## 2.2 Diaphyseal fractures: principles

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2.2 Diaphyseal fractures: principles

1 Introduction

The management of diaphyseal fractures is evolving and progressing. New reduction and fixation concepts are emerging based on better understanding of the biology of fracture repair and of the role of the soft tissues in the healing process [1].

- Restoration of length, axial alignment, and rotation is essential, but anatomical reduction of every fracture fragment is not necessary for normal limb function.

With more treatment options available, decision making has become more complex. The factors relevant to the correct management of an individual diaphyseal fracture must constantly be reviewed.

2 Functional considerations

The diaphysis of a long bone has many functions. The two most important are to maintain its proximal and distal joints in their correct spatial relationship and to provide attachment for muscles which move them. In the leg the normal mechanical axis of the limb (Fig 2.2-1) should be restored [2]. This requires union without shortening, angulation, or rotational deformity. Nevertheless, good function can be expected, even if the individual fracture fragments are not anatomically reduced.

Some residual deformity can be tolerated in the lower limb without causing functional problems for normal daily activity, eg, shortening of up to 1 cm or minimal angular deformities in the plane of adjacent joints. Up to 10° of anterior or posterior bowing of a healed tibial fracture is compatible with good ankle function, despite cosmetic deformity. However, valgus or varus deformity of even 5° may subject the joint to abnormal forces and lead to posttraumatic osteoarthritis [3]. In athletes, however, with higher requirements, anatomical restoration of axial alignment must be obtained.

Shortening of the humeral shaft produces little functional disability, and because the shoulder has the largest range of joint movement in the body, 20° of malrotation or 30° of angular

Fig 2.2-1 Diagram of the mechanical axis of the lower limb showing correct alignment of femur and tibia (according to Pauwels [3]).
deformity is tolerated as well. In contrast, the diaphyses of the radius and ulna, being part of a complex articulation that includes the proximal and distal radioulnar joints, require anatomical reduction for normal limb function.

3 Incidence

In many parts of the world improved car design and the use of seat belts have reduced the incidence of diaphyseal fractures [4]. However, in developing countries the sharp increase of mechanized transport, particularly motorcycles, is producing more diaphyseal injuries. Many of these injuries are open and presented late because of delay in transporting victims to hospital. While the number of pedestrian trauma incidence is stagnating, the percentage of open fractures is rising. An increasingly aging population [5] has raised the incidence of osteoporotic diaphyseal injuries.

4 Mechanism

Patterns of injury

Fractures can be caused by direct or indirect forces. Indirect trauma usually involves less energy than a direct blow and causes proportionately less fragment displacement and soft-tissue damage. Open fractures are a result of direct rather than indirect forces [6]. The differing injury patterns are recognized in the various AO classifications [7] (chapter 1.5; 1.6; 4.2).

Spiral (A1) and spiral wedge (B1) fractures result from indirect rotational forces. They have large areas of bone surfaces in contact, and minimal soft-tissue damage. Fracture healing is therefore usually swift and uneventful, although holding the reduction without fixation may be difficult.

Oblique wedge fractures (B2) are produced by bending forces. The force applied to the limb is considerable and the resulting damage to soft tissue and periosteum is significant. Union may take a long time and direct surgical approaches to the fracture site will further devitalize the bone.

Transverse fractures (A3), fragmented wedge fractures (B3) and complex fractures (type C) are usually caused by direct forces which are often enormous, especially in the femur. If the bone is of normal quality and the fracture is widely displaced, the degree of soft-tissue damage will be extensive. Even with intact skin, direct exposure of these fractures results in further insult to the soft tissues.

Therefore fracture type and displacement are good predictors of soft-tissue damage (Fig 2.2-2). This insight should guide the surgeon towards suitable methods of reduction and fixation. The greater the anticipated soft-tissue damage, the more important the timing of surgery and the choice of approach, reduction technique and implant (chapter 3.1.2; 3.1.3).

5 Initial evaluation

5.1 Patient status

A well taken case history is of foremost importance in assessing a diaphyseal fracture, particularly to discover the mechanism and forces which caused the fracture. The force generated in motor vehicle injury is approximately one hundred times that generated by a simple fall. Although the x-rays may look similar, the associated soft-tissue injury will be very different.

Most displaced fractures are identified by observation only. Palpation is only used to elicit bone tenderness if there is no obvious fracture. The most important elements of the physical
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Fig 2.2.2a–d  High-velocity injury (motor vehicle accident) to the proximal half of the tibia in a 30-year-old man.

a The closed injury is a multifragmentary fracture of the shaft of the tibia with proximal metaphyseal and intraarticular extension. The complex fracture pattern suggests extensive soft-tissue damage despite the fact that the fracture is closed.

b The intraarticular fracture component was treated by closed reduction and percutaneous cannulated screws, while the shaft fragments were bridged with a unilateral external fixator. Both procedures avoided any further soft-tissue damage to the zone of injury. The knee was then mobilized on a continuous passive motion (CPM) machine.

c 10 days after the accident, when the soft tissues had recovered, a bridge plate was planned and applied to the lateral side of the tibia through stab incisions at the upper and lower ends of the chosen plate. Because the plate alone would not have provided enough stability to prevent varus deformation, the bridging external fixator was kept in situ to allow mobilization of the patient. The external fixator was removed at 8 weeks when callus formation was seen at the fracture site.

d The fracture went on to uneventful union at 16 weeks. Note: the correct axis, length, and rotation have been preserved.
examination concentrate on any arterial or neurological damage. Certain fractures, including displaced fractures of the distal femur or proximal tibia, should attract a high level of suspicion of arterial injuries.

- **An arterial injury will dominate the decision-making process because of the immediate need for arterial reconstruction with appropriate stabilization of the fracture.**

- **Compartment syndrome requires urgent treatment. It is seen mostly in the lower leg, but can also occur in the thigh, forearm, buttock, and foot [8].**

The clinical picture and the management are fully described in chapter 1.6. Compartment syndrome may occur at any time during the first few days after trauma. It is most common in widely displaced fractures, but can occur in simple fractures, open fractures, and after intramedullary nailing.

### 5.2 Radiographic evaluation

X-rays are the mainstay of diagnosis. AP and lateral views including the adjacent joints will serve in most cases, while oblique projections may be helpful in the metaphysis. Standard views of the opposite side are very useful for preoperative planning (chapter 2.4). CT and MRI scanning have no role in the assessment of acute diaphyseal injuries, although they may be useful in planning reconstructive surgery of complex malunions.

X-rays allow accurate classification of diaphyseal fractures. Fractures which are widely displaced, multifragmentary, or transverse have usually been caused by higher energy than those that are minimally displaced, simple, or spiral.

In the lower extremity, load-sharing implants (intramedullary nails) which splint the bone and allow for early weight bearing are preferable to implants such as plates and screws, which are more prone to fatigue failure if healing is prolonged [6].

However, shaft fractures with metaphyseal or intraarticular extensions may not be suitable for intramedullary nailing and require direct reduction and absolute stability to maintain the anatomical relationships of articular fracture components.

- **Bone quality is highly important. Severe osteoporosis diminishes the holding power of screws or pins. External fixation [9] and plating of fractures using conventional plates and screws may fail in osteoporotic bone.**

- **Locked internal fixators give a better hold in osteoporotic bone.**

The treatment of pathological fractures may also demand special considerations. In a patient with a limited life expectancy it may be more sensible to aim for mobility and pain relief, rather than perfect reduction. The use of an adjuvant technique, eg, the use of bone cement [9], should also be considered, although it may retard bone healing.

### 5.3 Associated injuries

Soft-tissue injuries always influence and may frequently dictate the management options of a diaphyseal fracture. A closed, simple, displaced, transverse fracture of the tibial shaft can be managed by intramedullary nailing, plating, or external fixation. Severe skin contusion excludes the standard plating option because the surgical approach might further compromise the soft tissues. A badly contaminated wound
might be a deterrent to primary nailing because of the risk of sepsis. In this situation preliminary treatment with an external fixator would be the treatment of choice.

Similarly, acute arterial disruption and compartment syndrome both need emergency management. In cases requiring vascular repair or extensive release of the muscle compartments, the associated fracture must be stabilized at the same time. Thus the associated injury not only dictates the need for stabilization, but also determines its timing and the approach. Plating of the fracture through the exposure used for the vascular repair may be the treatment of choice, as there may not be time for anything else.

Management of life-threatening injuries always takes precedence over that of a diaphyseal injury. The overall approach described in chapter 2.1 should be followed.

- The presence of more than one fracture in the same limb may make it desirable to fix all of them, particularly if the combination has produced a “floating” joint.

Additional fractures in other limbs, eg, bilateral humeral shaft fractures, can render a patient almost helpless. This situation may dictate operative stabilization of a fracture that might well be treated nonoperatively, if isolated.

6 Indications for operative fracture fixation

The indications for internal or external fixation of diaphyseal fractures vary throughout the world depending on the available facilities. There are several absolute indications which can be grouped around two headings—saving life and saving limb.

6.1 Absolute indications

Saving life
Immediate stabilization of femoral shaft fractures in polytraumatized patients has been shown to decrease morbidity and mortality considerably (chapter 4.1) [10]. However, there are conflicting reports as to the use of intramedullary nails or plates, while external fixation may always be applied as a temporary expedient [11, 12]. Better understanding of the inflammatory processes associated with trauma and its treatment have led to an increased use of external fixation to stabilize femoral shaft fractures as a first aid measure in cases of poly-trauma. This philosophy of damage-control orthopedics has found considerable favor, especially in Europe.

- Early stabilization of femoral shaft fractures is life saving, but the type and method of stabilization remain controversial.

Saving limb
Stabilization of diaphyseal fractures is part of an emergency operation to save a limb in the case of an acute vascular injury, compartment syndrome as well as in open fractures (chapter 1.6; 4.1; 4.2). Fracture instability compromises not only the vascular repair but also the healing of any severe soft-tissue injury.

6.2 Relative indications

Inability to reduce or hold a fracture by means of conservative treatment: Fractures of the femoral shaft are very difficult to reduce and maintain in traction. Nonoperative treatment is indicated only exceptionally, if proper operating facilities do not exist.
Fractures of the tibial shaft are often easy to reduce by manipulation, but the stability of the reduction depends on the fracture pattern. Well reduced transverse fractures may be stable to axial loading, but union is often slow. Nonoperative treatment of unstable multifragmented fractures carries a high risk of shortening and malalignment, although fracture healing may be relatively fast.

Humeral shaft fractures are often difficult to reduce and hold by nonoperative means, but since significant degrees of malunion are compatible with good limb function, surgical fixation is indicated only in special cases.

Fractures of the forearm bones are difficult to reduce and hold anatomically by nonoperative means. As even minimal malalignment impedes normal limb function, surgery is usually indicated.

6.3 Early mobilization of patients

Early mobilization carries enormous benefits for patients, especially the aged. Stabilization of shaft fractures allows early movement of adjacent joints and avoids the “fracture disease” or complex regional pain syndrome seen with prolonged immobilization (chapter 4.7:3.2). Successful fracture fixation is also associated with earlier return to work, shorter hospital stays, and possibly reduced costs for compensation/invalidity [13].

There are also economic aspects; for example a femoral shaft fracture treated nonoperatively usually needs many weeks in hospital, compared to a few days after intramedullary nailing. This makes the cost of nonoperative treatment of femoral shaft fractures prohibitive in many developed countries. In case of a severe complication this may, however, change drastically [14]. In most developed countries patient demand and expectations are also an important factor in decision making. The widespread availability of the internet has resulted in a generation of informed patients, who are often unwilling to undergo significant periods of cast immobilization. Treating physicians, however, need to know that patient choice should not completely dominate their own decision-making processes and all patients should be made aware of the potential hazard of surgery, especially in those cases (eg, humeral shaft) where nonoperative treatment has been shown to give excellent results.

7 Nonoperative treatment

Nonoperative treatment, usually by traction and/or cast, may be used for temporary or definitive management. This usually avoids the risk of infection and the equipment needed is minimal. Time until bony union is, however, longer and there are higher risks of malunion, malalignment, and stiffness of the adjacent joints.

In adults some fractures are best managed nonoperatively. Nondisplaced or minimally displaced fractures of the tibia and humerus can very well be treated nonoperatively in a cast. This requires regular follow-up, since secondary displacements before bony union are quite frequent.

Operative management of displaced diaphyseal fractures usually produces better functional results than conservative treatment in all bones apart from the humerus [15].
Femoral shaft fractures should not be managed nonoperatively if adequate facilities and know-how exist for safe surgical care. Nonoperative management is very time-consuming and the incidence of shortening and angular deformity is high. If appropriate operating facilities and instrumentations do not exist locally, conservative treatment is still indicated even for femoral shaft fractures. It is probably better to end up with a malunion than with chronic osteomyelitis. Nonoperative treatment of femoral and tibial shaft fractures remains the treatment of choice in large areas of the world, even in the 21st century. The correct use of traction and splints remains a critical surgical skill in these areas of the world.

The two main nonoperative methods available are traction and plaster casting. Both require skill, experience, and supervision. Traction is time-consuming and may cause delayed union in the tibia. However, it is an excellent form of provisional fixation while waiting for definitive surgery. Casting, if properly applied, is very safe, although the frequent need to include adjacent joints may cause stiffness. This can be minimized by the use of hinged braces [16]. Angulation may be controlled by a well-applied cast; it may, however, be difficult to control rotation and shortening.

Sarmiento, who has published excellent results on the nonoperative treatment of tibial shaft fractures, has pointed out that a fracture will not displace in treatment more than its original maximum displacement. It must, however, be realized that a surgeon is usually unaware of the maximum displacement of a fracture. This occurs a few milliseconds after trauma. X-rays taken at the time of admission do not show the maximum displacement of the fracture that has occurred. casts in adults are therefore largely confined to those diaphyseal fractures which are initially hardly displaced and therefore quite stable.

8 General principles of operative treatment

For specific and more detailed information see chapter 6 of the book.

8.1 Timing

The timing of operative treatment of diaphyseal injuries is critical. No operative treatment should be contemplated until the patient’s general condition has been assessed. Vascular injuries and open fractures are special cases requiring emergency management.

In general terms, if direct open reduction and internal fixation are indicated, the sooner it happens the better. Swelling will develop, and operating through swollen tissues leads to difficulty in wound closure and the risk of subsequent breakdown. For direct open reduction, surgical intervention within 6–8 hours is recommended [17]. If, as sometimes happens, significant swelling occurs sooner than this, it is usually safer to establish provisional stabilization and wait 7–10 days for the swelling to subside.

- **If there is any doubt as to the viability of the soft tissues, it is much safer to apply a spanning external fixator as a temporary measure and wait for the soft tissues to declare themselves.**

Shaft fractures of the tibia and the femur are mostly treated by indirect reduction and intramedullary nailing. In this situation, swelling around the fracture site is less of a problem because the soft tissues are not invaded. Timing is therefore less critical. Every procedure demands a complex surgical set-up and may need to await an experienced surgical team and backup.
8.2 Preoperative planning and approaches

All operative fixations of diaphyseal fractures should be planned carefully. The details of available techniques are covered in chapter 2.4. Effective planning should ensure that the surgeon does not embark on a surgical procedure unless the required personnel and equipment are available.

In open fractures it is vital to look beyond the first operation to plan how definitive soft-tissue cover will ultimately be obtained. Otherwise an external fixator, used for provisional stabilization, may obstruct the placement of a soft-tissue flap. The surgical approach to a fracture clearly depends on the site, soft-tissue condition, and choice of fixation device. Knowledge of the anatomy is essential, while dissection must be gentle. When the planned approach is unfamiliar, reference to a standard work on surgical approaches is mandatory [18, 19] and dissection of cadaveric material is desirable.

Adoption of minimally invasive techniques calls for percutaneous access, usually carried out with x-ray control. These techniques may possibly minimize soft-tissue trauma, but are technically quite demanding. The need to master the relevant anatomy is even greater, as the surgeon cannot see the tissues and structures beneath which the operation is being carried out.

8.3 Reduction and fixation techniques

Diaphyseal fractures can be reduced directly or indirectly; the principles are described in chapter 3.1.

- Independent of the technique, any reduction maneuver should be as gentle as possible to the soft tissues and periosteum to preserve all existing blood supply.

In the treatment of diaphyseal fractures the fixation techniques used most commonly are intramedullary nailing, plating, and external fixation.

Intramedullary nails are internal splints which are load sharing and allow early weight bearing. Because they permit a degree of movement at the fracture site, their use is associated with callus formation and early bone union [7]. Locked intramedullary nails control rotation and allow multifragmentary fractures to be held out to length.

Plates and screws may be a good option for shaft fractures extending to the metaphyseal area or into a joint. They can be inserted either with direct or indirect reduction techniques. In simple fractures that can easily be reduced anatomically, the classical interfragmentary lag screw, combined with a protection plate, is still an excellent method of fixation.

- Bridge plating with relative stability is not a good option for simple diaphyseal fractures as the risk of nonunion is high.

Plating of complex, multifragmentary diaphyseal fractures should be done by minimally invasive techniques, with indirect reduction and the plate acting as bridge, providing relative stability and leaving the fracture site untouched (chapter 3.1.3; 3.2.2; 3.3.2).

 Locked internal fixators (chapter 3.3.4) have considerably expanded the indications for plate fixation in diaphyseal fractures, especially those extending into the metaphysis. Locked internal fixators provide greater stability than conventional plates and screws in osteoporotic bone and in fractures with a short metaphyseal segment that are not suitable for nailing. The development of precontoured plates for the proximal and distal tibia, distal femur, and proximal humerus has allowed...
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Diaphyseal injuries associated with metaphyseal or intra-articular fractures to be treated with a single implant.

External fixators are still the gold standard in case of severe soft-tissue problems and in those parts of the world where nails and plates are more difficult and risky to use for logistical and technical reasons, e.g., operating room sterility, lack of image intensification. However, fracture healing may be delayed and pin-track problems (infection, loosening) are common. Therefore, external fixators are not a popular choice for definitive fixation and a change of method is often considered once the early problems have been mastered (chapter 3.3.3). The use of external fixators as a temporary measure to allow the recovery of soft tissues has become increasingly popular, as has the use of temporary external fixation for the immediate stabilization of femoral shaft fractures in polytrauma.

9 Postoperative care

The mobilization of a given patient is often influenced by the presence of other injuries and general health.

- The most important factor in deciding about mobilization and functional loading is the surgeon’s assessment of the stability of the fixation.

Fracture anatomy and fixation technique must be considered together. When there is doubt, activity may need to be delayed and carefully monitored.

- Physiotherapy aimed at muscle rehabilitation should commence as soon as possible after surgery and continue until normal function of the limb is obtained.

Early active movements of the muscles and joints are best, but can be painful. Continuous passive motion [20], if used, should always be combined with active muscle exercises.

The combination most stable for early weight bearing is a perfectly reduced transverse fracture of the middle of the femur or tibia fixed anatomically with a dynamically locked intramedullary nail.

The combination most unstable would be a multifragmented fracture, extending almost from metaphysis to metaphysis, treated by a bridge plate or intramedullary nail.

Load transmission is a good stimulus for bone growth, and prolonged nonweight bearing is associated with profound disuse osteopenia, atrophy of articular cartilage, and muscle wasting. Therefore the aim should be to obtain a fixation construction that allows for early partial weight bearing in the compliant patient. Good preoperative planning is the key to avoiding fixations that are not strong enough to allow partial weight bearing.

10 Outcome

Patient outcomes vary with the severity of the injury; so do the complications, which are covered in chapter 5 of the book. Low-velocity injuries without associated soft-tissue damage should regain full function as a matter of course with appropriate treatment. High-velocity injuries with soft-tissue loss will not regain normal function, but careful assessment, preoperative planning, meticulous operative technique, preservation of soft tissues, and diligent postoperative rehabilitation will ensure best possible results for any patient.
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