1 Epidemiology of Fracture Fixation Failure

Paul L. Rodham, Vasileios Giannoudis,
Paul Tornetta III, and Peter V. Giannoudis

Introduction

Since the 1950s and following the introduction of fracture fixation techniques by the AO group in Switzerland, there has been a revolution of implant designs to allow fixation/reconstruction of fractures of all different anatomical areas of the human body [1]. Both internal and external fixation implants with or without specific anatomical profiles are currently being used in the clinical setting [1].

The objective is that the implant selected to stabilise the injured limb will provide adequate fracture stability to obtain bony union, and restore the affected limb axis, rotation, length and joint congruence [2]. It is anticipated that the implant will provide the appropriate biomechanical environment to allow fracture healing and then no longer be needed for physiologic loading. While implants have been divided to load sharing (Intramedullary nailing) and load bearing (plating systems; locking and non-locking) devices, both are at risk of failure prior to the fracture uniting.

The aetiology of metal work failure is multifactorial including selection of wrong implant, sub-optimal fixation technique, non-compliant patient, fragile bone, non-union and infection amongst others [3–5].

Although metal work failure post fracture fixation is infrequent, the overall incidence of this phenomenon is not well reported in the literature. Herein, we report the incidence of fixation failure prior to fracture union in different anatomical sites of the human body.

Proximal Humerus

Proximal humeral fractures are the third most common non-axial osteoporotic fracture, affecting 63/100,000 persons [6]. They most commonly affect elderly females sustaining these injuries from low-energy falls [7]. The majority of humeral fractures are low energy with low rates of non-union and can be managed non-operatively [8]. When operative treatment is planned, this can be either in the form of fixation or arthroplasty.

P. L. Rodham · V. Giannoudis
Academic Department of Trauma and Orthopaedics, School of Medicine, University of Leeds, Leeds, UK
e-mail: p.rodham@nhs.net; vasileios.giannoudis@nhs.net

P. Tornetta III
Boston University Medical Center, 85 East Concord St, Boston, MA, USA

P. V. Giannoudis (✉)
Academic Department of Trauma and Orthopaedics, School of Medicine, University of Leeds, Leeds, UK

NIHR Leeds Biomedical Research Center, Chapel Allerton Hospital, Leeds, UK

P. V. Giannoudis, P. Tornetta III (eds.), *Failed Fracture Fixation*,
https://doi.org/10.1007/978-3-031-39692-2_1

The use of locking plates has expanded the role of fixation of proximal humerus fractures, gaining better purchase and fixation in osteoporotic bone. Despite this the failure of these devices continues to be reported in between 7 and 14% of cases [9–13]. Factors associated with the loss of reduction when using locking plates include increasing patient age, presence of osteoporosis, initial varus displacement, degree of reduction achieved, residual varus following fixation and medial comminution [10, 11]. The reported rate for fixation failure in a recent systematic review examining the role of intramedullary nails in the management of proximal humerus fractures suggests a failure rate of up to 24%, with risk factors for failure including the use of this device in three and four-part fractures in addition to the aforementioned risk factors [14].

Humeral Shaft

Humeral shaft factors account for between 1 and 5% of all fractures, with an incidence between 13 and 20/100,000 patients [15]. They have a bimodal distribution with an initial peak in young men between the age of 21 and 30 years, often as a result of high-energy trauma; and a second peak in elderly females between 61 and 80 years, more commonly in the setting of low-energy injuries [15]. Operative management can consist of either plate fixation or fixation with an intramedullary nail, and is utilised in up to 60% of cases [16].

Failure of plate fixation is rarely reported, with small series reporting fixation failure in 4–6% of cases, most commonly associated with osteoporotic bone, short plate span and an early return to weight-bearing activities [17–19]. Similarly low rates of fixation failure are quoted for intramedullary nailing [19].

Distal Humerus

Distal humeral fractures represent one-third of all humeral fractures with an incidence of 6/100,000 patients [20]. As with humeral shaft fractures they have a bimodal distribution with young men sustaining high-energy fractures, and older women sustaining low-energy injuries [20]. Operative treatment is associated with good clinical outcomes, and therefore the role of non-operative management is reducing, generally restricted to undisplaced fractures or those who are not medically fit enough to undergo anaesthesia [21].

When fixation of distal humeral fractures is selected over arthroplasty options, dual plate fixation, either in a parallel or a perpendicular configuration, is generally undertaken. Fixation failure is reported to occur in between 0 and 27% of these cases [22]. Osteoporosis represents a significant risk factor for failure of fixation, and in its presence consideration should be given to the use of arthroplasty [23]. Other risk factors for failure include the use of perpendicular plating, metaphyseal comminution, inadequate volume of screws in the distal segment, usage of short screws in the distal segment [22, 24, 25].

Olecranon

Olecranon fractures are common injuries sustained in the elderly population, with an incidence of 15/100,000 patients [26]. As intra-articular fractures, an operative approach is generally recommended unless the fracture is undisplaced. In those <65 years, an operative approach is taken in 79% of cases, with this tactic reducing in the over 65 s at 65% [27]. Popular techniques for fixation of these fractures include the use of plate fixation, and tension band wiring [27].

Tension band wiring of olecranon fractures is appropriate with simple fracture patterns in the absence of comminution [28–30]. Failure of this technique is reported in between 4 and 16% of cases. Factors that appear to be most associated with failure include the placement of intramedullary wires as opposed to bicortical hold, the use of single knot constructs as opposed to dual knot techniques and failure to adequately secure the proximal end of the K-wire [31–33].

Plate fixation is often utilised in the context of increasing patient age, and increasing complexity of fracture pattern. When utilising plates, current failure rates are quoted to be between 3% and 17% [29, 34, 35]. Prior to locking plate technology the majority of plate fixation would be with the limited contact dynamic compression plate (LCDCP), with failure occurring through screw pull-out [36]. The advent of locking systems specifically for the olecranon has reduced this occurrence, though these constructs may still fail in severely osteoporotic bone, and in highly comminuted fractures [37].

Radial Head

Radial head fractures affect 11/100,000 persons, most commonly females in their 60s [38]. Trends towards operative treatment of these fractures are increasing from 69% in 2007, to 85% in 2016 [38]. This is most commonly performed using screw fixation, although plate fixation and radial head replacement remain options for more comminuted fractures.

Screw fixation is rarely associated with failure, reported in between 0 and 15% of cases [39–42]. Reported risk factors for fixation failure include the presence of osteoporosis, development of non-union, multifragmentary fractures and the use of convergent screw orientations [41, 43]. Plate fixation is less commonly utilised when compared to screw fixation, and as a result there are no clear data available reporting the rates of fixation failure in this cohort.

Forearm

Whilst the highest rates of forearm fractures occur in children, there is a significant increase in these injuries in women aged over 45, and men aged over 70 [44]. The true incidence is poorly defined, but thought to be between 1 and 10/100,000 persons [45]. An operative approach to management is generally advocated due to the risk of non-union, mal-union and subsequent difficulties with forearm rotation [46]. This is most commonly achieved with plate fixation in the adult population.

Failure of fixation is rare in this cohort, reported in just 2–4% of cases [47, 48]. As with many fracture types, the presence of comminution poses a risk of fixation failure. Additional risk factors include failure to provide compression to the fracture, and the use of short plates which has been demonstrated to be of a higher importance than the number of screws utilised in each segment [48].

Distal Radius

Distal radius fractures represent the most commonly sustained fracture seen by orthopaedic surgeons with an incidence of up to 195/100,000 persons in the United Kingdom [6]. They are increasingly frequently seen in female patients over the age of 60 as a result of a fall from standing height [49]. Extraarticular distal radius fractures that maintain an acceptable alignment can be reliable managed non-operatively; however, displaced fractures or those that extend into the joint surface require fixation. Currently between 14 and 16% of distal radius fractures are managed operatively, most commonly by plate fixation (62%) followed by K-wire fixation (30%) [50, 51].

Modern distal radial plate designs have expanded the scope of fixation including more reliable use in osteoporotic bone and distally based fractures. Within the current literature, the failure rates are noted to be between 1 and 13% [52–54]. Failure rates are reported to be higher in the setting of early return to weight-bearing, close proximity of the fracture to the volar rim with little plate coverage of the unstable fragment, multifragmentary volar rim fractures (AO23-B3), smaller width of the lunate fragment piece, greater ulnar variance on the pre-operative imaging and failure to achieve adequate articular reduction (Fig. 1.1) [54–57].

Fig. 1.1 A 42-year-old lady was involved in a rollover RTC sustaining an isolated closed distal radius and ulna fracture. She was taken to theatre on the morning following admission where following bridge plating of the ulna, her swelling did not allow for a second approach to the radius which was, therefore, managed with K-wires with a good intraoperative result. Unfortunately, she did not attend her early follow-up and returned at 6 weeks with a pin site infection, and a significant loss of reduction of the intermediate column of her wrist, resulting in incongruency of both her radiolunate and distal radioulnar joints. Given the concerns surrounding infection, she was treated with 4 weeks of antibiotics in order to suppress the infection until radiological union was achieved. She subsequently underwent removal of metalwork from the ulna accompanied by wrist denervation; however, she subsequently never returned for her planned ulna shortening and corrective radial osteotomy

Distal Ulna

Distal ulna fractures frequently occur in conjunction with distal radius fractures, with an incidence of 3.8/100,000 persons [58]. The majority of distal ulna fractures can be managed non-operatively, particularly when screened to be stable following the fixation of a distal radius; however, when fixation is pursued, this is most commonly in the form of a plate [59].

Outcome of distal ulna fixation is significantly less frequently reported when compared to the distal radius. In those small series, assessing the outcome of fixation of the distal ulna the reported failure rate is 0%. These studies frequently don't examine the ulna in isolation, having been fixed in conjunction with fixation of the distal radius [60–63]. Whilst clinical data do not currently exist, finite element analysis would suggest that the fixation is under the lowest stress when placed on the dorsal surface of the ulna, with three points of distal fixation [64].

Pelvic Ring

Pelvic ring fractures have an incidence of 23/100,000 persons, with a bimodal distribution affecting young males with high-energy mechanisms, and elderly females with low-energy falls [65]. Operative fixation of pelvic ring injuries is infrequently performed, selected in just over 8% of cases [66]. When operative management is selected, this is frequently a combination of percutaneous screw fixation with open reduction and internal fixation with plates, or use of anterior external fixation [66].

Failure of plate fixation is commonly reported, although frequently asymptomatic. Rates of failure are reported in between 5 and 46% of patients; however, less than 10% of these are symptomatic and require reoperation [67–71]. Risk factors for failure of anterior plate fixation include the use of the technique in osteoporotic bone, the use of a single implant as opposed to dual implant and the use of fewer than 3 holes per segment when spanning the symphysis (Fig. 1.2) [66, 68].

Similarly high rates of fixation failure when employing the technique of anterior external fixation are also reported, in between 23 and 57% of cases [72, 73]. Risk factors for failure of this technique include initial fracture displacement, inadequate reduction particularly in the setting of vertical shear injuries, fixator loosening and the use of this technique in lateral compression type injuries [72, 73].

Fixation of the posterior pelvic ring, typically achieved with percutaneous sacro-iliac (SI) screws, has much lower reported failure rates, occurring in between 4 and 16% of cases [74, 75]. Risk factors for failure of this technique include non-union, intraoperative malpositioning due to either surgeon error or inadequate fluoroscopy, use of a single screw as opposed to two SI screws and patient non-compliance with post-operative weight-bearing instructions [74, 75].

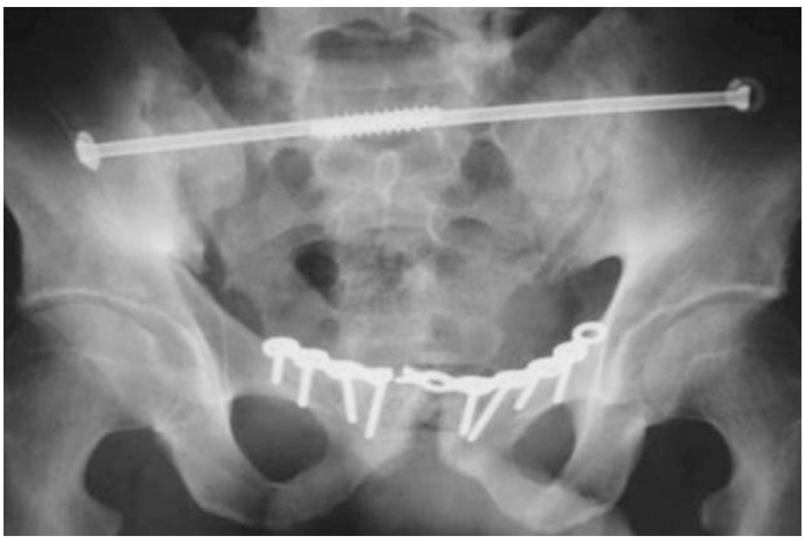

Fig. 1.2 Anteroposterior (AP) pelvic radiograph demonstrating a broken 3.5 mm matta plate. As a plate that spans the symphysis, this construct is continually exposed to bending stresses that lead to plate failure by fatigue (in this case the residual pubis diastasis that developed after failure of the plate did not require any further intervention as the patient was asymptomatic)

Acetabulum

Acetabular fractures are less commonly seen when compared to pelvic ring fractures, with an incidence of only 3/100,000 [76]. In contrast to pelvic ring injuries, they are more frequently observed in males, often as a result of a high-energy injury [77]. As an articular injury, an operative approach is more readily pursued when compared to the pelvic ring, across both the elderly and the non-elderly population [78]. Where fixation is performed, this is most commonly a combination of screw and plate fixation [78].

Failure of fixation is variably reported in the literature with many studies not directly commenting of fixation failure and instead reporting on rates of conversion to total hip arthroplasty (THA). Within the literature, the reported failure rate varies from 10 to 57% [79–82]. Risk factors for fixation failure in this population include increasing age, development of non-union, fracture comminution, initial articular displacement, inability to attain an anatomic articular reduction, fracture classification as an associated type particularly T-type with posterior wall involvement, obesity and surgeon error in siting the fixation device [83–85].

Proximal Femur

Proximal femoral fractures represent the second most commonly sustained osteoporotic fracture with an incidence of 129/100,000 persons [6]. The majority of these fractures affect the intertrochanteric region (60%), with 32% affecting the femoral neck, and 8% affecting the subtrochanteric region [86]. Management is almost exclusively operative unless the patient is unable to undergo an anaesthetic. Fixation is dependent on the location of the fracture and the degree of comminution, however, frequently involves the use of cannulated screws, a sliding hip screw, or a cephalomedullary nail [87].

Failure of fixation should generally be divided between those implant systems utilised in the management of intracapsular and extracapsular fractures. With regard to intracapsular fractures, the three most commonly utilised systems include the femoral neck system, cannulated screws and the dynamic hip screw with a derotation screw. The failure rates of the femoral neck system is currently reported in between 4 and 6% of cases; however, there is little literature examining this relatively novel implant [88, 89]. Failure rates of cannulated screw fixation are reported in between 13 and 39% cases, compared to failure rates between 0 and 20% when using a dynamic hip screw [90–96]. Risk factors for failure when managing intracapsular neck of femur fractures include increasing age, initial displacement, technical error in siting the implant, inadequate reduction, inferior cannulated screw distance >3 mm from the calcar, cannulated screw configuration (inverted triangle reduces in lowest failure rate) and a delay to fixation of greater than 24 h [88, 90, 97].

When considering extracapsular neck of femur fractures, the most commonly utilised fixation systems include the dynamic hip screw, and cephalomedullary nails. The rate of fixation failure utilising the dynamic hip screw is reported in between 4 and 28% of cases, whilst the rates of failure with an intramedullary nail are reported in between 0 and 13% of cases [98–105]. Risk factors for failure of fixation in extracapsular neck of femur fractures include increasing age, initial displacement, comminution, inadequate reduction, surgeon error, unstable fracture patterns (A2 or A3 compared with A1), comminution of the lateral cortex, calcar tip apex distance, notching of the screw aperture and reduction in a varus alignment (Fig. 1.3) [98–101, 106, 107].

Fig. 1.3 Initial AP pelvic radiograph demonstrating a subtrochanteric proximal femoral fracture in a 74-year-old male that was managed with a cephalomedullary nail. As can be seen, the reduction was not anatomic with residual translation in the sagittal plane, and a degree of malalignment of the medial calcar. The patient represented at 2 months with varus collapse and failure of the nail through the lag screw aperture. This was successfully managed with a proximal femoral replacement to facilitate early patient mobilisation and rehabilitation

Femoral Shaft

The worldwide incidence of femoral shaft fractures ranges between 10 and 21 per 100,000 per year [108, 109]. They have a bimodal distribution affecting young males with high-energy mechanisms, and elderly females with low-energy falls [108]. These fractures are almost exclusively managed operatively. Operative fixation with intramedullary nailing is the gold standard of treatment; however, in transverse fracture patterns use of plate fixation is also observed [110].

The incidence of nail failure is low, reported in between 0.5 and 10% of cases [111, 112]. This is lower than those failure rates seen with plate fixation, which is reported in 1 and 14% of cases [113–115]. Risk factors for failure of femoral shaft fixation include undersising of the nail diameter, failure to lock nail, malreduction, comminution, degree of initial displacement, soft tissue stripping, development of delayed union, sagittal plane malalignment and the use of a short fixation working length when utilising a plate (Fig. 1.4) [114, 116].

Fig. 1.4 Initial AP and lateral radiograph demonstrating a transverse midshaft femoral fracture in a 12-year-old boy. This was managed with compression plating performed via a lateral approach, as can be seen from the operative films the plate was not pre-contoured, and whilst a good reduction was achieved, there is still some residual gapping on the medial surface. The patient represented at 6 months post-operative with increased pain and swelling of the mid-thigh. Radiographs taken at the time demonstrated evidence of a hypertrophic non-union and breakage of the plate through fatigue. The fixation was removed and an antegrade trochanteric entry nail performed which went onto uneventful union

Distal Femur

Fractures of the distal femur are rare with a reported prevalence of 0.5% of all fractures; they have been slowly increasing in incidence over the past decade with most reported incidence of 8.7/100,000 person per annum [117]. These have been reported traditionally as fragility fractures and the increasing incidence is likely due to a shift towards an aging population worldwide. Distal femur fractures have a bimodal distribution, with patients either being young adults involved in high-energy trauma or elderly osteoporotic individuals who experience a fall from standing.

The most common fracture types are the 33-A1 or 33-A2. Type 33-C (complex articular fracture) is less common. Management is dependent on stability of the fracture pattern, involvement of the knee joint as well as patient-related factors. Where operations are deemed necessary, fixation is dependent on the location of the fracture and the degree of comminution. This normally involves the use of plate fixation (fixed angle blade plate vs. buttress plate vs. locking plate) or intramedullary nailing (antegrade vs. retrograde) [118–120].

The use of locking plates expanded the role of fixation within the distal femur, gaining better purchase and fixation in osteoporotic bone. Despite this, the failure of these devices has been reported in between 6 and 20% of cases [121, 122]. Factors associated with the loss of reduction when using locking plates include increasing patient age, presence of osteoporosis, initial varus displacement, poor initial reduction achieved, residual varus following fixation and medial or posteromedial comminution [121].

Proximal Tibia

Tibial plateau fractures account for 1% of all fractures and are typically sustained with high-energy mechanisms. The incidence of tibial plateau fractures is 10.3 per 100,000 people annually

[123]. They have a bimodal distribution with an initial peak in men younger than 50, often as a result of high-energy trauma; and a second peak in elderly females between years, more commonly in the setting of low-energy injuries leading to tibial plateau insufficiency fractures [123]. In intra-articular fractures, an operative approach is generally recommended unless the fracture is undisplaced. This can be either through the use of plates and screws, external fixator devices or alternatively arthroplasty [124, 125].

Failure of plate fixation has been reported, with small series reporting fixation failure in 30% of cases, most commonly associated with osteoporotic bone, fracture fragmentation and an early return to weight-bearing activities [126]. Failure of fixation elements when utilising a circular fixator is reported in 14% of cases [124].

Tibial Shaft

Tibial shaft fractures are common long bone injuries accounting for 2% of all adult fractures [127]. They have an incidence of 2/100,000 population with a bimodal distribution of peaks at ages 20 and 50 [128]. These injuries may be managed non-operatively if minimally displaced, alternatively they can be treated with Intramedullary nail fixation, external fixator devices or plate osteosynthesis [129]. A cross-sectional survey performed showed that 80% of surgeons treat these Injury patterns with operative intervention [130].

Intramedullary nail fixation failure has been listed as approximately 7.3% [131]. These patients have a higher percentage of open injuries with a higher degree of comminution and had been treated with smaller diameter nails when compared with the group of patients, who had no implant failure. Failure occurred most frequently at the transverse proximal locking screw when a single screw was used [131]. Failure of circular frames is infrequently reported, with most 'failures' constituting broken wires which do not necessarily require intervention in 0–5% of cases [132–134].

Distal Tibia

The incidence of distal tibia fractures is estimated to be 9.1/100,000 persons per annum [135]. Women appear to have an increasing incidence of distal tibia fractures when stratified by age whilst males have a fairly constant incidence [135]. Distal tibia fracture can be treated with a variety of operative treatment methods including external fixators, intramedullary nailing and internal plate fixation [136–138]. Of these fractures there is a reported incidence of 6.9/100,000 distal tibia fractures which are subsequently operated on [139].

Pilon fractures often pose challenging fracture configurations to adequately reduce. There is limited literature assessing failures of differing treatment modalities. Studies suggest a rates of fixation failure between 2 and 10% when utilising plate fixation, and 3% when utilising a circular frame [136, 140–143]. Most commonly cited issues include malreduction of the fracture site and there has been reported to be an association between the use of anteromedial plates and non-unions [140]. Further risk factors include the presence of comminution and periosteal stripping, often seen in open injuries (Fig. 1.5) [141, 142].

Fig. 1.5 A 34-year-old pregnant lady presented having been crushed between a van and a car. Her injuries included a lateral compression pelvic fracture, a left distal femur fracture and a right open tibial fracture. Following resuscitation, she was taken to theatre for caesarean section, pelvic fixation and debridement of her open tibial fracture with application of an ankle spanning external fixator. Two days following admission, she was returned to theatre for anterolateral plating of her distal tibial fracture and insertion of an antibiotics impregnated cement spacer with plans to reconstruct her bone defect via the Masquelet technique. She had her second stage Masquelet treatment at 6 weeks post first stage. Unfortunately, her graft failed to fully incorporate resulting in a distal tibial non-union and her plate failed via fatigue at 8 months post second stage. This was successfully managed with bone transport

Ankle

Ankle fractures, accounting for 3.9–10.2% of adult fractures, are the most common type of fracture of the lower extremity [144]. They have an incidence rate of 100/100,000 people per year, with the majority occurring secondary to low-energy falls (55%) [6, 145]. Operative management is dependent on the fracture configuration as well as patient-related factors. It may consist of either plate fixation or fixation with an intramedullary nail (Fibular nails/Hind foot nails).

The use of locking plates has significantly expanded the role of fixation within the ankle, gaining better purchase and fixation in osteoporotic bone, leading to a change in treatment paradigm in geriatric ankle fractures with few fixation failures reported. Surgical re-intervention has been reported to range between 1 and 2% [146]. The most common indication for surgical reintervention was syndesmotic malreduction (59%) in a cases series published. This is often secondary to fibula shortening leading to lateral translation with a potential rotational malalignment of the syndesmosis [146]. Furthermore, the importance in reduction of the posterior malleolus has also been shown in biomechanical studies to affect the syndesmosis. Other risk factors for failure fixation include obesity, inability to follow post-operative weight-bearing instructions and the presence of open fractures (Fig. 1.6) [147].

Fig. 1.6 AP and lateral radiograph of a trimalleolar ankle fracture in a frail 53-year-old female that was managed with open reduction and internal fixation with a fibula locking plate, and fragment specific fixation using 1/3 tubular plates for the posteromedial malleolus and the medial malleolar shear fragment. Due to frailty, the patient was not able to comply with post-operative instructions to non-weight-bearing and represented with increased pain and swelling 1 month post-operatively with repeated radiographs demonstrating proximal translation of the medial malleolus, loss of reduction and of joint congruence. Due to the patient's frailty, it was elected to revise this construct to a hindfoot nail which allowed the patient to weight bear without restrictions

Calcaneus

Calcaneal fractures are the most commonly fractured tarsal bone. The annual incidence of calcaneal fractures are 11.5/100,000 people, with a male to female ratio of 2.4:1, most common sustained following falls from height (70%) [148]. The fractures can be broadly classified into extra-articular injuries (25%) often secondary to Achilles avulsion type injuries or intra-articular fractures (75%) [149]. Operative fixation is often recommended when significant disruption to the 'angle of Gissane' or 'Bohlers angle' is present. This can be achieved through percutaneous screw fixation, plate fixation, primary subtalar arthrodesis or C-nails [150–154].

Failure of plate fixation has been documented to be between 0 and40% and has been most commonly associated with osteoporotic bone [151, 154, 155]. The increasing use of locking plates has attempted to overcome this. There is paucity in literature detailing rates of fixation failures and the rationale behind this. One case series showed that screw fixation had a 24% probability of failure, plates showed a 36% failure and the most unstable seem to be the C-nails with 42% probability of failure. The authors do suggest fixation failure is often linked to patient factors such as smoking status and non-compliance with post-operative weight-bearing status.

Lisfranc

Lisfranc fractures have an incidence of 16/100,000 persons per year [156]. However, there actual incidence may well be higher due to up to 24% of these injuries being missed on their original radiographs [157]. These injuries are more common in males (4 males: 1 female) and most commonly occur in the third decade of life [158].

If true disruption of the ligamentous Lisfranc complex is present, then surgical management is often recommended. Operative intervention can consist of either open reduction internal fixation (ORIF) or primary arthrodesis [158]. The fixation method has been contentious with some surgeons advocating arthrodesis given the decreased need to return at a later date for removal of metalwork and subsequent fusion. Failure of fixation associated with ORIF can often be linked to over compression during the fixation, malreduction of the fracture site when the plates are applied or plantar trajectory of the 'home run screw' [159]. With respect to primary arthrodesis underprepared joints prior to fusion have been implicated with fixation failure, as has an early return to weight-bearing due to poor compliance [159].

Whilst failure of fixation is nor frequently reported, unplanned re-operation rates are similar between ORIF and primary arthrodesis (29.5 vs. 29.6%), most commonly due to post-traumatic arthritis in patients treated with ORIF and non-union in those treated with primary arthrodesis [160].

Discussion

Metal work failure remains a rare complication of fracture fixation, though the overall incidence is poorly defined within the literature. A summary of the current reported rates of fixation failure defined by anatomic site is summarised in Table 1.1.

Table 1.1 Incidence and rates of fixation failure alongside risk factors for fixation failure separated by body site

Site	Incidence	Rate of fixation failure	Risk factors for fixation failure
Proximal humerus	63/100,000 [6]	Plate: 7–14% [9–13] IM nail: 24% [14]	Older age Osteoporosis Varus displacement Varus reduction Medial comminution
Humeral shaft	13–20/100,000 [15]	Plate: 4–6% [17–19] IM nail: 6% [19]	Osteoporosis Short plate span Early return to weight-bearing
Distal humerus	6/100,000 [20]	Plate: 0–27% [22]	Osteoporosis Perpendicular plates Inadequate fixation in distal segment Use of short screws distally
Olecranon	15/100,000 [26]	TBW: 4–16% [28–30] Plate: 3–17% [29, 34], [35]	Osteoporosis Intramedullary wire placement Single wire knot Comminution
Radial head	11/100,000 [38]	Screws: 0–15% [39–42]	Comminution Convergent screws Non-union
Forearm	1–10/100,000 [45]	Plate: 2–4% [47, 48]	Comminution Short fixation span Inability to apply compression
Distal radius	195/100,000 [6]	Plate: 1–13% [52–54]	Early weight-bearing Fracture proximity to volar rim + low size of rim piece AO 23-B3 type Small width of lunate facet fragment Greater ulna variance on pre-op radiographs Residual articular displacement

Table 1.1 (continued)

Site	Incidence	Rate of fixation failure	Risk factors for fixation failure
Distal ulna	3.8/100,000 [58]	Plate: 0% [60–63]	None reported
Pelvic ring	23/100,000 [65]	Plate: 5–46% [67–71] Anterior ex-fix: 23–57% [72, 73] SI screw: 4–16% [74, 75]	Osteoporosis Single symphyseal plate >2 screws per segment Initial displacement Inadequate reduction LC type injuries Fixator loosening Non-compliance Delayed union Inadequate fluoroscopy Second SI screw
Acetabulum	3/100,000 [76]	ORIF: 10–57% [79–82]	Increasing age Non-union Comminution Fracture reduction Associated fracture pattern Initial articular displacement Obesity Surgeon error
Proximal femur	129/100,000 [6]	Intracapsular: FNS: 4–6% [88, 89] Cannulated screw: 13–39% [90–94] DHS: 0–20% [92, 94–96] Extracapsular: DHS: 4–28% [98, 99, 102–104] IM nail: 0–13% [100, 101, 105]	Increasing age Technical error Inadequate reduction Initial displacement Non-inverted triangle configuration of CS Inferior screws distance >3 mm from calcar Delay to fixation >24 h Comminution Reverse obliquity in EC (A2 or A3 vs. A1) Tip apex distance >25 mm CalTAD Lateral cortex comminution Notching of the screw aperture Varus reduction
Femoral shaft	10–21/100,000 [108]	IM nail: 0.5–10% [111, 112] Plate: 1–14% [113–115]	Small nail size Failure to lock nail Malreduction Comminution Initial displacement Soft tissue stripping Delayed union Sagittal plane malalignment Short plate working length
Distal femur	8.7/100,000 [117]	ORIF: 6–20% [121, 122]	Increasing patient age osteoporosis Initial varus displacement, poor reduction Residual varus following fixation Medial or posteromedial comminution
Proximal tibia	10.3/100,000 [123]	Plate: Up to 30% [126] Frame: Up to 14% [124]	Osteoporosis Comminution Early return to weight-bearing

(continued)

Table 1.1 (continued)

Site	Incidence	Rate of fixation failure	Risk factors for fixation failure
Tibial shaft	2/100,000 [6]	IM nail: 0–7% [131] Circular frame: 0–5% [132–134]	Open fractures Comminution Smaller diameter nails
Distal tibia	9.1/100,000 [135]	Plate: 2–10% [136, 140, 141] Circular frame: 3% [143]	Comminution Periosteal stripping Malreduction Anteromedial plate
Ankle	100/100,000 [6]	ORIF: 1–2% [146]	Obesity Open fractures Syndesmotic malreduction
Calcaneus	11.5/100,000 [148]	ORIF: 0–40% [151, 154, 155]	Comminution Non-compliance Technical failures Smoking
Lisfranc	16/100,000 [156]	ORIF: 29.5% [160] Arthrodesis: 29.6% [160]	Over compression Malreduction Plantar trajectory of the home run screw Poor compliance with weight-bearing Inadequate joint preparation

Rates are currently extrapolated from small retrospective series and secondary outcomes of larger trials, varying from 0 to 57% depending on the location of the fracture and the technical application of the technique. Fixation failure is significantly higher in the lower limb where issues with ambulation introduce the risk of early weight-bearing and increased forces to which the fixation construct is exposed to.

Failure was reportedly highest when utilising techniques to stabilise the anterior pelvic ring, be that in the form of an external fixator or a plate. Fixation fails here at a much higher rate as the implant is spanning the symphysis, a joint that whilst stiff will never produce the same strain environment as a healed bone segment. Whilst pelvic 'fixation failure' is commonly reported, severe clinical symptoms are infrequently encountered nor is the requirement for removal of symptomatic hardware [67, 69].

Failure was similarly high in areas where high force transmission and poor vascularity predispose to slow healing, such as the femoral neck; in poor quality cancellous bone where fixation constructs struggle to gain adequate hold, such as the calcaneus; and in the pelvis where cancellous bone combined with an inability to prevent high stress due to its core position place significant stress in the implants utilised in the management of fractures here.

Reports regarding fixation failure are sparse, and often reported as secondary outcomes within larger studies. Whilst an extensive database search was conducted to examine its frequency, this report may still miss some studies which were not identifiable on a standard search. Similarly, the definition of fixation failure is not standardised across all studies, with some reporting on all cases where the integrity of the fixation construct was lost, and others simply reporting when a re-operation was required.

Reporting all cases of fixation failure will often identify metalwork complications that have no bearing on the clinical picture, such as the asymptomatic breakage of syndesmosis screws or loss of tension of an olive wire in a healing fracture segment [161]. Nonetheless reporting only those complications that require revision fixation will miss a number of patients that are symptomatic from their metalwork failure, who may need to alter their post-operative course through adjustment of weight-bearing or splintage, but do not require further operative management to achieve union in an acceptable alignment.

Conclusion

The overall incidence of fixation failure is poorly defined within the literature. Moving forward the true incidence of fixation failure does need to be more accurately defined, ideally via larger cohort studies, with a stricter definition that identifies those patients whose clinical course and outcome are altered by the construct failure.

References

1. Hodgson S. AO principles of fracture management. Ann R Coll Surg Engl. 2009;91(5):448–9. https://doi.org/10.1308/003588409X432419f.
2. Taljanovic MS, Jones MD, Ruth JT, Benjamin JB, Sheppard JE, Hunter TB. Fracture fixation. Radiographics. 2003;23(6):1569–90. https://doi.org/10.1148/rg.236035159.
3. Sharma AK, Kumar A, Joshi GR, John JT. Retrospective study of implant failure in orthopaedic surgery. Med J Armed Forces India. 2006;62(1):70–2. https://doi.org/10.1016/S0377-1237(06)80164-4.
4. Harris LJ, Tarr RR. Implant failures in orthopaedic surgery. Biomater Med Devices Artif Organs. 1979;7(2):243–55. https://doi.org/10.3109/10731197909117579.
5. Nunamaker DM. Orthopedic implant failure. Equine fracture repair; 2019:831–834. https://doi.org/10.1002/9781119108757.ch46.
6. Court-Brown CM, Caesar B. Epidemiology of adult fractures: a review. Injury. 2006;37(8):691–7. https://doi.org/10.1016/j.injury.2006.04.130.
7. Launonen AP, Lepola V, Saranko A, Flinkkilä T, Laitinen M, Mattila VM. Epidemiology of proximal humerus fractures. Arch Osteoporos. 2015;10:209. https://doi.org/10.1007/s11657-015-0209-4.
8. Jo MJ, Gardner MJ. Proximal humerus fractures. Curr Rev Musculoskelet Med. 2012;5(3):192–8. https://doi.org/10.1007/s12178-012-9130-2.
9. Dauwe J, Walters G, Holzer LA, Vanhaecht K, Nijs S. Failure after proximal humeral fracture osteosynthesis: a one year analysis of hospital-related healthcare cost. Int Orthop. 2020;44(6):1217–21. https://doi.org/10.1007/s00264-020-04577-y.
10. Lee C-W, Shin S-J. Prognostic factors for unstable proximal humeral fractures treated with locking-plate fixation. J Shoulder Elb Surg. 2009;18(1):83–8. https://doi.org/10.1016/j.jse.2008.06.014.
11. Jung S-W, Shim S-B, Kim H-M, Lee J-H, Lim H-S. Factors that influence reduction loss in proximal humerus fracture surgery. J Orthop Trauma. 2015;29(6):276–82. https://doi.org/10.1097/BOT.0000000000000252.
12. Agudelo J, Schürmann M, Stahel P, et al. Analysis of efficacy and failure in proximal humerus fractures treated with locking plates. J Orthop Trauma. 2007;21(10):676–81. https://doi.org/10.1097/BOT.0b013e31815bb09d.
13. Brunner F, Sommer C, Bahrs C, et al. Open reduction and internal fixation of proximal humerus fractures using a proximal humeral locked plate: a prospective multicenter analysis. J Orthop Trauma. 2009;23(3):163–72. https://doi.org/10.1097/BOT.0b013e3181920e5b.
14. Wong J, Newman JM, Gruson KI. Outcomes of intramedullary nailing for acute proximal humerus fractures: a systematic review. J Orthop Traumatol. 2016;17(2):113–22. https://doi.org/10.1007/s10195-015-0384-5.
15. Gallusser N, Barimani B, Vauclair F. Humeral shaft fractures. EFORT Open Rev. 2021;6(1):24–34. https://doi.org/10.1302/2058-5241.6.200033.
16. Schoch BS, Padegimas EM, Maltenfort M, Krieg J, Namdari S. Humeral shaft fractures: national trends in management. J Orthop Traumatol. 2017;18(3):259–63. https://doi.org/10.1007/s10195-017-0459-6.
17. Heim D, Herkert F, Hess P, Regazzoni P. Surgical treatment of humeral shaft fractures--the Basel experience. J Trauma. 1993;35(2):226–32.
18. Raghavendra S, Bhalodiya HP. Internal fixation of fractures of the shaft of the humerus by dynamic compression plate or intramedullary nail: a prospective study. Indian J Orthop. 2007;41(3):214–8. https://doi.org/10.4103/0019-5413.33685.
19. Putti AB, Uppin RB, Putti BB. Locked intramedullary nailing versus dynamic compression plating for humeral shaft fractures. J Orthop Surg (Hong Kong). 2009;17(2):139–41. https://doi.org/10.1177/230949900901700202.
20. Amir S, Jannis S, Daniel R. Distal humerus fractures: a review of current therapy concepts. Curr Rev Musculoskelet Med. 2016;9(2):199–206. https://doi.org/10.1007/s12178-016-9341-z.
21. Nauth A, McKee MD, Ristevski B, Hall J, Schemitsch EH. Distal humeral fractures in adults. J Bone Joint Surg Am. 2011;93(7):686–700. https://doi.org/10.2106/JBJS.J.00845.
22. Savvidou OD, Zampeli F, Koutsouradis P, et al. Complications of open reduction and internal fixation of distal humerus fractures. EFORT Open Rev. 2018;3(10):558–67. https://doi.org/10.1302/2058-5241.3.180009.
23. Obert L, Ferrier M, Jacquot A, et al. Distal humerus fractures in patients over 65: complications. Orthop

Traumatol Surg Res. 2013;99(8):909–13. https://doi.org/10.1016/j.otsr.2013.10.002.
24. Yetter TR, Weatherby PJ, Somerson JS. Complications of articular distal humeral fracture fixation: a systematic review and meta-analysis. J Shoulder Elb Surg. 2021;30(8):1957–67. https://doi.org/10.1016/j.jse.2021.02.017.
25. O'Driscoll SW. Optimizing stability in distal humeral fracture fixation. J Shoulder Elb Surg. 2005;14(1 Suppl S):186S–94S. https://doi.org/10.1016/j.jse.2004.09.033.
26. Duckworth AD, Clement ND, Aitken SA, Court-Brown CM, McQueen MM. The epidemiology of fractures of the proximal ulna. Injury. 2012;43(3):343–6. https://doi.org/10.1016/j.injury.2011.10.017.
27. Brüggemann A, Mukka S, Wolf O. Epidemiology, classification and treatment of olecranon fractures in adults: an observational study on 2462 fractures from the Swedish fracture register. Eur J Trauma Emerg Surg. 2022;48(3):2255–63. https://doi.org/10.1007/s00068-021-01765-2.
28. Romero JM, Miran A, Jensen CH. Complications and re-operation rate after tension-band wiring of olecranon fractures. J Orthop Sci. 2000;5(4):318–20. https://doi.org/10.1007/s007760070036.
29. Rantalaiho IK, Laaksonen IE, Ryösä AJ, Perkonoja K, Isotalo KJ, Äärimaa VO. Complications and reoperations related to tension band wiring and plate osteosynthesis of olecranon fractures. J Shoulder Elb Surg. 2021;30(10):2412–7. https://doi.org/10.1016/j.jse.2021.03.138.
30. Macko D, Szabo RM. Complications of tension-band wiring of olecranon fractures. J Bone Joint Surg Am. 1985;67(9):1396–401.
31. Mauffrey CPC, Krikler S. Surgical techniques: how I do it? Open reduction and tension band wiring of olecranon fractures. Injury. 2009;40(4):461–5. https://doi.org/10.1016/j.injury.2008.09.026.
32. Wu C-C, Tai C-L, Shih C-H. Biomechanical comparison for different configurations of tension band wiring techniques in treating an olecranon fracture. J Trauma Acute Care Surg. 2000;48(6):1063.
33. van der Linden SC, van Kampen A, Jaarsma RL. K-wire position in tension-band wiring technique affects stability of wires and long-term outcome in surgical treatment of olecranon fractures. J Shoulder Elb Surg. 2012;21(3):405–11. https://doi.org/10.1016/j.jse.2011.07.022.
34. Wise KL, Peck S, Smith L, Myeroff C. Locked plating of geriatric olecranon fractures leads to low fixation failure and acceptable complication rates. JSES Int. 2021;5(4):809–15. https://doi.org/10.1016/j.jseint.2021.02.013.
35. Campbell ST, DeBaun MR, Goodnough LH, Bishop JA, Gardner MJ. Geriatric olecranon fractures treated with plate fixation have low complication rates. Curr Orthop Pract. 2019;30(4):353–5.
36. Boden AL, Daly CA, Dalwadi PP, et al. Biomechanical evaluation of standard versus extended proximal fixation olecranon plates for fixation of olecranon fractures. Hand. 2019;14(4):554–9. https://doi.org/10.1177/1558944717753206.
37. Siebenlist S, Buchholz A, Braun KF. Fractures of the proximal ulna: current concepts in surgical management. EFORT Open Rev. 2019;4(1):1–9. https://doi.org/10.1302/2058-5241.4.180022.
38. Klug A, Gramlich Y, Wincheringer D, Hoffmann R, Schmidt-Horlohé K. Epidemiology and treatment of radial head fractures: A database analysis of over 70,000 inpatient cases. J Hand Surg Am. 2021;46(1):27–35. https://doi.org/10.1016/j.jhsa.2020.05.029.
39. Swensen SJ, Tyagi V, Uquillas C, Shakked RJ, Yoon RS, Liporace FA. Maximizing outcomes in the treatment of radial head fractures. J Orthop Traumatol. 2019;20(1):15. https://doi.org/10.1186/s10195-019-0523-5.
40. Lindenhovius ALC, Felsch Q, Doornberg JN, Ring D, Kloen P. Open reduction and internal fixation compared with excision for unstable displaced fractures of the radial head. J Hand Surg Am. 2007;32(5):630–6. https://doi.org/10.1016/j.jhsa.2007.02.016.
41. Ring D, Quintero J, Jupiter JB. Open reduction and internal fixation of fractures of the radial head. JBJS. 2002;84(10):1811.
42. Özkan Y, Öztürk A, Özdemir RM, Aykut S, Yalçın N. Open reduction and internal fixation of radial head fractures. Turkish J Trauma Emerg Surg. 2009;15(3):249–55.
43. Shi X, Pan T, Wu D, et al. Effect of different orientations of screw fixation for radial head fractures: a biomechanical comparison. J Orthop Surg Res. 2017;12(1):143. https://doi.org/10.1186/s13018-017-0641-9.
44. Abrahamsen B, Jørgensen NR, Schwarz P. Epidemiology of forearm fractures in adults in Denmark: national age- and gender-specific incidence rates, ratio of forearm to hip fractures, and extent of surgical fracture repair in inpatients and outpatients. Osteoporos Int. 2015;26(1):67–76. https://doi.org/10.1007/s00198-014-2831-1.
45. How HM, Khoo BLJ, Ayeop MAS, Ahmad AR, Bahaudin N, Ahmad AA. Application of WALANT in diaphyseal plating of forearm fractures: an observational study. J Hand Surg Glob Online. 2022;4(6):399–407. https://doi.org/10.1016/j.jhsg.2022.02.004.
46. Schulte LM, Meals CG, Neviaser RJ. Management of adult diaphyseal both-bone forearm fractures. J Am Acad Orthop Surg. 2014;22(7):437–46. https://doi.org/10.5435/JAAOS-22-07-437.
47. Stern PJ, Drury WJ. Complications of plate fixation of forearm fractures. Clin Orthop Relat Res. 1983;175:25–9.
48. Herscovici DJ, Scaduto JM. Failures in fixation of the forearm. Tech Orthop. 2002;17(4):409–16.
49. Stirling ERB, Johnson NA, Dias JJ. Epidemiology of distal radius fractures in a geographi-

cally defined adult population. J Hand Surg Eur Vol. 2018;43(9):974–82. https://doi.org/10.1177/1753193418786378.
50. Armstrong KA, von Schroeder HP, Baxter NN, Zhong T, Huang A, McCabe SJ. Stable rates of operative treatment of distal radius fractures in Ontario, Canada: a population-based retrospective cohort study (2004–2013). Can J Surg. 2019;62(6):386–92. https://doi.org/10.1503/cjs.016218.
51. Mc Colgan R, Dalton DM, Cassar-Gheiti AJ, Fox CM, O'Sullivan ME. Trends in the management of fractures of the distal radius in Ireland: did the distal radius acute fracture fixation trial (DRAFFT) change practice? Bone Joint J. 2019;101-B(12):1550–6. https://doi.org/10.1302/0301-620X.101B12.BJJ-2018-1615.R3.
52. Satake H, Hanaka N, Honma R, et al. Complications of distal radius fractures treated by volar locking plate fixation. Orthopedics. 2016;39(5):e893–6. https://doi.org/10.3928/01477447-20160517-05.
53. Foo T-L, Gan AWT, Soh T, Chew WYC. Mechanical failure of the distal radius volar locking plate. J Orthop Surg (Hong Kong). 2013;21(3):332–6. https://doi.org/10.1177/230949901302100314.
54. Beck JD, Harness NG, Spencer HT. Volar plate fixation failure for volar shearing distal radius fractures with small lunate facet fragments. J Hand Surg Am. 2014;39(4):670–8. https://doi.org/10.1016/j.jhsa.2014.01.006.
55. Cao J, Ozer K. Failure of volar locking plate fixation of an extraarticular distal radius fracture: a case report. Patient Saf Surg. 2010;4(1):19. https://doi.org/10.1186/1754-9493-4-19.
56. Izawa Y, Tsuchida Y, Futamura K, Ochi H, Baba T. Plate coverage predicts failure for volarly unstable distal radius fractures with volar lunate facet fragments. SICOT J. 2020;6:29. https://doi.org/10.1051/sicotj/2020026.
57. Lee DJ, Ghodasra J, Mitchell S. Failure of fixation of volar locked plating of distal radius fractures: level 3 evidence. J Hand Surg Am. 2015;40(9, Supplement):e17. https://doi.org/10.1016/j.jhsa.2015.06.033.
58. Soerensen S, Larsen P, Korup LR, et al. Epidemiology of distal forearm fracture: a population-based study of 5426 fractures. Hand (N Y). 2022:15589447221109968. https://doi.org/10.1177/15589447221109967.
59. Fish MJ, Palazzo M. Distal ulnar fractures. In: StatPearls [Internet]; 2022.
60. Stock K, Benedikt S, Kastenberger T, et al. Outcomes of distal ulna locking plate in management of unstable distal ulna fractures: a prospective case series. Arch Orthop Trauma Surg. 2022;143:3137–44. https://doi.org/10.1007/s00402-022-04549-4.
61. Lee SK, Kim KJ, Park JS, Choy WS. Distal ulna hook plate fixation for unstable distal ulna fracture associated with distal radius fracture. Orthopedics. 2012;35(9):e1358–64. https://doi.org/10.3928/01477447-20120822-22.
62. Nunez FAJ, Li Z, Campbell D, Nunez FAS. Distal ulna hook plate: angular stable implant for fixation of distal ulna. J Wrist Surg. 2013;2(1):87–92. https://doi.org/10.1055/s-0032-1333427.
63. Bakouri MAM, El-Soufy MAA, El-Hewala TA, Fahmy FS. Fixation of distal ulna fractures by distal ulnar locked hook plate. Egypt J Hosp Med. 2021;82(3):506–13. https://doi.org/10.21608/ejhm.2021.147000.
64. Zhang Y, Shao Q, Yang C, et al. Finite element analysis of different locking plate fixation methods for the treatment of ulnar head fracture. J Orthop Surg Res. 2021;16(1):191. https://doi.org/10.1186/s13018-021-02334-4.
65. Balogh Z, King KL, Mackay P, et al. The epidemiology of pelvic ring fractures: a population-based study. J Trauma. 2007;63(5):1063–6. https://doi.org/10.1097/TA.0b013e3181589fa4.
66. Buller LT, Best MJ, Quinnan SM. A nationwide analysis of pelvic ring fractures: incidence and trends in treatment, length of stay, and mortality. Geriatr Orthop Surg Rehabil. 2015;7(1):9–17. https://doi.org/10.1177/2151458515616250.
67. Morris SAC, Loveridge J, Smart DKA, Ward AJ, Chesser TJS. Is fixation failure after plate fixation of the symphysis pubis clinically important? Clin Orthop Relat Res. 2012;470(8):2154–60. https://doi.org/10.1007/s11999-012-2427-z.
68. Herteleer M, Boudissa M, Hofmann A, Wagner D, Rommens PM. Plate fixation of the anterior pelvic ring in patients with fragility fractures of the pelvis. Eur J Trauma Emerg Surg. 2022;48(5):3711–9. https://doi.org/10.1007/s00068-021-01625-z.
69. Giannoudis PV, Chalidis BE, Roberts CS. Internal fixation of traumatic diastasis of pubic symphysis: is plate removal essential? Arch Orthop Trauma Surg. 2008;128(3):325–31. https://doi.org/10.1007/s00402-007-0429-1.
70. Putnis SE, Pearce R, Wali UJ, Bircher MD, Rickman MS. Open reduction and internal fixation of a traumatic diastasis of the pubic symphysis: one-year radiological and functional outcomes. J Bone Joint Surg Br. 2011;93(1):78–84. https://doi.org/10.1302/0301-620X.93B1.23941.
71. Sagi HC, Papp S. Comparative radiographic and clinical outcome of two-hole and multi-hole symphyseal plating. J Orthop Trauma. 2008;22(6):373–8. https://journals.lww.com/jorthotrauma/Fulltext/2008/07000/Comparative_Radiographic_and_Clinical_Outcome_of.1.aspx
72. Lindahl J, Hirvensalo E, Böstman O, Santavirta S. Failure of reduction with an external fixator in the management of injuries of the pelvic ring. Long-term evaluation of 110 patients. J Bone Joint Surg Br. 1999;81(6):955–62. https://doi.org/10.1302/0301-620x.81b6.8571.

73. Bi C, Wang Q, Wu J, et al. Modified pedicle screw-rod fixation versus anterior pelvic external fixation for the management of anterior pelvic ring fractures: a comparative study. J Orthop Surg Res. 2017;12(1):185. https://doi.org/10.1186/s13018-017-0688-7.
74. Routt MLJ, Simonian PT, Mills WJ. Iliosacral screw fixation: early complications of the percutaneous technique. J Orthop Trauma. 1997; 11(8):584–9. https://doi.org/10.1097/00005131-199711000-00007.
75. Deng H-L, Li D-Y, Cong Y-X, et al. Clinical analysis of single and double sacroiliac screws in the treatment of tile C1 pelvic fracture. Ye C, ed. Biomed Res Int. 2022;2022:6426977. https://doi.org/10.1155/2022/6426977.
76. Singh A, Lim ASM, Lau BPH, O'Neill G. Epidemiology of pelvic and acetabular fractures in a tertiary hospital in Singapore. Singap Med J. 2022;63(7):388. https://journals.lww.com/SMJ/Fulltext/2022/07000/Epidemiology_of_pelvic_and_acetabular_fractures_in.8.aspx
77. Mauffrey C, Hao J, Cuellar DO 3rd, et al. The epidemiology and injury patterns of acetabular fractures: are the USA and China comparable? Clin Orthop Relat Res. 2014;472(11):3332–7. https://doi.org/10.1007/s11999-014-3462-8.
78. Antell NB, Switzer JA, Schmidt AH. Management of acetabular fractures in the elderly. J Am Acad Orthop Surg. 2017;25(8):577–85. https://journals.lww.com/jaaos/Fulltext/2017/08000/Management_of_Acetabular_Fractures_in_the_Elderly.4.aspx
79. Lehmann W, Spering C, Jäckle K, Acharya MR. Solutions for failed osteosynthesis of the acetabulum. J Clin Orthop Trauma. 2020;11(6):1039–44. https://doi.org/10.1016/j.jcot.2020.09.024.
80. Schnaser E, Scarcella NR, Vallier HA. Acetabular fractures converted to total hip arthroplasties in the elderly: How does function compare to primary total hip arthroplasty? J Orthop Trauma. 2014;28(12):694–9. https://journals.lww.com/jorthotrauma/Fulltext/2014/12000/Acetabular_Fractures_Converted_to_Total_Hip.5.aspx
81. O'Toole RV, Hui E, Chandra A, Nascone JW. How often does open reduction and internal fixation of geriatric acetabular fractures lead to hip arthroplasty? J Orthop Trauma. 2014;28(3):148–53. https://doi.org/10.1097/BOT.0b013e31829c739a.
82. Tannast M, Najibi S, Matta JM. Two to twenty-year survivorship of the hip in 810 patients with operatively treated acetabular fractures. J Bone Joint Surg Am. 2012;94(17):1559–67. https://doi.org/10.2106/JBJS.K.00444.
83. Ziran N, Soles GLS, Matta JM. Outcomes after surgical treatment of acetabular fractures: a review. Patient Saf Surg. 2019;13(1):16. https://doi.org/10.1186/s13037-019-0196-2.
84. Henstenburg JM, Larwa JA, Williams CS, Shah MP, Harding SP. Risk factors for complications following pelvic ring and acetabular fractures: A retrospective analysis at an urban level 1 trauma center. J Orthop Trauma Rehabil. 2021;28:22104917211006890. https://doi.org/10.1177/22104917211006890.
85. Lundin N, Berg HE, Enocson A. Complications after surgical treatment of acetabular fractures: a 5-year follow-up of 229 patients. Eur J Orthop Surg Traumatol. 2022;33:1245–53. https://doi.org/10.1007/s00590-022-03284-1.
86. Yaradılmış YU, Okkaoğlu MC, Ateş A, Kılıç A, Demirkale İ, Altay M. Proximal femur fracture, analysis of epidemiology, complications, and mortality: a cohort with 380 patients. J Surg Med. 2021;5(1):75–9. https://doi.org/10.28982/josam.787253.
87. Mittal R, Banerjee S. Proximal femoral fractures: principles of management and review of literature. J Clin Orthop Trauma. 2012;3(1):15–23. https://doi.org/10.1016/j.jcot.2012.04.001.
88. Davidson A, Blum S, Harats E, et al. Neck of femur fractures treated with the femoral neck system: outcomes of one hundred and two patients and literature review. Int Orthop. 2022;46(9):2105–15. https://doi.org/10.1007/s00264-022-05414-0.
89. Tang Y, Zhang Z, Wang L, Xiong W, Fang Q, Wang G. Femoral neck system versus inverted cannulated cancellous screw for the treatment of femoral neck fractures in adults: a preliminary comparative study. J Orthop Surg Res. 2021;16(1):504. https://doi.org/10.1186/s13018-021-02659-0.
90. Duckworth AD, Bennet SJ, Aderinto J, Keating JF. Fixation of intracapsular fractures of the femoral neck in young patients: risk factors for failure. J Bone Joint Surg Br. 2011;93(6):811–6. https://doi.org/10.1302/0301-620X.93B6.26432.
91. Wang C-T, Chen J-W, Wu K, et al. Suboptimal outcomes after closed reduction and internal fixation of displaced femoral neck fractures in middle-aged patients: is internal fixation adequate in this age group? BMC Musculoskelet Disord. 2018;19(1):190. https://doi.org/10.1186/s12891-018-2120-9.
92. Fixation using Alternative Implants for the Treatment of Hip fractures (FAITH) Investigators. Fracture fixation in the operative management of hip fractures (FAITH): an international, multicentre, randomised controlled trial. Lancet (London, England). 2017;389(10078):1519–27. https://doi.org/10.1016/S0140-6736(17)30066-1.
93. Dolatowski FC, Frihagen F, Bartels S, et al. Screw fixation versus hemiarthroplasty for nondisplaced femoral neck fractures in elderly patients: a multicenter randomized controlled trial. J Bone Joint Surg Am. 2019;101(2):136–44. https://doi.org/10.2106/JBJS.18.00316.
94. Li L, Zhao X, Yang X, Tang X, Liu M. Dynamic hip screws versus cannulated screws for femoral neck fractures: a systematic review and meta-analysis. J Orthop Surg Res. 2020;15(1):352. https://doi.org/10.1186/s13018-020-01842-z.

95. Schwartsmann CR, Jacobus LS, LDF S, et al. Dynamic hip screw for the treatment of femoral neck fractures: a prospective study with 96 patients. ISRN Orthop. 2014;2014:257871. https://doi.org/10.1155/2014/257871.
96. Schwartsmann CR, Lammerhirt HM, Spinelli LD, Ungaretti Neto AD. Treatment of displaced femoral neck fractures in young patients with DHS and its association to osteonecrosis. Rev Bras Ortop. 2018;53(1):82–7. https://doi.org/10.1016/j.rboe.2017.03.003.
97. Yang J-J, Lin L-C, Chao K-H, et al. Risk factors for nonunion in patients with intracapsular femoral neck fractures treated with three cannulated screws placed in either a triangle or an inverted triangle configuration. J Bone Joint Surg Am. 2013;95(1):61–9. https://doi.org/10.2106/JBJS.K.01081.
98. Kim WY, Han CH, Park JI, Kim JY. Failure of intertrochanteric fracture fixation with a dynamic hip screw in relation to pre-operative fracture stability and osteoporosis. Int Orthop. 2001;25(6):360–2. https://doi.org/10.1007/s002640100287.
99. van der Sijp MPL, de Groot M, Meylaerts SA, et al. High risks of failure observed for A1 trochanteric femoral fractures treated with a DHS compared to the PFNA in a prospective observational cohort study. Arch Orthop Trauma Surg. 2022;142(7):1459–67. https://doi.org/10.1007/s00402-021-03824-0.
100. Kashigar A, Vincent A, Gunton MJ, Backstein D, Safir O, Kuzyk PRT. Predictors of failure for cephalomedullary nailing of proximal femoral fractures. Bone Joint J. 2014;96-B(8):1029–34. https://doi.org/10.1302/0301-620X.96B8.33644.
101. Bovbjerg PE, Larsen MS, Madsen CF, Schønnemann J. Failure of short versus long cephalomedullary nail after intertrochanteric fractures. J Orthop. 2020;18:209–12. https://doi.org/10.1016/j.jor.2019.10.018.
102. Jasudason E, Jeyem M. Failure of dynamic hip screw (DHS) fixation for intertrochanteric fracture. Experience of a single district general hospital. Orthop Proc. 2018;88(B)
103. Lin JC-F, Liang W-M. Mortality, readmission, and reoperation after hip fracture in nonagenarians. BMC Musculoskelet Disord. 2017;18(1):144. https://doi.org/10.1186/s12891-017-1493-5.
104. Puram C, Pradhan C, Patil A, Sodhai V, Sancheti P, Shyam A. Outcomes of dynamic hip screw augmented with trochanteric wiring for treatment of unstable type A2 intertrochanteric femur fractures. Injury. 2017;48(Suppl 2):S72–7. https://doi.org/10.1016/S0020-1383(17)30498-9.
105. Pang Y, He Q-F, Zhu L-L, Bian Z-Y, Li M-Q. Loss of reduction after cephalomedullary nail fixation of intertrochanteric femoral fracture: a brief report. Orthop Surg. 2020;12(6):1998–2003. https://doi.org/10.1111/os.12828.
106. Taheriazam A, Saeidinia A. Salvage of failed dynamic hip screw fixation of intertrochanteric fractures. Orthop Res Rev. 2019;11:93–8. https://doi.org/10.2147/ORR.S215240.
107. Petfield JL, Visscher LE, Gueorguiev B, Stoffel K, Pape H-C. Tips and tricks to avoid implant failure in proximal femur fractures treated with cephalomedullary nails: a review of the literature. OTA Int. 2022;5(2S):e191. https://journals.lww.com/otainternational/Fulltext/2022/04001/Tips_and_tricks_to_avoid_implant_failure_in.1.aspx
108. Weiss RJ, Montgomery SM, Al Dabbagh Z, Jansson K-A. National data of 6409 Swedish inpatients with femoral shaft fractures: stable incidence between 1998 and 2004. Injury. 2009;40(3):304–8. https://doi.org/10.1016/j.injury.2008.07.017.
109. Enninghorst N, McDougall D, Evans JA, Sisak K, Balogh ZJ. Population-based epidemiology of femur shaft fractures. J Trauma Acute Care Surg. 2013;74(6):1516–20. https://doi.org/10.1097/TA.0b013e31828c3dc9.
110. Rudloff MI, Smith WR. Intramedullary nailing of the femur: current concepts concerning reaming. J Orthop Trauma. 2009;23(5 Suppl):S12–7. https://doi.org/10.1097/BOT.0b013e31819f258a.
111. Aggerwal S, Gahlot N, Saini UC, Bali K. Failure of intramedullary femoral nail with segmental breakage of distal locking bolts: a case report and review of the literature. Chin J Traumatol (English Ed). 2011;14(3):188–92. https://doi.org/10.3760/cma.j.issn.1008-1275.2011.01.013.
112. Harrington P, Sharif I, Smyth H. Failure of femoral nailing in the elderly. Arch Orthop Trauma Surg. 1997;116(4):244–5. https://doi.org/10.1007/BF00393721.
113. May C, Yen Y-M, Nasreddine AY, Hedequist D, Hresko MT, Heyworth BE. Complications of plate fixation of femoral shaft fractures in children and adolescents. J Child Orthop. 2013;7(3):235–43. https://doi.org/10.1007/s11832-013-0496-5.
114. Hsu C-L, Yang J-J, Yeh T-T, Shen H-C, Pan R-Y, Wu C-C. Early fixation failure of locked plating in complex distal femoral fractures: root causes analysis. J Formos Med Assoc. 2021;120(1, Part 2):395–403. https://doi.org/10.1016/j.jfma.2020.06.017.
115. Min B-W, Lee K-J, Cho C-H, Lee I-G, Kim B-S. High failure rates of locking compression plate Osteosynthesis with transverse fracture around a well-fixed stem tip for periprosthetic femoral fracture. J Clin Med. 2020;9(11):3758. https://doi.org/10.3390/jcm9113758.
116. Said GZ, Said HG, el-Sharkawi MM. Failed intramedullary nailing of femur: open reduction and plate augmentation with the nail in situ. Int Orthop. 2011;35(7):1089–92. https://doi.org/10.1007/s00264-010-1192-4.
117. Elsoe R, Ceccotti AA, Larsen P. Population-based epidemiology and incidence of distal femur fractures. Int Orthop. 2018;42(1):191–6. https://doi.org/10.1007/s00264-017-3665-1.
118. Kolb K, Grützner P, Koller H, Windisch C, Marx F, Kolb W. The condylar plate for treatment of dis-

tal femoral fractures: a long-term follow-up study. Injury. 2009;40(4):440–8. https://doi.org/10.1016/j.injury.2008.08.046.
119. Higgins TF, Pittman G, Hines J, Bachus KN. Biomechanical analysis of distal femur fracture fixation: fixed-angle screw-plate construct versus condylar blade plate. J Orthop Trauma. 2007;21(1):43–6. https://doi.org/10.1097/BOT.0b013e31802bb372.
120. Leung KS, Shen WY, So WS, Mui LT, Grosse A. Interlocking intramedullary nailing for supracondylar and intercondylar fractures of the distal part of the femur. J Bone Joint Surg Am. 1991;73(3):332–40.
121. Siddiqui YS, Mohd J, Abbas M, Gupta K, Khan MJ, Istiyak M. Technical difficulties and mechanical failure of distal femoral locking compression plate (DFLCP) in management of unstable distal femoral fractures. Int J Burns Trauma. 2021;11(1):9–19.
122. Collinge CA, Reeb AF, Rodriguez-Buitrago AF, et al. Analysis of 101 mechanical failures in distal femur fractures treated with 3 generations of precontoured locking plates. J Orthop Trauma. 2023;37(1):8–13. https://doi.org/10.1097/BOT.0000000000002460.
123. Elsoe R, Larsen P, Nielsen NPH, Swenne J, Rasmussen S, Ostgaard SE. Population-based epidemiology of tibial plateau fractures. Orthopedics. 2015;38(9):e780–6. https://doi.org/10.3928/01477447-20150902-55.
124. Canadian Orthopaedic Trauma Society. Open reduction and internal fixation compared with circular fixator application for bicondylar tibial plateau fractures. Results of a multicenter, prospective, randomized clinical trial. J Bone Joint Surg Am. 2006;88(12):2613–23. https://doi.org/10.2106/JBJS.E.01416.
125. Scott CEH, Davidson E, MacDonald DJ, White TO, Keating JF. Total knee arthroplasty following tibial plateau fracture: a matched cohort study. Bone Joint J. 2015;97-B(4):532–8. https://doi.org/10.1302/0301-620X.97B4.34789.
126. Ali AM, El-Shafie M, Willett KM. Failure of fixation of tibial plateau fractures. J Orthop Trauma. 2002;16(5):323–9. https://doi.org/10.1097/00005131-200205000-00006.
127. Laurila J, Huttunen TT, Kannus P, Kääriäinen M, Mattila VM. Tibial shaft fractures in Finland between 1997 and 2014. Injury. 2019;50(4):973–7. https://doi.org/10.1016/j.injury.2019.03.034.
128. Anandasivam NS, Russo GS, Swallow MS, et al. Tibial shaft fracture: a large-scale study defining the injured population and associated injuries. J Clin Orthop Trauma. 2017;8(3):225–31. https://doi.org/10.1016/j.jcot.2017.07.012.
129. Tay W-H, de Steiger R, Richardson M, Gruen R, Balogh ZJ. Health outcomes of delayed union and nonunion of femoral and tibial shaft fractures. Injury. 2014;45(10):1653–8. https://doi.org/10.1016/j.injury.2014.06.025.
130. Busse JW, Morton E, Lacchetti C, Guyatt GH, Bhandari M. Current management of tibial shaft fractures: a survey of 450 Canadian orthopedic trauma surgeons. Acta Orthop. 2008;79(5):689–94. https://doi.org/10.1080/17453670810016722.
131. Ruiz AL, Kealey WD, McCoy GF. Implant failure in tibial nailing. Injury. 2000;31(5):359–62. https://doi.org/10.1016/s0020-1383(00)00002-4.
132. Foster PAL, Barton SB, Jones SCE, Morrison RJM, Britten S. The treatment of complex tibial shaft fractures by the Ilizarov method. J Bone Joint Surg Br. 2012;94(12):1678–83. https://doi.org/10.1302/0301-620X.94B12.29266.
133. Dickson DR, Moulder E, Hadland Y, Giannoudis PV, Sharma HK. Grade 3 open tibial shaft fractures treated with a circular frame, functional outcome and systematic review of literature. Injury. 2015;46(4):751–8. https://doi.org/10.1016/j.injury.2015.01.025.
134. Giotakis N, Panchani SK, Narayan B, Larkin JJ, Al Maskari S, Nayagam S. Segmental fractures of the tibia treated by circular external fixation. J Bone Joint Surg Br. 2010;92(5):687–92. https://doi.org/10.1302/0301-620X.92B5.22514.
135. Wennergren D, Bergdahl C, Ekelund J, Juto H, Sundfeldt M, Möller M. Epidemiology and incidence of tibia fractures in the Swedish fracture register. Injury. 2018;49(11):2068–74. https://doi.org/10.1016/j.injury.2018.09.008.
136. Borg T, Larsson S, Lindsjö U. Percutaneous plating of distal tibial fractures. Preliminary results in 21 patients. Injury. 2004;35(6):608–14. https://doi.org/10.1016/j.injury.2003.08.015.
137. Tyllianakis M, Megas P, Giannikas D, Lambiris E. Interlocking intramedullary nailing in distal tibial fractures. Orthopedics. 2000;23(8):805–8. https://doi.org/10.3928/0147-7447-20000801-13.
138. Leung F, Kwok HY, Pun TS, Chow SP. Limited open reduction and Ilizarov external fixation in the treatment of distal tibial fractures. Injury. 2004;35(3):278–83. https://doi.org/10.1016/s0020-1383(03)00172-4.
139. Ylitalo AAJ, Dahl KA, Reito A, Ekman E. Changes in operative treatment of tibia fractures in Finland between 2000 and 2018: a nationwide study. Scand J Surg. 2022;111(3):65–71. https://doi.org/10.1177/14574969221111612.
140. Queipo-de-Llano A, Jimenez-Garrido C, FDB D-R, Mariscal-Lara J, Rodriguez-Delourme I. Complications after plating of articular pilon fractures: a comparison of anteromedial, anterolateral and medial plating. Acta Orthop Belg. 2020;86(3):102–13.
141. Lomax A, Singh A, Jane Madeley N, Senthil KC. Complications and early results after operative fixation of 68 pilon fractures of the distal tibia. Scott Med J. 2015;60(2):79–84. https://doi.org/10.1177/0036933015569159.
142. Ene R, Panti Z, Nica M, et al. Mechanical failure of angle locking plates in distal comminuted Tibial fractures. Key Eng Mater. 2016;695:118–

22. https://doi.org/10.4028/www.scientific.net/KEM.695.118.
143. Lovisetti G, Agus MA, Pace F, Capitani D, Sala F. Management of distal tibial intra-articular fractures with circular external fixation. Strateg Trauma Limb Reconstr. 2009;4(1):1–6. https://doi.org/10.1007/s11751-009-0050-7.
144. Koval KJ, Lurie J, Zhou W, et al. Ankle fractures in the elderly: what you get depends on where you live and who you see. J Orthop Trauma. 2005;19(9):635–9. https://doi.org/10.1097/01.bot.0000177105.53708.a9.
145. Scheer RC, Newman JM, Zhou JJ, et al. Ankle fracture epidemiology in the United States: patient-related trends and mechanisms of injury. J Foot Ankle Surg. 2020;59(3):479–83. https://doi.org/10.1053/j.jfas.2019.09.016.
146. Ovaska MT, Mäkinen TJ, Madanat R, Kiljunen V, Lindahl J. A comprehensive analysis of patients with malreduced ankle fractures undergoing re-operation. Int Orthop. 2014;38(1):83–8. https://doi.org/10.1007/s00264-013-2168-y.
147. Prediger B, Tjardes T, Probst C, et al. Factors predicting failure of internal fixations of fractures of the lower limbs: a prospective cohort study. BMC Musculoskelet Disord. 2021;22(1):798. https://doi.org/10.1186/s12891-021-04688-6.
148. Mitchell MJ, McKinley JC, Robinson CM. The epidemiology of calcaneal fractures. Foot (Edinb). 2009;19(4):197–200. https://doi.org/10.1016/j.foot.2009.05.001.
149. Jiménez-Almonte JH, King JD, Luo TD, Aneja A, Moghadamian E. Classifications in brief: sanders classification of intraarticular fractures of the calcaneus. Clin Orthop Relat Res. 2019;477(2):467–71. https://doi.org/10.1097/CORR.0000000000000539.
150. Weber M, Lehmann O, Sägesser D, Krause F. Limited open reduction and internal fixation of displaced intra-articular fractures of the calcaneum. J Bone Joint Surg Br. 2008;90(12):1608–16. https://doi.org/10.1302/0301-620X.90B12.20638.
151. Jain S, Jain AK, Kumar I. Outcome of open reduction and internal fixation of intraarticular calcaneal fracture fixed with locking calcaneal plate. Chin J Traumatol. 2013;16(6):355–60.
152. Bèzes H, Massart P, Delvaux D, Fourquet JP, Tazi F. The operative treatment of intraarticular calcaneal fractures. Indications, technique, and results in 257 cases. Clin Orthop Relat Res. 1993;290:55–9.
153. Schepers T. The primary arthrodesis for severely comminuted intra-articular fractures of the calcaneus: a systematic review. Foot Ankle Surg. 2012;18(2):84–8. https://doi.org/10.1016/j.fas.2011.04.004.
154. Pompach M, Carda M, Amlang M, Zwipp H. Treatment of calcaneal fractures with a locking nail (C-nail). Oper Orthop Traumatol. 2016;28(3):218–30. https://doi.org/10.1007/s00064-016-0441-0.
155. Yu HH, Ardavanis KS, Durso JT, Garries MP, Erard UE. Novel technique for osteosynthesis of tongue-type calcaneus fractures in osteoporotic bone: a case report. JBJS Case Connect. 2020;10(4):e20.00476. https://doi.org/10.2106/JBJS.CC.20.00476.
156. Hardcastle PH, Reschauer R, Kutscha-Lissberg E, Schoffmann W. Injuries to the tarsometatarsal joint. Incidence, classification and treatment. J Bone Joint Surg Br. 1982;64(3):349–56. https://doi.org/10.1302/0301-620X.64B3.7096403.
157. Haapamaki VV, Kiuru MJ, Koskinen SK. Ankle and foot injuries: analysis of MDCT findings. AJR Am J Roentgenol. 2004;183(3):615–22. https://doi.org/10.2214/ajr.183.3.1830615.
158. Moracia-Ochagavía I, Rodríguez-Merchán EC. Lisfranc fracture-dislocations: current management. EFORT Open Rev. 2019;4(7):430–44. https://doi.org/10.1302/2058-5241.4.180076.
159. Lewis JSJ, Anderson RB. Lisfranc injuries in the athlete. Foot Ankle Int. 2016;37(12):1374–80. https://doi.org/10.1177/1071100716675293.
160. Buda M, Kink S, Stavenuiter R, et al. Reoperation rate differences between open reduction internal fixation and primary arthrodesis of Lisfranc injuries. Foot Ankle Int. 2018;39(9):1089–96. https://doi.org/10.1177/1071100718774005.
161. Khurana A, Kumar A, Katekar S, et al. Is routine removal of syndesmotic screw justified? A meta-analysis. Foot. 2021;49:101776. https://doi.org/10.1016/j.foot.2021.101776.