the soft tissues.

There may be some limb overgrowth, rarely >1 cm, with conservative treatment and hence it is acceptable to allow the fracture to heal with some shortening. Overgrowth is more marked between the ages of 2 and 10 years. IM nailing beyond the age of 12 years, avoiding violation of the distal epiphysis, is considered safe practice.

## ications

- Fat embolus: 1%.
- Infection: 5% after open nailing.
- Infection: <1% after closed nailing.
- Delayed union: 6–9% (defined as 6 months).
- Non-union: 2%.
- Shortening: up to 1.5 cm is compatible with good function.
- External rotation of up to 15° is seen in 20% of patients and well tolerated.

## gement of infection and non-union

A deep infection site should be explored and debrided. The IM nail should be removed, the canal reamed up 1 mm, another locked nail inserted and appropriate antibiotics commenced. The fracture will usually heal over 6 months.

Delayed union is uncommon and removal of unbroken locking screws is occasionally required. Established non-union of the femur is rare and should be addressed by exchange IM nailing and occasionally autogenous bone grafting, if the IM bone reamings are thought inadequate.

## er reading

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## Related topics of interest

Femoral fractures – distal, p. 46; Femoral neck fractures – extracapsular, p. 52; Femoral neck fractures – intracapsular, p. 55; Intramedullary implants – reamed and unreamed, p. 125; Intramedullary nailing techniques, p. 128; Polytrauma – management and complications, p. 200

# FEMORAL NECK FRACTURES – EXTRACAPSULAR

Extracapsular fractures may be intertrochanteric (between the trochanters) or pertrochanteric (through the trochanters), and are common in the elderly and osteoporotic patient, often following minimal trauma. Extracapsular fractures account for almost 50% of all femoral neck fractures and the proportion is increasing. The mean age of presentation is 80 years, higher than for intracapsular fractures. Eighty per cent occur in women. As the fracture is extracapsular the blood supply to the femoral head is good and the aim of treatment is early surgical stabilization and mobilization. Union rates are high, and late complications of the fracture itself uncommon. However, as the majority of patients are elderly, often with additional medical problems, surgery and bed rest are tolerated poorly, leading to mortality of 33% at 6 months and 38% at 12 months. Mortality is higher than for intracapsular fractures.

Extracapsular fractures occur in younger patients following high-velocity trauma. Subtrochanteric fractures account for the minority of proximal femoral fractures and have a bimodal distribution presenting in young adults and over 65 year olds.

## Classification

The AO classification is widely accepted: 31-A1 or 31-A2 for pertrochanteric fractures and 31-A3 for intertrochanteric fractures, with subtypes to describe the morphological pattern. Classification and stability depend upon the degree of comminution and trochanteric involvement. The Boyd and Griffin classification (1949), based on the ease of obtaining and maintaining reduction of the fracture, is often quoted, as is the Evans classification (1949), dividing fractures into stable and unstable groups. Subtrochanteric fractures occur within 2.5 cm of the lesser trochanter.

## Radiology

Where the diagnosis is not confirmed by plain AP and lateral X-rays, the hip should be assessed with tomograms, an isotope bone scan, MRI or under the image intensifier. When there is no obvious fracture and pain persists, X-rays should be repeated.

## Treatment

The aim of treatment is to achieve early mobilization of the patient, avoiding the attendant complications of prolonged bed rest. Young patients should be treated in the same manner. Rehydration and urgent medical assessment of all patients is vital. Surgery should be performed within 48 hours of the fracture, as confusion, pneumonia, the incidence of pressure sores and the duration of hospital stay all increase significantly after this period if surgery is further delayed.

***1. Closed treatment,*** with skin or skeletal traction for 6–8 weeks will usually achieve sound union and should be reserved for the 2 or 3% of patients where surgery is contraindicated or declined.

Undisplaced fractures can be treated with early mobilization and partial weight-bearing. The fracture should be reassessed regularly with X-rays. Where pain persists, the fracture displaces or the patient is unable to cooperate with mobilization, internal fixation should be performed.

2. ***Internal fixation*** is the treatment of choice, followed by early mobilization and weight-bearing as tolerated. Careful placement of the patient on the fracture table is essential and an anatomical reduction can often be achieved before opening the fracture.

A variety of devices may be used, but a sliding hip screw-plate system (a dynamic hip screw) is the most popular. Within the femoral neck and head, the sliding screw should lie below the midline on the AP view, centrally on the lateral view and within 10 mm of the subchondral bone, to reduce the possibility of screw cut out. With an anatomical reduction, sliding screw-plate systems are well tolerated. Unstable fractures may require osteotomy or medial displacement of the shaft to enhance stability, as bone continuity along the medial aspect of the upper femur is essential.

Short intramedullary devices may be used, but are less popular. Flexible IM nails, inserted into the femoral neck and head from the condylar region (condylocephalic nails) are popular in parts of Europe, with good results.

Subtrochanteric fractures can be treated with a sliding hip screw, but insertion of an intramedullary device by closed means with sound fixation by locking screws into the femoral head is preferable.

3. ***Isolated greater and lesser trochanter fractures*** are rare and can usually be treated symptomatically.

## Additional considerations

Hip fractures consume a large proportion of health care, costing the National Health Service (NHS) £330 million a year, and have a massive impact on society. The incidence of proximal femoral fractures is still rising. The associated morbidity carries major functional, social and financial implications. Preventative measures to reduce the fracture incidence, including hormone replacement therapy (HRT), need further development.

The morbidity following extracapsular fractures is greater than intracapsular fractures and can be measured in the elderly by a variety of means including pain, residential status, use of walking aids and function. The Peterborough Hip Scoring System (PHSS) scores function from 9 to 0 on the ability to perform three functions – shopping, getting out of the house and getting about the house, depending on the level of independence or assistance required. The Mental Test Score can be used to predict mortality, but the PHSS has a superior predictive value.

## Complications

- Mortality: 6 months – 33%; 12 months – 38% (3% <60 years, 50% >90 years).
- In-hospital mortality: 15%.
- Delayed union: 1–2%.
- Wound infection: 2–15%.
- Implant failure and screw cut out: 5–16%
- Avascular necrosis: <0.5%.

## Further reading

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## Related topic of interest

Femoral neck fractures – intracapsular, p. 55

# FEMORAL NECK FRACTURES – INTRACAPSULAR

Intracapsular fractures are subcapital (at the junction of the head and neck) or transcervical (passing through the neck), and are common in the elderly or osteoporotic patient, often following only a slight injury. Intracapsular fractures account for just under 50% of all femoral neck fractures and the proportion is decreasing. The mean age of presentation is 78 years, lower than for extracapsular fractures. Eighty per cent occur in women. Subcapital fractures are uncommon in the presence of an osteoarthritic hip.

As the fracture is intracapsular, the blood supply to the femoral head is at risk and, especially when displaced, there is a substantial incidence of ovascular necrosis or non-union of the femoral head. With displaced fractures, the risk of avascular necrosis is 20 to 55% and the risk of non-union is 10 to 30%, although it can sometimes be difficult to distinguish the two. Historically, the risk has been considered so great that the majority of displaced subcapital fractures in the elderly have been treated by hemiarthroplasty. Treatment is directed at early mobilization for elderly patients whether following internal fixation or hemiarthroplasty. Surgery and bed confinement are tolerated poorly in the elderly, who often present with co-morbidity, leading to a mortality rate of 24% at 6 months and 29% at 12 months following intracapsular fractures – lower than for extracapsular fractures.

Intracapsular fractures may occur after high-velocity trauma in younger patients and the principle of treatment must be to reduce and stabilize the fracture, accepting a significant risk of failure. Twenty per cent are associated with an ipsilateral femoral shaft fracture. Joint replacement should be considered, but the complication rate following an acute fracture is significantly higher than for total hip replacement (THR) under elective conditions for degenerative disease.

## Classification

The Garden classification (1961), based on the degree of displacement on the AP X-ray, is the most popular classification (*Figure 1*). Garden stage I fractures are incomplete or impacted into valgus; Garden II fractures are complete with minimal or no displacement; Garden III fractures are displaced with angulation of the

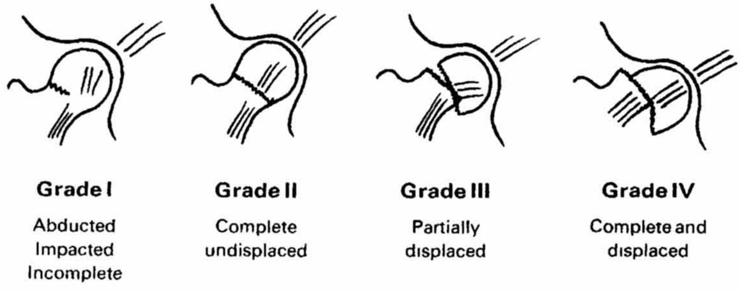


**Figure 1.** Garden classification of subcapital femoral neck fractures. The trabecular lines help in differentiation, particularly between types III and IV. From Keene G, Parker M (1993) The fractured neck of femur – proximal femoral fractures. *Postgraduate Doctor Middle East*, vol. 16, pp. 244–253. Reprinted by permission of PMH Publications.

trabecular lines; and Garden IV fractures are grossly displaced, with the trabecular lines of the head and acetabulum parallel. Stages I and II (20%) have a similar prognosis, as do stages III and IV (80%). The AO classification is also widely accepted: 31-B1, 31-B2 and 31-B3. Pauwel's classification is based on the angle of the fracture line across the femoral neck.

## Radiology

Where the diagnosis is not confirmed by plain AP and lateral X-rays, the hip should be assessed with tomograms, an isotope bone scan, MRI, image intensifier, or ultrasound.

## Treatment

The aim of treatment is early mobilization, avoiding the attendant complications of bed rest, either by mobilization alone, internal fixation or arthroplasty. Rehydration and urgent medical assessment of all patients is vital. Surgery should be performed within 48 hours of the fracture as confusion, pneumonia, the incidence of pressure sores and the duration of hospital stay all increase significantly with further delay.

***1. Impacted fractures*** can be mobilized early when the head is tilted into valgus, weight-bearing as tolerated. However, there is a significant risk of displacement on mobilization, so stabilization of the fracture with three parallel screws is a wise precaution. This can be performed under local anaesthetic if required. Without stabilization, regular radiological review is advisable to assess displacement.

***2. Undisplaced fractures*** should be stabilized with three parallel screws or a sliding hip screw with an additional screw to prevent rotation. Where patients are aged over 80 years, there is evidence to suggest a more favourable and predictable outcome with hemiarthroplasty, although the complication rates are higher.

***3. Displaced fractures*** are traditionally treated by hemiarthroplasty, with an uncemented Austin Moore type stem, or a cemented stem. The results of late conversion of a hemiarthroplasty to a THR are good. There are no reported benefits of a bipolar prosthesis in patients over 80 years.

There is increasing evidence to suggest that the incidence of avascular necrosis and non-union are not as high as previously perceived, even for displaced fractures. This is a contentious issue and may relate to improved fixation techniques and intra-operative imaging. The current literature suggests more fractures should be reduced and stabilized with parallel screws, rather than performing a hemiarthroplasty. Large randomized controlled trials are needed to assess this further. However, this approach conflicts with reports of a more favourable outcome where hemiarthroplasty is used in patients over 80 years for undisplaced or minimally displaced fractures, rather than internal fixation.

A subcapital fracture can be reduced on the traction table with longitudinal traction and internal rotation, or by the Leadbetter manoeuvre (traction along the line of the femur with the hip and knee flexed at 90°, followed by internal rotation and abduction). The capsule should be incised following internal fixation to release any intracapsular haematoma, which may jeopardize the venous drainage.

4. ***In younger patients*** treatment is directed at preserving the femoral head by reduction and fixation within 6 hours of the fracture, accepting that a proportion will develop avascular necrosis requiring further surgery. A good outcome can be expected in 70 to 84% of patients. If a primary THR is performed, the incidence of infection, heterotopic bone formation, early failure and dislocation are all higher than elective situations.

### Additional considerations

Hip fractures have a massive impact on society and consume a large proportion of health care resources. The incidence of proximal femoral fractures is rising and costs the NHS around £330 million a year. Although mortality is important, the associated morbidity carries major functional, social and financial implications. Preventative measures to reduce the fracture incidence, including HRT, need further development.

The morbidity following intracapsular fractures is less than in extracapsular fractures and can be measured in the elderly by a variety of means including pain, residential status, use of walking aids and function. The Peterborough Hip Scoring System (PHSS) scores function from 9 to 0 on the ability to perform three functions – shopping, getting out of the house and getting about the house, depending on the level of independence or assistance required. The Mental Test Score can be used to predict mortality, but the PHSS has a superior predictive value.

### Complications

- Mortality: 6 months – 24%; 12 months – 29%; following dislocation of hemiarthroplasty – 60–70% at 12 months.
- In-hospital mortality: 15%.
- Infection: 2–20%.
- Non-union: 7–25% in young patients.
- Avascular necrosis: 20–55% ($\propto$ to displacement – 80% in some series).
- Osteoarthritis: 5%.
- Dislocation after THR: 15–30%.

## Further reading


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## Related topic of interest


Femoral neck fractures – extracapsular, p. 52

# FOOT – CALCANEAL FRACTURES

Calcaneal (os calcis) fractures account for 1% of all fractures and 75% of tarsal fractures. They occur most frequently in males of working age and often lead to significant socio-economic problems. The calcaneus has a complex shape, articulating on four surfaces with the talus and cuboid. The calcaneus is important for weight-bearing, lever arm force transmission and foot shape, all of which may be altered by a fracture.

There are two groups of fractures:

xation, allow early mobilization. Internal fixation is undertaken once swelling has subsided, at 7 to 10 days. Most commonly, the extensile lateral approach is favoured. The sural nerve is preserved and the peroneal tendons reflected 'en masse' to expose the sub-talar joint. The tuberosity and sustentacular fragments are exposed and reduced, followed by the sub-talar joint, before reconstructing the lateral wall. Lag screws and a specially shaped lateral wall buttress plate are used for internal fixation. Surgery is exacting. Post-operatively, management is similar to the undisplaced with early non-weight-bearing movement.

## Complications – non-operative

1. ***Foot shape.*** A widened heel leads to heel pain, ill-fitting shoes, peroneal tendon impingement and tendinitis.

2. ***Articular disruption.*** This leads to degenerative change, with subsequent pain and stiffness in the sub-talar joint, especially on rough or uneven ground.

As many as 30–50% of patients walk with pain, require a stick, cannot wear a normal shoe and are unable to return to their previous employment. Twenty five per cent may require late sub-talar fusion.

## Complications – operative

1. ***Early problems*** are wound healing, infection, sural nerve and peroneal tendon injury.

2. ***Late problems*** are chronic deep infection, implant prominence and failure. Similar long-term problems related to foot shape and sub-talar joint stiffness described above are also encountered. With careful selection and surgical skill, operative complications may be reduced to <5%. Foot shape is improved, but it remains to be shown if the outcome with respect to sub-talar joint function is different.

## Further reading

**Eastwood DM, Gregg PJ, Atkins RM.** Intra-articular fractures of the calcaneum. (Parts I and II). *Journal of Bone and Joint Surgery*, 1993; **75B**: 183–195.
**Eastwood DM, Phipp L.** Intra-articular fractures of the calcaneum: why such controversy? *Injury*, 1997; **28**: 247–259.
**Stockenhuber N, Wildburger R, Szyszkowitz R.** Fractures of the os calcis. *Current Orthopaedics*, 1996; **10**: 230–238.

## Related topics of interest

Foot – talar fractures, p. 65; Tibial pilon fractures, p. 284

# FOOT – METATARSAL AND PHALANGEAL FRACTURES

## Metatarsal fractures

Metatarsal fractures are usually the result of a direct blow, although twisting of the forefoot can cause spiral fractures. Fractures at the base of the fifth metatarsal

occurs. In these cases, the fragment is shelled out or the tibialis posterior tendon and the tendon resutured to the bone. Very rarely the acute fracture is displaced >1 cm and acute operative repair is indicated.

***3. Navicular body fractures*** are associated with other injuries, but can occur in isolation. Vertical or longitudinal fractures usually occur in combination with the complex Main and Jowett mid-tarsal injuries. Sangeorzan (1989) described three injury patterns:

- Type 1: fracture in the coronal plane.
- Type 2: the fracture line is dorso-lateral to plantar-medial. The main fragment displaces medially and the forefoot adducts.
- Type 3: a comminuted fracture with lateral displacement of the forefoot.

Treatment is in plaster for the non-displaced fracture. If displaced, type 1 fractures can often be fixed with lag screws. Type 2 and 3 fractures are often comminuted and fixation is difficult. It is permissible to fix fragments to the cuneiforms, but effort should be made to avoid fixing the talo-navicular joint, due to its functional importance.

### Cuboid fractures

Fractures of the cuboid can either be avulsion fractures, or compression fractures.

Compression fractures have been described as 'nutcracker fractures'. These are significant because the lateral column of the foot is shortened. These are therefore Main and Jowett lateral stress injuries. Injuries with minimal impaction can be treated with a below-knee walking plaster. Those with severe comminution and lateral column shortening should be opened, reduced, bone-grafted and fixed. This approach gives superior results, avoiding the later need to distract the lateral column and fuse the calcaneal cuboid joint.

### Cuneiform fractures

These are rare in isolation and no large series exist. Conservative treatment is favoured.

### Stress fractures

Stress fractures of the cuboid and navicular occur, and can usually be treated in a non-weight-bearing cast.

## Further reading


**Main BJ, Jowett RL.** Injuries of the mid-tarsal joint. *Journal of Bone and Joint Surgery*, 1975; **57B**: 89–97.

**Sangeorzan BJ, Benirschke SK, Mosca V *et al.*** Displaced intra-articular fractures of the tarsal navicular. *Journal of Bone and Joint Surgery*, 1989; **71A**: 1504–1510.


## Related topics of interest


Foot – metatarsal and phalangeal fractures, p. 61; Foot – talar fractures, p. 65; Foot – tarsal dislocations, p. 69

# FOOT – TALAR FRACTURES

Fractures of the talus are uncommon, but important in view of the complex bony articulations, architecture and vascularity. The talus has a head, neck and body. The head articulates with the navicular, and the body articulates with the ankle mortise and the large posterior

cular ligament intact. Sub-talar dislocations often follow high-energy injuries are associated with other fractures in 50% of cases. Forty five per cent are open ries.

*Radiographic evaluation.* The most useful view is an AP of the foot, looking lislocation of the talo-navicular joint. CT is not helpful acutely, but may define ciated fractures.

*Treatment.* Closed reduction under general anaesthesia should be prompt to d skin necrosis. Closed reduction fails in 10–20% of cases, as a result of soft e or bone interposition. After reduction, the leg is maintained in a below-knee for 4 weeks, after which mobilization is commenced to prevent stiffness.

*Prognosis and complications.* Long-term results are variable. Some series rt 54% poor results, while others report 88% of patients with no activity iction at 5 years. The principal complaint is of sub-talar stiffness. When assod with an open wound, there is a high incidence of infection. Osteonecrosis is ively rare, as are recurrent dislocation and subluxation.

### slocation

is a very rare, but devastating injury. Most are open injuries. There is a high lence of persistent infection (90%), often requiring talectomy and subsequent on. Osteonecrosis and arthritis are common sequelae.

### jury

mid-tarsal region is a relatively stable area; injuries are rare, but range in rity from a sprain, through subluxation, to the occasional dislocation. The

acute diagnosis is difficult, but the consequence of missing the diagnosis is severe for the patient. Diagnosis is based upon careful initial clinical assessment and evaluation of the radiographs.

***1. Classification.*** Main and Jowett (1975) identified five patterns of injury, based on the mechanism of injury:

- Medial stress. Inversion of the foot, injuring the mid-tarsal joint. The injury is usually a sprain, but dislocations have been reported.
- Longitudinal stress. A longitudinal force applied through the metatarsal 'splits' the rays and often leads to a longitudinal fracture of the navicular or cuboid.
- Lateral stress. The lateral column of the foot collapses, with the anterior process of the calcaneus, or the cuboid being compressed – the 'nutcracker' fracture.
- Plantar stress. A plantar force is the most common cause of pure dislocation in the mid-foot. The navicular and cuboid are displaced plantarwards.
- Crush injury. High-energy wounds, which are difficult to classify.

***2. Treatment.*** The non-displaced injury is treated in a cast for 6 weeks and early diagnosis is important. The displaced injury usually requires reduction and percutaneous wires to hold the reduction.

## Tarso-metatarsal joint disruption (Lisfranc's dislocation)

Tarso-metatarsal joint injuries are rare. Intrinsic stability is by bony architecture with the base of the second metatarsal recessed in between the medial and lateral cuneiform bones. There are strong ligamentous connections between the bases of the lateral four metatarsals. Lisfranc's ligament runs between the medial cuneiform and the base of the second metatarsal. There is no ligament attachment between the first and second metatarsals, representing a relatively weak portion in the tarso-metatarsal joint.

***1. Mechanism of injury.*** The classic mechanism of injury was twisting, e.g. a

...cations: long-term follow-up of 39 cases. *Injury*, 1992; 23: 97–100.
...osis and treatment of injuries to the Lisfranc joint complex. *Orthopedic Clinics of* ... 20: 655–664.
... sur les luxations du métatarse (luxations métatarso-tarsiens) du diastasis entre le ... *evue de Chirurgie*, 1909; 39: 281–336.

## ...of interest

...; Foot – calcaneal fractures, p. 58; Foot – metatarsal and phalangeal ... – mid-tarsal fractures, p. 63; Foot – talar fractures, p. 65

# GUNSHOT INJURIES

The prevalence of ballistic injuries in civilian practice has gradually increased, but the majority of surgeons will only have limited experience of treating such trauma. The key to management depends on the state of the soft tissue envelope and the fracture pattern, which are determined by transfer of energy from the missile at the time of injury. The principles of management are broadly similar to open fracture management. A bullet or shrapnel wound may cause:

- A soft tissue wound.
- A vascular injury.
- A transient or permanent neurological deficit.
- A fracture.
- Bacterial contamination.

## Ballistics

When a bullet penetrates biological tissue, energy is transferred from the missile to the tissues, which generates a destructive force. The available energy depends upon the mass and velocity ($E = \frac{1}{2}MV^2$). The amount and rate of energy transfer, which cause the soft tissue damage, depends on other factors which include both the type of weapon, the distance from the victim and type of missile. Generally, high velocity weapons (>2000 ft/sec) do more extensive damage. Different types of weapons have a varying muzzle velocity (velocity as the missile leaves the barrel):

- Low velocity (<1000 ft/sec): hand guns.
- Medium velocity (1–2000 ft/sec): magnum handguns and shotguns.
- High velocity (>2000 ft/sec): hunting rifles and military weapons.

Bullets may be of differing mass, shape and composition. Hollow, unjacketed and partially jacketed (dum-dum) bullets cause greater tissue damage.

*1.* ***Soft tissue wounds.*** As a missile passes through tissue, the missile tumbles or spins within its path. This effect and the energy transfer causes temporary cavitation, stretching the surrounding tissues, leading to necrosis and haemorrhage. This effect may draw foreign material (clothing, dirt, etc) into the wound, causing deep contamination. A missile may travel some way into tissue before giving up a maximal amount of energy, so the extent of cavitation varies in the wound track. Missile exit wounds are typically bigger than entry wounds. Military weapons and shotguns fired at close range are generally responsible for the most severe soft tissue injuries.

*2.* ***Vascular injuries.*** Missiles may cause damage to vessels either by effects of cavitation, or direct penetration.

*3.* ***Nerve damage.*** A local blast effect may cause a transient neurapraxia or axonotmesis, as well as a traumatic laceration.

*4.* ***Fractures.*** Missiles cause a fracture with a variable degree of comminution, depending on the rate of energy transfer. The periosteal envelope may be largely intact or grossly disrupted again depending on energy transfer

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**Related to**

# HAND – CARPAL DISLOCATION

There are three patterns of carpal dislocation – radiocarpal, transverse and axial. Transverse dislocations, which include lunate and perilunate dislocations, are of particular interest, representing one end of the spectrum of carpal instability, predisposing to volar and dorsal intercalated segmental instability (VISI and DISI). Pure radiocarpal (wrist) dislocation is rare, as there is usually an associated dorsal or volar (Barton's) fracture.

### Anatomy

Understanding the ligamentous anatomy of the wrist is fundamental to appreciating these complex injuries. The ligaments are divided into intrinsic (within the carpus) and extrinsic (radius to carpal) groups.

1. ***Intrinsic ligaments.*** These are short, strong ligaments binding each carpal bone to its neighbour, on both the volar and dorsal aspects of the carpus. The most important are the scapholunate and the triquetrolunate, connecting the bones of the proximal carpal row (scaphoid–lunate–triquetrum). Sectioning the scapholunate ligament allows the lunate to extend with the triquetrum (DISI), whereas sectioning the triquetrolunate allows the lunate to flex with the scaphoid (VISI). The ligaments of the distal row (trapezium–trapezoid–capitate–hamate) seldom fail clinically.

2. ***Extrinsic ligaments.*** These are dorsal and volar capsular condensations, acting as accessory stabilizers of the intrinsic ligaments, but are also injured in perilunate dislocation. Less emphasis is placed on their repair.

## Radiocarpal dislocation

The commonest purely ligamentous radiocarpal injury is ulnar translation. Purely ligamentous dorsal or volar dislocation is rare. Treatment is open repair of the damaged extrinsic dorsal and volar radiocarpal ligaments, supplemented with K-wire stabilization. Radiocarpal fracture dislocation (Barton's fracture) is usually treated operatively.

## Transverse dislocation

The lunate is the 'key' to wrist stability. Perilunate dislocations and fracture dislocations are the extremes of carpal instability. Perilunate dislocation can be caused by rupture of the ligaments attaching the lunate to its neighbouring carpals – a 'lesser arc' injury. Dislocation associated with a fracture of the radial styloid, scaphoid, capitate, or triquetrum is classified as a greater 'arc' injury. Ninety five per cent of greater arc injuries involve the scaphoid. Trans–scaphoid–perilunate dislocation is the commonest pattern.

### Clinical presentation

The most common mechanism of injury is a fall on the out-stretched hand, which extends with ulnar deviation and supination. The scapholunate, capitolunate and triquetrolunate joints fail in sequence, leaving the lunate free to dislocate. Dorsal perilunate dislocations often reduce spontaneously.

Up to 25% of these injuries are misdiagnosed acutely, although the diagnosis should be suspected clinically from the degree of swelling. Eight per cent are open; neurovascular and tendinous injury occurs and the median nerve is most commonly affected.

## Imaging

1. ***The two most important X-rays are the PA and lateral,*** with the wrist in neutral. There are two patterns of lunate dislocation. Most commonly the lunate remains aligned with the radius – *perilunate dislocation*. Alternatively, the lunate displaces in a volar or dorsal direction, the carpus aligning with the radius – *lunate dislocation*. The principles of treatment of both injuries are the same and recognition of associated fractures is essential.

2. ***An acute dislocation that reduces spontaneously,*** or an isolated ligament rupture, is difficult to diagnose. Malalignment between the proximal and distal carpal rows on the PA X-ray raises suspicion, but the lateral X-ray is more useful. The alignment of the radius, lunate, capitate and metacarpals should be confirmed. Arthrography, CT, MRI and wrist arthroscopy are valuable diagnostic tools.

3. ***DISI is associated with widening of the scapholunate interval*** by >2–3 mm ('Terry Thomas' sign), and a 'cortical ring' sign caused by excessive scaphoid flexion on PA X-ray. On the lateral, the lunate lies volar to the capitate, is extended (>10°) and the scapholunate angle is increased. In VISI the lunate lies dorsal, flexed (>15°) and the scapholunate angle is <30°.

4. ***In summary,*** a scapholunate angle <30° (VISI) or >80° (DISI) is abnormal and an angle of 60–80° is equivocal.

## Treatment

The aim of treatment is to reduce frank dislocation and prevent progression to chronic instability, caused by failure of ligamentous healing. A spectrum of treatment modalities, from plaster to ORIF, is used.

The majority of perilunate dislocations are unstable, irreducible or open. In these cases the reduction can be held with K-wires, or open ligamentous repair undertaken. With dorsal dislocation a palmar approach usually suffices; in other cases combined palmar and dorsal approaches are necessary. The palmar approach allows decompression of the median nerve, repair of the palmar ligaments, and scaphoid fixation. The dorsal approach allows better visualization of the joints and repair of the dorsal ligaments.

Some consider open ligament repair is indicated in all cases, even if normal alignment is achieved after reduction in plaster, because ligamentous healing is unpredictable and the results of closed treatment are also unpredictable.

## Prognosis

Closed treatment of perilunate dislocation has been associated with loss of position in 60% of cases, whereas with internal fixation reduction is maintained in 75%. Failure of ligamentous healing can manifest as chronic DISI or VISI deformities. These patients typically have wrist pain, popping, catching and weakness. Even with good early management, 50% of perilunate dislocations develop degenerative change.

## Axial

Longitudinal separation of the finger rays follows high-energy trauma. The ulnar or radial rays typically separate from the long finger ray, which usually remains intact. The majority of these injuries are open, necessitating debridement and stabilization. Arterial and nervous (usually ulnar) injury is frequent. The prognosis is determined by the severity of the soft tissue injury and return to work often limited by diminished grip strength.

## Further reading


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**Ruby LK.** Carpal instability. *Journal of Bone and Joint Surgery*, 1995; **77A**: 476–487.


## Related topic of interest

Radius and ulna – distal fractures, p. 233

# HAND – CARPAL FRACTURES (EXCLUDING SCAPHOID)

Carpal fractures are usually the result of a fall on the out-stretched hand. Non-scaphoid fractures are rare, as 79% of carpal fractures involve the scaphoid. Of the remainder, 14% involve the triquetrum and 2% the trapezium. Avascular necrosis (AVN) has been reported with the scaphoid, lunate, capitate and pisiform.

## Triquetrum

Triquetrum fractures may occur in association with perilunate dislocation. Other fracture patterns are caused by impingement of the ulnar styloid, or dorsal avulsion in wrist flexion. Treatment in a cast for 4–6 weeks is usually adequate.

## Trapezium

There are three main fracture patterns:

- Fractures of the body.
- Marginal fractures of the trapeziometacarpal joint.
- Fractures of the trapezial ridge.

Trapezial dislocation occurs and is most commonly volar. Diagnosis may be difficult and special radiographic views helpful. Carpal tunnel radiographs are necessary to show fractures of the ridge.

Undisplaced fractures are treated in a cast for 4–6 weeks. Displaced body fractures often extend into the joint and require ORIF. Ridge fractures that remain symptomatic are excised. With dislocation, an attempt at closed reduction is made and if this fails, open reduction and K-wire fixation is required. This is covered in more detail in the topic 'Hand – thumb fractures and dislocations', p. 97

## Lunate

Acute lunate fractures are a rarer cause of presentation than Kienbock's disease, but the relationship between the two is unclear. The blood supply is from both the dorsal and palmar aspects. Fractures can be of the dorsal horn, volar horn, or body. Fractures of the body are most frequently transverse.

***Diagnosis and treatment.*** Acute diagnosis can be difficult, as the fracture may not be visible on plain X-ray. Bone scintigraphy, tomography, MRI or CT can confirm the diagnosis, if the clinical findings and plain X-rays are suggestive. Failure to diagnose the acute injury may delay presentation until Kienbock's disease becomes established.

An acute fracture should be treated in a cast and followed up with repeat radiographs, or preferably tomograms. The aim is to detect collapse of the lunate into itself, as collapse increases the incidence of non-union and AVN. When collapse occurs, treatment is ORIF of the fracture and reduction of the compressive forces across the joint. Compressive forces can be reduced by the correction of any ulnar minus deformity with ulnar lengthening, or preferably radial shortening. External fixation of the wrist in distraction has been advocated.

## Trapezoid

Isolated fracture of the trapezoid is rare. The fracture is usually part of a more complex injury, such as axial dislocation or dislocation of the index finger ray. Plain radiographs may be difficult to interpret. Treatment is with a below-elbow cast for 6 weeks.

## Capitate

Fractures of the capitate are rare, but there are two principal points of interest. Firstly, the proximal portion of the capitate is intra-articular and therefore at risk of AVN or non-union. This is treated by bone grafting, arthrodesis or excision. Secondly, capitate fractures are most commonly associated with a perilunate injury and manifest as a combined capitate and scaphoid waist fracture. The proximal capitate fragment rotates through 90° to 180°. This 'scaphocapitate' syndrome is treated with ORIF.

## Hamate

Hamate fractures are either of the articular surface, body or hook. The hamate rarely dislocates. Fractures and dislocations are usually the result of high-energy trauma (crush or blast) and associated with axial dislocation of the fifth ray.

Fractures of the hook occur at the base, often as a result of racquet sports or golf. Presentation is with local tenderness and the injury is best visualized on a carpal tunnel radiograph. When diagnosed acutely, treatment in a cast for 6 weeks is appropriate. Left untreated, non-union is common, which may cause chronic pain, ulnar nerve symptoms, or flexor tendon attrition. Treatment is by excision, or ORIF and bone grafting.

## Pisiform

The pisiform can be fractured, subluxed or dislocated. Radiological imaging requires a carpal tunnel view, or lateral view of the wrist with the forearm in 30° supination. Symptomatic non-union or post-traumatic arthritis is treated by pisiform excision and reconstruction of the flexor carpi ulnaris.

# Related topics of interest

Hand – carpal dislocation, p. 75; Hand – thumb fractures and dislocations, p. 97

# HAND – FINGER DISLOCATIONS AND LIGAMENT INJURIES

The joints of the fingers are primarily stabilized by soft tissues, rather than bone. The volar plate and two collateral ligaments form a ligamentous box around the joint. Disruption of two of the three structures is necessary for dislocation.

The proximal interphalangeal joint (PIPJ) is the most commonly injured and functionally the most important joint in the hand. The distal interphalangeal joint (DIPJ) is protected by a shorter lever arm, and the metacarpo-phalangeal joint (MCPJ) by the adjacent tendons and the deep transverse metacarpal ligament connecting the volar plates.

## PIPJ injury

Dorsal, volar, rotatory and lateral dislocations of the PIPJ occur.

1. ***Dorsal dislocation*** is caused by hyperextension, typically in a sporting accident. The major structure injured is the volar plate, which may be avulsed with a fragment of bone visible on a lateral X-ray. Treatment is mobilization with neighbour strapping for 3 to 6 weeks. Neighbour strapping prevents hyperextension. Left untreated, the PIPJ can hyperextend and a swan-neck deformity develops. Rarely the volar plate or flexor tendons become interposed in the joint and surgical removal is required.

   In cases where >30% of the volar lip of the middle phalanx is avulsed, the joint is potentially unstable. A large single fragment can be surgically reattached. More commonly, the fragment is comminuted and these unstable injuries can be treated non-operatively with an extension block splint. The extension block is discarded at 4 weeks and neighbour strapping is then used to prevent hyperextension. Alternatively, the bony fragments may be excised, and the volar advanced and reattached (volar plate arthroplasty of Eaton). The Eaton procedure can be used for late presentation – after 2 weeks.

2. ***Volar dislocation*** is rare. Significantly the injury is often associated with avulsion of the central extensor tendon slip, sometimes with an attached bony flake. The integrity of the central slip must be tested. If it is not intact, the PIPJ is splinted in extension for 4 to 6 weeks, preventing the development of a boutonnière deformity.

3. ***Rotatory dislocation*** presents with one condyle of the proximal phalanx buttonholed through a tear in the extensor hood, trapped between the central slip and the lateral band. Open reduction is frequently required.

4. ***Lateral dislocation*** is primarily a collateral ligament injury and complete rupture is diagnosed clinically by opening of the joint >20° on stress testing. Treatment is with neighbour strapping for 3 to 6 weeks. The chronic (>6 weeks) case may require surgical reconstruction if symptomatic.

## DIPJ injury

DIPJ dislocation is rare and typically dorsal. Treatment consists of reduction and early mobilization. Dorsal avulsion and volar fracture/subluxation occurs with mallet finger (see the topic 'Hand – phalangeal fractures', p. 88).

Irreducible and open dislocations require operative treatment. The FDP, volar plate, bony fragments or capsule can all block reduction.

### MCPJ injury

Dorsal, volar and lateral dislocations of the MCPJ occur. Dorsal is the most common.

*1.* ***Dislocation can be 'simple' or 'complex' (irreducible)*** and differentiating the two is important, to avoid making a simple injury complex. The simple dislocation appears more dramatic, with the finger in 60° or more of hyperextension, compared to a few degrees with the complex. In complex dislocation, the metacarpal head is buttonholed through the capsule, often with puckering of the palmar skin.

The simple dislocation is reduced by flexing the wrist and finger. Distraction of the joint should be avoided as this may allow the volar plate into the joint. Complex dislocation usually requires open reduction. A palmar approach is used with great care to avoid the neurovascular bundle. Both injuries are mobilized with neighbour strapping after reduction.

*2.* ***Volar dislocation*** is extremely uncommon, reduction can be blocked by the volar plate or dorsal capsule.

*3.* ***Lateral dislocation*** is treated by immobilization in 30° of flexion for 3 weeks. If a bony fragment is displaced by >3 mm, surgical reattachment should be considered.

### The locked MCPJ

The MCPJ can become locked and should be differentiated from trigger finger, which involves the PIPJ. The cause of locking is usually a collateral ligament catching on an osteophyte or prominent metacarpal condyle. Presentation can be acute following trauma.

Treatment is either an attempt at gentle closed reduction, inflation of the MCPJ with local anaesthetic, or surgical excision of the bony block.

### Complications of finger joint dislocations

The principal complications are swelling and stiffness. It takes 1 year for the swelling to resolve. Stiffness may be very prolonged.

Persistent stiffness is best avoided by early mobilization (less than 4 weeks). Should stiffness become a problem, treatment is initially with physiotherapy and dynamic splintage. If this fails, particularly in the PIPJ, surgical treatment with collateral ligament and volar plate release is performed. This increases the range of movement (up to 100%) without leading to instability.

## Related topics of interest

Hand – phalangeal fractures, p. 88; Hand – thumb fractures and dislocations, p. 97

# HAND – METACARPAL FRACTURES

Hand fractures are common, accounting for 30% of all fractures, and most are treated non-operatively, with the emphasis on functional recovery.

Indications for operative treatment are:

- Malrotation.
- Intra-articular fractures.
- Open fractures.
- Associated neurovascular or tendon injury.
- Bone loss.
- Polytrauma.
- Multiple fractures in a single hand.

## Classification

Metacarpal fractures are classified according to:

1. ***Anatomical location*** – head, neck, shaft and base. The neck is the weakest and most frequently fractured site.

2. ***Fracture configuration*** – transverse, oblique, spiral and intra-articular.

## Clinical examination and imaging

Examination includes assessment of the tendon and neurovascular structures. [redacted]

# HAND – PHALANGEAL FRACTURES

Most phalangeal fractures can be treated non-operatively, like metacarpal fractures, with the emphasis on functional recovery.

The indications for operative treatment are:

- Malrotation.
- Intra-articular fractures.
- Subcapital and peri-articular fractures.
- Open fractures.
- Associated neurovascular or tendon injury.
- Bone loss.
- Polytrauma.
- Multiple hand fractures.

## Clinical examination and imaging

Careful examination is mandatory to assess neurovascular and tendinous integrity. Assessment for malrotation and shortening of the finger is important. Malrotation in extension is greatly magnified in flexion. AP and lateral radiographs should be obtained.

## Principles of treatment

***1. Displacement and stability*** determine management. Transverse fractures are more stable than spiral or oblique fractures. Undisplaced, stable fractures are treated non-operatively. Only 15% of displaced fractures are stable after closed reduction, so percutaneous K-wire fixation is frequently required. If open reduction is necessary, stable fixation to allow early mobilization gives the best result.

***2. Treatment of the soft tissues*** is important and some series identify the severity of soft tissue, rather than bony injury, as the most important factor in determining outcome. The incidence of stiffness increases if the hand is immobilized for more than 4 weeks.

## Fractures of the proximal and middle phalanges

Deformity depends on the relation of the fracture to the inserting tendons. Fractures of the proximal phalanx present with flexion of the proximal fragment due to the pull of the interossei. In the middle phalanx, angulation of the fragments is determined by the position of the fracture relative to the central slip of the extensor tendon which inserts proximally and the FDS which inserts along much of the volar aspect.

***1. Shaft fractures.*** Undisplaced, stable shaft fractures are treated with mobilization of the fingers by 'neighbour strapping'. Closed reduction and immobilization is suitable for fractures that are displaced, but stable on reduction. The MCPJ is immobilized at 70°–90° of flexion, with the interphalangeal joints in extension – the *intrinsic plus* position. The collateral ligaments are at their maximum length and splinting in this position prevents contracture. Burkhalter recommended dynamic splintage – a dorsal extension block splint, allowing finger flexion.

If the fracture is unstable following closed reduction, percutaneous K-wires, an external fixator, or screws and plates should be used. Percutaneous K-wires leave the soft tissue envelope intact by transfixing deep structures, but may not achieve precise fracture reduction. Plates provide the strongest fixation, but are bulky and require more extensive soft tissue dissection. External fixation has a role in the comminuted fracture, or in the presence of gross soft tissue contamination.

***2. Subcapital fractures of the proximal phalangeal neck.*** These should be reduced and fixed with K-wires. More common in children, the phalangeal head is typically 60° or more dorsally angulated. Reduction is usually easy, but lost without fixation.

***3. Intra-articular fractures.*** Undisplaced intra-articular fractures are rare and can be treated non-operatively, but should be closely reviewed with X-rays. Condylar fractures need accurate reduction, by open or closed means, and then stabilization with wires or screws. A pure dorsal approach, splitting the extensor tendon, is favoured. Avulsion fractures around the base of the middle phalanx are associated with injury of the central slip, collateral ligaments or volar plate, and are discussed in the topic 'Hand – finger dislocations and ligament injuries', p. 80.

Comminuted intra-articular fractures are difficult to treat and not readily amenable to ORIF. Recently dynamic external fixators have been used for this injury.

## Fractures of the distal phalanx

***1. Tuft fractures.*** The role of surgery is to repair the nail bed and drain a subungual haematoma.

***2. Transverse fractures.*** If displaced, reduction and splinting, or K-wire fixation are required. The distal fragment angulates in a volar direction, from the pull of the flexor digitorum profundus (FDP). If the nail root is avulsed, the bed should be repaired, replacing the nail as a splint. If the nail bed becomes entrapped in the fracture, non-union follows.

***3. Mallet finger.*** This is either a purely tendinous injury, or associated with a distal phalangeal fracture and DIPJ subluxation. Most authors recommend splintage of the DIPJ in extension (Stack splint) for 6 to 10 weeks. The indications for ORIF include displacement of the bony fragment by >3 mm, avulsion of >30% of the joint surface or volar subluxation. Surgery is technically difficult and does not always improve the outcome, so most mallet fingers, whether of bony or tendinous origin, are treated by splintage. The prognosis after distal phalangeal fractures is disappointing, with 70% of patients reporting stiffness, pain and diminished sensibility at 6 months.

***4. Associated tendon injuries.*** The FDP and extensor tendons can be avulsed from the distal phalanx, with or without a bony fragment. FDP avulsion, 'jersey finger', occurs with a variable-sized fragment of bone (see topic 'Hand – tendon injuries', p. 93).

## Complications

1. ***Malrotation*** is corrected by phalangeal or metacarpal osteotomy. Metacarpal osteotomy causes less stiffness and allows correction up to 20°.

2. ***Angulation*** can be corrected by an opening wedge and bone graft, or a closing wedge. Shortening is difficult to correct. Osteotomy, arthrodesis or arthroplasty can correct intra-articular malunion.

3. ***Non-union*** is rare and usually atrophic. When non-union occurs, early treatment at about 4 months is advised, avoiding excessive splinting and consequent stiffness. Radiological union occurs later (4–5 months) than clinical union in the hand.

4. ***Stiffness*** is prevented by avoiding immobilization for >4 weeks. When stiff-

## Complications

*1.* ***Non-union*** is defined as a failure of progression of fracture healing on three separate monthly X-rays; after treatment for 6 months the overall rate is 10%. In about half of these, the fracture was undiagnosed or not treated initially. The natural history of non-union is controversial. It is not clear how many develop symptomatic degenerative osteoarthritis or carpal collapse.

If asymptomatic, the risk of degeneration should be discussed and observed. If symptomatic, consider open Russe cortico-cancellous bone graft +/– restoration of anatomy and fixation; this has a 90% success rate. An assessment of proximal pole vascularity is essential either by pre-operative MRI or intra-operatively. Thirty per cent may be avascular and grafting may not be successful.

*2.* ***AVN.*** Five to ten per cent overall. The anatomy of the scaphoid blood supply leaves the proximal pole at risk of AVN. The principal blood supply enters through the dorsal waist and there are intraosseous canals running up and down the scaphoid. A third of people lack canals to the proximal pole, thus a third of proximal pole fractures have no blood supply and risk AVN. Early identification and separation from delayed or non-union is difficult – MRI is helpful.

Procedures for AVN include bone graft and staple or screw fixation, vascularized bone graft, excision of proximal pole, radial styloidectomy for radio-carpal osteoarthritis, proximal carpal row carpectomy and arthrodesis.

# Further reading

Proctor M. Non-union of the scaphoid: early and late management. *Injury*, 1994; 5: 5–20.

# Related topics of interest

Hand – carpal dislocation, p. 75; Hand – carpal fractures (excluding scaphoid), p. 78

# HAND – TENDON INJURIES

## Flexor tendons

The majority of flexor tendon injuries follow a laceration. The anatomy is complex. A synovial sheath surrounds the tendons, containing synovial fluid for nutrition and lubrication. A fibro-osseous tunnel encloses the sheath, consisting of five thickened annular (A) bands, and three cruciform (C) pulleys. The A2 and A4 pulleys are the most important in preventing bow stringing and overlie the shaft of the proximal and middle phalanges respectively.

Flexor tendon injuries are classified according to the anatomical zones of injury; from distal to proximal these are (*Figure 1a*):

- Zone I: FDP injuries distal to the FDS insertion
- Zone II: Bunnell's 'no man's land', from the level of the distal palmar crease (A1 pulley) to zone I, containing the FDP and FDS decussation in a tight canal.
- Zone III: the palm.
- Zone IV: the carpal tunnel.
- Zone V: proximal to the deep transverse ligament.

Similar zones are described in the thumb, prefixed by 'T'.

### Clinical examination

(if the stump is >1 cm long), pullout suture into bone, or screw if the bony
nt is large enough.

***ne II.*** Repair in this zone is technically demanding. Both the FDP and FDS be repaired if possible, and the A2 and A4 pulleys preserved.

***her zones.*** The same principles of repair apply.

### obilization

nobilization increases the tensile strength and vascularity of the repair, s adhesions and gives superior clinical results. The repair is weakest at 7 to 10

einert described an extension block splint with a rubber band to passively e fingers. Recently, attention has turned to active flexion. In the Duran mme, passive flexion is used for the first 4 weeks, protecting the repair with ension block splint, and active flexion is introduced over the ensuing ht. Grip-strengthening exercises and lifting is avoided for 3 to 4 months. ontrolled active mobilization (Belfast regime) gives better results still.

onths, recovery of the range of movement is 90% of what can be expected. sis is seldom considered before 6 months.

NDON INJURIES

Techniques for late reconstruction include DIPJ fusion, tendon transfer and tendon grafting. With modern rehabilitation, good and excellent results have increased from 50% to 95%.

## Extensor tendons

Extensor tendon injuries have long been the Cinderella of hand injuries. There is growing realization that this confidence is ill-founded, with only 60% good or excellent results. Loss of flexion is more of a problem than loss of extension.

The extensor system is divided into zones; from distal to proximal these are (*Figure 1b*):

- Zone I: distal to the central slip of the PIPJ.
- Zone II: MCPJ to the central slip.
- Zone III: distal to the extensor retinaculum.
- Zone IV: under the extensor retinaculum.
- Zone V: in the forearm.

### Clinical examination

Clinically a mallet deformity is obvious. A closed boutonnière is more difficult to diagnose, especially in the absence of bony avulsion from the middle phalanx. The diagnosis is confirmed by dorsal tenderness and swelling. Boye's test examines the integrity of the central slip – passive flexion of the MCPJ extends the PIPJ, unless the central slip has ruptured.

### Repair by zone

1. ***Zone I.*** Mallet finger. Closed treatment in a splint. See 'Hand – phalangeal fractures', p. 88.

2. ***Zone II.*** Rupture of the central slip leads to development of a boutonnière deformity, with subluxation of the lateral bands. Closed treatment with a spring-loaded dorsal (Capner) splint holds the PIPJ in extension and is worn for 6 weeks, during which the DIPJ is actively and passively flexed. Indications for operative treatment are a large bony avulsion, which should be reduced, or an open injury, often communicating with the joint.

3. ***Zone III to V.*** Injuries are repaired with standard suture techniques and simple post-operative splinting. Particular care should be taken with human bite wounds over the MCPJ, which often penetrate the joint. The wound should be extended; the joint exposed, debrided and irrigated. Closure and tendon repair is delayed.

4. ***Following surgery.*** The traditional position for immobilization of extensor

open reduction and internal fixation. The usual technique
ng. With the thumb adducted and pressure applied to the
s held by two wires passed into the trapezium, trapezoid or
IF is rarely required.
e is more difficult to treat and is fortunately rare. Ideally,
This may be so technically difficult that it is preferable to use
n and an external fixator across the joint, or to use the 'bag of
early mobilization.

n

d reflects pure avulsion of the anterior oblique ligament. If
ould be reduced and held in a spica. Supplementary K-wires
ld the reduction. Subluxation is often overlooked and the

most helpful X-ray is a stress radiograph taken with both thumbs pushing against one another. If the thumb subluxes, immobilization in a spica for 4 weeks is appropriate.

## Further reading


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## Related topics of interest

Hand – metacarpal fractures, p. 82; Hand – phalangeal fractures, p. 88

# HEAD INJURIES

Head injuries generally follow high velocity trauma. An altered level of consciousness is the hallmark, usually evident immediately, which may progress within hours. Occasionally, late complications become evident after a few weeks. Sixty per cent of all road trauma deaths are due to head injury. Immediate action, to prevent anoxia, maintain cerebral perfusion, reduce cerebral compression and prevent infection, are the aims of treatment. Rehabilitation following a major head injury requires prolonged, expensive, intensive, multidisciplinary therapy.

## Nature of injury – anatomy, physiology and pathology

*1.* ***Skin.*** A head injury may include a scalp laceration and haemorrhage can be significant, especially in children.

*2.* ***Bone.*** There may be an associated skull fracture, linear or depressed, closed or open. Depressed skull fractures can be associated with epilepsy, more commonly in children, and even without neurological compromise, may need elevation if the depression is greater than the thickness of the skull. Basal skull fractures may not be seen on X-ray and are characterized by CSF leakage from the ear (otorrhoea) or nose (rhinorrhoea), periorbital bruising and intracranial gas. The use of prophylactic antibiotics (penicillin and sulphadimidine) is controversial.

*3.* ***Meninges.*** The dura, arachnoid and pia mater form the meninges.

- Extradural haematomas follow haemorrhage of meningeal vessels, between the skull and dura mater, into the potential extradural space. These occur more frequently in younger patients, after lower velocity trauma. Deterioration can be rapid, and if treated early, is reversible. A declining level of consciousness in a previously alert patient is a neurosurgical emergency.
- Acute subdural haematomas follow violent deceleration and are often associated with intracerebral damage.
- Chronic subdural collections are usually of insidious origin, with minor trauma in the elderly, and may cause late effects at 2 to 6 weeks.

*4.* ***Brain.*** Brain tissue may be damaged by direct trauma, intracerebral haemorrhage, or by the effects of intracranial collections, causing initially local and subsequently generalized compression. A diffuse or focal brain injury follows.

Diffuse brain injuries are either:

- Concussion with a good prognosis.
- Diffuse axonal injury, characterized by prolonged coma and a variable, often poor, outcome.

Focal injuries with localized damage can cause a generalized effect. These include:

- Contusion – single or multiple. Contusion may be at the site of impact (coup injury) or opposite the site (contracoup injury), or a combination.
- Intracranial haemorrhage.
- Acute extradural (1% of all head injuries).

- Subdural – usually acute, occasionally chronic.
- Subarachnoid.
- Intracerebral haemorrhage.
- Impalement and bullet wounds: rare in the UK and often fatal.

5. ***Level of consciousness.*** This may be altered either by direct injury to the cerebral cortex, or secondary to the effects of rising intracranial pressure, and the resulting diminished cerebral blood flow and tissue oxygenation. The intracranial pressure (ICP) is proportional to the sum of the volume of CSF, blood and brain (Monroe–Kellie hypothesis). Intracranial haemorrhage can be accommodated by reducing the volume of CSF and venous blood, for a collection of up to 50 ml. Larger collections raise the ICP and diminish cerebral perfusion pressure (CPP) (CPP = BP – ICP). An ischaemic brain injury is likely if the ICP falls below 60 mmHg. The arterial blood volume is regulated by arterial $pCO_2$ and can be decreased by hyperventilation. This is critical to head injury management.

## Assessment of injury

Ongoing assessment is vital to determine any deterioration. The Glasgow Coma Scale (GCS) (*Table 1*), based on the best visual, verbal and motor responses, scored out of 15, is a quantitative measure of consciousness. (A score of 3 corresponds to no response and brainstem death.) Full neurological assessment includes briskness and equality of the pupillary response to light, and peripheral neurological status.

The GCS score can be used to categorize patients and is a guideline for management. Patients with a score of 14 have a minor head injury and can often be discharged from an accident department, if they have suitable supervision at home and no skull fracture. Patients with a score of ≤8 have a major head injury, are in coma and require neurosurgical consultation, investigation including CT scan, and treatment. Patients between these two levels, a score of 9 to 13, have a moderate head injury requiring close observation, a CT scan and neurosurgical referral.

## Treatment

Treatment of the trauma victim is aimed at resuscitation and treatment of all injuries according to clinical priority, starting with maintenance of the airway, stabilization of the cervical spine, high-flow oxygen, breathing and circulation.

After resuscitation, treatment priorities of a head injury are maintaining cere-

**Table 1.** The Glasgow Coma Scale

| Best visual response (eye opening) | Score | Best verbal response | Score | Best motor response (to painful stimuli) | Score |
|---|---|---|---|---|---|
| Spontaneously | 4 | Orientated | 5 | Obeys commands | 6 |
| To verbal command | 3 | Confused | 4 | Localizes | 5 |
| To painful stimuli | 2 | Inappropriate words | 3 | Withdraws | 4 |
| No response | 1 | Incomprehensible sounds | 2 | Flexes | 3 |
| | | No response | 1 | Extends | 2 |
| | | | | No response | 1 |

bral perfusion, controlling ICP, and constant reassessment. A severe head injury requires controlled ventilation, ICP monitoring, nursing care, drug therapy and possibly surgical intervention.

In moderate and severe head injuries, drug therapy may be valuable, including:

- Diuretics. 20% mannitol, 1 g/kg. Loop diuretics such as frusemide, are seldom given.
- Anti-epileptics for a fitting patient: initially diazepam 10 mg and if ineffective, phenytoin 1 g at 50 mg/min, followed by 100 mg 8-hourly.
- Steroids are seldom administered.

Definitive management is undertaken in a neurosurgical centre for the majority of cases. The indications for surgical intervention, in addition to controlled ventilation and hypocapnia, depend upon the pathology. There are seldom indications for the inexperienced to perform blind burr holes.

Depressed skull fractures need careful assessment and possibly elevation. Open depressed fractures require surgical debridement and meticulous dural repair.

## Treatment of orthopaedic injuries

Stabilization of orthopaedic injuries is vital, but this does not always equate with the immediate need for prolonged surgery, which may destabilize cerebral perfusion, unless the fracture is open or limb viability dubious. The most suitable window of opportunity for open surgical long bone fixation is often at the time of admission, or following emergency neurosurgery, if the clinical situation and surgical facilities allow. However, stabilization such as external fixation, plaster or possibly traction, can rapidly be applied and an anatomical reduction deferred for a few days, until the clinical situation permits. The consequences of intramedullary reaming at 1 to 6 days following a major head injury may be catastrophic.

## Prognosis

The duration of post-traumatic amnesia is a good clinical guide to the severity of a head injury. Recovery following a major head injury is usually exponential, with the greatest recovery in the first 6 months. It may continue for many years.

## Fitting, epilepsy and driving (UK DVLA regulations)

An epileptic fit following a head injury may lead to the suspension of a driving [illegible]

with a cephalad fracture (above or including the fovea centralis); ty
femoral head and neck fracture; and type IV with an associated ac
fracture.

Central fracture dislocations are usually more complex fractures,
anterior or posterior column, and should be considered within the L
Judet classification.

### Radiology

The diagnosis can be confirmed from plain AP pelvic radiographs,
quality to exclude a large rim fragment. Following reduction, radiogra
and any rim or head fracture investigated with a CT scan. Only if the i
unusual should a CT scan be obtained before closed reduction – anoth
likely to be required after reduction. Post-reduction CT helps plan
show intra-articular loose bodies.

often a full general anaesthetic is required. With a posterior dislocation, greater mechanical advantage for traction can be achieved with the patient on the operating room floor. If the reduction is stable, 2.5 to 5 kg of skin or skeletal traction should be applied.

AP X-rays will confirm the reduction, and when there is doubt about the congruity of the reduction, a CT scan should be obtained.

2. ***Immediate open reduction*** is required when the dislocation cannot be reduced or the hip is grossly unstable. The joint should be opened, the hip reduced and the rim fracture stabilized.

3. ***Retained loose fragments*** should be removed by arthrotomy or hip arthroscopy. Fragments can abrade the articular surface and accelerate post-traumatic degenerative change.

4. ***Significant rim fractures*** require open reduction and internal fixation under appropriate conditions. Where there is less than one third of the posterior rim remaining, the hip may be unstable. Fragments are usually posterior, often comminuted, and should be stabilized with interfragmentary screws and a reconstruction plate. In the presence of extensive comminution, restoration of stability and bone stock for a subsequent reconstructive procedure may necessitate iliac crest bone graft.

5. ***Large head fragments*** require open reduction and fixation, or removal if not involving the weight-bearing area. This is best performed through an anterior approach to the joint, as cephalad fragments are attached to the ligamentum teres and cannot be adequately visualized or reduced through a posterior approach. The fragment can be fixed with small fragment screws, Herbert screws or absorbable pins.

6. ***Mobilization*** can start after closed or open reduction as soon as pain allows. In the past, patients with a simple dislocation have been treated with bed rest and traction for 6 weeks prior to mobilization. This is unnecessary and patients should start to move the hip early and be mobilized when their pain permits, usually around 5 to 10 days with 5 kg partial weight bearing for 6 weeks, increasing to full

*2. **Operative management.*** The aim of surgery is to re-establish proximal humeral anatomy, with an intact rotator cuff which does not impinge. Care must be taken not to devascularize fragments, or leave hardware that interferes with shoulder motion.

- Two-part fractures of the surgical neck can usually be treated conservatively, although occasionally removal of an interposed bicipital tendon is required. Greater tuberosity fragments displaced by >1 cm require ORIF and rotator-cuff repair.
- Three-part fractures have a better outcome if the bony anatomy can be restored. Plate and screw fixation is associated with AVN rates of 30%, which has led to a move away from plate fixation to less invasive techniques. Closed reduction and percutaneous pinning is technically demanding, but useful in selected patients. ORIF using wires and tension bands is gaining popularity. This technique reduces impingement and disturbance to blood supply.
- Four-part fractures have a poor result with non-operative management, which led Neer to introduce the hemiarthroplasty in the 1950s. This gives a pain-free shoulder, with active forward flexion to 90° or more. The technique is technically demanding – the rotator cuff should be reattached and the natural humeral head retroversion of 35° maintained. Recent publications indicate the rate of AVN following these fractures is not as high as previously thought and so reconstruction with wires and tension-band fixation has become more popular. The results of early hemiarthroplasty are better than those of delayed primary arthroplasty, or late arthroplasty to revise failed internal fixation.

*3. **Fracture/dislocation.*** Fracture of the greater tuberosity often reduces after closed reduction of the shoulder, but failure of the fragment to reduce requires ORIF and cuff repair. Care should be taken not to convert a non-displaced fracture dislocation into a displaced injury during manipulation. Two- or three-part fracture dislocations can be treated by ORIF. Four-part injuries generally have a poor prognosis due to AVN and are treated by hemiarthroplasty.

*4. **Impaction or splitting of >45% of the articular surface.*** This is an indication for prosthetic replacement.

## Complications

- **Neurological:** up to 36% of patients have neurological impairment. The axillary nerve is the most commonly injured, but injury to the suprascapular, musculocutaneous and radial nerves have been reported. Ninety per cent recover spontaneously within 4 months.
- **Vascular:** axillary artery damage occurs in up to 5%, and in 27% of these the distal pulses remain palpable.
- **AVN** is related to the severity of the injury and occurs in 5–15% of three-part fractures and 10–34% of four-part fractures. Recent studies show that these figures maybe an overestimate.
- **Malunion** can lead to impingement of the greater tuberosity and limitation of range of movement.
- **Shoulder stiffness** follows a poor rehabilitation programme, myositis ossificans, malunion and AVN.

### Paediatrics

Fractures in children of <5 years are most commonly Salter–Harris type I, and >13 years Salter–Harris type II. Between 5 and 12 years, the physis is seldom involved. The most remarkable factor in these injuries is their ability to remodel, and hence surgical intervention is rarely required.

## Further reading

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## Related topic of interest

Humeral fractures – shaft, p. 113

# HUMERAL FRACTURES – SHAFT

The humeral shaft extends proximally from the upper border of pectoralis major insertion to the supracondylar ridge distally. Shaft fractures constitute 3% of all fractures and most are treated conservatively. The principal issues are avoidance of non-union, radial nerve palsy, and the role of IM nailing.

## Clinical examination and imaging

1. ***Diagnosis.*** This rarely presents a challenge, except in the unconscious. The neurovascular status of the limb should be documented before any manipulation. Radiological evaluation consists of full-length AP and lateral radiographs, including the shoulder and elbow.

2. ***Proximal fragment displacement.*** This depends upon the fracture location relative to muscular insertions. In the more proximal fracture, the rotator cuff abducts and rotates the proximal fragment, while in slightly more distal fractures, pectoralis major serves to adduct. In more distal fractures the deltoid abducts the proximal fragment.

## Classification

The humerus is divided into thirds for descriptive purposes and the fracture described according to configuration (transverse/spiral/oblique etc.). The AO numeric code for the humeral shaft is '12'.

## Management

1. ***Non-operative treatment.*** This is associated with good or excellent results in 95% of patients. Acceptable displacement includes <3 cm shortening, <20° of antero-posterior angulation and <30° varus – valgus angulation. Mean time to union is 6 weeks, with 95% of fractures united at 10 weeks and 90% of patients having normal function at 10 weeks. The most favoured methods of splinting are:

- Hanging cast over the upper arm and forearm. The length of the sling or collar 'n' cuff controls varus/valgus alignment. The position of a loop on the forearm controls AP alignment. A heavy cast can distract the fracture, predisposing to

3. ***Non-union.*** Defined as >4 month
It is most common in the proximal
systemic (age, diabetes, nutritional s
distraction, soft tissue interposition,
operative with a plate and bone graft (
nail (union rate 87%). The complicat
21%). Closed insertion of the IM nail is

### Pathological fractures

A non-reamed, locked IM nail gives the best biomechanical fixation. For proximal and distal fractures a plate can be used, possibly with methylmethacrylate augmentation.

### Paediatrics

There is little difference between the paediatric and adult fracture, with the emphasis being on non-operative management. Radial nerve palsy occurs in children and guidelines for management are similar to those in adults.

## Further reading

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## Related topics of interest

Humeral fractures – distal, p. 107; Humeral fractures – proximal, p. 110

# IMAGING IN TRAUMA

Clinical assessment should be undertaken before imaging. For major trauma, initial imaging is undertaken simultaneously with resuscitation; and AP chest, AP pelvis and lateral cervical spine X-rays are mandatory.

Good quality, correct exposure plain radiographs should include the joint above and the joint below an injury. However, this rule is broken with many obvious intra-articular or peri-articular fractures, such as the distal radius, elbow, hip, tibial plateau, ankle, etc. This is acceptable, provided there are no other adverse clinical findings.

In addition to plain X-rays at presentation, further imaging may be required to determine management and plan operative procedures.

Additional imaging modalities include:

- Special plain radiographs – obliques, tomograms, stress views.
- Fluoroscopy.
- Computerized tomography.
- Magnetic resonance imaging.
- Ultrasound.
- Arthrography.
- Isotope scintigraphy.
- Arteriography.

## Special plain radiograph views

1. ***Additional plain views*** are often of benefit, to demonstrate the characteristics and extent of an injury, and to plan the surgical approach to management. Examples include X-rays such as axial views of the glenohumeral joint, a tunnel view of the wrist for hamate fractures, a tunnel view of the knee for condylar fractures and loose bodies, 15° oblique views of the tibial plateau, 60° pelvic inlet and outlet views for pelvic fractures and 45° Judet views for acetabular fractures.

2. ***Tomograms*** may be used to demonstrate the extent of a fracture, or degree and direction of articular displacement, by imaging a thin horizontal slice of bone which is in focus, with the rest of the bony structure blurred out of focus. A large dose of irradiation is required and many centres now favour the use of spiral CT imaging for this purpose. The technique remains of value in demonstrating odontoid peg fractures, in the lateral plane.

3. ***Stress views*** are helpful in the diagnosis of soft tissue ligamentous injuries, most notably for collateral ligament injuries in the thumb, knee and ankle.

## Fluoroscopy

***Fluoroscopy*** is the examination of a bone or joint, under X-ray video images. This technique is useful to demonstrate the presence or absence of a fracture, such as a proximal femoral or proximal humeral fracture, as the structure can be manipulated and the extent of displacement or degree of instability established.

## Computerized tomography

*1.* ***Computerized axial tomography*** generates transverse images of a structure, which is especially valuable for imaging the axial skeleton and intra-articular fractures of the shoulder, hip, knee and calcaneum.

*2.* ***Modern spiral imaging*** with sophisticated computer software means exposure to irradiation is kept relatively low and 3D images can be constructed from planar images. Some software allows integration with machine tools or lasers to produce a resin model of the bone structure, which again helps plan surgical reconstruction.

## Magnetic resonance imaging

MRI is of limited benefit in acute trauma care. However, MRI generates excellent images of the axial skeleton and spinal cord, which is relevant in spinal trauma, especially the cervical spine, and some brachial plexus injuries. MRI is valuable in some acute soft tissue injuries to the knee or shoulder. In the acute setting, there may be evidence of bone bruising or oedema following peri-articular injuries. Diagnostic information may be obtained with stress fractures and occult fractures.

MRI is a valuable prognostic indicator to demonstrate recovery or avascular necrosis following peri-articular injuries, such as femoral head fractures, and is more reliable than isotope scintigraphy. Non-ferrous fixation devices are required to prevent signal voids during imaging.

MRI is more frequently applied to the diagnosis of chronic shoulder, spinal and knee conditions.

## Ultrasound

Ultrasound should not be underestimated as a diagnostic tool in acute trauma care. Soft tissue injuries are excellently demonstrated, such as muscle tears, partial quadriceps or Achilles tendon ruptures, and ulnar collateral ligament ruptures in the thumb. An acute effusion or haemarthrosis can be demonstrated and aspirated, most usefully around the hip joint. Ultrasound can also be used to subsequently assess the healing process following a muscular or tendinous injury.

## Arthrography

Arthrography is a valuable aid in paediatric trauma, as cartilaginous structures may not be visible on plain X-rays, and is an especially useful adjunct in demonstrating the extent of elbow fractures.

## Isotope scintigraphy

Isotope scintigraphy contributes to the early management of trauma, most commonly following possible scaphoid fractures. $^{99}$Technetium-labelled methylene diphosphonate is administered and uptake imaged at various phases with a gamma camera. It is a useful adjunct in acute assessment of the paediatric or adult hip following a possible injury, with equivocal radiological findings and for the diagnosis of stress fractures. Sensitivity is good, but specificity is poor. Localization can be improved by co-registration with plain X-rays on computer software to localize a lesion.

### Arteriography

Displaced fractures in the vicinity of a vessel relatively tethered to bone, where the distal circulation is in jeopardy, may require imaging of the vascular structures. Typical injuries include displaced fractures of the distal or proximal humerus and fractures or fracture-dislocations around the knee.

## Further reading

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# INFECTION AND TRAUMA

This chapter deals with viral and bacterial infection in the trauma patient, and discusses the implications of HIV and viral hepatitis for the surgical team.

## Bacterial infection

Wound contamination is defined by the presence of bacteria, not clinical indicators of infection. The bacterial count is important, with >100 000 micro-organisms per gram necessary to cause infection (β-haemolytic streptococci can cause infection at lower levels). The number of bacteria required to cause infection can be reduced if there is local (e.g. necrotic tissue, foreign bodies), or systemic immuno-compromise. For example a silk stitch in a wound reduces the number of staphylococci required to cause infection by 10 000 times.

The mean infection rate after an open fracture is 16%. (Gustilo–Anderson grade I: 7%; grade II: 11%; grade IIIA: 18%; grade IIIB/C: 56%.)

When a fracture is internally fixed, a closed injury is converted to an open one. All possible measures should be taken to avoid infection – careful soft tissue handling, no touch technique, etc. Studies both recommend and discourage prophylactic antibiotic use, but the evidence probably favours prophylaxis. The first dose of antibiotics is the most critical and should be given 10 min before tourniquet inflation.

### Reduction of wound infection

The factors that help to reduce wound infection after an open injury are:

1. ***Debridement*** to remove bacteria, dead tissue, etc. Wound debridement should be undertaken early, as bacterial counts increase rapidly from 100 per gram at 2 hours, to over the 100 000 threshold at 5 hours.

2. ***Copious irrigation*** – preferably with large volumes of pulsed lavage saline (>9 l). The addition of antibiotics to the irrigation is controversial.

3. ***Systemic antibiotics*** are an adjunct to debridement, as dead tissue is not perfused.

### Tetanus

1. ***Clostridium tetani*** is an anaerobic gram-positive rod, widespread in the environment and particularly in human or animal faeces. Deep anaerobic wounds containing necrotic tissue are the ideal environment for multiplication.
2. ***The disease*** is caused by the exotoxin *tetanospasmin*. There are two forms of the disease, local and systemic. Local disease is rare and causes muscle spasms. Systemic disease causes muscle spasm, trismus and dysphagia, progressing to generalized convulsions. The mean incubation period is 1 week and the mortality from systemic disease 20–60%.
3. ***Treatment*** is with penicillin, streptomycin and immunoglobulin. Surgically, the wound should be debrided; otherwise, treatment is supportive, particularly of the airway.

4. ***Prophylaxis*** consists of:

- Adequate wound debridement.
- Tetanus toxoid (0.5 ml i.m.) for patients who have not had a booster in the last 5 years.
- Tetanus immunoglobulin (250 units i.m. at a different site to the toxoid) for patients who have not been immunized in the last 10 years. This should be considered in all patients with tetanus-prone or farmyard injuries.
- Consider adding penicillin or oxytetracycline.

### Gas gangrene

***Clostridium perfringens*** and ***Clostridium septicum*** (anaerobic gram-positive rods) are the most important pathogens in man. These organisms produce several exotoxins, including lecithinase, causing cell wall destruction and tissue death, with the production of carbon dioxide and hydrogen sulphide.

Gas in the tissues is not diagnostic of gas gangrene, as gas is also seen in necrotizing fasciitis, anaerobic cellulitis and infected vascular gangrene, or from an open wound. The diagnosis is principally clinical. There is a history of a deep wound, usually of the buttock or thigh, less than 3 days previously. Local pain and swelling are severe, with a serosanguineous discharge. The patient is apprehensive and fearful of dying. Initially there is no pyrexia, but the patient is tachycardic. The production of gas is rarely abundant, but the systemic toxaemia leads to haemolysis, renal and hepatic failure.

Modern treatment, with mortality <10% includes:

- Repeated surgical debridement and fasciotomy.
- Antibiotics (penicillin).
- Supportive measures.
- Hyperbaric oxygen.

There is no immunization against the microbe or toxins. Prophylaxis consists of adequate initial wound debridement and prophylactic antibiotics.

## Viral infection

### Human immunodeficiency virus (HIV)

HIV is a retrovirus, synthesizing DNA from its own RNA, and causes lysis of the CD4 (T helper) lymphocyte. CD4 counts are an indicator of disease activity. In urban areas 10% of trauma patients may be HIV positive.

The seroconversion rate by inoculation is 0.4% per incident. The risk of seroconversion after parenteral exposure is 0.1% and 0.6% after mucous membrane exposure. An infective dose may be carried by 0.3 ml of blood. Trauma surgery has one of the highest incidences of blood contact during operative cases (48%) and the cumulative lifetime risk for a surgeon has been estimated at 1–4%. Surgeons should protect themselves by taking 'universal precautions', including wearing double or impervious gloves, boots, impervious gowns or aprons and space suits. Sharp instruments should not be passed from hand to hand and suturing with hand needles should be avoided.

In operating on HIV positive patients for trauma (not patients with full-blown AIDS), the infection rate is 16%, as opposed to 5% in controls. In open fractures the infection rate is 55%, so open treatment must be performed with great discretion.

## Hepatitis

Five types of hepatitis virus account for 95% of cases. Types A and E are parenterally transmitted.

Hepatitis B is transmitted much more readily than HIV. Exposure results in infection in 10–30% following a needle-stick injury, with 1% dying acutely of fulminant hepatitis and 15–25% dying prematurely from cirrhosis or hepatocellular carcinoma. Five to ten per cent become chronic carriers. Recombinant vaccine is safe and has 95% seroconversion rates.

Hepatitis C is the principal cause of non-A, non-B hepatitis. Spread is blood-borne with the highest levels in haemophiliacs and drug abusers. The seroconversion rate after exposure is <10%, although 60% of those infected develop chronic liver disease and many of these progress to chronic hepatitis or cirrhosis after several years. Hepatitis C may also be a cause of hepatocellular carcinoma. No vaccine is available against hepatitis C.

In hepatitis D, the delta agent coats itself with hepatitis B surface antigen, and thus only occurs in the presence of hepatitis B. Hepatitis D often results in severe acute hepatitis or rapidly progressive chronic liver disease.

# Further reading

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# Related topics of interest

Infection control and viral prophylaxis, p. 122; Open fracture management, p. 156

# INFECTION CONTROL AND VIRAL PROPHYLAXIS

Infection control is summarized by the phrase 'prevention is better than cure'. Patient and healthcare workers in trauma surgery are exposed to high risks of bacterial and viral infection.

## Infection control

Prevention of bacterial infection is by reducing the inoculum and assisting the host's natural defences, *before*, *during* and *after* surgery.

### Reducing the inoculum

***1. Ward hygiene and management.*** Reducing the bacterial inoculum starts with procedures such as separating pre-operative patients from infected cases and reducing the opportunity for blood or airborne contamination. Screening for concurrent sepsis, practised in elective surgery, is not always possible.

- Soiled skin is cleaned and casts removed prior to entering the operating theatre.
- Reducing skin-scale loads is useful, but antiseptic baths do not reduce sepsis rates and risk colonization with resistant bacteria.
- Shaving is undertaken immediately prior to surgery. Earlier shaving increases skin colonization with *Staphlococcus aureus* due to multiple small abrasions.

***2. Theatre design is aimed at reducing contamination.*** Theatre blocks are located away from thoroughfares and wards, with designated clean and dirty areas. Pressurized ventilation systems reduce airborne infection.

***3. Ventilation systems.*** There are several types, with variable methods of airflow delivery and filter pore size. Ultra-clean air filters (pore size 0.5 μm), laminar flow and 200 air changes/hour reduce infection rates by 50%. Efficiency is measured by air changes/hour and particles/m$^3$, or colony forming units/m$^3$.

- The *plenum system* is most commonly used. Filtered air is injected through theatre ceiling vents at a higher pressure than surrounding rooms, providing 30 changes/hour, exiting through balanced flap valves in the walls. Turbulent airflow is contaminated by convection currents and recirculation.
- *Laminar or linear flow* is low velocity, low turbulence air movement. Filtered air passes into the theatre over a large ceiling or wall diffuser, creating a continuous bank of air with unidirectional movement. This bank of air passes the operating site once, removing airborne particles, with minimal recirculation. Vertical delivery is more effective than horizontal, reducing particles by 98% and 90%, respectively. Hanging side 'curtains' improve efficiency by reducing entrainment of particles at the periphery. Three to four hundred changes/hour and particle counts of 10–20/m$^3$ are optimal.
- *Ex-flow, or exponential ceiling flow* is the most effective system. Air enters over a large area in the manner of linear flow, with high pressure in the centre, reducing peripherally. Particle counts are typically 2–8/m$^3$.

- *UVC light units* are more effective than linear flow units, but a major health risk to personnel.

***4. Theatre personnel*** are the principal source of bacteria; the number of personnel in theatre should be minimized and they should be adequately clothed. Skin scales are 12 μm in size, carry an average of four bacteria/scale and easily transgress standard cotton theatre garments with a pore size >80 μm. Humans disperse 3000–60 000 bacteria per person per minute, increasing with activity and higher in men! Tightly weaved material and newer fabrics have a smaller pore size. Exhaust suits reduce infection rates by >25%.

***5. Meticulous hand washing*** with alcoholic chlorhexidine solutions reduce bacterial counts most effectively – 97% with a single wash, 99% with subsequent washes.

- Nailbrushes should only be used on nails, as skin abrasion brings bacteria to the surface.
- Rings are associated with increased glove perforations.
- Double-gloving is recommended in trauma surgery.

***6. Skin preparation*** with alcoholic chlorhexidine or povidone iodine solutions removes 98% of bacteria.

- Adhesive drapes secure drapes in place and prevent scales moving to the wound site, but have not been shown to reduce infection.
- Newer, tightly woven drapes are more effective at reducing contamination than cotton drapes.

***7. Surgical technique***, with careful non-traumatic tissue handling, meticulous haemostasis and adequate drainage reduce haematoma formation – an ideal bacterial culture medium.

***8. Pulsed saline lavage*** reduces wound bacterial counts by 80%, more with aqueous chlorhexidine. Debridement of contaminated wounds is fundamental to open wound management.

***9. Dressings*** should only be changed when there is concern or heavy soiling. Sutures and drains are removed at the earliest opportunity.

***10. Poor general health, malnutrition and immunocompromise*** increase infection rates and measures to minimize these should be undertaken. Major surgery is avoided at the peak metabolic response to trauma, i.e. 2–5 days.

## Enhancing the defence

***1. Antibiotic prophylaxis*** for 16 hours is effective in trauma and elective surgery, and should be broad-spectrum, covering organisms likely to be encountered. In prolonged surgery, (more than 2 hours), the antibiotic half-life should be considered and additional doses given.

***2. Antibiotics*** are given 10 min before tourniquet inflation.

# Viral prophylaxis

Viruses presenting a risk to healthcare personnel are HIV and Hepatitis B and C.

## HIV

The retrovirus HIV synthesizes DNA within CD4 lymphocytes. CD4-lymphocyte death occurs, leading to impaired immunological function and infection susceptibility. The risk of infection after hollow needle-stick injury exposure is 1:200. The lifetime risk to a surgeon depends on the prevalence of HIV and the size of the inoculum – the minimum inoculum is estimated at 0.1 ml, and the risk may be 1–4%. Worldwide, 35 health staff, including 4 surgeons, have become infected with HIV through blood contact. No vaccine exists and prophylaxis depends on prevention of exposure.

## Hepatitis B

Hepatitis B is transmitted more easily than HIV and the minimum inoculum required is 0.004 ml. The risk of infection after hollow needle-stick exposure is 1:3. Vaccination is a requirement for all UK surgeons. Failure to develop antibodies occurs in 10%. Antibody levels are checked and boosters required every 5 years.

## Hepatitis C

Hepatitis C is responsible for most post...

*nailing* causes minimal disturbance of the soft tissue at the fracture
hrows out bone graft into the fracture site, which may assist fracture
r, reaming disturbs the endosteal blood supply and generates heat,
ecrosis. Studies suggest better blood supply to a fracture site, for a
of time, after nail compared to plate fixation.

***ting the canal,*** with a broach, reamer, or unreamed nail increases
llary pressure to >1000 mmHg, which also causes necrosis.
n of the canal releases medullary products, especially marrow fat,

into the circulation, which can have serious respiratory consequences. The release is greater after reaming. A distal venting hole in the bone has limited benefit. The effects of embolic phenomenon are greater if nailing is delayed beyond 48 hours after the fracture and greater during instrumentation of pathological fractures. This is demonstrated with transoesophageal echocardiography.

***3. The harmful effects of reaming*** have stimulated interest in unreamed implants. An unreamed implant possibly does less damage to the endosteal blood supply, but the implants usually have less torsional and bending rigidity. Provided the nail is not too flexible, this may help fracture healing and revascularization is more rapid.

***4. Unreamed femoral and tibial nails*** are valuable in polytrauma and for open fractures, but fixation with these implants should not be considered as reliable as reamed implants.

***5. Infection rates*** with reamed and unreamed implants are similar, but the infection rates may be higher with stainless steel implants.

## Dynamization

There was a vogue for removing locking screws at 6 weeks in the past, after stability had been achieved by early bone healing. Dynamization allows greater consolidation of the fracture site. This is no longer regarded as necessary. Ninety eight per cent of femoral fractures heal without dynamization. Consideration should be given to removing locking screws at 6 to 8 weeks after unreamed tibial nailing, if there are no signs of healing and if there is any fracture distraction.

## Alternatives to IM nailing

Protagonists of plate fixation claim that plating is a quick surgical procedure, the endosteal blood supply is not damaged and blood loss is minimal if a tourniquet is used. A 'minimally invasive plating technique' or 'bridge plating', through a limited surgical exposure with subcutaneous tunnelling may be a good compromise.

## Future advances

Traditionally, nailing has been carried out using an antegrade approach for all bones except the humerus and the approach for the humerus is controversial. Supracondylar femoral nails have been introduced and longer femoral nails for retrograde insertion are available. Small IM devices, allowing static locking, are being developed for narrow long bones, such as the radius and ulna.

## Plating

This remains the treatment of choice for:

***1. Humerus.*** In polytrauma, intra-articular extension and some radial nerve lesions.

***2. Femur.*** In pre-adolescent children, fractures with associated vascular injury, ipsilateral pelvic or acetabular fractures, and some polytrauma cases.

time should therefore be taken to set the limb up on traction and achieve reduction prior to passage of the guide wire, obviating the need to open the fracture secondarily.

***4. Entry portal.*** Care must be taken in developing this portal. The entry portal affects nail placement, fracture reduction and overall alignment. Malpositioning can result in fractures of adjacent bone, or damage to the soft tissues at the entry portal.

***5. Reaming.*** When using a reamed nail, care should be taken not to over-ream so as to weaken the cortex. Over-reaming not only removes excessive quantities of bone, but may also result in thermal necrosis, increased operation time and blood loss, and additional comminution of the fracture fragments. However, the medulla must be over-reamed adequately for the safe passage of the nail – generally 0.5 mm for slotted nails and 1–1.5 mm for rigid nails.

## Complications

***1. Fat emboli.*** Identification of patients at risk (polytrauma, ARDS, pulmonary injuries, hypovolaemia) will alert one to this serious complication. Excessive reaming in these cases should be avoided, as this has been associated with increased fat and platelet aggregates as shown on transoesophageal echocardiography. Unreamed nails still cause fat emboli.

***2. Implant size and length.*** The biomechanical characteristics of modern nails is such that smaller, stronger nails can be used with safety. Interlocking of these nails is recommended as there is a 98% union rate in the static mode, whereas shortening or mal-rotation can occur when leaving the nail unlocked.

Smaller diameter nails can be associated with a higher incidence of screw breakage, if the patient is allowed to weight-bear prematurely. Progressive weight-bearing should begin when callus is visible.

***3. Infection.*** This is low in closed fractures (1–2%), but obviously greater in those with open fractures or those with significant soft tissue injuries.

Normal sterility and care with soft tissue handling reduces the infection rate. Treatment in the early stages can be with simple i.v. antibiotic therapy, but an exchange nailing procedure may be required for those with delayed union and infection.

***4. Non-union and delayed union.*** The incidence of non-union in femoral fractures is relatively low (2%). Dynamization of the fracture fragments is rarely

third of patients will be able to compensate and pursue normal recreational sports and will not require surgery. A further third will be able to compensate, but would have to reduce their sporting activities with the possible avoidance of jumping, pivoting or cutting exercises. The final third of patients do poorly and develop instability with not only sporting activities, but with the simple activities of daily living. In this group of patients early surgery will be required.

Daniel has suggested that early reconstruction reduces the risk of secondary degenerative change and the incidence of further meniscal damage. There is, however, at this stage, no evidence to suggest that an early reconstruction will allow the patient to return to unrestricted sporting activities without further problems, such as developing osteoarthritic change or a further meniscal tear.

***2. Conservative treatment*** involves the re-education of the quadriceps and hamstring muscles. Emphasis should be placed on the hamstrings as they can restrict the amount of anterior tibial translation on the femur.

***3. Operative treatment*** has traditionally used either an intra-articular reconstruction, an extra-articular reconstruction, or a combination of both. Isolated extra-articular reconstruction may be useful in the skeletally immature, when there is concern about damage to the growing physis. In isolation, extra-articular reconstruction is prone to failure within 3 to 5 years.

Primary intra-articular repair often fails unless there is clear evidence of bony avulsion from either the femoral or tibial attachments, where this can be re-apposed. In the majority of cases a reconstructive technique is required and a bone–patellar–tendon–bone or hamstring graft is the most frequently used method of reconstruction. These grafts may be used in conjunction with an extra-articular tenodesis (MacIntosh type) to augment stability.

### Results

The results of conservative treatment depend upon patients' expectations and a desire to return to sporting activities. Low demand patients, who do not desire a return to sporting activities, do well without operative repair.

The results of operative reconstruction obviously vary, but the majority of studies suggest that 80–90% of patients can return to their pre-injury sporting activities. Long-term osteoarthritic degeneration is largely dependent on the state of the menisci, and when these can be resutured in preference to a partial or total meniscectomy, the risk of long-term degenerative change is lessened.

Patellar fractures, patellar tendinitis, patellar tendon ruptures and donor site pain have all been reported following bone–patellar–tendon–bone graft harvest.

## Posterior cruciate ligament

### Clinical history

The PCL is often injured in motor vehicle accidents as a result of a direct injury against the dashboard, when the knee is flexed to 90°. Falls on the flexed knee with the foot in plantar flexion, or forced hyperextension on the knee, can similarly result in PCL injuries. In isolation, even with total disruptions, there is often little long-term instability. When associated with postero-lateral or postero-medial injuries, stability of the knee is dramatically reduced.

Dashboard injuries are associated with injuries to the patellar tendon, patella and patello-femoral articulation. In those ruptures sustained as a result of a fall or twisting injury, 80% of patients may sustain a posterior third medial meniscal injury and the majority have anterior cruciate or medial collateral ligament tears.

The diagnosis is often relatively easily made on the history, but the posterior sag or posterior draw test, with the knee between 70 and 90° of flexion, is indicative of a tear of the PCL. The degree of posterior sag is graded according to the displacement of the tibia posteriorly on the femoral condyle. The reverse pivot shift test (with the tibia held in external rotation) helps identify postero-lateral corner injuries. Care should be taken in assessing damage to the postero-medial structures on valgus stress tests. Radiographic evaluation, with or without a posterior stress test, may show the degree of posterior subluxation. MRI not only demonstrates the cruciate injury, but again also helps to delineate other injuries within the knee.

### Management

Non-operative treatment of isolated PCL tears is often successful. The initial aim is to reduce swelling and pain, and restore normal joint kinematics. Early active and isometric quadriceps exercises are used. Rarely is surgical treatment of the isolated PCL rupture necessary. In cases with associated ligamentous injury and gross instability or dislocation, reconstruction of the cruciate could be considered. In those cases with bony avulsion from the femoral or tibial attachment this can be fixed directly. In chronic cases, an autograft of patellar tendon, hamstring or an allograft can be used.

### Results

The results of PCL reconstruction have been reported as poor, whereas conservative treatment of the isolated tear is generally adequate.

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## Related topics of interest

Knee – acute collateral ligament instability, p. 131; Knee – haemarthrosis, p. 142

# KNEE – DISLOCATION

Traumatic dislocation of the knee is relatively rare, but is a severe and potentially limb-threatening injury. High-energy trauma, usually an RTA, is the most common cause. Dislocation may occur following lesser injuries, such as a fall or sporting accident.

## Classification

Several classifications are described relating to energy, position or ligament involvement. The simplest and most frequently used is that describing position, based on the displacement of the tibia with respect to the femur:

- Anterior: 35%.
- Posterior: 25%.
- Lateral: 10%.
- Medial: 5%.
- Rotatory: 5%.
- Occult: 20% (spontaneous reduction).

A classification based on the involved anatomical structures (torn ligaments) is complicated, but more relevant for surgical planning, prognosis and outcome comparison.

## Mechanism and anatomical involvement

***1. Anterior dislocation*** is principally a hyperextension injury, following a direct force to the anterior thigh with the foot fixed (for example on the floor). Hyperextension of >30° results in sequential disruption of the posterior capsule, PCL and ACL. Damage to the popliteal artery occurs with hyperextension beyond 50°.

***2. Posterior dislocation*** may result from a dashboard-type injury, where the force is directed posteriorly on the flexed knee. The PCL is first disrupted, followed by the ACL and eventually the artery.

***3. Lateral dislocation*** results from valgus stress, often with the tibia fixed and the thigh adducted. The MCL, postero-medial capsule and meniscal attachments are first disrupted, followed by the ACL and PCL.

***4. Medial dislocation*** results from a varus force to the thigh, but may involve a rotational component. Lateral side structures are ruptured first.

***5. Rotatory dislocation*** is usually associated with a twisting injury, on a fixed foot. The ACL, PCL and MCL or LCL may be disrupted, with rotation occurring on the intact collateral.

***6. Open injury*** to the knee occurs in 30% of cases.

## Assessment

This includes stability, vascularity and nerve function.

***1. Stability.*** Gross deformity is the most striking feature on presentation, leaving little doubt of the diagnosis. However, the diagnosis of a true knee dislocation may initially be missed, as spontaneous reduction and re-alignment of the limb at the scene of the accident occurs in 20%.

Clues to the severity of the injury may be found on examination in extension. Significant varus or valgus instability in extension, indicates tears of the cruciate ligaments, as well as the corresponding collateral ligament. Exaggerated hyper-extension (recurvatum) implies combined cruciate and capsular instability.

2. ***Vascularity.*** This must be carefully assessed. Colour, temperature, capillary return, pedal pulses and non-invasive vascular studies, such as doppler ultrasound, must be undertaken in all cases. The presence of peripheral pedal pulses does not exclude a vascular injury.

3. ***Neurological function.*** This must be carefully assessed. The incidence of nerve injury is 25%.

## Investigations

1. ***Plain X-rays*** should be undertaken following immediate reduction of the gross deformity. Bony avulsions of ligaments or capsule are often seen.

2. ***Early MRI*** is useful to assess complex ligament disruption and plan surgery.

3. ***Arteriography*** is required for vascular compromise. Some authors feel that an arteriogram is mandatory in all cases after reduction of a knee dislocation. The importance of recognizing a vascular injury cannot be underestimated.

## Management

Priorities are reduction, revascularization and ligament stabilization.

1. ***Closed reduction*** and examination under anaesthetic is undertaken as soon as possible. Open reduction is required for open or irreducible cases. Most irreducible

The
on,

re-attached anatomically and
joint should be immobilized,
to allow healing prior to starti

140 KNEE – EXTENSOR MECHAN

Rupture of the quadriceps or patellar tendon should be repaired when the patient is unable to perform a resisted straight leg raise or actively extend the knee. Direct repair, using non-absorbable materials is preferable. Augmentation of patellar tendon repair with a wire around the patella and through the tibial tuberosity facilitates early mobilization, while protecting the repair. In those patients presenting late with quadriceps tendon ruptures, the operative repair is often complicated by the contraction of the quadriceps muscle proximally. If it is impossible to re-approximate the torn portions of the quadriceps tendon, a reinforcement of the repair with a Scuderi flap can be considered. V–Y advancement flaps, with attachment of the lengthened tendon to the patella via bone drill holes, has also been advocated.

Care should be taken when attempting to re-attach the tibial tubercle in the skeletally immature, as there is a risk of further damage to the growing physis.

### Fractures

1. ***Tibial tuberosity.*** Tibial tuberosity fractures can follow a direct injury, but again are more common as a result of an avulsion. These have been classified by Ogden, according to the size and displacement of the fragment.

2. ***Patellar fractures.*** Patellar fractures are classified according to the degree of displacement and extent of comminution. A sleeve fracture may occur in children, with a sizeable portion of articular cartilage.

3. ***Treatment.*** Undisplaced fractures that have not disrupted the continuity of the extensor mechanism, and therefore allow some active knee extension and a straight leg raise, can be treated in an extension cast or brace. Active quadriceps rehabilitation is instituted at an early stage. When stable with minimum disruption, a cast may not be necessary provided patients are carefully supervised.

Sleeve fractures in children require reduction and fixation. Displaced fractures in adults require open reduction and internal fixation (see 'Knee – patellar fractures', p. 146).

## Further reading

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## Related topics of interest

Knee – acute collateral ligament instability, p. 131; Knee – cruciate ligament instability, p. 134; Knee – haemarthrosis, p. 142; Knee – meniscal injuries, p. 144; Knee – patellar fractures, p. 146

# KNEE – HAEMARTHROSIS

Haemarthrosis of the knee is extremely common. Approximately 400 per 300 000 population attend Accident and Emergency Departments annually with such a complaint.

## Classification

1. ***Primary (spontaneous) haemarthrosis*** occurs without trauma. Disorders of coagulation, such as haemophilia or anticoagulant therapy, may result in spontaneous haemarthrosis. Unless controlled with prophylactic treatment, or early medical intervention, this can result in extensive damage to the joint and secondary osteoarthritic changes.

   Vascular tumours or malformations within the knee, although rare, can occur and bleed spontaneously following mild trauma. Arteriography is often required to confirm the diagnosis, followed by appropriate surgery.

2. ***Secondary haemarthrosis*** is a result of trauma:

- Eighty per cent follow damage to the ACL.
- Ten per cent follow dislocation of the patella.
- The remaining 10% include peripheral third meniscal separations, capsular tears, and osteochondral or osteophyte fractures.

## Mechanism

In young patients, a sporting injury is common (70%), especially from netball, soccer or skiing. In the elderly, a fall is more common.

In the majority of cases there is a characteristic history of non-contact injury, twisting on the semi-flexed knee. Damage to the cruciate ligament can occasionally occur following hyperextension, or direct contact. The patient often describes hearing something 'go', being unable to continue playing and swelling within the first 4 to 6 hours. The rapid onset of swelling distinguishes haemarthrosis from an effusion, which is more often associated with a torn meniscus and characteristically does not develop for at least 6 hours following injury, or until the next day.

## Investigations

Plain X-ray may reveal fractures or the fluid level of a lipohaemarthosis. MRI may be increasingly available, but is unlikely to alter the management when compared with experienced clinical examination. Indications for MRI include: children, elite athletes, multiple ligament disruption and inconclusive examination.

## Management of primary haemarthrosis

Adequate medical prophylaxis in those patients with a bleeding disorder, or rapid treatment of this disorder after an acute haemarthrosis, will lessen the chance of ongoing damage within the joint. Aspiration of the joint can be considered, although this risks further bleeding.

## Management of secondary haemarthrosis

1. ***Initial management.*** The objectives are to alleviate initial symptoms, make a diagnosis and plan definitive treatment. Initial management consists of aspiration and re-examination.

**2. *Aspiration*** relieves tension, and hence pain, in the capsular lining. This reduces quadriceps and hamstring spasm, allowing better clinical examination. The aspirate is inspected for fat globules, which indicate exposure of cancellous bone and a fracture.

**3. *Examination*** attempts to make a definitive diagnosis and three groups emerge:

- A clear diagnosis.
- No diagnosis despite adequate examination.
- No diagnosis, but inadequate examination.

Where there is a clear diagnosis, specific treatment is commenced. When the diagnosis is unclear, despite adequate examination, an expectant policy is adopted, with mobilization, physiotherapy and subsequent re-evaluation. In those patients where examination has been inadequate, further investigation may be required to confirm the diagnosis, with EUA, arthroscopy or MRI.

**4. *Arthroscopic assessment and irrigation*** are difficult acutely, but allow a more accurate diagnosis. In cases with a peripheral third meniscal separation, direct meniscal suture can be performed.

**5. *Definite indications for acute arthroscopy*** include:

- Locked knee.
- Osteochondral fracture.
- Severe grinding on Lachman test.

**6. *Relative indications for acute arthroscopy*** include:

- Fat in the aspirate: concern over possible osteochondral fracture.
- Elite athletes: to confirm a diagnosis and optimize recovery.

## Further reading


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## Related topics of interest


Knee – acute collateral ligament instability, p. 131; Knee – cruciate ligament instability, p. 134; Knee – extensor mechanism disruption, p. 140; Knee – meniscal injuries, p. 144

# KNEE – MENISCAL INJURIES

The meniscus, once considered a vestigial structure, is now known to contribute not only to the load sharing, but also to the stability of the knee. When the knee is loaded in full extension, 70% of the compressive load through the lateral compartment is transmitted through the lateral meniscus and up to 50% of the medial load through the medial meniscus. The meniscus also provides secondary stability in resisting anterior tibial translation and this is especially important in the cruciate-deficient knee. Fairbank (1948) documented the degeneration of the knee following total menisectomy. Degeneration is more frequent with damage of the lateral meniscus.

Meniscal tears are caused by axial loading with rotational force. Damage to the meniscus can occur in isolation or in combination with ligamentous or chondral surface damage. In general, traumatic tears of the menisci occur in younger individuals and degenerative tears in patients over 35 years old. Degenerative tears are frequently associated with significant chondral damage.

## Diagnosis

*1.* ***Symptoms*** are usually as a result of mechanical irritation within the knee, including 'locking', 'clicking', 'grinding' or 'giving-way'. Pain, although a frequent feature, is not always consistent. An effusion is common on the day following the original injury, but may settle completely.

*2.* ***Physical signs*** include the meniscal provocation tests of McMurray, Apley and Steinman. Joint line tenderness is frequently noted, but no single test is pathognomonic of a meniscal tear.

*3.* ***MRI*** is a useful diagnostic aid for selected patients, when the clinical signs are equivocal.

## Classification

For ease of classification the meniscus is divided into anterior, middle and posterior thirds. The tear pattern is generally classified in accordance with the location in the meniscus and the type of tear. Further classifications relate to the vascularity of the meniscus. The peripheral or outer third of the meniscus is vascularized, whereas the middle two-thirds are not. Tears in the outer third may heal primarily or may be amenable to secondary suture.

Tears are further classified according to whether the tear pattern is vertical, longitudinal, radial or oblique. Vertical tears in the mid-substance of the meniscus usually extend to produce the classic bucket-handle tear, which can be well localized to the posterior third, the posterior/middle third or throughout the whole of the meniscus. Radial tears are more commonly found in the lateral meniscus, as are oblique or parrot break tears. Degenerative tears in association with a horizontal cleavage component can result in meniscal cyst formation. These are more commonly noted on the lateral side, although have been reported from the medial meniscus.

## Treatment

*1.* ***Symptomatic meniscal tears*** warrant arthroscopic treatment, preserving as much meniscal tissue as possible. Tears in the periphery of the meniscus where there is a reasonable vascular supply, are often amenable to re-suture. Tears in the avascular inner two-thirds are usually excised arthroscopically, leaving a stable rim of peripheral meniscal tissue. Care should be taken to avoid excessive removal of meniscal tissue, especially on the lateral side, in the region of the popliteal hiatus.

2. ***Meniscal repair*** can be performed with sutures or meniscal arrows, using an inside-out, all inside or outside-in technique. The aim of the procedure is to anchor the meniscal tear to the menisco-synovial junction. Meniscal arrows and other such fixation devices have recently been developed to facilitate an 'all inside' technique. Pullout strengths of these devices are inferior to suture techniques.

### Results

Partial menisectomy is preferable to total menisectomy, but only 50–60% of people are satisfied with the outcome. Although often satisfied initially, the long-term results of menisectomy can be poor, with osteoarthritic degeneration within the knee. Approximately 44% of patients have pain after excessive or physical work at 8 to 10 years following partial menisectomy.

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## Related topics of interest

Knee – acute collateral ligament instability, p. 131; Knee – cruciate ligament instability, p. 134; Knee – haemarthrosis, p. 142

# KNEE – PATELLAR FRACTURES

Fractures of the patella account for 1% of all skeletal injuries and occur mostly within the 20–50 year age group. The incidence in males is twice that in females. Patellar fractures are usually the result of direct injuries and can be in isolation or in combination with ipsilateral femoral or tibial fractures. An indirect injury, as a result of tripping or stumbling, can result in avulsion fractures of the proximal or distal poles in adults. In the skeletally immature patient, indirect trauma is associated with a sleeve or chondral surface fracture.

## Classification

Patellar fractures can be classified into:

- Transverse: 50–80%.
- Stellate (comminuted): 30%.
- Longitudinal (vertical): 12%.
- Proximal/distal pole (marginal).
- Osteochondral.

Displacement is defined as an articular step exceeding 2 mm, or separation exceeding 3 mm.

## Methods of treatment

The history and physical findings are often very typical and there may be extensive contusion of the overlying skin. The treatment depends on the age of the patient and whether the extensor mechanism is intact, as there may be extensive tearing of the medial and lateral retinacular expansions. If the patient can perform a straight leg raise or has active knee extension, the extensor mechanism is intact. Extensor insufficiency with radiographic evidence of fracture displacement is the prime indication for surgical intervention.

*1.* ***Non-operative treatment*** is adequate for non-displaced fractures with a preserved extensor mechanism. If a tense haemarthrosis is present, aspiration is recommended, prior to immobilization in a cylinder or removable brace. Quadriceps exercises are recommended after a period of rest. The brace can be removed after 4 to 6 weeks.

*2.* ***Open reduction and internal fixation*** has been described with a cerclage wire, tension band wire and two Kirschner wires, or lag screw fixation. The surgical approach is through a mid-line incision. In those cases with extensive comminution, removal of the small fragments may be necessary. Immobilization is advisable until wound healing has begun, but early mobilization should be encouraged within a few days.

*3.* ***Partial patellectomy*** with repair of the extensor mechanism is preferable to internal fixation, when it is impossible to obtain a smooth articular surface. Resection of the inferior pole is only indicated in those with severe comminution, as this predisposes the patient to patella baja. Reconstruction of the normal anatomy is the goal in the majority of cases.

4. Total patellectomy is indicated in severely comminuted fractures, where there

ma (OS) variants. The following are useful distinguishing features from
e difficult to make this distinction, necessitating further investigation):

diaphysis (OS over the metaphysis).
of MO decreases with time (unlike OS).
x is intact with MO (unlike OS).
a zonal pattern, with differentiated mature tissue peripherally.

ns and massive trauma are associated with MO. Prolonged immobiliz-
passive movement are thought to contribute to MO, while early active
nethacin for 4 weeks are protective.

***tis ossificans progressiva*** is a rare, non-traumatic condition, autosomal with a high mutation rate, related to fibrodysplasia. Early in life, swellings appear, affecting the head, neck or trunk, followed by ossifi- onnective tissue in the muscles of the trunk and limbs. The thumbs and be short, due to a short first ray, and are occasionally absent. The con- ricts movement and is usually fatal, due to respiratory compromise.

***atic localized MO*** is the formation of heterotopic bone in the striated ering a fracture, restricting the movement of nearby joints. The cause is but may be related to joint movement which is too early and too

ost common site is around the elbow, some 3 or 4 weeks after a fracture ion, when movement spontaneously becomes restricted and painful, s showing calcification anteriorly. Treatment is rest, usually in a plaster few weeks, before commencing mobilization again. The mass of n gradually reduces and movement increases. Late excision may be

ay follow a soft tissue injury, without a fracture, most commonly in the process starts soon after injury and is characterized by an enlarged, rm thigh. Radiographic changes are seen within a couple of weeks. A of calcified tissue eventually forms, which may require excision.
er common site is around the hip, after a dislocation or acetabular

SIFICANS

fracture. The incidence after a dislocation of the hip is 2%, but is increased by open surgery. Following an acetabular fracture the incidence is 5%, increasing to 35% after open surgery. The incidence can be reduced by a single fraction of radiotherapy, or preferably indomethacin for 4 weeks after surgery.

Proximal humeral fracture-dislocations are associated with MO, especially when chronically neglected.

***3. Non-traumatic localized MO*** occurs spontaneously, without a documented history of trauma. The features are similar to traumatic localized MO, most commonly affecting the thigh of the young athlete.

### Histology

A mature lesion of MO has zonal characteristics. Peripherally there is calcified woven bone, with trabeculae radiating towards the centre, where there are areas of immature trabecular bone, with proliferative osteoblasts and osteoclast-like giant cells. Early lesions have scattered fibroblasts and giant cells, in disorganized trabeculae and granulation tissue, which can mimic OS.

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## Related topics of interest

Bone healing, p. 31; Bone structure, p. 34; Elbow dislocation, p. 43

# NON-UNION – INFECTED

An infected fracture non-union is a disastrous complication. Management is difficult, prolonged and not always successful. It is important to determine whether the infection is still active, to identify the organism, and to determine whether the non-union is atrophic or hypertrophic and whether there is any sequestrated dead bone. When these factors have been determined, definitive management can be planned. Thirty per cent of non-unions are infected and 70% follow open fractures. The most common site is the tibia (~ 60% of cases). *Staphylococcus aureus* is isolated in 75% of cases.

## Aetiology

The specific cause is not always apparent, but is related to injury severity and initial management factors, including:

- High grade open fractures.
- Inadequate debridement.
- Early inadequate internal fixation, especially with rigid plates and screws.
- Wound breakdown.

## Assessment

1. ***History.*** A thorough and meticulous review of the history of the original injury and all management events, procedures, radiographs, microbiological cultures and antibiotic therapy, is vital to define the aetiology and infecting organisms. Relevant medical history and smoking habits should be reviewed.

2. ***Examination.*** An assessment of the local features is undertaken to consider the site of the injury, soft tissue viability, vascularity, sinus tracts, scars and pin sites, neurological function and viability of adjacent joints. Systemic assessment includes consideration of age, medical condition, nutritional status and other limb function.

3. ***Investigation.*** Full blood count, erythrocyte sedimentation rate (ESR), C-reactive protein (CRP), albumin and blood cultures are taken as indicators of the severity of infection. Wound swabs and samples are cultured, but often show contaminants only. Plain X-rays, tomograms, CT, MRI, technetium, gallium and indium labelled white cell scintigrams all have a place in the initial investigation. At surgery, methylene blue sinograms assist in identifying the precise location and extent of the infected tissue and dead bone.

## Treatment

Treatment options are limb reconstruction or amputation. Amputation and a prosthesis may be the best option in the elderly or those not prepared to tolerate lengthy surgical reconstruction and rehabilitation. The outcome with a prosthesis is surprisingly good.

Reconstruction principles are:

- Debridement of dead tissue.
- Eradication of infection.
- Establishment of a healthy vascular bed with soft tissue cover.
- Bony reconstruction, stability and union.

Surgery may be staged. Quiescent cases without active signs of infection for 3 months may be managed as for a sterile non-union with a single-stage procedure. Active infection requires several stages to eliminate infection prior to achieving stability and union. Techniques vary considerably and depend on many factors including site, soft tissue deficit and bone loss, but in broad terms surgery can be considered in three stages.

***Stage 1: Debridement, stabilization and eradication of infection.*** Radical debridement of all dead tissue, removal of metalwork and initial skeletal stabilization, usually with external fixation, is the first requirement. Dead bone can be difficult to identify, but extensive excision is preferential. Generous samples of tissue must be sent for prolonged enhanced culture before administration of antibiotics. A period of antibiotic administration is undertaken, usually i.v. over 2–6 weeks, augmented by local delivery, through cement beads or gel. Continuous irrigation (Lautenbach) may be utilized for extensive medullary sepsis of the femur. Repeated debridement may be necessary.

***Stage 2: Soft tissue and bone reconstruction.*** Once adequate debridement has been achieved, soft tissue cover and elimination of potential dead space is required. Cancellous bone grafting, wound closure and irrigation may be undertaken. Inadequate soft tissue cover may be addressed by:

- **Papineau open technique** with open wet dressings on the clean cancellous grafted bed. When granulation tissue fills the defect a split skin graft can be applied.
- **Local or free flaps** may be used to reconstruct the soft tissues. Muscle flaps bring in an additional blood supply.

Small bone defects, <6 cm, may be managed by petalling and cancellous bone grafting. Stabilization may be achieved with internal or external fixation depending on the site. Large bone defects are better managed by vascularized graft (fibular) or bone transport with ring frames such as the Ilizarov. Bone transport involves radical bone excision, acute shortening and then a distant corticotomy, followed by distraction osteogenesis. This is attractive but complex, and should only be attempted in experienced hands.

***Stage 3: Rehabilitation.*** Fixators may need to be in place for 6–9 months, with several surgical procedures during this period. Cast support is often required for up to 2 years. A multidisciplinary team approach to patient care and family support is essential in order to cope with the prolonged treatment and complications. Physical therapy is important to limit contractures and joint stiffness.

## Complications

Complications are common in this complex management and include:

- Recurrent infection of bone, wound, pin sites, etc.
- Malunion or non-union.
- Soft tissue contracture.
- Neurovascular damage.
- Reflex sympathetic dystrophy.

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## Related topics of interest

nge IM nailing and antibiotic treatment. More resistant cases of infection staged procedure with external fixation to stabilize the fracture and followed y bone grafting.

***mputation*** and a well-fitted orthosis should be considered for some cases ected non-union and may be more appropriate than prolonged attempts at struction. Amputation has a predictable outcome with rapid recovery and to society, without extensive hospital treatment, pain and suffering.

***e tibia is the most common site for non-union*** and warrants special deration. The literature suggests a 90% union rate with exchange IM nailing ut bone grafting for non-union, with the exception of grade IIIB and IIIC fractures which require open bone grafting. Exchange nailing should be d out at 16 to 20 weeks, but is complicated by infection in 10% of cases. ures with >30% circumferential bone loss, grade IIIB and IIIC fractures d be grafted at 6 to 8 weeks as part of the primary treatment programme. ing and exchange IM nailing of grade IIIB and IIIC fractures may reactivate ent infection. For grafting, the fracture is exposed through a postero-lateral ach.

## ding

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## ics of interest

31; Infection and trauma, p. 119; Non-union – infected, p. 150

# OPEN FRACTURE MANAGEMENT

Open fractures occur in isolation or in combination with polytrauma and are often high energy injuries with associated soft tissue damage. The open fracture is an orthopaedic emergency and immediate treatment is imperative, often in collaboration with plastic surgeons.

## Classification

The Gustilo and Anderson classification divides open fractures into:

- Type I, puncture wound <1 cm with minimal soft tissue damage.
- Type II, wound >1 cm with moderate tissue damage.
- Type III, extensive tissue devitalization.

Gustilo, Mendosa and Williams expanded the original classification into: type IIIA, large wound, typically >10 cm, and extensive muscle damage but adequate skin cover; type IIIB, extensive periosteal stripping, with skin damage requiring a reconstructive procedure to close the defect; type IIIC, associated vascular injury requiring repair.

The mechanism of injury, degree of contamination and soft tissue damage are the key to the classification, not the length of visible skin wound. By definition, high energy, segmental or contaminated fractures are type IIIA, wounds requiring a skin graft or flap are type IIIB and high velocity missile wounds are type IIIB or IIIC – small entry wounds camouflage extensive soft tissue damage.

The AO classification distinguishes skin, muscle–tendon and neurovascular damage in separate categories. Skin wounds are: IO1, from inside-out; IO2, <5 cm skin breakage from outside; IO3, >5 cm skin breakage; IO4, considerable skin damage, contusion and loss; IO5, degloving. Muscle-tendon and neurovascular damage are graded from MT1 to MT5 and NV1 to NV5, respectively.

## Management

Initial open fracture management includes assessment and resuscitation, soft tissue debridement, and fracture stabilization, which should all be achieved within six hours of the injury. Once the fracture is stabilized, wound care is easier and definitive skin cover can be achieved within a few days.

***1. Assessment and resuscitation*** starts in the emergency department, with appropriate treatment of other injuries. The skin wound is documented, photographed, swabbed for microbiological culture and covered with an aqueous povidone–iodine or saline soaked gauze, which is not removed until definitive treatment in the operating theatre.

Intravenous antibiotics, historically flucloxacillin and benzylpenicillin (although there is a trend in favour of third generation cephalosporins), are started in the emergency department. Contaminated wounds require cover for Gram negative organisms. Tetanus prophylaxis must be considered.

***2. Treatment of the soft tissues*** follows resuscitation, and the patient should be transferred to theatre for debridement and irrigation of the wound. Under general anaesthesia, foreign debris is removed, the skin margins excised and devitalized soft tissues debrided. The wound and fracture should be generously irrigated – minimum 6 l of warm saline. Aqueous chlorhexidine (0.05%) solution is more effective. A pressurized lavage system is preferable to remove debris, but there is some concern this may drive debris into the tissues.

To achieve adequate exposure of devitalized tissue, the wound may need extending with a longitudinal incision. This portion of a wound may be closed primarily, provided there is no skin tension.

***3. Stabilization of the fracture*** depends upon the nature of the bone injury. Long bone fractures should be stabilized with an external fixator or IM nail. The choice remains controversial, with good results reported for external fixation and IM nailing up to type IIIB fractures. Unreamed nailing is advocated to reduce damage to the endosteal blood supply, although this subject is similarly controversial. External fixator pins must be carefully placed to avoid jeopardizing subsequent skin cover procedures. The use of plate fixation is contra-indicated, with the possible exception of forearm fractures where muscle cover is adequate. Intra-articular fractures should be reconstructed with the minimum of metalware. Type IIIC fractures, which do not require amputation, should be stabilized with an external fixator.

Some long bone fractures can be treated in plaster, but wound management is awkward.

***4. Skin cover.*** There are no exceptions to the rule that skin wounds over an open fracture are not closed primarily. A joint capsule should be closed where possible, leaving the skin wound open. Viable soft tissues are placed without tension to cover the bone and the wound packed with a gauze and bandaged. The wound should be re-inspected within 48 hours, in consultation with the plastic surgeons, under full general anaesthesia in an appropriate operating theatre environment. Small wounds may be left to granulate. Larger wounds may be amenable to secondary closure, if the wound is healthy and the margins are not tight.

Large soft tissue defects require a reconstructive procedure. This may be a split skin graft or complex flap procedure – fasciocutaneous, myofascial, or microvascular free flap. The goal of treatment is to achieve definitive wound closure within 5 days of the injury.

***5. Duration of antibiotic therapy.*** For type I, II and IIIA fractures, there is no benefit in giving antibiotics for more than 48 hours. A three-dose regimen may be adequate. More severe fractures require a longer course of treatment, which continues until skin cover is achieved.

## Complications

As high energy injuries, open fractures are associated with a higher incidence of delayed and non-union. The incidence of infection is 1.5–2.5% for type II injuries and as high as 19–28% for type IIIB fractures. The overall incidence of non-union is 9%.

## Pitfalls

Compartment syndrome necessitating fasciotomy may occur, despite the open injury. Inadequate debridement may lead to delayed wound healing and infection.

Debridement must be thorough and non-viable tissue excised at subsequent wound inspections.

Early wound closure, while desirable, should be delayed if the tissues are swollen or tight. Skin has elastic recoil and a superior cosmetic result can be achieved by securing the skin edges across an open wound with elastic bands stapled to the skin margins.

Neurovascular complications are associated with high-energy trauma. If the distal circulation is dubious, an arteriogram and vascular opinion are required. Nerve injuries should generally be repaired as a secondary procedure at 6 to 12 weeks from injury, although some may be treated earlier if appropriate.

## Further reading

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## Related topics of interest

Amputation and replantation, p. 158; Intramedullary implants – reamed and unreamed, p. 125; Non-union and delayed union, p.153; Principles of external fixation, p. 214

# PAEDIATRIC FEMORAL FRACTURES

Femoral fractures represent 5% of all fractures in children, are generally mid-shaft, and treated by traction or stabilization in a hip spica. However, some femoral fractures are more challenging to manage and warrant special consideration. Under the age of 2 years, 70% are associated

nique and most suitable for 10–15 yea

- Rigid IM nails may damage the epip femoral head during insertion, and a maturity. Advantages include early m reduced cost, when compared to non-
- ORIF with a plate is reserved for su victims as an alternative to flexible na management.
- External fixation is a relatively safe an year olds with open fractures and poly

***7. Complications.*** Length discrepancy mon, but seldom noticed unless >1.5 cm initially or develop during non-operative growth, resulting in an average overgrowt puberty. Thus anatomical reduction in the reduction includes shortening to compens

Malunion and angular deformity dep plane of deformity. Varus/valgus deformi remodels in infants, but in adolescents onl

## Distal femoral epiphyseal fractures

Distal femoral fractures, previously descr caught between the spokes was the trad energy RTA or sports injuries.

*1.* ***Classification.*** Fractures are described by direction, degree of displacement and Salter–Harris type. S–H II are most common.

*2.* ***Management.*** Undisplaced fractures are managed in a cast for 6 weeks. Displaced fractures require anatomical closed or open reduction. Fixation is advised for displaced S–H II and mandatory for displaced S–H III and IV fractures. Fixation is by K-wires or intra-epiphyseal screws.

*3.* ***Complications.*** These include injury to the popliteal vessels or peroneal nerve. Redisplacement and growth arrest, leading to length discrepancy and angular deformity may occur. Growth disturbance occurs in 30% of displaced fractures, which is significant as the distal femur contributes 70% of femoral growth at an average of 1 cm/year.

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## Related topics of interest

Femoral fractures – shaft, p.49; Paediatric fracture principles, p.165.

**Proximal ulna**

*1.* ***Metaphyseal fractures*** are uncommon and

elbow fractures. Classification: A, flexion; B, ext

# PAEDIATRIC FRACTURE PRINCIPLES

Paediatric bones differ from their adult counterparts in three main ways: the presence of a growth plate, different biomechanical properties and the ability to remodel during growth.

## Bone growth

There are two major mechanisms of growth:

1. ***Intramembranous ossification.*** The cranial bones, facial bones and part of the clavicle are formed by intramembranous ossification. Cells of mesenchymal origin develop sites of primary ossification in the absence of a cartilaginous precursor. Intramembranous ossification is responsible for the increase in the diameter of long bones during growth.

2. ***Endochondral ossification.*** A cartilaginous precursor is replaced by osseous tissue, commencing in the ossification centres. The primary ossification centre of all the long bones is present by the twelfth week *in utero* and secondary ossification centres appear after birth. The exception is the secondary ossification centre of the distal femur, which is present at birth.

The secondary ossification centres lie within the epiphysis. The epiphysis is separated from the metaphysis by the 'physis' or 'growth plate'. The physis is divided into zones based on function. The zones, in order, from epiphysis to metaphysis are:

- Reserve.
- Proliferative.
- Hypertrophic.

Classically, physeal injuries were considered to occur through the zone of provisional calcification, which is a subzone of the hypertrophic zone. In reality, the injuries can occur in any zone.

## Paediatric fracture patterns

Paediatric bone is more porous and more elastic, with a thicker periosteum, than adult bone. Thus paediatric bone is less likely to fracture across both cortices and the fracture is less likely to be comminuted. As the child approaches adolescence, the fracture patterns become similar to the adult. The following fracture patterns are not seen in adult bone.

1. ***Greenstick.*** An incomplete fracture. The cortex and periosteum remain intact on the compression side.

2. ***Torus.*** A buckle fracture secondary to compression. Torus fractures are most common in the porous bone of the metaphysis.

3. ***Plastic bowing.*** The bone bends under a compressive load. When the elastic limit of the bone is exceeded the deformity becomes irreversible.

## Physeal injuries

*1. **The physis fails in torsion.*** The physis is normally stabilized by *mammillary projections* and *lappets*. The *mammillary projections* are interdigitating bumps between the metaphysis and epiphysis. The *lappets* are extensions of the physis up and around the metaphysis. Physeal injuries make up approximately 15% of all childhood fractures and are most commonly seen in the phalanges (37%), distal radius (18%), distal tibia (11%) and distal fibula (7%).

*2. **Salter and Harris (1963)*** have classified five types of injury (*Figure 1*). Rang (1969) added a sixth type and Ogden (1981) added types seven, eight and nine.

- Type I (8%). Complete separation of the epiphysis and metaphysis through the physis. This is seen in younger children.
- Type II (73%). A physeal fracture, extending into the metaphysis. A triangular fragment of metaphysis is created – on X-ray this is known as the 'Thurston–Holland' sign.
- Type III (6.5%). A split of the epiphysis, extending into the joint.
- Type IV (12%). A vertical split through the epiphysis, physis and metaphysis.
- Type V (<1%). Compression of the physis. This is often not recognized acutely as the X-ray is normal. The patient presents late with growth arrest.
- Type VI (<0.5%). Injury of the perichondral rim (zone of Ranvier) around the physis.
- Types VII, VIII and IX are discussed in Ogden's paper (see Further reading).

## Treatment of physeal injuries

***Type I.*** Closed reduction and immobilization is usually satisfactory. Approximately 3% develop a growth arrest.

***Type II.*** Closed reduction, but a K-wire is occasionally required. Reduction is sometimes blocked by interposed periosteum, particularly in the distal tibia. The wire is best placed through the Thurston–Holland fragment; however, it is permissible to pass a thin, non-threaded wire across the physis. Manipulation after 5–7 days is

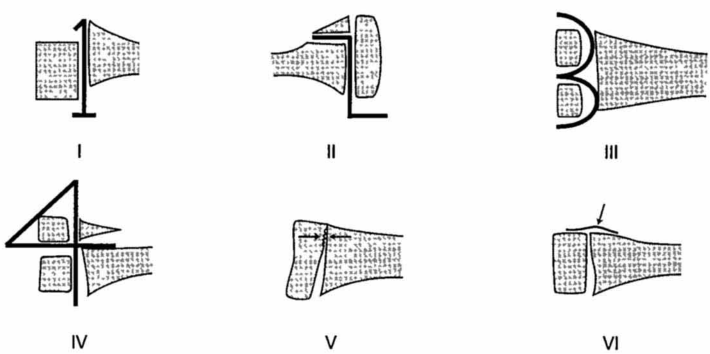


Figure 1. The Salter and Harris classification of physeal fractures. Types I to IV can easily be remembered, although it should be noted that type II is viewed as a mirror image. Type IV is the 'Rang' fracture, with injury of the perichondral rim.

controversial – some consider this will further damage the physis, and prefer to perform a late osteotomy.

***Type III.*** Requires anatomical reduction usually with ORIF. Some authors do not even accept 2 mm of displacement. Fixation is with transverse wires or screws, fixing epiphysis to epiphysis. Growth arrest is common, but frequently unimportant as the fracture occurs around the time of skeletal maturity.

***Type IV.*** As with type 3, this is an intra-articular fracture and often needs ORIF.

***Type V and VI.*** These are diagnosed late.

## Complications of paediatric fracture

1. ***Overgrowth.*** Particularly in the femur, fracture of the diaphysis may lead to overgrowth of the bone, secondary to disruption of the periosteum, which acts as a restraint to growth.

2. ***Shortening.*** Either due to malunion or complete physeal arrest.

3. ***Malunion.*** Potential for remodelling is greatest in the younger child, with an injury close to the physis and angulation in the same plane as the major plane of motion of the joint. Rotational deformity does not correct spontaneously.

4. ***Angular deformity.*** From partial physeal arrest.

## Physeal arrest

Physeal arrest is most commonly secondary to trauma (70%); other causes include infection, irradiation, tumour and developmental abnormalities. Growth arrests occur in the 2 years following injury. The 'transverse lines of Park' or 'Harris lines' are useful markers of growth arrest. A line converging on the physis suggests growth arrest.

1. ***Complete growth arrest*** causes shortening and is treated with a shoe-raise or leg lengthening. Alternatively epiphysiodesis or shortening of the opposite side may be performed.

2. ***Partial growth arrest*** causes angular deformity or shortening. Ogden and Bright divided partial growth arrest into three patterns:

- Central bridges – shortening with less angular deformity.
- Peripheral bridges – involving the zone of Ranvier, producing angular deformity.
- Linear bridges – more common after Salter–Harris type IV injuries, producing angular deformity and shortening.

In a teenager approaching maturity, surgical treatment may not be required. A leg length discrepancy of 2.5 cm is well tolerated. Menelaus has shown that ultimate discrepancy can be predicted by assuming that the distal femur grows by ⅜ of an inch, and the proximal tibia by ¼ of an inch per year, and that boys stop growing at 16 and girls at 14.

The classic operation for partial arrest is resection of the bone bridge (Langenskiöld), giving the best results when <50% of the physis is involved and there is >2 years growth remaining. Central or linear bridges respond better than peripheral bridges.

Most cases requiring surgical treatment are in the distal femur (35%), distal tibia (30%) and proximal tibia (16%). The bone bridge is localized by X-ray, tomography and CT. Treatment is resection and interposition grafting. Fat has been interposed, but solid, load sharing grafts, such as silastic, elastomer or polymethylmethacrylate are better.

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(>2 mm) and completely displaced. Some displaced fractures are grossly rotated, with the fragment hinging on the collateral ligament complex.

Type I injuries show some metaphyseal bone on X-ray and are usually stable. Undisplaced fractures can be supported in plaster for 3 weeks before starting mobilization. Ten per cent of minimally displaced fractures displace in plaster and check X-rays should be obtained at 5–7 days.

Displaced Milch type I and II fractures require open reduction and fixation, either with smooth K-wires or small fragment screws. Where there is doubt about the degree of displacement or stability, there should be a low threshold for surgical exploration and fixation. The fracture is exposed through a postero-lateral approach, reduced with minimal disturbance of the soft tissues (especially posteriorly) and stabilized. If possible, fixation should be through the metaphyseal bone spike. To prevent rotation, two pins are required and where the metaphyseal spike is small, the pins can pass through the epiphysis, without causing significant growth disturbance in the majority of cases. One transverse and one oblique K-wire provides the greatest rotational stability. Screw fixation through the metaphyseal fragment is more stable, and very good results are reported, without growth disturbance. Overall, 90% of patients have excellent or good results.

Stabilization should be augmented with plaster immobilization. The K-wires are removed at 4 weeks if union is adequate and the elbow mobilized. Delayed or non-union may occur.

2. ***Medial condylar fractures*** are less common than lateral condylar fractures. The principle of treatment is the same, with a low threshold for stabilization of displaced fractures.

3. ***Medial epicondylar fractures*** represent 10% of all elbow injuries in the child. The fracture is rare before the age of 10 and usually an avulsion injury which can be treated conservatively. More severe injuries may be associated with elbow dislocation and instability of the lateral collateral ligament complex. The fragment can occasionally become trapped in the joint. On rare occasions with a displacement greater than 1 cm, or elbow instability, screw or K-wire fixation may be required. However, the results of conservative treatment are good. Stiffness can be a problem and early mobilization is recommended.

4. ***Intercondylar fractures*** are rare (1%) and when displaced, require internal fixation.

## Complications

1. ***Non-union***, defined as >12 weeks, should be treated by bone graft and revision fixation.

2. ***Cubitus valgus*** is caused by non-union of a lateral condylar fracture, or occasional growth arrest of the epiphysis. This can be corrected with an opening lateral osteotomy, or a closing medial osteotomy, supplemented with bone graft and fixation. The deformity is greater following Milch type II injuries, and lateral displacement with an opening wedge osteotomy of the distal humerus will be required to prevent an unacceptable cosmetic deformity.

3. ***Tardy ulnar nerve palsy*** is a late consequence of cubitus valgus deformity, developing over a period of 2 to 3 decades.

## Further reading


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## Related topics of interest

Humeral fractures – distal, p. 107; Paediatric humeral supracondylar fractures, p. 172

# PAEDIATRIC HUMERAL SUPRACONDYLAR FRACTURES

Supracondylar fractures account for 65% of fractures around the elbow in the child. With much of the paediatric skeleton being cartilage, radiological interpretation may be difficult and the extent of the fracture, degree of displacement, or rotation, easily overlooked. Caution should be exercised and where the diagnosis is uncertain, an arthrogram can be helpful. X-rays of the opposite elbow provide a useful comparison. Inappropriate treatment, or a missed diagnosis, can cause severe long-term complications. Neurovascular injuries are common and should be carefully assessed.

Supracondylar fractures are more common in boys, in the left arm and around 5 to 8 years of age. Baumann's angle (the angle between the long axis of the humerus and the physeal line of the lateral condyle, with a true AP X-ray), ranges from 64° to 82°, mean 75°.

## Fracture patterns and associated injuries

1. ***Displacement into extension,*** with the distal fragment posterior, is the most common pattern and classified as type I, undisplaced; type II, displaced with the posterior cortical hinge intact; type III, completely displaced. Type III injuries more commonly have postero-medial displacement, but displacement may be postero-lateral. The approach to fixation is different.

2. ***Displacement into flexion*** occurs in 2 to 6% of cases and requires more aggressive treatment.

3. ***Floating elbow*** occurs in 5% of cases, with a forearm fracture in addition to the supracondylar fracture. Fixation is usually required.

4. ***Neurovascular injuries*** occur in a substantial number of patients and include:

- Neurological injury in 3 to 15% of cases. The radial nerve is most frequently involved – 55% radial, 30% median, 15% ulnar. There may be subtle impairment of the anterior interosseus nerve, with weakness of FDP to the index finger and FPL, and normal sensibility. Almost all neurological injuries recover within 2 to 3 months.
- Vascular injury is much higher than the 0.5% reported historically. Figures up to 38% have been reported, including simple compression, spasm, an intimal tear, or rarely complete rupture of the brachial artery. Where there is clinical suspicion of a vascular injury which does not respond to reducing the fracture, further investigation is by Doppler measurement, comparing the wave form with the opposite limb, or arteriography if time permits. Urgent surgical exploration should be undertaken in consultation with a vascular surgeon if the clinical signs are obvious, or if there is any delay with investigation. A digital pulse oxymeter can be misleading and unreliable, as there is usually sufficient collateral circulation to maintain skin perfusion distally. However, there may not be sufficient perfusion of forearm muscle.
- Compartment syndrome occurs in <1%, necessitating fasciotomy for decompression.

## Management

1. ***Undisplaced fractures*** should be immobilized in a plaster slab, with the elbow flexed 100° and the forearm neutral. Undisplaced fractures can displace and a check X-ray at 1 week is necessary. The plaster can be discarded at 3 weeks and the elbow mobilized.

2. ***Displaced fractures*** require urgent treatment and are always easier to reduce and stabilize before swelling obscures the landmarks. Type III injuries are unstable, as are some type II injuries and internal fixation may be required. The literature on this subject is extensive and controversial. Treatment options include:

- Closed reduction and plaster immobilization, with the elbow flexed 110° provided a good pulse is maintained, is suitable for many type II and some type III injuries. The fracture is reduced by traction along the pronated forearm with the elbow extended. The elbow is hyperextended, exaggerating the deformity, then flexed as the distal fragment is manipulated by direct posterior pressure. On a true lateral X-ray, a crescent sign is caused by medial or lateral tilt with the distal humerus overlying the ulna.
- Closed reduction and percutaneous K-wire fixation is favoured where the fracture is unstable. Some units advocate K-wiring of all type III fractures. Crossed K-wires placed from the medial and lateral sides provide the greatest stability and rotational control. However, there is a risk of iatrogenic ulnar nerve damage, and the incidence can be reduced with a small skin incision and dissection down to bone, or by identifying the ulnar nerve with a nerve stimulator and placing the wire anterior to this. The medial wire should be placed first with the postero-medially displaced fracture, and the lateral wire first with postero-lateral displacement. The medial wire should start posteriorly and be directed anteriorly, while the lateral wire should start anteriorly and be directed posteriorly. This procedure is best performed after closed reduction, with the elbow over the image intensifier and the arm abducted. Two parallel wires can be placed from the lateral side, but fixation is less secure. Wires are removed at 3–4 weeks and the elbow mobilized.
- Open reduction and K-wire fixation is occasionally required if the fracture cannot be reduced. Skin puckering at presentation suggests penetration of the brachialis by the humerus, and is a useful indicator that open reduction may be necessary. Postero-lateral displacement should be exposed through an antero-medial approach, visualizing the median nerve and brachial artery. Postero-medial displacement should be exposed through an antero-lateral approach

deformity, which can be secondary to bony deformity, or more co
neuromuscular imbalance. Late neurological deterioration should be
and if present, evaluated by MRI to exclude a syrinx.

## Further reading

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## Related topics of interest

Spine – C3 to C7, p. 269; Spine – occiput to C2, p. 272; Spine – thoracic and lumb p. 275; Spine – whiplash and associated disorders, p. 278

# PAEDIATRIC TIBIAL FRACTURES

The most common fractures of the lower limb in children are of the tibia and fibula, classified by site and pattern.

## Tibial eminence fractures

Avulsion of the ACL tibial insertion is more common than cruciate rupture in the immature skeleton and not infrequent in adolescents playing sport. Haemarthrosis is the usual presentation with a fracture on X-ray.

1. ***Classification.*** 'Meyers and McKeever' (lateral X-ray).

- Type I: minimal displacement.
- Type II: hinged anteriorly, attached posteriorly.
- Type III: detached +/– rotated.

2. ***Management.*** Type I and II may be treated in a knee extension cast for 6 weeks. A check X-ray should be obtained to ensure reduction, as the intermeniscal ligament may be trapped under the anterior lip, preventing reduction. Type III and unreduced type II fractures require surgical reduction – open, arthroscopic-assisted or totally arthroscopic. Anatomical reduction and fixation with either a postero-inferiorly directed lag screw within the epiphysis, or tie over sutures passed out through the proximal tibia, is required. A cast brace is used for 6 weeks.

## Proximal tibial epiphyseal fractures

These are rare injuries, as the collateral ligaments insert below the epiphysis, but may follow a direct valgus blow in adolescents. This is occasionally 'mis-diagnosed' as collateral ligament sprain. Vascular injury occurs in 10%, and peroneal palsy in 3%.

1. ***Classification.*** Salter–Harris II is the most common (43%), but S–H III (22%) and S–H IV (27%) also occur.

2. ***Management.*** Immobilization following reduction in an above knee cast for 6 weeks. Operative fixation is required for the unstable S–H II and to reduce the intra-articular extension of the S–H III and S–H IV fractures.

## Proximal tibial apophysis and tubercle fractures

Chronic apophyseal problems such as Osgood–Schlatter's disease are common, but acute fractures are rare. However, as with eminence fractures, these are increasing in frequency and associated with adolescent sport. Fractures follow sudden resistance to quadriceps contraction, such as kicking the ground.

1. ***Classification (Ogden).***

- Type 1

solitary metastases in only 9% of cases. A solitary metastasis may b
undiagnosed malignancy.

## Metabolic disease

Pathological fractures occur in bone affected by meta
osteoporosis or osteomalacia, and in other systemic d
genesis imperfecta, Paget's disease, polyostotic fibrous c
The most common sites of osteoporotic fractures are th

Where appropriate, fractures through metastatic deposits should be treated aggressively, with internal fixation or joint replacement, to achieve early mobilization and discharge of the patient, who will usually, but not always, have a short life-expectancy. Liver function, blood clotting and the bleeding time may be deranged. Reaming causes embolization of tumour, as well as marrow products, and this may cause death during surgery. Where fixation is tenuous because of diseased bone, polymethylmethacrylate bone cement may be used to improve implant fixation. Tissue must be sent for histological confirmation. The development of further deposits, locally or systemically, following surgery has not been proven.

Following surgery, adjunct radiotherapy or chemotherapy should be considered.

Before surgery, the entire affected bone must be X-rayed, to exclude another deposit in the bone. Preferably before surgery, and certainly before mobilizing the patient, a technetium bone scintigram should be obtained to exclude other deposits, or a skeletal survey performed. Deposits from myeloma are not always identified by bone scintigraphy.

Consideration should be given to prophylactic fixation of painful secondary

cult to expose and reduce, may require a sequential anterior and posterior approach. An extensile approach, such as a tri-radiate transtrochanteric or an extended ilio-femoral incision, is also used.

The general principle of surgery is to achieve anatomical reduction and fixation with a combination of lag screws and contoured pelvic reconstruction plates. Patients should be mobilized early, with minimal weight-bearing for the first 8 weeks.

Where there is significant destruction of the articular cartilage, total hip replacement may be appropriate. This is undertaken either after the fracture has healed, or on occasion acutely, using bone graft and the multiple screw holes of an uncemented acetabular cup to stabilize the fracture and act as supplementary plate fixation.

3. ***Ipsilateral femoral shaft and acetabular fracture.*** This is one of the few indications for compression plate fixation of the femoral shaft. A retrograde femoral IM nail is another option. The shaft fracture should be stabilized acutely, keeping the wound away from the pelvis and the acetabular fracture addressed a few days later, after appropriate investigation.

## Complications

1. ***Sciatic nerve injury*** occurs in up to 30% of acetabular fractures; femoral and superior gluteal nerve injuries are occasionally encountered. A subclinical traumatic injury to the sciatic nerve at the time of the accident may be dramatically aggravated by surgery and per-operative EMG monitoring of the calf should be available. Post-operative sciatic nerve palsies tend to recover; traumatic nerve injuries are permanent in 10% of fractures.

2. ***Thromboembolism*** occurs in a significant proportion of cases and anticoagulation should be routine.

3. ***Infection*** is reported to occur in 3–5% of cases.

4. ***Heterotopic ossification*** with an incidence varying from 5 to 15% (may be as high as 70%) is reported in the literature, yet only a minority of patients have significantly impaired movement. The prophylactic roles of indomethacin and radiotherapy are yet to be defined for this type of surgery.

**Letournel E, Judet R.** *Fractures of the Acetabulum.* New York: Springer-Verlag, 1993.
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## Related topics of interest

Hip dislocation, p. 104; Pelvis – ring fractures, p. 189

# PELVIS – RING FRACTURES

Fractures of the pelvis follow high-energy trauma, frequently in association with other major skeletal, thoracic, abdominal and pelvic trauma. Stability of the fracture depends upon the integrity of the pelvic ring. Blood loss may be dramatic, requiring swift intervention. Twenty to twenty five per cent of fatal accidents have associated pelvic fractures and the mortality rate following pelvic fractures is 9–19%. Less severe fractures occur in the elderly osteoporotic patient following low-energy trauma.

## Anatomy and classification

An understanding of the anatomy and ligamentous structures of the pelvis is essential in order to appreciate the classification system. Fractures are classified according to the deforming force and stability depends upon the integrity of supporting ligaments. The closed ring of the pelvis is chiefly stabilized posteriorly by the congruity of the sacroiliac joints, interosseous sacroiliac, anterior sacroiliac, posterior sacroiliac, sacrotuberous, sacrospinous and ilio-lumbar ligaments. Anteriorly, the symphysis pubis plays a lesser role in supporting the closed ring.

The classification of Burgess and Young is commonly used, with four injury patterns including lateral compression (LC), antero-posterior compression (APC), vertical shear (VS) and combined mechanism (CM) injuries.

- **LC injuries** with a deforming force from the side are of three subtypes (LC-I, LC-II and LC-III), differentiated by disruption of the posterior sacroiliac structures. Pubic rami fractures are generally transverse, may buckle or overlap and are best seen on the pelvic inlet view. In LC-I injuries, the pubic rami are fractured, but there is no posterior instability. A crush fracture of the sacrum is common. In LC-II injuries, medial displacement of the anterior hemi-pelvis is associated with rupture of the posterior sacroiliac ligament complex or a fracture of the sacroiliac joint/wing, producing posterior instability. In LC-III injuries, the pelvis opens on the contralateral side as the deforming force is transmitted through the pelvis, resulting in a windswept pelvis. LC injuries are associated with acetabular fractures.
- **APC injuries** follow direct anterior or posterior trauma and are divided into subtypes (APC-I, APC-II or APC-III), depending on the degree of displacement. APC-I injuries have minimally displaced, usually vertical, pubic rami fractures or mild symphysis pubis diastasis (<2 cm). The anterior sacroiliac, sacrospinous and sacrotuberous ligaments are violated in APC-II injuries, as the pelvis splays open like a book. In APC-III injuries, all the sacroiliac structures, including the posterior ligaments, are disrupted. APC-II and APC-III fractures have the highest risk of haemorrhage.
- **VS injuries** typically follow a fall from a height, with a fracture pattern through the pubic rami and posterior pelvis, displacing the hemi-pelvis vertically.
- **CM injuries** result in a combined fracture pattern – most frequently LC and APC.

Tile classifies fractures as: A, stable; B, rotationally unstable, but vertically stable; and C, rotationally and vertically unstable. Isolated fractures of the sacrum, pubic rami, iliac wing or crest and avulsion fractures may occur.

## Imaging

Plain X-rays may confirm a suspected injury, and should be included in the initial radiographic evaluation of all major trauma. Further assessment is with Judet views (see p. 186), and pelvic inlet and outlet views (X-ray beam angled 40° caudad and 40° cephalad). Where the state of the acetabulum is in doubt, a CT scan should be obtained. While CT has traditionally not been part of the investigation for assessment and planning of surgery, the advent of spiral CT with rapid 3D reconstruction may change the approach to radiological investigation.

## Associated soft tissue injuries

***1. Vascular.*** Haemorrhage from a pelvic fracture is often dramatic, either from the sacral venous plexus and other great veins, or an artery in close proximity to bone. The superior gluteal artery is the most frequently damaged, as it passes through the sciatic notch. Significant haemorrhage may also occur from exposed bony surfaces.

***2. Urological.*** Urethral injury, more common in males, occurs in 15% and bladder rupture occurs in 5% of pelvic fractures. Injuries to the ureter are rare. Urethral injuries manifest as blood at the meatus, penile bruising, a high riding prostate on PR examination, or haematuria. Urological advice is required before attempted catheterization. Suprapubic catheterization is often preferable and further investigation includes a retrograde urethrogram, cystogram, intravenous pyelogram (IVP) or CT scan.

***3. Neurological.*** Sacral fractures through neural foramina may compromise the lumbosacral plexus. The sciatic and other nerves may be damaged, depending on the injury pattern.

## Treatment

***1. Emergency management.*** Pelvic fractures may present with major haemorrhage. A widely displaced fracture, in a haemodynamically unstable patient despite fluid replacement, needs the pelvis closed and stabilized as a resuscitative measure in the emergency room, using an external fixator to tamponade blood loss. Two or three 5 mm pins should be passed into the anterior iliac crest and the fixator applied. An external fixator may be suitable for definitive management and should be retained for 8–12 weeks. A Ganz clamp can be applied to close the pelvis posteriorly.

When pelvic haemorrhage is uncontrollable despite the compression and tamponade effects of an external fixator, angiography and embolisation may be indicated. With a pelvic fracture, laparotomy is ill-advised without an external fixator applied.

***2. Conservative treatment.*** Stable fractures, where displacement is minimal, may be treated conservatively. Minimally displaced pelvic ring fractures should be mobilized with protected weight-bearing after a period of 6 to 8 weeks bed rest. 'Stable' injuries can displace and radiological review is advisable. Simple pubic rami fractures can be mobilized early, to the tolerance of pain.

3. ***Operative stabilization.*** Occasionally the pubic symphysis needs to be stabilized anteriorly, using a two or four-hole plate through a Pfannenstiel incision. Double plating is more stable. Displaced posterior injuries need fixation, either by a direct posterior, or anterior (extended ilio-inguinal) approach to the sacroiliac joints. Methods of fixation include reconstruction plates, trans-iliac rods or carefully placed ilio-sacral screws. Such surgery is complex, prone to hazard and should be undertaken by experienced surgeons in adequately equipped centres. In skilled hands, screws may be inserted percutaneously with image intensifier control.

### Complications

1. ***Infection and thromboembolism.*** There are few accurate figures available for these complications.

2. ***Malunion.*** This can result in substantial disability, with abnormal gait, leg length inequality and attendant complications. The incidence is around 5%.

## Further reading


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## Related topics of interest


Pelvis – acetabular fractures, p. 185; Polytrauma – management and complications, p. 200

# PERIPHERAL NERVE INJURIES AND REPAIR

Each peripheral nerve contains many nerve fascicles. The fascicles and intervening connective tissue are bound by a sheath of epineurium. Fascicles contain many individual nerve fibres surrounded by perineurium. A nerve fibre consists of an axon with a Schwann cell covering, bound by endoneurium.

Nerve fibres may be myelinated (A and B) or unmyelinated (C). The myelin sheath is produced by the Schwann cell. Sequential Schwann cells surround myelinated fibres, separated at the nodes of Ranvier. Each Schwann cell supports only one axon. In unmyelinated fibres, one Schwann cell may support several axons.

Myelinated fibres are larger (1–10 μm) than unmyelinated fibres (0.2–2 μm) and the conduction velocity is much faster (10–70 m/s compared with 2 m/s). Conduction velocity is faster due to the saltatory or skip conduction effect of the myelin sheath. Loss of the myelin sheath results in absent or delayed conduction.

## Classification of nerve injury

Seddon (1943) described the most widely used classification of nerve injury:

1. ***Neurapraxia.*** A physiological block to conduction associated with either temporary ischaemia or focal demyelination.

2. ***Axonotmesis.*** Axon disruption, but the nerve covering or 'tube' remains intact.

3. ***Neurotmesis.*** Transection of both axon and nerve sheath/covering.

Sunderland (1951) expanded axonotmesis into three grades, differentiating whether the endo-, peri-, or epineurium were intact.

## Mechanisms of injury

A peripheral nerve may be compressed acutely or chronically, stretched, transected, burnt or irradiated. Acute or chronic compression may cause neurapraxia or axonotmesis. Severe compression may cause axonal death. Stretching may cause any type of injury, but typically axonotmesis (>15% elongation). Transection usually follows a penetrating injury, causing neurotmesis.

## Pathophysiological response to injury

1. ***Neurapraxia.*** Temporary ischaemia is reversed and function recovers. Focal demyelination is followed by remyelination over a period of 2 to 6 weeks.

2. ***Axonotmesis and neurotmesis.*** Axonal (Wallerian) degeneration occurs in the whole distal axon and the proximal stump up to the nearest node. Wallerian degeneration consists of enzymatic degradation and ingestion of the axon and myelin by macrophages and Schwann cells. This takes 1 to 3 months, leaving an empty neural tube, continuous or divided.

   Nerve regeneration is governed by neurotrophism (growth stimulating factors) and contact guidance (Schwann cells). Regeneration occurs after a delay of 1 month, by axonal budding from the proximal stump and proceeds at a rate of

1 mm/day (1 inch/month) in adults. The bud is directed down the Schwann cell tube, but the regenerate fibre is smaller and less myelinated, with slower conduction.

The lack of an intact Schwann cell tube (neurotmesis) severely interferes with effective regeneration. The axonal buds lack direction, resulting in a functionless mass.

## Clinical findings

Nerve dysfunction is usually immediately apparent, by either altered or absent sensory or motor function. Occasionally signs may evolve after the acute event, so repeated examination is important.

## Electrophysiology

Nerve conduction studies (NCS) and EMG are used to assess the type of injury, recovery and prognosis. Timing of studies is important, as the type of injury cannot be identified before 2–3 weeks. Prior to this, axonal degeneration may not have occurred, leading to false results. At 3–6 months, repeat studies can assess the mode and degree of recovery.

In a neurapraxia, there is normal nerve conduction above and below, but not across the site of injury, where nerve conduction is slowed. In axonotmesis and neurotmesis, both EMG and NCS are abnormal. There is no conduction distal to the injury, and muscle exhibits denervation fibrillation within 3 weeks. Later EMG studies may predict both the mode (collateral sprouting or regeneration – see below) and degree of recovery in the case of axonotmesis, but not neurotmesis.

## Recovery

- Most neurapraxias recover fully within 2 to 6 weeks, but occasionally take 3 months.
- Functional recovery from axonotmesis has two mechanisms. Firstly, by *collateral sprouting* from other axons at the nerves' destination, which effects fast functional recovery (3–6 months), but requires at least 30% of axons to be intact. Secondly, by *nerve regeneration* as above. This is slower and often incomplete. If nerve lesions are very proximal, the distal Schwann cell tubes may become obliterated prior to the fibre reaching the end plate (18 months) and recovery is incomplete. Prognosis is poor.
- Spontaneous recovery from neurotmesis is poor, with no collateral sprouting or effective regeneration.

## Management

***1. Closed injury.*** Observation, with baseline NCS/EMG documentation at 3 weeks and follow-up studies at 3 months is required. Joint and muscle contracture should be prevented by physiotherapy. Surgical exploration is considered after 6 months and neurolysis, co-aptation (repair) or resection and grafting may be required. The final outcome is assessed at 2 years. Evidence of nerve injury following manipulation of a closed fracture may require early exploration.

***2. Open injuries.*** These should be explored, and acute co-aptation undertaken within 2 weeks. Clean, guillotine divisions are best co-aptated without delay. However, dirty, crushed or avulsed lesions should be debrided, allowed to heal and secondarily repaired.

### Nerve co-aptation

Direct repair is undertaken if there is $<2.5$ cm nerve gap. Scarred portions should be excised. Both epineurial and group fascicular repairs have been advocated. No studies have shown any advantage of fascicular repair.

Recovery is hampered by intraneural oedema and scarring. The future may see the use of bioabsorbable tubes, into each end of which the cut nerve ends are placed. The proximal axons will grow to the distal Schwann cell tube, guided by intrinsic factors. This will avoid the use of sutures and may improve topography and subsequent functional outcome.

### Grafting for segmental defects

Following exploration and mobilization of the nerve, intervals of $>2.5$ cm should be grafted to avoid tension and failure of repair. Nerve, muscle, vein conduit and synthetic materials have all been used. Nerve grafts are the most common, but have the disadvantage of donor site morbidity. The grafts are usually non-vascularized, but vascularized grafts can be used if the graft site is very scarred. The sural, medial and lateral cutaneous nerves of the forearm are commonly used.

Current research is investigating the use of frozen/thawed muscle grafts and synthetic tubes as conduits for nerve growth and repair. Results of muscle grafts have so far been disappointing.

### Recovery: phases and prognosis

There are three phases of recovery:

- Axon growth.
- Simple protective function.
- Useful motor and sensory function.

Best outcomes are achieved in distal guillotine divisions of young, pure nerves rather than proximal crush or avulsion type injuries in old, mixed nerves.

## Further reading


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## Related topic of interest

Shoulder – brachial plexus injuries, p. 243

# PERI-PROSTHETIC FRACTURES (HIP AND KNEE)

Fractures around prosthetic implants most commonly affect the hip and knee, although fractures around shoulder and elbow prostheses occur. Fractures occur as an acute event following a fall, or as an acute on chronic process with established implant loosening and osteolysis, resulting in a fracture after minimal trauma. Management is best within a specialist revision arthroplasty unit.

## Classification

It is essential to determine whether the fracture has occurred around a loose or well-fixed implant, as this has implications for definitive treatment and pre-operative planning. Sixty per cent of peri-prosthetic femoral shaft fractures occur around a loose stem and 25% occur around a loose stem in the presence of advanced loss of bone stock.

Several classifications exist for fractures around a total hip replacement (THR). The important factors are the degree of displacement and where the fracture occurs. The fracture can occur around the upper femur leaving a soundly fixed prosthesis below, around the tip of the prosthesis, or below the prosthesis. Johansson proposed a type I, II and III classification on this basis. The six-part American Academy of Orthopedic Surgeons (AAOS) classification of fractures integrates with the AAOS classification for femoral bone stock loss. Peri-prosthetic acetabular fractures without established lysis are rare.

Distal femoral fractures in relation to a total knee replacement (TKR) occur at the upper margin or above the level of the prosthesis. Fractures of the proximal tibia are rare.

## Management

Treatment depends upon the level of the fracture, whether the prosthesis is well-fixed or loose and, if loose, the extent of osteolysis. Loose prostheses generally require revision surgery.

With the exception of very proximal and distal femoral fractures, conservative treatment is rarely successful as it is difficult to control alignment of the femur accurately. There is also a high incidence of subsequent prosthetic loosening. Should a patient require revision at a later date, malunion compromises surgery and an osteotomy through the previous fracture may be required.

When plate fixation is chosen, a specially designed plate can be fixed to the femur with cerclage cables at the level of the prosthesis and with large fragment screws below the prosthesis – four cables above a fracture are required for adequate fixation. Long stem prostheses for peri-prosthetic fractures should pass two femoral shaft diameters below the fracture site. Prostheses with distal cross locking bolts may be useful to control rotation.

***1. Fractures around a loose THR*** should be treated with a revision THR, removing the implant and reconstructing the femur, unless medical conditions or age dictate otherwise. The femur may need reconstruction with a plate and cables, strut allograft or morsellized impaction grafting. Soft tissue attachments to bone fragments should be carefully preserved. Sometimes bone loss is so severe that a combination of techniques is used, but it is important to restore bone stock and implant stability. Stable fixation of the stem into intact host bone is essential. Distal fixation is therefore required after reconstructing the femur. A cemented or uncemented implant may be used. It is important to ensure that cement does not interdigitate with the fracture site as this may prevent fracture union. An uncemented implant should have a porous coated stem or distal grooves. With advanced osteolysis, a massive allograft or femoral replacement prosthesis may be required.

2. ***Fractures of the proximal femur around a well-fixed THR*** can be treated conservatively if there is minimal displacement. A period of bed rest and traction is followed by mobilization and partial weight-bearing when the patient regains leg control.

3. ***Fractures around the lower end of a well-fixed THR*** require open reduction, fixation and bone grafting. Generally, a cemented prosthesis should be removed and the femur reconstructed before inserting a long stemmed prosthesis. Where there is minimal comminution, reconstruction of the femur with cables or wires alone may suffice before cementing a long stem prosthesis. Alternatively, an uncemented prosthesis may be favoured. With extensive comminution, allograft struts, plate and cables, augmented with morsellized autograft or allograft will be required.

A soundly fixed uncemented prosthesis may not need exchange, if the femur can be adequately reconstructed around the stem of the prosthesis.

4. ***Fractures of the femur below a well-fixed THR*** require open reduction and internal fixation with a plate and cables, augmented with strut allograft, morsellized autograft or allograft.

5. ***Undisplaced fractures of the distal femur around a TKR*** can be treated conservatively in traction and subsequently in a plaster or cast brace. Regular radiological assessment is required to check alignment is maintained.

6. ***Displaced fractures of the distal femur around a TKR*** require open reduction and internal fixation with a contoured large fragment plate, or similar fixation device. Sometimes a blade plate or condylar screw plate may be used, depending on the presence of stems or pegs on the prosthesis. When plate fixation is employed, bone grafting is required.

An alternative to extramedullary fixation is supracondylar IM nailing. Provided a small diameter nail passes through the centre of the condylar prosthesis, adequate fixation can be achieved and additional bone grafting is rarely required. Good results are reported using this technique, with the advantage of minimal soft tissue disturbance.

In some circumstances a stemmed revision is required as definitive treatment. Controlling alignment of the distal femur is crucial, as varus or valgus malunion accelerates failure of the prosthesis.

7. ***Fractures of the proximal tibia are rare.*** A stress fracture at the tip of a tibial stem may occur and often heals with conservative treatment. Occasionally, revision with a long stemmed prosthesis is required.

8. ***The principles of treating fractures around shoulder and elbow prostheses are similar.*** Fractures around a total shoulder replacement can generally be treated conservatively with early mobilization – prolonged immobilization leads to poor function. Fractures around a total elbow replacement (TER) are a more common complication, affecting around 5% of all reported TER series; treatment may be conservative or operative, with internal fixation or revision. The specific management of these problems is beyond the scope of this chapter.

### Complications

- With good operative techniques non-union is rare, although revision arthroplasty surgery is prone to major complications and these are increased in the presence of a fracture.
- Malunion compromises subsequent surgery and may promote loosening.
- A large proportion of solid implants treated without revision become loose within a few years.

## Further reading

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## Related topics of interest

Femoral fractures – shaft, p. 49; Pathological fractures, p. 183

# POLYTRAUMA – FAT EMBOLISM AND RESPIRATORY DISTRESS

Fat embolism is the systemic release of bone marrow fat, or other fat, into the circulation. As the peripheral arterial circulation is affected, the term 'embolism' is a misnomer. Fat embolism syndrome (FES) is the systemic response to this phenomenon. Although FES is an infrequently recognized complication of trauma, the effects can be dramatic, a major cause of mortality, and an important cause of adult respiratory distress syndrome (ARDS). FES is really part of the spectrum of trauma-related insults which can lead to ARDS and treatment is aimed at reversing respiratory compromise.

The early stabilization of fractures and early patient mobilization may account for the falling incidence of FES.

## Incidence

FES follows 0.5 to 2% of long bone fractures and 10% of polytrauma cases. The incidence is higher during treatment of metastatic deposits. Subclinical fat embolism follows 50% of long bone fractures, and occurs after instrumentation of the medullary canal in both trauma and joint replacement surgery.

## Pathophysiology

The pathogenesis of FES remains unclear. After trauma there is probably a change in lipid solubility and membrane stability. There is also a change in microcirculatory flow, causing increased tissue permeability and tissue hypoxia. Fat in the circulation is not purely from bone marrow. The volume released is not a

2. ***The turning point phase.*** This occurs from approximately the fifth to the tenth day, with a reversal of hormonal influences, a change to an anabolic state with positive nitrogen and potassium balance, and negative water and sodium balance.

3. ***Protein anabolism phase.*** This phase may last 4 to 5 weeks, as corticosteroid levels normalize and growth hormone levels increase. Plasma protein (such as albumin) levels rise and muscle is restored.

4. ***Fat anabolism phase.*** The final phase is slower and prolonged over several months. Insulin stimulates lipogenesis, as fat stores and body weight are regained.

## ongation of the injury phase

The essential metabolic response may become exaggerated and detrimental, with 'failure to exit' leading to prolongation of the injury phase. This is called the

*systemic inflammatory response syndrome* (SIRS). This is more likely to become established with the presence of pre-injury factors such as poor nutritional state, young adult males, severe injury, pain, fear, and the complications of trauma: sepsis, hypoxia, hypovolaemia, starvation, and acid/base disturbance.

SIRS is characterized by endothelial breakdown in multiple organs, particularly the lung and gut. This leads to ARDS and subsequently to multi-organ failure. The mechanism is thought to be related to cytokine-mediated free radical release. Once initiated, the outcome is poor, so preventing prolongation of the injury phase is vital. The polytrauma patient is especially at risk. Preventative measures should be taken from the outset, with particular attention paid to optimal oxygenation, fluid balance, nutrition, decontamination and analgesia.

Fat embolism syndrome is one of the trauma-related insults which also leads to ARDS. This can contribute to prolonging the injury phase.

### Timing of surgery

Surgical 'insults' can prolong the injury phase, such as undertaking major operations at a time when the body is least able to cope (e.g. low acute phase proteins and immunocompetent cells).

Operative intervention should avoid the maximal catabolic phase, to reduce the risk of decompensation. Major operations should ideally be scheduled before day 2 or after day 5. Fracture stabilization should be undertaken on day one, with only dressing changes between day 2 and 5. Further major definitive fracture surgery is delayed until after this period.

## Further reading

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## Related topics of interest

Polytrauma – fat embolism and respiratory distress, p. 198; Polytrauma – management and complications, p. 200; Polytrauma – resuscitation and ATLS, p. 209

- *The first peak* occurs within minutes, du
logical or vascular events.
- *The second peak* occurs within an hour o
injuries.
- *The third peak* occurs after several days o
infection.

## ATLS concept

ATLS started in Nebraska, North America, a his plane, injuring his family. He found th inadequate. The aim of ATLS and resuscitat life-threatening injuries, which become evide trauma. ATLS provides a simple, structured s ment, re-evaluation, stabilization and possi enabling a physician to single-handedly an without specialist expertise.

ATLS emphasizes the need to treat tra addressing resuscitation of life-threatening i under the ABCDE mnemonic:

- Airway and cervical spine protection.
- Breathing and ventilation.
- Circulation and haemorrhage control.
- Disability and neurological status.
- Exposure and environment.

This forms the basis of the primary sur assessment and simultaneous treatment of survey.

## Primary survey

***1. Airway and cervical spine protection*** m patent airway, while stabilizing a presumed c respond to removal of debris, vomit and sec tissues of the palate with a chin lift or

oropharyngeal airway, or establishment of a definitive airway by endotracheal intubation, may be required. Oxygen should be delivered with a flow of 10–12 l/min.

Protection of the cervical spine and cord is initially by manual in-line immobilization, followed by a rigid cervical collar, sand bags, tape and a full spine board.

2. ***Breathing and ventilation*** are essential for adequate gas exchange, once the airway is secured. The chest should be exposed and examined. Examination may reveal an open chest wound, flail segment, tension pneumothorax or haemothorax, requiring immediate treatment.

A circulatory injury, such as massive haemorrhage or cardiac tamponade, may manifest as, and is easily confused with, a ventilatory problem. A haemothorax should not be drained until venous access is established. A simple pneumothorax, demonstrated on X-ray, may be treated by close observation unless ventilation or transfer are required, when a tube thoracostomy is indicated.

3. ***Circulation and haemorrhage control*** can be rapidly addressed. Haemorrhage is the main preventable cause of death in the 'golden' hour. Visible haemorrhage should be controlled by local pressure. Venous access should be established with two wide bore (16 gauge) cannulae, placed peripherally, in the femoral vein, or by venous cutdown. Blood is sent for analysis and cross-match. Fluid replacement may be with warmed crystalloid, but blood may be required. The blood may be fully cross-matched, type-specific or O negative, depending on the urgency.

Young or athletic patients have a large physiological reserve, but the elderly may only have a limited ability to respond following blood loss. Massive blood loss affects the level of consciousness. Immediate surgical intervention may be required for uncontrolled internal haemorrhage. Cardiac output may be reduced by cardiac tamponade – pericardiocentesis of a small amount of blood can have a dramatic effect.

4. ***Disability and neurological status*** should be assessed with the AVPU scale and measurement of pupillary size and reaction. This gives an indication of the neurological status of the patient. The Glasgow Coma Scale score is recorded during the secondary survey. AVPU denotes:

- Alert.
- Verbal stimulus response.
- Painful stimulus response.
- Unresponsive.

Breathing, circulatory problems and drugs may cause a diminished level of consciousness.

5. ***Exposure and environment*** is a reminder to expose and examine a victim, while keeping them warm and protecting medical personnel form risk and danger.

## Resuscitation

Resuscitation is undertaken in tandem with the primary survey, addressing life-threatening injuries as they are identified.

## Monitoring

Regular observations are essential and should be accurately recorded. Monitoring includes using an ECG monitor and pulse oximeter. A nasogastric tube and urinary catheter, which is a good monitor of perfusion, should be inserted.

## Secondary survey

The secondary survey includes obtaining a history, thorough examination, appropriate X-rays and specialist investigations.

## Specialist treatment and transfer

When a particular injury is identified, assistance from the relevant discipline should be requested, or the patient transferred to a suitable centre if local assistance is not available. Urgent transfer may be appropriate, or need arranging, before the secondary survey.

## Re-assessment

Constant re-assessment of a patient is vital during the resuscitation period. If there are signs of deterioration, or failure to respond, the safest course of action is to return to the start of the primary survey, re-evaluate and request assistance.

## X-rays

Chest and pelvic X-rays are mandatory requirements during initial resuscitation. A lateral cervical spine X-ray is required if there are any indicators of a neck injury.

# Further reading

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# Related topic of interest

Polytrauma – management and complications, p. 200

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## ...d topics of interest

...ects, transport and late reconstruction, p. 25; Non-union and delayed union, p. 153; ...ture management, p. 156; Principles of operative fracture management, p. 220

# PRINCIPLES OF NON-OPERATIVE FRACTURE MANAGEMENT

The closed treatment of fractures follows the standard algorithm of reduce, immobilize and rehabilitate. The three principal forms of immobilization are casting, functional bracing and traction. Operative fracture treatment has advantages in many cases; however, there are patients for whom non-operative treatment is preferable and others for whom non-operative treatment augments operative methods.

## Reduction

The principles of adequate closed reduction are:

1. ***Anaesthesia*** to provide analgesia and in some cases muscle relaxation.

2. ***Planning***, with a rehearsal of reduction and cast application.

3. ***Reduction*** to re-align the fracture. When skeletal stability is lost, the soft tissues may provide some stability. Charnley described utilization of the soft tissue hinge or 'ligamentotaxis', on the concavity of a fracture (dorsally in a Colles' fracture). In high-energy injuries the soft tissue envelope is disrupted to a greater extent than in low-energy injuries – consequently reduction will be less stable.

4. ***The reduction manoeuvre*** consists of the following (Colles' fracture procedure described in parentheses):
   - Disimpaction: traction, followed by increasing the deformity (dorsiflexing the distal fragment).
   - Reduction: the mechanism of injury is reversed (pronation and palmar flexion).
   - Locking the reduction: the distal fragment is brought into rotational alignment with the proximal; rotation is then exaggerated to lock reduction (further pronation).

5. ***Splint application*** with a moulded cast, to achieve three-point fixation, placing the soft tissue hinge under tension. (In a Colles' fracture the three points are dorsal, proximal and distal to the fracture, and volar just proximal to the fracture.)

6. ***Clinical and radiological assessment*** of the result and, if inadequate, repetition of the process.

7. ***Excessive swelling, haematoma or soft tissue interposition*** make the reduction more difficult. Interposed soft tissue requires open removal.

## Casts

Undisplaced fractures require splintage for analgesia and to prevent displacement. Displaced fractures, which have been reduced, require a moulded cast, as outlined above. Fractures without a soft tissue hinge are inappropriate for cast management.

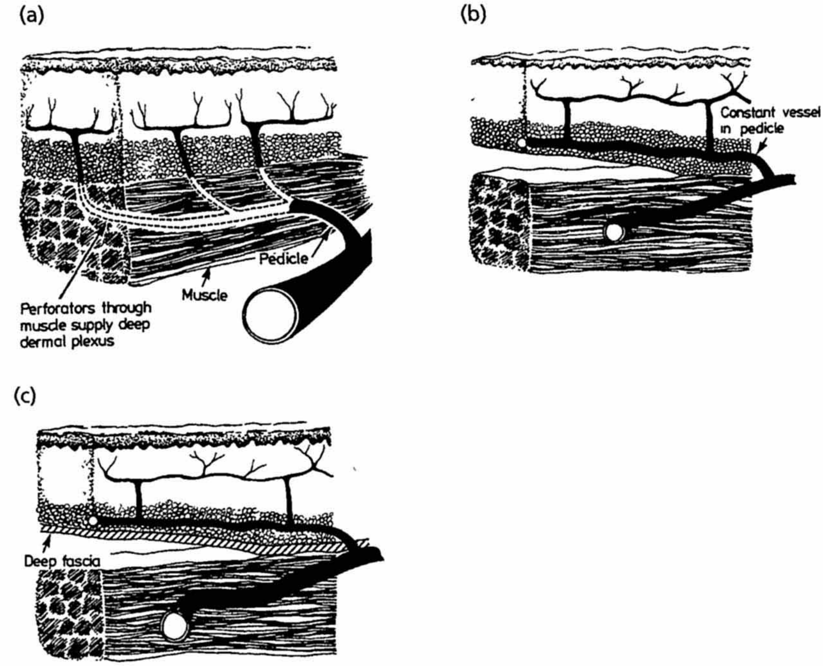


Figure 1. Blood supply to the skin. (a) Random pattern and myocutaneous flaps are based on perforating vessels from the muscle. The muscle can be rotated with or without the overlying skin. (b) An axial pattern flap. (c) A fasciocutaneous flap. This figure was first published in the BMJ (Davies DM Plastic and Reconstructive Surgery: Skin Cover, *BMJ* 1985, vol. 290, pp. 765–767) and is reproduced in modified form by permission of the BMJ.

the groin flap on the superficial circumflex iliac artery), where a specific cutaneous artery arising from a large artery, runs superficially to muscle in the subcutaneous fat. These vessels reinforce the musculocutaneous blood supply. The flap is raised so the vessels run axially, which allows the flap to be raised for a greater length than a random pattern flap. Such flaps are known as 'axial pattern' flaps (*Figure 1b*).

Random pattern flap size is limited, but can be increased by raising a flap with the deep fascia. This incorporates the superficial plexus of vessels into the random flap, forming a 'fasciocutaneous flap' (*Figure 1c*).

## The reconstructive ladder

In order of increasing complexity, wound closure can be achieved in the following ways.

***1. Delayed primary closure.*** This involves suturing the wound when the tissues are viable and not too tight.

***2. Healing by secondary intention.*** Allowing a wound to granulate and epithelialize may be appropriate in certain cases. However, this leaves a portal of entry for microbes, allows drying of tissue and often an unsightly scar.

**3. *Split skin grafting.*** This is frequently employed, often in combination with other techniques. A vascularized bed is required, so split skin grafts cannot be applied to bone (in the absence of periosteum), cartilage, tendon or nerve. The graft relies on vascular in-growth and to improve 'take rates' the graft should be sutured to its bed. Haematoma should be avoided by attention to haemostasis of the bed, or by applying the graft after a delay of 48 hours. Split skin can be 'meshed' to increase the area of coverage. Skin can be stored in saline gauze at 4°C for 2 weeks.

**4. *Full thickness skin or composite grafts***

**5. *Local flaps.*** These include:

- Cutaneous – random pattern, fasciocutaneous and axial pattern flaps. Random pattern flaps have a limited length, which is equal to the width of the base. Fasciocutaneous and axial pattern flaps can be raised to greater lengths.
- Muscle – a local muscle is rotated into the defect on a vascular pedicle.
- Myocutaneous – muscle, fascia and skin.

**6. *Free flaps.*** These include:

- Cutaneous – such as the groin flap.
- Muscular – commonly used muscles are latissimus dorsi, gracilis and the radial free forearm flap.
- Myocutaneous – free muscle with its overlying skin.
- Complex – including bone (free fibula or radius) and nerve. Nerve grafting can either give protective sensation (e.g. on the sole of the foot), or movement (e.g. gracilis to the forearm after Volkmann's).

## Choice of cover

Choice of tissue cover depends on:

- The nature of the injury. Low-energy injuries can often be reconstructed with a cutaneous or fasciocutaneous flap. For high-energy injuries, reconstruction with muscle improves the local blood supply, which clears staphylococci better than a cutaneous flap. In a high-energy injury, local damage may preclude the use of local tissues, necessitating a free flap.
- Surgical experience.
- The location of the injury. A flap of a size and contour that does not interfere with function should be used. Local flaps have obvious restrictions in the area covered.

## Skin flap failure rates

Failure rates can be reduced by avoiding:

- Systemic hypotension.
- Smoking.
- Infection.
- Haematoma.

- Tension in closure.
- Poor arterial inflow, which is more important than venous congestion.

With good technique, failure rates are <10% and may be lower for free rather than local flaps.

### Reconstruction techniques by location

Examples of these techniques are given below:

- Knee: one, or both heads of gastrocnemius.
- Tibia: proximal third – gastrocnemius.
  middle third – soleus.
  distal third – for low-energy wounds, a fasciocutaneous flap may suffice, but the majority require a free flap.
- Ankle: dorsalis pedis island pedicle flap, or a free flap, such as the radial free forearm. Both can be harvested as sensate flaps.
- Foot: plantar wounds require stable and sensate tissue. The medial plantar arch can be used as a sensate flap to cover the heel. For plantar wounds, innervated radial free forearm flaps have been used.

## Further reading


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## Related topic of interest

Amputation and replantation, p. 3

# RADIATION EXPOSURE

It is accepted that there is no safe dose of radiation. While the average dose to the orthopaedic surgeon in a single year has been shown to fall within national guidelines, understanding of the principles of radiation protection is important.

## Fundamentals of radiation biology

Ionizing radiation (e.g. X-rays, $\gamma$-rays) is defined as radiation with sufficient energy to release electrons from the atom. The electron release damages biological tissue, principally DNA. The unit of radiation absorbed is the Gray (Gy). The Gray is defined as 1 joule of ionizing radiation absorbed by 1 kg of matter; however, the Gray makes no allowance for the type of ionizing radiation. This is important as different types of ionizing radiation deliver their energy with differing spatial distribution and biological effect. Thus $\alpha$-particles are 20$\times$ more damaging than X- and $\gamma$-rays. This 'quality' factor (Q) is multiplied by the absorbed dose (D) to give the 'dose-equivalent' (H). H is measured in 'sieverts' (Sv).

As well as factors associated with radioactivity, different tissues have different sensitivities and the relative sensitivities are expressed as 'tissue weighting factors' ($w_t$). The organs most at risk are the gonads ($w_t = 0.25$), red bone marrow, lung, colon and stomach ($w_t = 0.12$). Gonadal irradiation causes both impairment of fertility and mutagenesis with resultant effects on offspring.

## The effects of radiation

Ionizing radiation can:

- Kill cells.
- Cause long-term damage.
- Cause site-specific effects such as cataracts.

Long-term damage is mediated through damage to DNA. While cell killing is not significant in diagnostic imaging, long-term effects remain a concern. Animal studies have shown that 1 Gy non-specifically reduces life expectancy by 5%. This non-specific effect is unproven in man. However, there is no doubt that radiation can induce cancer; osteosarcomas are reported in radium-dial painters and excess malignancy is reported in patients with ankylosing spondylitis treated by radiation.

## Environmental radiation

The average UK background radiation is 2.2 mSv per year (range 1.5–7.5 mSv), made up from various sources:

- 50% from radon gas, particularly in Devon and Cornwall.
- 14% from medical sources, such as X-rays, nuclear medicine scans and radiotherapy.
- 14% from $\gamma$-radiation in rocks and building materials.
- 11.5% from natural radionuclides ingested in food and drink.
- 10% from cosmic radiation.
- 0.5% from occupational sources, nuclear weapons testing, discharges and other sources.

**Table 1.** Dose from various common radiological procedures compared to a chest X-ray and background radiation levels

| | Typical effective dose (mSv) | Equivalent number of chest X-rays | Equivalent period of background radiation |
|---|---|---|---|
| Limbs and joints (excl. hips) | <0.01 | <0.05 | <1.5 days |
| Hip | 0.3 | 15 | 7 weeks |
| Pelvis | 0.7 | 35 | 4 months |
| Lumbar spine | 1.3 | 65 | 7 months |
| $^{99m}$Tc bone scan | 4 | 200 | 1.8 years |
| CT pelvis | 10 | 500 | 4.5 years |

*Table 1* summarizes the dose from various common radiological procedures, compared to a chest X-ray and background radiation levels.

## Principles of radiation protection

Radiation protection is based on three principles:

- Justification – a proposed intervention should do more good than harm.
- Optimization – the magnitude of the dose should be kept as low as reasonably achievable (abbreviated as 'ALARA').
- Limitation – exposure of individuals should be subject to a dose limit.

*1.* ***Staff safety.*** Adequate training and local rules are paramount. New members of staff should be trained and copies of the rules should be available. There are three physical factors involved in protection:

- Time – reduction of the time of exposure to radiation.
- Distance – ionizing radiation obeys the inverse square law, such that the dose reduces as the square of the distance between the individual and source increases.
- Shielding – protective screens, lead aprons, etc.

The International Radiological Protection Board recommend an occupational limit on the effective dose of 20 mSv for an individual in a single year. This corresponds to an increased lifetime risk of an induced fatal cancer of 4% and compares to the population risk of dying from cancer of 20–25%.

Monitoring is important and local rules dictate that some, or all, staff should wear a personal dosimeter, which may either be of the film or thermoluminescent sort.

*2.* ***Patient safety.*** The number of radiological examinations should be minimized. CT imaging must be carefully justified, as CT contributes almost half of the collective dose from all radiological examinations. The additional risk of a lifetime cancer is 1:1 000 000 for a chest X-ray compared to 1:2000 for an abdominal CT scan. However, these figures are small in comparison to the overall risk of 1:4.

*3.* ***Children.*** Children are at increased risk for two reasons:

- Under the age of 10 years there is an increased risk of carcinogenesis.
- The dose equivalent depends on organ mass. The organ mass in children is smaller, thus the dose equivalent in a child will be greater for the same administered dose.

*4.* ***Pregnancy and protection of the foetus.*** There is evidence of leukaemia and mental retardation when the foetus *in utero* is exposed to ionizing radiation. The Royal College of Radiologists recommend the following:

- Irradiation of the foetus should be avoided whenever possible.
- Women of reproductive age should be asked if they are, or may be pregnant when the pelvic area is going to be irradiated. This in effect includes any X-ray between the diaphragm and knees.
- If pregnancy is a possibility, the radiologist and referring clinician need to decide whether to delay investigation until after the next menstrual period.
- If pregnancy cannot be excluded, but the menstrual period is NOT overdue and the procedure gives a relatively low dose to the uterus, the examination may proceed. Examinations giving high doses of irradiation (e.g. IVP, pelvic and abdominal CT) should be performed in the first 10 days of the cycle. If the examination is considered necessary, despite the possibility of pregnancy, the dose of irradiation should be minimized and the decision to proceed clearly recorded.

Even if the foetus has been irradiated the risk rarely merits either invasive foetal diagnostic studies (e.g. amniocentesis), or termination of pregnancy.

## Further reading

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# RADIUS AND ULNA – DIAPHYSEAL FRACTURES

The bowed radius rotates around the ulna allowing supination and pronation. The aim of treatment is to restore bony anatomy and preserve movement.

## Classification

The most commonly used classification is one which divides the bones into thirds

4. dislocation in association with both radius and ulna fracture.

erally, a stable radial head reduction is achieved with ORIF of the ulna frac-
casionally open reduction is required, reduction being blocked by inter-
psule or annular ligament.

### ıre

ated ulna shaft fracture is usually not significantly displaced (angulation
anslation <50%) and can be treated in plaster. Displaced fractures require

### e

nt consists of ORIF of the radius (in some series 20% present with a
of both radius and ulna). Careful DRUJ assessment is essential. There are
ssible situations:

le DRUJ reduction (most common). Early mobilization is allowed.
ıced, but unstable DRUJ. A long-arm cast in supination usually holds the
ction. Occasionally K-wire fixation is required for 3 weeks.
DRUJ is irreducible, necessitating open reduction.

### early

***partment syndrome*** – vascular injury, coagulopathy and a crush injury
se to this emergency.

***e injuries*** are rare, excepting a posterior interosseous nerve palsy which is
20% of Monteggia fractures. This is usually a neurapraxia if occurring
eduction and most resolve spontaneously in 3 months.

***ular injuries*** which involve both vessels require urgent repair. Single vessel
associated with higher non-patency rates, possibly due to back flow.

### Complications – late

*1.* ***Stiffness*** depends upon the severity of the initial injury and precision of bony reduction. With ORIF, early mobilization is encouraged.

*2.* ***Fixation failure*** follows infection or poor surgical technique.

*3.* ***Infection rates*** are low, and should be treated by soft tissue debridement and maintenance of the plate fixation.

*4.* ***Synostosis*** occurs in 3%. The incidence is increased by: high-energy trauma, head injury, fracture of both bones at a single level, infection, a single surgical approach, surgery delayed more than 2 weeks, and screws or graft near the interosseous membrane. Synostosis is classified by Vince and Miller according to location:

- Type 1: at the DRUJ – responds poorly to resection.
- Type 2: middle two-thirds – amenable to resection.
- Type 3: proximal third – intermediate prognosis.

Resection is attempted after 1 year and before 3 years. These time intervals may be altered by the adjuvant use of single fraction radiotherapy.

*5.* ***Removal of metalwork*** should be performed with caution. Refracture rates are 4–20% and neurological injury 10–20%. Risk factors for refracture are removal of a 4.5 mm plate and early metalware removal. Bone density underneath a plate does not return to normal until a mean 21 months. Removal of symptomatic metalware is associated with worsening of symptoms in 9%.

## Further reading

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## Related topics of interest

Radius and ulna – distal fractures, p. 233; Radius and ulna – fractures around the elbow, p. 236

# RADIUS AND ULNA – DISTAL FRACTURES

Fractures of the distal radius and ulna represent one sixth of fractures presenting to the emergency department. Two characteristic fracture patterns present – the young patient with an intra-articular fracture following high-energy trauma, and the elderly osteoporotic patient who falls on the outstretched hand, suffering an extra-articular fracture.

## Classification

There are many classifications and Frykman (1967) was the first to differentiate between intra- and extra-articular fractures (*Figure 1*). Melone's (1980) classification subdivided intra-articular radial fractures depending on involvement of the radio-scaphoid, or scapho-lunate articulation, describing four principal bone fragments – the shaft, radial styloid and lunate fossa, split into dorsal and volar fragments. The AO system is the most complete, with 27 classes, however, inter-observer reliability is poor.

## Radiological imaging

On plain radiographs the most important normal values are:

- Volar tilt – 11°.
- Radial length – 11 mm between a transverse line across the radial styloid and across the distal ulna.
- Radial inclination – 22°.

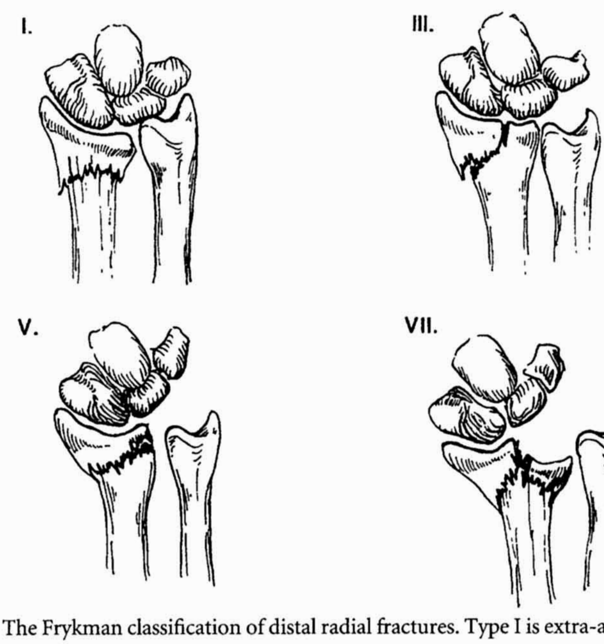


**Figure 1.** The Frykman classification of distal radial fractures. Type I is extra-articular, type III enters the radio-carpal joint, type V enters the radio-ulnar joint and type VII enters both the radio-carpal and radio-ulnar joints. The even numbers denote an associated ulnar styloid fracture (thus a type II fracture is an extra-articular fracture, associated with an ulnar styloid fracture, etc.). Modified from Kozin S.K. and Berlet A.C. *Handbook of Common Orthopaedic Fractures*, 1989, pp. 17, 19. Reprinted by permission of Medical Surveillance Inc.

These criteria determine treatment of extra-articular fractures. Less favourable results follow volar tilt changed >10°, radial inclination changed >5°, or >2 mm shortening. With intra-articular fractures, a step of >2 mm is significant. Articular disruption is better appreciated with CT or tomograms.

## Treatment

anatomical reduction protects patients with intra-articular fractures from degen-erative change. In extra-articular fractures the main predictor of a good result is th restoration of normal radio-carpal alignment.

### Distal radio-ulnar joint

The DRUJ is formed between the ulna and the sigmoid notch of the radius. The fl distal end of the ulna is covered by the triangular fibrocartilage complex (TFCC attaching to the fovea at the base of the styloid process.

DRUJ injury can be isolated (rare), or associated with other fractures. Th classic is the Galeazzi fracture dislocation, but DRUJ injuries occur in associatio with fractures of both forearm bones and distal radial fractures.

The most helpful radiograph is a true lateral of the wrist – judged by the supe imposition of the scaphoid, capitate and lunate. In this position the radius shou overlie the distal ulna. Avulsion at the base of the ulnar styloid is indicative of major TFCC injury. CT can be used to assess joint congruity. Isolated dislocatio are reduced and treated by a long arm cast applied in supination for dors dislocation and pronation for volar dislocation.

A small avulsion fracture from the ulnar styloid, associated with a distal radi fracture can be ignored. When the fracture are at the base, some advocate intern fixation, using a screw or tension band wire. Chronic radio-ulnar instability, arthritis, secondary to an old intra-articular fracture, are treated by the Sauve Kapandji operation.

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## Related topics of interest


Hand – carpal dislocation, p. 75; Radius and ulna – diaphyseal fractures, p. 230

# RADIUS AND ULNA – FRACTURES AROUND THE ELBOW

Simple fractures involving the radial head, coronoid process or olecranon, must be differentiated from fractures associated with ligamentous damage and elbow instability.

## Radial head

There are two principal ligamentous injuries associated with radial head fractures; firstly, elbow dislocation, and secondly, disruption of the radio-ulnar interosseous ligament – acute longitudinal radio-ulnar dissociation (ALRUD). With dislocation the aim is to prevent valgus instability and with ALRUD to prevent longitudinal forearm collapse.

1. ***Classification*** of radial head fractures is based upon the 'Mason' classification:

- Type 1 – non/minimally displaced.
- Type 2 – displaced >2 mm or 30°.
- Type 3 – comminuted.
- Type 4 – associated with elbow dislocation.

2. ***Clinical examination*** reveals a swollen elbow, secondary to haemarthrosis. The haemarthrosis can be aspirated and local anaesthetic instilled into the joint. As well as providing analgesia, this allows the pronation and supination to be assessed.

3. ***Radiological evidence*** of a fracture may only amount to a 'fat pad' sign.

4. ***Treatment*** is determined according to Mason's type.

- Type 1. Early mobilization.
- Type 2. There is no universal consensus. A common approach is to examine the patient for a mechanical block to supination/pronation. In the absence of a block, the treatment is early mobilization. Where there is a block, ORIF is performed. In comparison to non-operative treatment, this reduces pain and increases motion and grip strength. If the head is non-reconstructable it should be excised.
- Type 3. The head is excised and early mobilization commenced. The optimum timing for radial head excision is controversial. While late excision reduces pain and improves function, early excision gives even better results in the majority. If the elbow is unstable following radial head excision, the treatment options are the same as following fracture dislocation – see below. Radial head excision reduces the movement by 15° and leads to a mean 2 mm of positive ulnar variance, but seldom leads to elbow or wrist pain.
- Type 4. With associated dislocation, an attempt must be made to preserve the radial head, as acute excision leads to recurrent dislocation and valgus instability. If the radial head is not salvageable, even temporarily, there are three options:

(a) The collateral ligaments should be repaired.
(b) If the elbow remains unstable a prosthetic radial head is implanted.
(c) The final option is a hinged external fixator to maintain mobility during healing.

***5. ALRUD.*** Disruption of the interosseous ligament, or the Essex–Lopresti injury, can lead to progressive collapse of the radius on the ulna, if the radial head is excised. In these cases it is desirable to maintain radial length, by reconstructing the radial head, or using a metallic radial head prosthesis (silastic is inadequate). Temporary DRUJ stabilization with wires may also be helpful. Acutely, the problem is distinguishing this more serious pattern of injury from simple radial head fracture, but associated wrist and forearm pain may be indicative.

## Coronoid process

The coronoid process forms an anterior buttress to the elbow. The anterior capsule and medial collateral ligament attach to the coronoid process and the brachialis inserts just distal. Two to ten per cent of elbow dislocations have associated coronoid fractures. A third of coronoid fractures are secondary to elbow dislocation. Malunion of large coronoid fragments can lead to elbow instability or cause a mechanical block to motion.

***1. Classification.*** Regan and Morrey described three types:

- Type 1 – avulsion of the coronoid tip.
- Type 2 – <50% of the process.
- Type 3 – >50% of the process.

***2. Treatment.*** Type 1 fractures are stable and treated with early mobilization. All type 3 and some type 2 injuries are unstable, requiring fixation. If ORIF does not stabilize the elbow, a hinged external fixator is added.

## Olecranon

Olecranon fractures are most commonly caused by the pull of the triceps, or a fall onto the olecranon.

***1. Classification.*** Numerous systems exist and that described by Colton is popular:

- Type 1. Non-displaced and stable.
- Type 2. Displaced.
    - A. Avulsion.
    - B. Transverse.
    - C. Comminuted.
    - D. Fracture/dislocation.

***2. Non-displaced fractures.*** These are treated in a cast for 3 weeks, after which supervised mobilization is commenced.

***3. Displaced fractures.*** Many techniques are described for displaced fractures, but tension band wiring, plating and olecranon excision are the principal options.

Transverse fractures are usually treated by tension band wiring, converting the tensile force into a compressive force. The tension band is supplemented by K-wires or a screw; 97% excellent or good results are reported. A screw reduces the irritation caused by prominent hardware. Oblique fractures can shorten with tension band wiring. Shortening is overcome by using a lag screw or a plate (pelvic reconstruction), which is preferable in the comminuted fracture.

Some authors prefer excision of the olecranon and reattachment of the triceps in the elderly. Up to 60% of the olecranon can be excised without destabilizing the joint.

***4. Elbow dislocation.*** An olecranon fracture associated with elbow dislocation requires stable ORIF with a plate. Tension bands and wires do not have sufficient strength to resist the large AP forces.

***5. Complications.*** Metalware prominence from backing out of wires, is probably the commonest complication. Non-union, reported in 5%, can be treated by grafting and refixation, or excision of the fragment and triceps repair. Limited range of motion occurs in 50%, but <5% of patients complain.

## Further reading

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Morrey BF. Complex instability of the elbow. *Journal of Bone and Joint Surgery*, 1997; **79A**: 460–469.

## Related topics of interest

Elbow dislocation, p. 43; Humeral fractures – distal, p. 107

# SHOULDER – ACROMIOCLAVICULAR AND STERNOCLAVICULAR DISLOCATION

## Acromioclavicular joint

### Classification

Tossy classified injury of the ACJ into three types. This has been increased to six by Rockwood (*Figure 1*). Of these six types, 98% are type I, II or III (*Table 1*). Controversies regarding operative or non-operative management centre around type III which make up 40% of all ACJ injuries.

ed traction injuries account for >75% of lesions. Lesions may be at more than level.

e 1. Leffert classification of brachial plexus injuries

| | | |
|---|---|---|
| Open | | |
| Closed | IIA | Supraclavicular |
| | | Preganglionic – nerve root avulsion |
| | | Postganglionic – traction injuries |
| | IIB | Infraclavicular |
| Radiotherapy induced | | |
| Obstetric | IVA | Upper root (Erb's palsy) |
| | IVB | Lower root (Klumpke's palsy) |
| | IVC | Mixed |

The Sunderland classification is also popular, with five degrees of brachial us injury of increasing severity – neurapraxia is 1st degree, axonotmesis 2nd ee, lesions of increasing severity but in continuity 3rd and 4th degree, and plete transection is 5th degree.

### and investigation

areful history and detailed examination, with a sound appreciation of the omy, will reveal the nature of the lesion in only 60% of cases. Associated ular (15%) and musculoskeletal injuries are common.

Root avulsions occur proximal to the dorsal root ganglion, with loss of dorsal sensibility and denervation of dorsal neck muscles; plexus ruptures occur more distally. Mapping sensory and motor defects gives a good indication of the nature of the injury. Paralysis of the rhomboids or serratus anterior implies a proximal, usually preganglionic lesion, at the C5 or C6 level, respectively. Horner's sign (ptosis, miosis, anhidrosis, enophthalmos) implies a preganglionic C8/T1 lesion of the cervical sympathetic chain.

Chest, cervical spine and shoulder X-rays are mandatory. Further assessment with EMG studies may be necessary to localize the site of the injury. Supraclavicular injuries may need investigation with a CT myelogram or MRI, if surgery is contemplated. In cases of root avulsion pseudomeningoceles may be seen, which alter the prognosis and management. Investigation should be delayed a few weeks to allow CSF leaks to seal.

At a later stage, usually 3–4 weeks, the development of Tinel's sign implies recovery of a postganglionic injury – a favourable prognostic sign.

## Treatment

Open, or penetrating injuries require primary surgical exploration and repair. Nerve roots cannot be reattached – although research is making some progress into this.

In the past, most closed injuries were treated by observation for 3 months, maintaining passive movement and using functional bracing if suitable. When there are no signs of recovery, or recovery ceases, surgical exploration with neurolysis and nerve grafting was undertaken.

The timing of surgery is controversial and now changing. Where the lesion is extensive there is now an increasingly strong argument in favour of early exploratory surgery, as both a diagnostic and therapeutic procedure. Surgery after 6 months has very poor results. When surgery is delayed, fibrous tissue encases the nerves, making the anatomy and pathology more difficult to define.

## Surgical reconstruction

1. ***Priorities of surgery*** are to restore:

- Shoulder stability.
- Shoulder external rotation.
- Elbow flexion (some clinicians make this the priority).
- Wrist extension.

2. ***Principles of surgery*** are to perform:

l (10%) thirds (Allman).
teral third are subclassified into types I to V, based upon
lavicular ligament (CCL) complex:

ed.
roximal to conoid and trapezoid ligaments.
etween the conoid (proximal) and trapezoid ligaments.
to ACJ.
l separation (children).
fracture, with intact ligaments connected to the middle frag-

ion

elated to the brachial plexus, subclavian and axillary vessels,

***3. Many techniques for operative fixation have been described.*** Intramedullary techniques allow closed fixation, but there is a significant risk of implant breakage or migration in this anatomically complex area. Plate fixation requires wide fracture exposure and raises the incidence of non-union. This is reduced by a low threshold for bone grafting.

***4. Other techniques employed*** are coracoclavicular screw fixation for distal-third fractures with CCL disruption, and resection of the distal clavicle in cases of degenerative change following type III distal-third fractures.

***5. A 'sensible' approach*** is to recommend non-operative treatment in the majority of middle-third fractures. In those cases requiring surgery, a plate and bone graft can be used. Distal third types I and III are treated conservatively, but type II and V fractures have higher non-union rates and the results of ORIF are superior.

## Complications

***1. Non-union*** is defined as the absence of clinical or radiological union at 6 months, occurring most frequently in distal-third fractures, although because middle-third fractures are more common, these patients present most frequently.

In the middle third, risk factors are severe trauma (with greater displacement and soft tissue disruption), primary ORIF, refracture, inadequate immobilization and patient age. Following non-operative treatment, the reported incidence varies from 0.1 to 4.0%. Neer reported a series with non-union of 0.1% after non-

ding to rehabilitation and rarely requiring surgery with an inferior capsular shift RI). This topic deals with acute management of the dislocated shoulder, rather than c instability.

## fication

The direction of dislocation is the most useful system of classification for acute dislocation, as TUBS and AMBRI refer to non-acute situations. Thirty eight per cent of all joint dislocations involve the glenohumeral joint, of which 98% are anterior. Anterior dislocation is usually subcoaracoid, but can be subglenoid, subclavicular, or even intrathoracic. The remaining 2% are posterior, with the exceptional inferior 'luxatio erecta' and superior dislocation.

## al examination

Anterior dislocation occurs with the shoulder in extension, abduction and external rotation. Following dislocation the upper arm is held in slight abduction and external rotation. Characteristic emptiness is felt beneath the acromion.

More than 50% of posterior dislocations are missed at first presentation. The diagnosis should be suspected if the patient has a flat anterior contour of the shoulder, a prominent coracoid and difficulty abducting the arm. The most striking clinical finding is inability to externally rotate the shoulder.

Inferior dislocation presents with an arm fixed in abduction and the humeral head locked under the glenoid.

## logical evaluation

Three views are recommended:

- AP in the plane of the shoulder (plate parallel to the scapula, not the body).
- Scapular lateral.
- Axillary.

**2. *Posterior dislocation.*** Traction is applied along the adducted arm. Forceful external rotation should be avoided, as it can cause fracture.

**3. *Inferior dislocation.*** This can usually be reduced by traction, but occasionally the head buttonholes through the capsule, necessitating open reduction.

## Post-reduction care

Following reduction, neurovascular evaluation and radiographs should be repeated. Many surgeons use immobilization for 3 to 6 weeks following anterior dislocation. However, there is little evidence that the duration of post-reduction immobilization is related to the incidence of recurrent dislocation. Indeed there is evidence that an early rehabilitation programme reduces the incidence of recurrence, particularly in patients with an AMBRI lesion.

Early mobilization is particularly desirable in the patient over 40 years old. The emphasis should be on avoiding stiffness, strengthening the muscular stabilizers and avoiding positions provoking instability in this age group.

Up to 10% of patients can have significant neurological impairment, o

injuries of the brachial plexus.

Simple fractures of the body of the scapula do well with closed treatmen sling, followed by assisted mobilization. Even in the presence of significan placement, the resultant disability from body fractures is small.

Fractures of the scapular neck can result in a high incidence of residual disability. Patients with a displaced neck fracture with $>40°$ of angulation in either the transverse or coronal plane, or $>1$ cm of displacement, may require open reduction and internal fixation. Displaced fractures of the glenoid, especially when associated with glenohumeral instability, should be reduced and fixed in order to lessen the subsequent risk of glenohumeral osteoarthritic change or shoulder instability.

Fractures of the spine of the scapula can result in rotator cuff malfunction with pain and weakness on abduction. Scapular spine fractures at the base of the acromion and those with $>5$ mm of displacement may be at risk of non-union and should be considered for surgical treatment.

### Surgical approach

The surgical approach is anterior for anterior glenoid rim and coracoid fractures. Posterior glenoid rim, neck and glenoid fossa fractures are best accessed through a posterior (Judet) approach.

### Results

The reports of surgical fixation are few, but good or excellent results are reported in 79% of cases, in some series.

## Further reading


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## Related topics of interest


Humeral fractures – proximal, p. 110; Humeral fractures – shaft, p. 113; Shoulder – acromioclavicular and sternoclavicular dislocation, p. 239; Shoulder – brachial plexus injuries, p. 243; Shoulder – clavicle fractures, p. 246; Shoulder – dislocation, p. 249

# SPINAL CORD INJURY – ASSESSMENT AND MANAGEMENT

The management principles for the patient with spinal injuries are:

- Resuscitation.
- Assessment and investigation.
- Spinal immobilization.
- Prevention and management of complications.
- Rehabilitation.

## Resuscitation

The priority in trauma management is, of course, resuscitation, following the principles of ATLS, with airway, breathing, circulation and haemorrhage control, 'saving life before limb'. Control of the spine is paramount during resuscitation and transfer. The spine is immobilized in the neutral supine position, on a long spinal backboard, with a hard neck collar, tape and sandbags.

Hypotension may be due to hypovolaemia or neurogenic shock. In most cases, particularly in multi-system trauma, hypovolaemia is the usual cause of shock. Treatment is initially volume replacement; failure to respond may indicate neurogenic shock. Typically with neurogenic shock there is a bradycardia. Treatment with leg elevation, atropine and occasionally vasopressors is required.

## Assessment and investigation

***1. History.*** A clear description of the accident is useful in determining whether there is an occult spinal injury, the extent and level of primary cord or root trauma, and any likely associated injuries. Polytrauma may result in delayed diagnosis of spinal injury, especially in the cervical spine.

***2. Examination and special tests.*** A full examination of the spine and detailed peripheral neurological assessment is undertaken. The patient is log-rolled, by four experienced personnel, with the examiner observing for visual signs of head or spinal injury such as abrasions, tenderness, step off, interspinous widening, etc.

***3. Neurology.*** Levels of motor and sensory function are summarized in *Table 1*. Reflex activity is indicative of the nature and level of cord injury (*Table 2*). Absent reflexes are indicative of spinal shock, or a lower motor neurone lesion. Brisk reflexes are indicative of an upper motor neurone lesion or intracranial event. The bulbocavernous reflex and anal wink test are indicators of spinal cord function. The return of these reflexes marks the cessation of spinal shock.

***4. Investigations.*** Initially, plain X-rays are sufficient to establish spinal alignment and bony deformity. CT is useful to determine the extent of a fracture and plan operative intervention. MRI delineates cord injury, especially local haemorrhage or oedema. MRI is particularly useful where there is no obvious bony injury and in bifacet cervical dislocations where disc prolapse is suspected.

Table 1. Levels of motor and sensory function

| Level | Motor function | Sensory function |
|---|---|---|
| C3,4,5 | Diaphragm | |
| C4 | | Clavicle |
| C5 | Elbow flexion | Lateral arm |
| C6 | Wrist extension | Radial forearm/thumb |
| C7 | Finger extension | Long finger |
| C8 | Finger flexion | Ulnar hand |
| T1 | Finger abduction | Ulnar forearm |
| T2 | Intercostals | Medial arm/axilla |
| T4 | Intercostals | Mid sternum |
| T7 | Intercostals | Xiphoid |
| T10 | Intercostals | Umbilicus |
| T12 | Intercostals | Inguinal |
| L1 | Hip adductors | Upper thigh |
| L2 | Hip flexion | Mid thigh |
| L3 | Knee extension | Knee |
| L4 | Ankle dorsiflexion | Medial shin |
| L5 | Great toe extension | Lateral calf, dorsum foot |
| S1 | Ankle plantar flexion | Lateral foot, posterior leg |
| S2 | | Posterior thigh |
| S3,4,5 | | Peri-anal |

Table 2. Reflexes levels

| Reflex | Level |
|---|---|
| Biceps | C5 |
| Supinator | C6 |
| Triceps | C7 |
| Knee | L4 |
| Ankle | S1 |

## Spinal immobilization

***1. Immobilization*** of the 'unstable' spinal column is required to prevent secondary injury. This may be achieved by non-operative or operative means. Non-operative immobilization may be safely continued, with bed-rest, supervised nursing care, neck collar, tape and sandbags, etc. Skeletal traction via tongs or a halo is more secure and makes nursing easier in cervical spine injuries. Halo traction can be converted to halo-vest immobilization for early rehabilitation.

***2. Operative immobilization*** of spinal fractures in the patient with a cord injury is controversial.

(a) Absolute indications for operative intervention:

- Severe malalignment.

- Progressive neurological deficit.
- Cauda equina syndrome.

(b) Relative indications for operative intervention:

- Incomplete deficit.
- Complete deficit with unstable fracture configuration.
- Polytrauma.
- To facilitate earlier transfer, nursing care and rehabilitation.
- Unacceptable alignment (angulation exceeding 30° in the saggital plane).

*3.* ***Surgical decompression.*** There is no clear evidence to support operative decompression except in the case of a progressive neurological deficit.

## Prevention and management of complications

*1.* ***Complications.*** These include:

- Pressure sores.
- Infection – urinary, respiratory, skin.
- Gastrointestinal perforation or haemorrhage.
- Deep venous thrombosis (DVT) and pulmonary embolism.
- Shock.
- Autonomic dysreflexia.
- Joint contractures.
- Death.

Urinary retention or faecal impaction may precipitate autonomic dysreflexia, which manifests as headache, anxiety, sweating, nasal obstruction and blurred vision.

*2.* ***Prevention.*** The patient with a spinal cord injury is best managed in a specialized unit and early transfer after initial stabilization is advised. Most hospitals have a 'spinal protocol' for medical and nursing staff to follow. The protocol should include:

- Spinal immobilization control at all times on a spinal bed.
- Skin care with 2-hourly turning, logrolling, a well-padded mattress, etc.
- Gastric decompression by nasogastric tube if required.
- Intravenous fluid support.
- Bladder catheterization.
- Mechanical DVT prophylaxis.
- Monitoring for neurogenic shock and autonomic complications.
- Judicious antibiotic administration for infections.
- Adequate analgesia.
- Early physiotherapy.

*3.* ***Cord oedema control (steroids).*** The present evidence marginally favours early steroid administration in cord injury, in an attempt to reduce secondary cord injury and reduce the level of injury from oedema. However, such treatment has obvious risks and remains highly controversial. Methylprednisolone acts by membrane stabilization, decreasing inflammation and oedema; whether this leads to improved useful motor function is unclear. However, the gain of even minor grades of motor function at the cervical level may make a considerable difference.

The standard regime is a bolus dose of methylprednisolone (30 mg/kg) within 8


**Figure 1.** Denis' three columns. ALL, anterior longitudinal ligament; PLL, posterior longitudinal ligament; SSL, supraspinous ligament. Reprinted from Browner BD, Jup Levine AM, Trapton PG, *Skeletal Trauma*, 1998, p. 967, fig 32–20, by permission of W Saunders Company.

- Posterior: facet joints, ligamentum flavum, posterior arch, spinous p and interspinous and supraspinous ligaments.

The principle of Denis' system is that if two columns are fractured th spine is likely to be 'unstable'. Remember, however, that a column constitut tissue as well as bone!

***3. AO alphanumeric system.*** An accurate comprehensive, mechanistic s incorporating the concepts of stability. While this system may prove to b dictive, it is not yet universally accepted as 'usable'. It is based upon Holdsw two-column model.

- Type A: vertebral body compression; 1: impaction, 2: split, 3: burst. U stable.
- Type B: anterior and posterior element injury with distraction; po disruption; 1: ligament, 2: bony, 3: + anterior disruption.
- Type C: anterior and posterior element injury with rotation; 1: typ rotation, 2: type B + rotation, 3: rotational shear.

### Sacral fractures

***1. Vertical.*** These form part of a pelvic injury. Classified by Denis into ty III; type I – lateral to neural foramen, type II – through foramen, and typ medial to foramen.

***2. Transverse.*** Fractures are undisplaced or displaced and are really fractures which do not affect pelvic stability. Treatment is symptomatic.

## C. Stability

Stability is defined as 'the ability of the spine under normal physiological lo maintain a normal relationship between vertebrae, such that neurological tures are not injured and deformity or pain does not develop'. It is best to co this with respect to the *acute* and *chronic* states.

***1. Acute.*** If the patient is mobilized immediately, will one vertebra move with respect to its neighbour, putting the cord or nerve roots at risk?

***2. Chronic.*** Will 'physiological loads', for example walking, in time lead to progressive unacceptable deformity and pain?

If the answer to either of these questions is 'yes', then the spine may be considered 'unstable' and management to control stability should be instigated. This may be non-operative or operative.

## Further reading


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## Related topics of interest


Spinal cord injury – assessment and management, p. 254; Spine – C3 to C7, p. 269; Spine – occiput to C2, p. 272; Spine – thoracic and lumbar fractures, p. 275


- TLO: Thoracolumbar orthosis.
- TLSO: Thoracolumbosacral orthosis.
- LSO: Lumbosacral orthosis.

Most spinal orthoses act as static splints using the princi
are made from various materials, ranging from soft elastic
depending on the degree of support required.

### Cervical orthoses

The degree of immobilization varies with ve
material and design (*Table 1*). The range of devi

***1. Soft collars.*** These are constructed from fo
tissue support, but minimal skeletal support.
type' injuries, stable fractures (such as clay sh
collars.

***2. Semi-rigid collars.*** For example the 'Phil
for partial immobilization of stable flexion fra
two-piece plastazote collar, which provides g
restricting flexion and extension. The Airflow
ethylene with or without a chin extension.

Table 1. Extent of immobilization achieved with cervical orthoses

| Orthosis | Reduction in movement (%) | | |
|---|---|---|---|
| | Flexion/extension | Rotation | Lateral flexion |
| Soft | 20 | 15 | 10 |
| Semi-rigid | 70 | 20 | 40 |
| Rigid | 95 | 90 | 90 |
| SOMI | 70 | 70 | 40 |
| Halo | 95 | 95 | 95 |

## Thoracolumbosacral orthoses

Many orthoses are available, ranging from simple elasticated canvas belts, to rigid plastic or plaster jackets with increasing degrees of immobilization. None is very effective in supporting above T8. In the trauma setting there are essentially two types:

- Hyperextension brace.
- TLSO.

Both utilize three-point fixation with anterior sternal, suprapubic/pelvic and posterior thoracolumbar pads to resist flexion. Hyperextension braces are used for stable flexion fractures. The TLSO extends to the pelvis, providing some rotation and lateral bending resistance.

6. ***Further imaging.*** CT can be used for evaluation. The role of MRI to exclude a disc herniation is unclear. Cases of neurological deterioration due to disc retropulsion during reduction have been reported, but a risk/benefit assessment is required. If obtaining MRI causes unacceptable delay, especially in a conscious patient who is having the spine reduced under neurological and radiological monitoring, a scan is not obligatory.

## Unilateral facet dislocation

Classical presentation is with the chin turned to the opposite side and the neck laterally flexed to the injured side. Seventy per cent have a radiculopathy, 20% are normal and 10% have spinal cord injury. The vertebral body is anteriorly subluxed 25% on plain lateral X-ray. The injury is often missed and is more easily demonstrated on oblique views. Reduction is by traction (often unsuccessful), or open reduction. Stabilization is either with a halo, or preferably posterior cervical fusion due to the incidence of non-union.

## Bilateral facet dislocation

On lateral X-ray there is 50% anterior shift of the vertebral body. This is frequently associated with spinal cord injury and 9% of patients have disc material in the canal. In the absence of extruded disc material, reduction is usually achieved by traction. Immobilization using a halo has been associated with an unacceptably high incidence of non-union, and surgical fusion has been recommended.

## Flexion injuries

If the anterior column is <25% compressed, the fracture is technically stable and can be treated with an orthosis. Fractures involving >25% anterior column compression, or the middle column, are unstable. Immobilization in a halo, or open reduction (usually anterior corpectomy) and stabilization, is required. The teardrop fracture (triangular fragment from the antero-inferior vertebral body) is associated with compression injury of the spine and instability. This can be treated by anterior decompression and fusion.

## Extension injuries

Extension injuries are usually associated with compression. The most common pattern is fracture of the laminae, facets and pedicles. Laminar fracture is often associated with a facet or pedicle fracture. Bilateral laminar fractures are associated with major vertebral body injuries.

## Ankylosing spondylitis

Fractures of the cervical spine in patients with ankylosing spondylitis are unstable, easily overlooked and associated with a high incidence of neurological injury. Immobilization in a halo or with surgical stabilization is required.

## Clay shoveller's fracture

This is an isolated fracture of the spinous processes, most commonly C7, and is a stable injury in the absence of further ligamentous damage. Assessment is by flexion/extension views, and if the spine is stable, treatment is symptomatic in a collar.

## Principles of treatment

*1.* ***Traction.*** The cervical spine can be stabilized using Gardner–Wells tongs and 5 kg of traction. After application, a lateral film should be obtained and neurological observations undertaken. Closed reduction should be attempted in all patients with malalignment. Reduction is performed under close radiological and neurological

## Occipito-atlantal dislocation

Usually a fatal injury caused by a combination of hyperextension, rotation ar distraction. X-rays can be dramatic, but less severe injuries may be overlooke Injuries are of three types, with the occiput lying anterior, posterior, or distracte from its articulation with the atlas. Acute treatment is by application of a halo vest traction is contraindicated. Definitive treatment is with occipito-cervical fusion.

## C1 fractures

- Axial loading of C1 can cause the ring to fracture and the classic 'Jefferso fracture is a four-part fracture in which the lateral masses are displace laterally. Instability is determined according to the integrity of the transver ligament, implied on the plain X-ray if the atlanto-dens interval is >3 mm, or the measured sum of the overhang of the lateral masses is >8 mm. CT ma show bony avulsion of the ligament and MRI images the ligament directly.
- Stable fractures are treated in a hard collar.
- Unstable fractures require 8 weeks in a halo, followed by 4 weeks in Philadelphia collar.

- Some patients progress to stable fibrous union and, if asymptomatic, do not require treatment. If symptomatic (causing pain and torticollis), but stable, a C1–C2 fusion can be performed.
- If there is residual instability, an occipito-C2 fusion is necessary.

## C1–C2 subluxation

Rupture of the transverse ligament is diagnosed when the atlanto-dens interval is >4 mm. If associated with bony avulsion confirmed on CT, a halo can be used; otherwise C1–C2 fusion is indicated.

## Atlanto-axial rotatory subluxation

Rotation between C1 and C2 is typically seen in children, but also in adults, and occurs either spontaneously, or following trauma. The classification is based upon the paediatric spinal classification of Hawkins and Fielding. The only difference is that rupture of the transverse ligament should be suspected if the atlanto-dens interval is >3 mm (rather than 5 mm in children). Treatment with a short period of traction is followed by a cervical orthosis. Posterior fusion is rarely indicated.

## Odontoid peg fractures

Peg fractures have been classified by Anderson and D'Alonzo (*Figure 1*).

- Type 1 fractures are at the tip, above the transverse ligament, and are caused by alar ligament avulsion. These fractures are stable and treated in a collar or brace.
- Type 2 fractures are level with the body of the axis, which is a watershed for the blood supply. Non-union rates of 67% have been reported. The risk of non-union increases with displacement of >4 mm, angulation of >10°, in patients who smoke and those over 40 years old. The results of treatment in a halo are better if the fracture is reduced. Surgical techniques include posterior C1/C2 fusion and transoral fixation with one or two screws into the peg.
- Type 3 fractures pass into the cancellous body of C2, with an 85–90% union rate after 12 weeks of halo treatment.

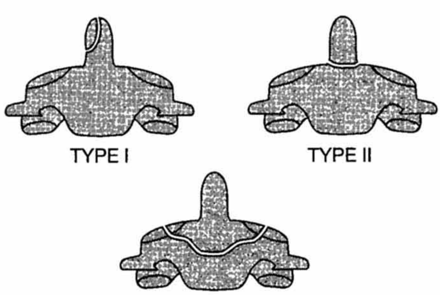


**Figure 1.** The Anderson and D'Alonzo classification of odontoid fractures. From Anderson LD, D'Alonzo RT (1974) Fractures of the odontoid process of the axis. *Journal of Bone and Joint Surgery*, vol. 56A, pp. 1663–1674. Redrawn by permission of the Journal of Bone and Joint Surgery, Inc.

### Traumatic spondylolisthesis of the axis

This injury is caused by hyperextension and axial loading. Typically these injuries widen the spinal canal and therefore rarely produce neurological damage. The traditional 'Hangman's fracture' (extension in association with distraction) is seldom seen today. Spondylolisthesis of the axis was classified by Effendi and later modified by Levine:

- Type I: a stable injury with <3 mm displacement, treated in a collar for 6 weeks.
- Type II: an unstable injury, with >3 mm C2/3 displacement and angulation. Traction in slight extension usually achieves reduction, followed by application of a halo for 6 to 8 weeks.
- Type IIA: Levine proposed 5% of patients have this pattern of injury, from **flexion**-distraction and resultant C2/3 disc disruption. Angulation between C2 and C3 is more severe. These injuries mimic the traditional Hangman's fracture and with traction the cord can be distracted. A halo in slight compression and extension is required.
- Type III: a pars fracture, with uni- or bi-facet dislocation of C2/C3 and associated neurological injury. Treatment is again with traction, followed by halo immobilization. If the dislocation is irreducible, MRI is required to exclude disc herniation. A posterior fusion is performed between the inferior facet of C2 and the spinous process of C3. If the reduction of the body of C2 cannot be maintained, anterior fusion should be considered.

## Further reading


**Clark CR, White AA.** Fractures of the dens: a multicenter study. *Journal of Bone and Joint Surgery*, 1985; **67A**: 1340–1348.

**Fielding JW, Francis WR Jr, Hawkins RJ *et al.*** Traumatic spondylolisthesis of the axis. *Clinical Orthopaedics*, 1989; **239**: 47–452.

**Levine AM, Edwards CC.** Fractures of the atlas. *Journal of Bone and Joint Surgery*, 1991; **73A**: 680–691.


## Related topics of interest

Paediatric spine trauma, p. 177; Spine – C3 to C7, p. 269

# SPINE – THORACIC AND LUMBAR FRACTURES

The objectives of spinal management are to prevent further displacement and neurological injury. Pre-hospital transport involves in-line immobilization on a long spinal board and a hard cervical collar. The initial management of the patient with a spinal injury in the Accident and Emergency Department follows ATLS guidelines, to identify and treat life-threatening conditions. Assessment, management and transfers should maintain in-line spinal control with log rolls and five-person lifts. Patients should be cared for in dedicated wards by personnel experienced in spinal injuries and many units have a spinal injury protocol.

## Initial management

39 (Australia) and 70 (Quebec) per 100 000. There are an estimated 250 000 cases per annum in the UK.

The most common age group involved is 20–24 years. Women are affected twice as often as men, and front seat passengers twice as often as those in the rear.

## Treatment

1. ***Mobilization.*** Soft collars do not immobilize the neck. Immobilization, or 'rest', of the neck has been shown to slow recovery. The recommendation is that mobilization (Maitland manipulations encourage neck movement) is started within 72 hours – this may be supervised by a physiotherapist, or take the form of education and home exercise. In all cases the emphasis is on early return to normal activities, and reassurance that the injury is a benign and self-limiting condition for the majority.

*...ronchial tree ruptures* are uncommon, occurring in fewer than ... chest injuries. The diagnosis is suspected if widespread surgical

emphysema or prolonged drainage through a thoracostomy tube are observed. Surgical closure is required.

*8.* ***A haemothorax*** occurs in isolation or with a pneumothorax. This can lead to ventilatory and circulatory collapse. Drainage of the blood is required after establishing venous access, as there may be sudden massive haemorrhage. Haemorrhage is usually self-limiting. If the initial drainage exceeds 1500 ml, or persistent drainage exceeds 200 ml/hour, surgical thoracotomy is required.

*9.* ***Rupture of the diaphragm,*** usually on the left, with herniation of abdominal viscera, impairs ventilation. Initial X-rays can be difficult to interpret. A nasogastric tube may help the diagnosis. Surgical repair is required. Late presentation occurs and 50% of hernias are diagnosed more than 1 year after injury.

*10.* ***Penetrating cardiac injuries and cardiac tamponade*** follow a sharp or penetrating injury. The diagnosis is often difficult in a noisy resuscitation room and a high index of suspicion is required. Draining 10 to 20 ml of blood from the pericardium can increase the cardiac output by 2 l/min.

*11.* ***Great vessel disruption*** usually results in sudden death. However, smaller defects in the great vessels are often repairable, if diagnosed promptly. Failure to respond to fluid resuscitation, or a widened mediastinum on chest X-ray are indicative of this injury.

*12.* ***Myocardial contusion and valve damage*** may follow a severe crush injury.

## Investigation

In addition to clinical signs, a chest X-ray, ECG or CT scan may be required.

## Resuscitation procedures

*1.* ***Needle thoracocentesis*** is performed as a life-saving procedure to relieve a tension pneumothorax in a rapidly deteriorating patient. An over-the-needle wide bore (14 gauge) cannula is passed over the second rib in the mid-clavicular line, after skin preparation and, ideally, local anaesthetic. Leaving the cannula in place, attached to a three-way tap, allows relief of any reaccumulation prior to establishing a definitive tube thoracostomy.

*2.* ***Insertion of a thoracostomy tube*** is a surgical procedure and should be undertaken by skilled personnel, with appropriate facilities. Ideally the insertion site is the fifth intercostal space in the anterior axillary line. After advising the patient of the procedure, the skin is cleaned and infiltrated with local anaesthetic. A transverse incision is made, followed by blunt dissection through the subcutaneous tissues and over the fifth rib, through the pleura. A finger is inserted into the thorax before introducing a clamped thoracostomy tube (26–30 French gauge). This is connected to an underwater sealed drain or a flutter valve. The thoracostomy tube is sutured in place and dressed.

*3.* ***Needle pericardiocentesis*** is performed with a 16 gauge, 15 cm over-the-needle catheter, with a three-way tap. Monitoring with ECG is essential. The needle is advanced at an angle of 45° to the skin, from an entry site 2 cm below the xiphoid, towards the tip of the left scapula. If the myocardium is penetrated the

and minimize swelling. High elevation with or without cr

Correction of deformity and stabilization is by simpl

or traction with a calcaneal pin or external fixator.

Further imaging is undertaken over the next few days

## 284 TIBIAL PILON FRACTURES

## Definitive management

The objectives are:

- Anatomical reduction of the articular surface.
- Restoration of length.
- Bone union.
- Non-infected, viable soft-tissue envelope.
- Early movement and restoration of function.

1. ***Grade I fractures*** may be managed non-operatively, with cast immobilization for 6 weeks, followed by 6 weeks graduated weight-bearing. Surgical stabilization allows earlier movement.

2. ***Grade II and III fractures*** are difficult and unforgiving injuries. Various techniques have been advocated.

Open reduction with a fibular plate to restore length, a medial tibial buttress plate, with bone grafting and reconstruction of the plafond with interfragmentary screws, has >80% good or excellent results in low-energy grade I and II injuries. More than 50% of high-energy grade III injuries suffer major complications.

External fixation or traction alone provide ligamentotaxis and effect indirect joint reduction. Results are no better than ORIF in grade III injuries.

Combined fixation with a fibular plate to restore length and a medial external fixator crossing the ankle joint, with minimal open reduction, bone grafting and interfragmentary screw fixation, has similar results to ORIF for grade II injuries, but >70% good results for grade III injuries.

Newer techniques include Ilizarov circular frames in combination with minimal internal fixation, allowing early mobilization of the ankle. As yet, there is no substantiated evidence that these will improve previous results; however, any system allowing earlier joint movement is theoretically beneficial.

Early arthrodesis is a reasonable option for the non-reconstructable joint and facilitates rehabilitation.

## Current recommendations

- Low-energy (Grade I/II): ORIF
- High-energy (Grade III): combined internal/external fixation with fine wire frames

## Complications

Early complications are:

- Delayed wound healing.
- Infection of wound, pin tracks, or osteomyelitis.
- Loss of reduction.

Late complications include:

- Mal/non-union.
- Joint pain, stiffness and instability.
- Joint degeneration occurs despite optimal management and follows cartilage damage at the time of injury. Late arthrodesis is 50% in some series for grade III injuries.

## Further reading

**Ruedi T, Allgower M.** The operative treatment of intra-articular fractures of the lower end of the tibia. *Clinical Orthopaedics*, 1979; **138**: 105–110.
**Tornetta P, Weiner L, Bergman M** ***et al.*** Pilon fractures: treatment with combined internal and external fixation. *Journal of Orthopaedic Trauma*, 1997; 7: 489–496.

## Related topics of interest

Ankle fractures, p.6; Principles of external fixation, p. 214

# TIBIAL PLATEAU FRACTURES

Tibial plateau fractures follow high-energy trauma in young adults. Cotton and Berg first described these as 'bumper' or 'fender' fractures in the late 1920s. RTAs account for 40–60% of tibial plateau fractures. In the elderly, with osteoporotic bone, tibial plateau fractures follow lesser trauma.

The degree of comminution, displacement and compression of the articular surface is variable. Management depends on the severity of the injury and the demands of the patient, but the aim of treatment is to restore alignment of the knee joint and congruity of the articular surface.

## Classification

Hohl and Luck's classification of the 1950s has been superseded by Schatzker's classification (*Figure 1*) with six fracture patterns:

- Type 1 – vertical shear.
- Type 2 – vertical shear and compression.
- Type 3 – local compression.
- Type 4 – medial condyle fracture (a fracture/subluxation of the knee).
- Type 5 – bicondylar.
- Type 6 – tibial plateau and segmental fracture (separating metaphysis and diaphysis).

AO classify the fractures as: 41-B or 41-C.

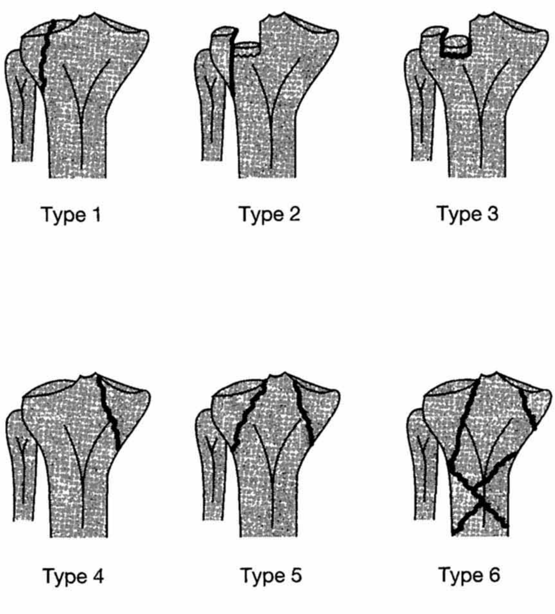


**Figure 1.** Schatzker classification of tibial plateau fractures. Modified from Schatzker, J., McBroom, R. and Bruce, D. The tibial plateau fracture. The Toronto experience 1968–1975. *Clinical Orthopaedics and Related Research*, vol. 138, 1979, pp. 94–104. With permission from Lippincott Williams & Wilkins.

## Imaging

Plain AP and lateral X-rays are insufficient. Imaging with a plateau view (X-ray beam angled a few degrees off vertical), oblique views or tomograms give better evaluation of the injury. A CT scan with 3D reconstruction demonstrates the fracture pattern in considerably more detail and greatly assists surgical reconstruction.

## Associated ligament injuries

Collateral ligament injuries occur in 4–25% of isolated fractures and are most common in compression fractures of the articular surface. Less than 10% of tibial plateau fractures are fracture/dislocations and ligament injuries occur in 60% of this group.

## Management

1. ***Traction and early mobilization*** was advocated by Apley in the 1950s, who reported excellent or good results in 78% of patients. The current indication for conservative management is a depressed fracture of less than 4 mm. Conservative treatment consists of early mobilization in skeletal traction, followed by a cast brace for at least 6 weeks, touch-weight bearing initially. In the osteoporotic patient, pin loosening and infection on traction can be reduced with a double Steinmann pin technique.

Fractures with 4 to 8 mm of depression should be considered for elevation, bone grafting and internal fixation, depending on the age and physical demands of the patient. Where varus/valgus instability is >15°, or there is >8 mm depression, internal fixation is indicated.

Multifragmentary fractures in the elderly often benefit from manipulation and moulding with an Esmarch bandage, from distal to proximal.

2. ***Arthroscopically assisted reduction of a vertical shear fracture,*** without depression of the articular surface, can often be achieved with minimal exposure and large fragment transverse cancellous lag screws. Arthroscopy allows irrigation of the haemarthrosis, visualization of fracture reduction and confirms congruity of the articular surface. Type 1 fractures are more common in young people.

3. ***Surgical approach.*** A midline incision should be used, with dissection around the joint line and an arthrotomy beneath the meniscus. An extensive lateral approach jeopardizes the opportunity for late reconstructive surgery, but a small lateral incision may be used for type 1 fractures.

4. ***Elevation, bone graft and buttress plate fixation*** are required for depressed articular surface fractures. The antero-lateral (or antero-medial) aspect of the upper tibia is exposed and a cortical fenestration fashioned with a drill and osteotome. Using a punch, the articular surface can be elevated 'en masse' and graft from the ipsilateral iliac crest impacted, which is supported with two large fragment cancellous screws incorporating a contoured buttress plate. The joint surface must be visualized to ensure restoration of the articular surface, and in some instances to remove a meniscus displaced into the fracture. In skilled hands, arthroscopy is an alternative to arthrotomy. However, adequate visualization is difficult. After the

procedure the joint surface should be slightly convex as there will be some collapse of the fracture and graft.

**5. *Post-operative management.*** Early movement is encouraged after surgery and the knee supported with a cast brace for 8 weeks, avoiding more than touch-weight bearing for the first 6 weeks. Even if the articular surface cannot be accurately reconstructed, realignment of the knee joint is important for subsequent reconstructive surgery.

**6. *External fixation*** may be required for bicondylar and segmental fractures, or cases where the skin and soft tissues are severely traumatized. Such injuries follow high-energy trauma, often with extensive comminution or soft tissue damage. Aggressive surgical intervention should be avoided, as extensive exposure with both medial and lateral plates is associated with wound breakdown and chronic infection. One series reports an 82% wound failure rate. These fractures may be stabilized with an external fixator across the knee for 6 to 8 weeks, followed by a hinged cast brace and intensive physiotherapy to regain movement. Alternatively a peri-articular ring can be used and knee movement started early. Stabilization of the articular surface may be augmented with percutaneous cancellous screws.

### Pitfalls

- Type 4 (medial plateau) fractures tend to displace, with the knee assuming a varus deformity. Aggressive surgical treatment is required to prevent this.
- Type 4, 5 and 6 fractures are associated with neurovascular complications.

### Complications

**1. *Wound healing.*** Primary skin contusion and substantial swelling follow these injuries. The upper tibia is poorly covered by soft tissue, especially on the medial side, and wound breakdown, which can be catastrophic, is common without a meticulous surgical approach.

**2. *Joint stiffness.*** Stiffness is not usually severe, with the majority of patients achieving full extension and flexion in excess of 90°.

**3. *Osteoarthritis.*** The incidence is variable and relates to the degree of comminution and the reduction achieved. Residual malalignment, medial and bicondylar fractures are poor prognostic factors. Symptoms may develop over a period of one to two decades following the injury. There is a poor correlation between radiological and functional results. Depending on the age, occupation and lifestyle of the patient, a knee replacement is appropriate. An osteotomy should be considered for varus malunion.

## Further reading

Schatzker J, McBroom R, Bruce D. The tibial plateau fracture. The Toronto experience 1968–1975. *Clinical Orthopaedics*, 1979; **138**: 94–104.

Wiss DA, Watson JT. Fractures of the proximal tibia and fibula. In: Rockwood CA, Green DP, Bucholz RW, Heckman JD, eds. *Rockwood and Green's Fractures in Adults.* Philadelphia: Lippincott-Raven, 1996; 1919–1956.

## Related topics of interest

Femoral fractures – distal, p. 46; Knee – dislocation, p. 137

# TIBIAL SHAFT FRACTURES

Fracture of the tibial shaft is the most common long bone fracture. The numerous management approaches to closed fractures should be tailored to the morphology of the fracture and

# VASCULAR INJURIES

## Arterial injury

### Epidemiology and mechanism

Arterial injury may result from 'trauma' or 'surgery'. Most peripheral vascular injuries follow penetrating trauma – in Europe largely stab wounds and in North America low-velocity gunshot wounds. Blunt vascular trauma is less common. Certain fractures and dislocations predispose to arterial injury (*Table 1*).

In children, 1% of supracondylar elbow fractures have an associated vascular injury. In adults, 50% of fractures or dislocations about the knee have a vascular injury and 10% require surgical management. Open tibial fractures have a 10% incidence of vascular injury.

Some orthopaedic surgical procedures can have arterial complications. Presentation is typically intra-operative, but may be delayed with a pseudoaneurysm or arteriovenous fistula. Common sites are given in *Table 2*.

**Table 1.** Fracture/dislocation and the corresponding arteries predisposed to injury

| Bone | Artery |
|---|---|
| **1. Upper extremity** | |
| Clavicle and first rib | Subclavian |
| Shoulder dislocation | Axillary |
| Distal humerus | Brachial |
| **2. Lower extremity** | |
| Femoral shaft | Superficial femoral |
| Supracondylar femur | Popliteal |
| Knee dislocation | Popliteal |
| Proximal tibia | Popliteal/tibial/peroneal |
| Distal tibia | Tibial/peroneal |

**Table 2.** Surgical procedures and the arteries that can be affected

| Procedure | Artery |
|---|---|
| Clavicle plating | Subclavian |
| THR/acetabulum | Iliac/gluteal/common femoral |
| TKR | Popliteal |
| Spine | Iliac/aorta |

### Classification of arterial injury

Five types of arterial injury are described:

- Spasm.
- Intimal flap tear or haematoma.

- Wall defect.
- Transection.
- Arteriovenous fistula.

Spasm and intimal flaps may be associated with blunt trauma. The remaining types follow penetrating trauma.

## Presentation

The classic presentation of arterial insufficiency or injury are the five Ps (pallor, pulselessness, paraesthesiae, paralysis and pain), but the most acute and dramatic presentation is massive haemorrhage. Other hard signs are an expanding haematoma, a thrill or bruit. These signs usually indicate the need for urgent surgical intervention.

Subtle features in both the history and examination should raise suspicion of an arterial injury. These include penetrating trauma, location of the wound, associated nerve injury, non-pulsatile haematoma over an artery, tardy capillary refill (>2 sec) and clinical awareness in certain fracture or dislocation patterns.

## Investigations

***1. Doppler flow.*** In the absence of palpable pulses, the quickest test is with a hand-held Doppler flow probe. The ankle/brachial index may be calculated (<0.9



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