Calcaneus fractures: facts, controversies and recent developments

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Summary The management of calcaneus fractures and their associated soft tissue injuries are challenging tasks for the surgeon. Open reduction and stable internal fixation with a lateral plate and without joint transfixation has been established as a standard therapy for displaced intra-articular fractures with good to excellent results in two-thirds to three-quarters of cases in larger clinical series. Bone grafting appears not useful in the vast majority of cases. Anatomical reduction of joint congruity and the overall shape of the calcaneus are important prognostic factors. The quality of joint reduction should be reliably proven intra-operatively either with Broden views, high-resolution fluoroscopy or open subtalar arthroscopy. Treatment results are adversely affected by open fractures, delayed reduction after more than 14 days and individual risk factors such as high body mass index and smoking. The extended lateral approach respects the neurovascular supply to the heel and allows a good exposure of the fractured lateral wall, and the subtalar and calcaneocuboid joints in most fractures. In selected fracture patterns percutaneous screw fixation, possibly with arthroscopic control, is a good alternative. Open fractures, compartment syndrome and fractures with severe soft tissue compromise are treated as emergency cases. Early, stable soft tissue coverage appears promising in treating complex open fractures. The benefits of newly developed plate designs and subtalar arthrolysis at the time of hardware removal remains to be proven in further studies. Calcaneal malunions after conservative therapy of displaced fractures are disabling conditions that can be treated successfully with a staged protocol according to the type of deformity. Treatment options include lateral wall decompression, subtalar in situ, or corrective, arthrodesis and calcaneal osteotomy along the former fracture line.

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series have highlighted a considerable learning curve. On the other hand, conservative treatment of displaced calcaneus fractures frequently leads to severe functional impairment with considerable disability. To avoid the feared soft tissue complications, several minimally-invasive and percutaneous approaches have been proposed throughout the history of calcaneal fracture treatment and recently gained popularity for selected injury patterns. Comparison of the various treatment methods is hampered by the lack of a uniform fracture classification and outcome measurement. A well-accepted fact is, however, that the sequelae of calcaneus fractures have a considerable socio-economic impact since a great percentage of these injuries occur in young and middle-aged male industrial workers. The treatment of calcaneus fractures has to be tailored not only to the individual fracture pattern and soft tissue damage but also to the functional demand, comorbidities and compliance of the patient. This article reviews the current concepts and new developments regarding the treatment of these difficult injuries.

**Historical review**

The apparent difficulties in treating calcaneal fractures are reflected in dramatic changes in the treatment of these injuries. During the 18th and 19th centuries, the prevention of life-threatening infections was the primary goal of fracture treatment. Partial or total calcanectomy was frequently carried out to salvage the limb and prevent the patient from tetanus or gas gangrene. Malgaigne, in his landmark atlas of 1856, described the complex anatomy of calcaneus fractures with high precision (Fig. 1), exactly as it has been reproduced by biomechanical and clinical studies using computed tomography more than a century later. The surgeons of the French school of the 1920s pioneered open reduction and internal fixation of displaced intra-articular calcaneus fractures with staples and screws and even defect filling with autologous bone grafts. The German surgeon Westhues, in 1934, introduced a percutaneous pin into the tuberosity for reduction of the main fragments and subsequent plaster immobilisation. This method has not only been used widely for percutaneous treatment of calcaneal fractures, it is also considered helpful in present-day open reduction and internal fixation, Böhler, who has brought considerable insight into fracture mechanisms and reconstructive options, changed his treatment strategy several times during his long engagement with calcaneal fractures. He concluded finally, that anatomical reduction and permanent retention of the fracture with skeletal traction and transfization were essential for good results. In a remarkable review, Goff, in 1938, described no less than 41 different operative treatment methods for calcaneus fractures. However, high infection rates and inadequate fixation devices led to a decline of calcaneus surgery in the mid-20th century, with many surgeons advocating delayed primary triple arthrodesis or secondary subtalar arthrodesis. The famous notion of McLaughlin, likening attempts of fixing calcaneus fractures to 'nailing a custard pie to the wall' and the results of a comparative study that showed superior results with non-operative treatment dominated the philosophy of conservative fracture treatment during the 1960s and 1970s. However, the unsatisfactory functional results after conservative treatment of intra-articular calcaneus fractures and the routine availability of CT scanning for diagnosis have resulted in a reappraisal of the surgical approach. French and Italian surgeons were the first to treat greater patient series with open reduction and lateral plate osteosynthesis in the 1970s. French and Italian surgeons were the first to treat greater patient series with open reduction and lateral plate osteosynthesis in the 1970s. Today open reduction and internal fixation is favoured by most surgeons for displaced, intra-articular calcaneus fractures, although the individual indications and surgical strategy remains a matter of debate.

**Anatomical and biomechanical considerations**

A profound knowledge of the irregular anatomy of the calcaneus and its neighbouring bones and a
three-dimensional imagination are indispensable in assessing and treating calcaneus fractures. The calcaneus is the largest bone of the foot. It makes up the essential posterior part of the longitudinal foot arch and the lateral foot column. Through the action of the Achilles tendon, the plantar fascia and intrinsic foot muscles it acts as a strong lever arm during walking, standing and crouching.

The bony architecture is characterised by a cortical shell of varying thickness and a vault-like trabecular pattern of the cancellous bone (Fig. 2). The latter reflects the axial compression forces transmitting the body weight through the calcaneus and tensile forces generated by tendinous and fascial insertions. Consequently, the trabeculae are condensed beneath the posterior facet of the subtalar joint forming the thalamic portion.33 A triangle with sparse subthalamic trabeculae beneath (neutral triangle) is prone to impaction in the typical compression fracture. The cortical bone is especially thin at the lateral wall of the calcaneus, which leads to its frequently observed bulging in calcaneal fractures. Along the neck of the calcaneus a thick cortical layer forms Gissane’s crucial angle35 with a normal value of 120—145° in the lateral radiographic projection. Further posteriorly the cortical bone forms the tuberosity—joint angle varying considerably from 25 to 40° (Böhler’s angle10), frequently used as a measurement for the quality of restoration of the anatomical shape after calcaneal fractures.

The most stable part of the calcaneus is the sustentaculum tali, emanating from its medial wall. It is connected to the talus via strong medial and lateral talocalcaneal ligaments. The flexor hallucis longus tendon runs beneath its inferior border exerting a dynamic press-fit force. These structures preserve the anatomical position of the sustentaculum in relation to the talus in many fracture patterns. The peroneal tendons are guided by grooves located on the lateral wall, above and below the peroneal tubercle, and by the distal peroneal retinaculum. The anterior process serves as a strong buttress of the lateral foot column leading to the navicular and cuboid bones, which are attached to it by the strong bifurcate and dorsal calcaneocuboid ligaments.

The superior aspect of the calcaneus has three joint facets belonging to the subtalar joint complex that articulates with the talus. The largest and functionally most important is the convex-shaped posterior facet. The concave-shaped middle facet and the anterior facet, which is flat, are merged in about one-fifth of all cases.90 The posterior facet is separated from the smaller anterior and middle facets by the calcaneal sulcus which forms the inferior border of the narrow tarsal canal medially and the wider sinus tarsi laterally. Within the sinus tarsi lies the strong talocalcaneal interosseous ligament complex. The biconcave, saddle-shaped joint surface which connects the calcaneus to the cuboid, is part of the mid-tarsal (Chopart’s) joint.82,90

The subtalar joint acts in close coupling with the ankle joint and strongly influences the performance of the more distal foot articulations. It is essentially a mitred hinge between the talus and the calcaneus with a single axis that passes from medial to lateral at an angle of approximately 16° to the sagittal plane and approximately 42° above the horizontal plane.48,66 The subtalar joint complex allows a considerable inversion/eversion movement of the hindfoot that is essential for shock absorption during heel strike, adaptation of the foot to the ground in mid-stance and rigidity of the foot during push-off.48

Pathomechanics

Fractures of the calcaneus are typically produced by axial force. The vast majority result from heavy deceleration, such as a fall from a height or motor vehicle accidents with the foot pressed firmly against a pedal. Men are affected four to five times more often than women.67,113 The highly variable fracture pattern is affected by the magnitude and direction of the impacting force, the foot position, the muscular tone, and the mineral content of the bone.

The vertical load axis of the talus lies medially to that of the calcaneus (Fig. 3). The typical primary fracture line, described in detail by
Essex-Lopresti,\textsuperscript{35} is a result of the eccentrically directed vertical axial force and the diverging longitudinal axes of the talus and the calcaneus, which form an angle of about 25–30°. The impacting force of the lateral talar process exerts a wedge-like action on the calcaneus, forcing the subtalar joint into eversion. The sustentaculum tali is sheared off the body of the calcaneus. This sagittal plane fracture results in two main fragments: a superomedial (sustentacular) and a posterolateral (tuberosity and body) portion. With the hindfoot in eversion (valgus) at impact the fracture line runs laterally creating a large superomedial fragment, whereas with the hindfoot in inversion (varus) the fracture line lies more medially (Fig. 3), sometimes producing isolated fractures of the sustentaculum.\textsuperscript{110} The fracture mechanism consistently results in a lateral wall blow out (lateral bulge), leading to entrapment of the soft tissues around the fibular tip (abutment) and the peroneal tendons especially in cases with severe lateral shift of the posterolateral part.

If the energy of the impact is not completely expended, secondary fracture lines develop, beginning at the posterior aspect of the subtalar joint.\textsuperscript{35} In joint depression type fractures the secondary fracture line runs downward posterior to the impacted posterior facet, only marginally involving the tuberosity. In tongue type fractures the secondary fracture line extends longitudinally into the tuberosity, resulting in a complex deformity of the hindfoot, abolishing, and sometimes even reversing, the tuberosity–joint angle. These fundamental clinical observations of Essex-Lopresti have been validated by experimentally created calcaneal fractures.\textsuperscript{24,110,113} Although a great variety of joint depression and tongue type fractures were created, constant primary and secondary fracture lines and resulting main fragments were seen. Variable tertiary fracture lines may extend anteriorly and lead to a step-off in the calcaneocuboid joint, forming a further, anterolateral fragment. If an anterior fracture line also cuts across the medial facet, another, anteromedial fragment results.\textsuperscript{112} Altogether, up to five main fragments are reproducibly seen in clinical and experimental settings (Fig. 4), forming the basis of fracture classification.\textsuperscript{111}

Special fracture types are avulsions of the bifurcate ligament at the superomedial tip of the anterior process or of the Achilles tendon at the superior aspect of the tuberosity (beak fracture). The first are seen in supination type injuries of the hindfoot and may be associated with ligamentous instability at the ankle and subtalar joint, making diagnosis sometimes difficult.\textsuperscript{115} The latter occur predominantly in children and adolescents and result from reflex contraction of the triceps surae muscle complex when falling from a height. Isolated compression fractures of the anterior process are seen after excessive abduction of the forefoot against
the mid-foot, resulting in a compression of the lateral column of the foot. These injuries, therefore, are regarded as part of fracture-dislocations at the mid-tarsal joint resulting from a mechanism distinct from the typical calcaneus fracture.

Clinical features

Clinical assessment of patients with injuries to the hindfoot is crucial, not only for making the diagnosis in low-energy injuries, but also for staging the soft tissue injury, which is important for further management. Special attention must be paid not to overlook foot injuries in multiply injured patients. Typical features of calcaneal fractures are swelling and haematoma of the hindfoot and ankle. The heel is tender to palpation. The patients are unable to bear weight on the affected leg, or fully to pronate and supinate the foot. Frequently, lateral bulging and valgus deformity of the hindfoot are seen.

Continuous assessment of the soft tissue status is of great importance for the fate of calcaneus fractures because blister formation may develop within a few hours and with severe fragment pressure from within a full-thickness skin necrosis may occur. In any case of severe soft tissue swelling, a compartment syndrome of the foot has to be ruled out. An isolated pressure elevation within the deep calcaneal compartment containing the quadratus plantae muscle and the lateral plantar nerve has been associated with calcaneus fractures in cadaver injection studies. Selective catheterisation of traumatised feet has shown that the calcaneal compartment is subject to relatively higher pressures than the other foot compartments. In unconscious patients compartment pressure is measured with multi-stick invasive catheterisation. It is generally agreed, that dermatofasciotomy is indicated with pressures exceeding 30 mmHg, a recommendation drawn from multiple studies at the forearm and leg. In the authors’ preference this limit has been lowered to 25 mmHg, since the intrinsic foot muscles are highly susceptible to permanent ischaemic damage from elevated compartment pressures resulting in the frequently observed development of claw toes.

Radiographic assessment

The lateral view of the calcaneus allows assessment of Böhler’s and Gissane’s angles, loss of height, compression and avulsion fractures at the calcaneal body and the anterior process (Fig. 2). Broadening of the heel and varus/vulgar alignment can be evaluated on axial radiographs of the hindfoot. An anteroposterior (dorsoplantar) view of the foot with a 30° caudally tilted tube allows evaluation of the calcaneocuboid joint. Anteroposterior films of the ankle joint demonstrate the amount of fibulocalcaneal abutment and lateral talar tilting in severe fracture-dislocations. Lateral X-rays of the unaffected side are useful in determining the patient’s normal individual Böhler’s and Gissane’s angles. Brodén’s series of oblique views show the extent of damage to the subtalar joint. The foot is placed in neutral ankle position and internal rotation of 40°, while the X-ray tube is angled 10°–40°, the former showing the posterior, the latter the anterior portion of the subtalar joint. While the information from these views can be deduced more precisely by computed tomography (CT) scanning, the technique is useful for intra-operative assessment of reduction.

Figure 4  The reproducible five main fragments, as seen on CT, are: (1) tuberosity; (2) sustentaculum; (3) posterolateral joint fragment (usually depressed and tilted); (4) anterolateral joint fragment (anterior process); (5) anteromedial joint fragment. The heel is usually in varus in the horizontal plane. Note also the bulging of the lateral calcaneal wall.
If an intra-articular fracture or major displacement is suspected, CT scans are carried out. These allow for a three-dimensional analysis of fracture morphology and determination of joint involvement and are extremely helpful in planning the surgical approach. Primary axial and coronal scans of 2 mm thickness are made for exact assessment of the fracture morphology. Technetium scans and MRI are useful in detecting stress fractures of the calcaneus, but have no current place in the acute setting.

Classification

Böhler\textsuperscript{12} was one of the first to provide an extensive calcaneal fracture classification system. Eight groups of fractures were described, four of them extra-articular (groups 1–4) and four intra-articular (groups 5–8). A broad range of different fracture pathoanatomy was covered by this classification, including beak fractures (group 1), isolated sustentacular fractures (group 3), classical dislocations of the posterior facet (groups 5 and 6), as well as dislocations in the talonavicular (group 7) and calcaneocuboid joints (group 8). However, there was no correlation of fracture type and expected outcome. Palmer\textsuperscript{78} and, most notably, Essex-Lopresti\textsuperscript{35} based fracture classification on the proposed fracture mechanism. The result was a simple distinction between two principal fracture types based on the location of the secondary fracture lines in intra-articular fractures as described earlier: joint depression and tongue types. These terms are still in use for describing the overall appearance of the fractured calcaneus. Soeur and Remy\textsuperscript{93} presented a classification based on the number of articular bone fragments as seen on lateral, axial and anteroposterior radiographs. Non-displaced fractures were classified first degree, secondary fracture lines resulting in three fragments as second degree and comminuted fractures as third degree. Their work served as a basis for today’s classifications.

Since computed tomographic scanning allows exact assessment of the fracture pathology, present-day classification systems of calcaneal fractures are based partly or solely on CT scans.\textsuperscript{29,86,111,113} The most widely used classification is that by Sanders et al.,\textsuperscript{86} which is based purely on the amount and location of fracture lines in the coronal CT scans at the level of the posterior calcaneal facet. Extra-articular fractures are classified type I, one fracture line equals type II, two fracture lines equal type III and three or more fracture lines are classified type IV. Laterally situated fracture lines are encoded with the letter A, intermediate with B and medial ones with the letter C. Zwipp and co-workers\textsuperscript{111,113} introduced a 12-point fracture scale, that reflects the number of main fragments (2–5, Fig. 4) and involved joint surfaces (0–3) as well as the extent of soft tissue trauma\textsuperscript{107} and accompanying fractures of neighbouring bones (additional 4 points), because the latter two features are crucial in determining outcome after calcaneal fractures. In the respective author’s hands, both classification systems have proved to be of prognostic value within greater patient populations.\textsuperscript{84,86,112} A recent CT morphometry study found a predictive impact for both classifications with a higher correlation of the Zwipp scale for the choice of therapy.\textsuperscript{2}

Indications and timing of surgery

The question whether, when and how to operate calcaneal fractures still generates lively debate. Most authors would agree, that severely displaced extra-articular fractures and those with intra-articular step-offs should be reduced anatomically in the absence of systemic or local contraindications.\textsuperscript{6,8,9,30,31,60,84,86,112} Opinions differ on what amount of displacement is considered severe. Since step-offs of 1–2 mm in size in the posterior facet are associated with a substantial load shift in the experimental setting,\textsuperscript{71,88} and inferior functional results in clinical series,\textsuperscript{9,13,20,84,94} surgical reduction of intra-articular fractures with joint displacement of 2 mm and more appears reasonable. Extra-articular fractures with a substantial hindfoot varus/valgus, or considerable flattening, broadening, or shortening, should also be treated operatively. General contraindications to open surgery include severe neurovascular insufficiency, ”insulin-dependent” diabetes mellitus, poor compliance, immunodeficiency and severe systemic disorders with a poor overall prognosis. There is no clear age limit; treatment depends rather on the patient’s overall condition and functional demand.

Emergency procedures

For the timing of surgery, the soft tissue conditions and associated injuries are of paramount importance. Open fractures and closed fractures with compartment syndrome, or severe incarceration of the soft tissues from severely displaced sharp fragments, are treated as emergency cases. Emergency procedures for open fractures include initial debridement of the wound which is typically situated medially, temporary closure with skin
substitutes, and minimally-invasive fracture reduction with K-wire fixation, supplemented by external fixation.\textsuperscript{116} The latter may be applied as tibiometatarsal transfixation or a medial three-point distractor introduced into the talar head, cuboid and calcaneal tuberosity. After 48–72 h, a second look with repeat debridement is carried out and the type of soft tissue coverage determined. A standard osteosynthesis is done after soft tissue recovery mostly within 10–14 days. Alternatively, in patients with a good overall condition, early osteosynthesis within 120 h may be supplemented by a local, or free, flap procedure to achieve complete wound closure in order to reduce infection rates and to allow for early functional after-treatment.\textsuperscript{15} With severely displaced fragments and threatening breakdown of the soft tissues, percutaneous reduction and temporary external and K-wire fixation is indicated. In case of a compartment syndrome of the foot an anteromedial dermatofasciotomy is carried out; the deep calcaneal compartment is released by a separate hindfoot incision similar to that used for a plantar fascial release.\textsuperscript{65,87} In polytraumatised patients, this procedure is followed by indirect reduction, and K-wiring and external fixation. In patients with isolated calcaneal fractures, the compartment release may be followed by a standard osteosynthesis. Our personal experience has shown, that early evacuation of the haematoma, open reduction and internal fixation are equally effective in treating both impeding and manifest compartment syndrome.

Not only may open fractures cause soft tissue problems, but the vast majority of closed calcaneal fractures are accompanied by considerable soft tissue compromise. In a large patient population we have observed a minimum of Tscherne grade II soft tissue damage\textsuperscript{107} in more than two-thirds of closed calcaneal fractures.\textsuperscript{84} Most authors prefer delayed osteosynthesis after the swelling has markedly decreased, usually within 10 days. Within this time period, transfer of the patient to a trauma centre experienced in the treatment of calcaneal fractures is possible. However, surgery should not be delayed beyond 14 days after the injury, when consolidation of the fracture begins. Two recent studies have shown that surgery beyond that date is associated with more postoperative soft tissue problems and inferior results.\textsuperscript{84,99}

### Non-operative treatment

Non-operative treatment is generally favoured for non- or minimally-displaced fractures and in the presence of local or general contraindications to surgery as outlined earlier.\textsuperscript{30,87,113} Anti-oedematous therapy consists in initial rest, ice and elevation of the affected foot for 3–4 days. After that, ankle and subtalar range of motion exercises are started and patients are mobilised with partial weight-bearing of 20 kg on the affected leg for 6–10 weeks, depending on the severity of the fracture. Omoto and Nakamura\textsuperscript{76} have described a manual closed reduction manoeuvre of repeated squeezing and strong longitudinal traction with the patient in prone position and spinal anaesthesia, followed by immobilisation in an below-the-knee walking cast in 45° of equinus. This method relies on intact interosseous and fibulocalcaneal ligaments and should be performed within 3 days after the injury. The authors state good to excellent results in 89 of 102 cases, while ‘‘severe’’ tongue type and ‘‘comminuted’’ joint depression type fractures could not be reduced successfully. Unfortunately, no criteria for ‘‘successful’’ reduction were given and no CT classification of the fractures was provided. This method could possibly be useful in patients with severe displacement of the calcaneus and contraindications to surgery.\textsuperscript{113}

### Minimally-invasive treatment

Indirect, closed reduction and percutaneous osteosynthesis of displaced calcaneal fractures may minimise the incidence of soft tissue-related complications, but carries the risk of inadequate reduction, especially with complex fracture patterns. Patients with simple injury patterns may benefit from minimally-invasive procedures,\textsuperscript{40,105} as do patients in a critical overall condition, or with local soft tissue conditions that preclude extensive approaches.\textsuperscript{113} Some authors have developed considerable expertise in percutaneous treatment and generally approach calcaneal fractures with these methods in order to minimise costs and complication rates while obtaining good overall results.\textsuperscript{36,96} Indirect reduction of the main tuberosity fragment is achieved either by traction, or by percutaneous leverage with an introduced pin. The latter was first described by Westhues,\textsuperscript{109} and later popularised by Gissane\textsuperscript{43} and Essex-Lopresti,\textsuperscript{35} who found it to be particularly useful in tongue type fractures. These authors used plaster immobilisation for maintenance of the reduction. Recently, this method has found a place for less severe fracture patterns, such as Sanders type IIC fractures, with the posterior facet being displaced as a whole.\textsuperscript{105} Tornetta III used Steinmann pins first for fracture fixation and later changed to percutaneous screw placement after observing drainage
and complaints related to shoe friction or pressure at the pin site scars. When combining this method with arthroscopic control of the subtalar joint, the indication may be expanded to Sanders type IIA and IIB fractures and selected cases of Sanders type III fractures, without the risk of inadequate reduction of the posterior facet. A Schanz screw is placed centrally into the main portion of the fragment parallel to the upper aspect of the tuberosity and directed to the most distal portion of the displaced posterior facet. Screw leverage is then used to loosen the impacted fragments and to restore calcaneal height and alignment. Separate lateral posterior facet and intermediate fragments are manipulated percutaneously with additional Kirschner wires, or an elevator. The fragments are then fixed with cortical screws (Fig. 5) introduced percutaneously via stab incisions under fluoroscopic guidance. In these selected cases excellent 1 year results were seen in a pilot series of 16 patients.

Skeletal traction has a long history in calcaneal fracture treatment. Böhler applied axial traction with a pin introduced transversely through the calcaneal tuberosity and the leg put in a specially designed frame. He also used Westhues’ pin leverage method and supplemented both traction and leverage with percutaneous wire-fixation of the fragments. Forgon applied a three-point distraction system to the calcaneal tuberosity, talar trochlea and cuboid, thereby being able to manipulate the fragments separately. After ensuring correct reduction, fluoroscopically, the fragments are fixed with percutaneously placed screws. The authors report on 89% good to excellent results in a series of 265 cases treated exclusively with that method. Stehlik and Stulik use a combination of direct percutaneous reduction of the articular surfaces, using a Steinmann pin, or elevator, and indirect reduction of the anatomical shape of the calcaneus with compression and traction. Fixation of the calcaneal fragments is achieved with radiating K-wires, without joint transfixation. The authors report 72% good to excellent results in 160 cases, with an infection rate below 1% in closed fractures. K-wire transfixation of the subtalar and/or calcaneocuboid joint should be reserved for extremely unstable fracture-dislocations, when reduction cannot otherwise be obtained. For routine use, joint transfixation is not encouraged, since it precludes functional after-treatment. In patients with severely compromised soft tissues, K-wire fixation is supplemented by tibiometatarsal transfixation, or three-point distraction (calcaneal tuberosity, talar head and cuboid), with an external fixator.

Figure 5 Percutaneous screw fixation of a Sanders type IIA fracture.
The same may apply for polytraumatised or otherwise unstable patients, when duration of surgery has to be kept to a minimum until definite osteosynthesis becomes feasible. If no internal fixation is done, K-wires and external fixation devices are removed after 10–12 weeks.

Operative treatment: open reduction and internal fixation

Open reduction and internal fixation of intra-articular calcaneal fractures aims at the restoration of the overall shape of the calcaneus, anatomical reconstruction of the affected joint surfaces and stable osteosynthesis, without joint transfixation, to allow early mobilisation. Several lateral, medial, plantar, posterior and combined approaches have been advocated. Many authors of larger series favour the extended lateral approach for displaced intra-articular calcaneal fractures.\(^6,9,60,87,112\) It allows direct visualisation and reconstruction of the destroyed lateral wall of the calcaneus, the posterior facet of the subtalar joint and the calcaneocuboid joint. With a medial approach\(^21,69\) the sustentaculum tali and medial wall are visualised, but only indirect reduction of the displaced posterior facet, lateral wall and calcaneocuboid joint is possible. A small medial approach (sustentacular approach\(^113\)) has been suggested for isolated sustentacular fractures, or in addition to the extended lateral approach with fragmentation of the sustentaculum in more complex intra-articular fractures. In rare cases of destruction of the medial joint facet in comminuted fractures a combined McReynolds/lateral approach seems beneficial.\(^51,98,113\) However, Stephenson\(^98\) reports a 27% incidence of wound edge necrosis with this approach. An alternative is the combination of the extended lateral approach with a sustentacular approach.\(^113\)

Medial approach\(^69\)

The medial approach to the calcaneus allows no control over joint congruity of the posterior facet and only indirect reduction of the main fragments. It has been used predominantly for simple two-part or extra-articular fractures, and in cases of medial wall blow out.\(^114\) Burdeaux uses it as standard approach,\(^21\) but needed an additional lateral incision to obtain joint reduction in one fifth of cases.\(^22\) The incision is made horizontally, or as a lazy S-cut about 8–10 cm exactly halfway between the tip of the medial malleolus and the sole. The neurovascular bundle is identified and carefully retracted. The abductor hallucis longus muscle is retracted downward, whereas the flexor hallucis longus tendon is only identified and left in place. The sustentacular fragment can be visualised fully and the medial facet controlled directly. The tuberosity fragment is reduced indirectly under axial pull against the sustentacular fragment and the anterior process, if separated from the main tuberosity fragment. After temporary K-wire transfixation, definitive fixation is achieved with a small plate used in an antiglide fashion.\(^21,111\) While Burdeaux\(^22\) saw good results and few wound complications, Paley and Hall\(^77\) observed a 25% incidence of damage to the calcaneal branch of the posterior tibial nerve with the medial approach.

Sustentacular approach\(^113\)

This small approach minimises the hazards of neurovascular damage and tendon irritation as compared to the McReynolds approach.\(^114\) It is useful only in isolated sustentacular fractures as well as to supplement the extended lateral approach in complex intra-articular fractures with fragmentation of the sustentaculum tali and its medial joint facet. The 3–5 cm incision runs horizontally directly over the palpable sustentaculum that lies about 2 cm below and 1 cm distal to the tip of the medial malleolus (Fig. 6). The adjacent tendons are held away, but the posterior tibial neurovascular bundle is not routinely exposed. After controlling the medial joint facet, the sustentaculum is usually fixed with long 3.5 mm compression screws, which are introduced along its axis into the calcaneal body (Fig. 6). The screws have to be aimed slightly in a plantar direction in order not to compromise the posterior joint facet, or the sinus tarsi.

Extended lateral approach\(^60\)

This standard approach is most useful with displaced intra-articular calcaneal fractures that involve the posterior facet, which is fractured in more than 90% of these cases.\(^6,113\) The patient is placed on a radiolucent operating table, allowing intra-operative fluoroscopy, in a lateral decubitus position on the non-injured side, or in a prone position.

An extended lateral approach to the calcaneus was first been used routinely by Letournel\(^59\) and successfully applied in several large clinical series.\(^6,86,112\) The skin incision is L-shaped over the lateral aspect of the heel, running between the lateral malleolus and the posterior and inferior border of the heel, respectively (Fig. 7a).\(^46\) With respect to the blood supply to the lateral aspect of the heel via the lateral calcaneal artery and the
course of the sural nerve, the incision is not placed exactly halfway between the lateral malleolus and the foot edge, but directed more towards the sole and the border of the Achilles tendon. The approach is developed as a full-thickness flap. The peroneal tendons are mobilised within their sheath and gently held back with a Penrose drain in order to prevent postoperative adhesions. Several smaller, direct approaches to the lateral calcaneal wall, resembling the classical Palmer (Kocher) approach have been carried out, but with either the same or even higher incidence of soft tissue problems, probably because they cut through the angiosome of the lateral calcaneal artery and the strong retraction needed for complete exposure of the fractured calcaneus. For certain fractures, a posterolateral (Gallie) approach is a viable alternative that can be completed to an extended lateral approach, if necessary.

After exposure of the subtalar joint and identification of the primary fracture line at Gissane’s angle, reduction of the tuberosity fragment can be helped in many cases with an axially placed 6.5 mm Schanz screw (modified Westhues manoeuvre). Alternatively, Benirschke et al. place a 4.5 to 5.5 mm screw from laterally. This manoeuvre also allows better visualisation and easier elevation of the depressed posterior facet fragment(s). With percutaneous leverage, downward displacement of the tuberosity as well as varus or valgus malalignment are corrected (Fig. 7c). The fractured posterior facet is reduced in a sequential fashion from medial to lateral (Fig. 7d). The reconstructed posterior facet as a whole is then brought into alignment with the tuberosity and the anterior process fragments and transfixed with additional K-wires.

Control of reduction

Due to the irregular shape of the posterior facet, control of articular congruity at this stage is difficult, but crucial. Sanders et al. recommends intraoperative Brodén views to assure joint congruity.
(Fig. 8); others recommend intra-operative, early postoperative CT scans, which is rather cumbersome and time-consuming. With newer generations of fluoroscopes, including 3D imaging, intra-operative fluoroscopy should provide a precise assessment of the subtalar joint. In the authors' experience, open subtalar arthroscopy (Fig. 8) allows a quick and most thorough evaluation of the quality of joint reduction. A small diameter arthroscope is introduced into the exposed subtalar joint via a standard anterior, or posterolateral portal. If residual step-offs are seen, joint reduction is repeated after temporarily removing the K-wires.

Defect filling and plate design

Elevation of the depressed thalamic portion regularly leaves a bony defect zone, resulting from impaction of this fragment into cancellous bone and the neutral triangle. The need for defect filling either with bone grafting from the ipsilateral iliac crest or with bone substitutes is controversial. While several authors deny the necessity of defect filling completely and refer to the regenerative capacities of cancellous bone, others use bone grafting for larger defects in highly unstable fractures, which may be the case in about 20–50%. In a prospective randomised study, the use of bone graft did not lead to superior results.

Internal fixation is completed with the use of an anatomically shaped plate fixed to the restored lateral wall of the calcaneus. The use of several plates has been advocated, such as 3.5 mm reconstruction plates, one or two (double or triple) H-shaped plates, a single Y-shaped plate, a "low contact" plate, and a "perimeter" plate with oblique strut. In most studies, a sufficient degree of stability could be achieved with the use of a single lateral plate that displays the anatomical features of the calcaneus, providing support to the tuberosity, thalamic portion and anterior process, like the AO (Tampa) calcaneus plate (Fig. 8). More recently, an interlocking anatomical (Synthes) plate has been
Figure 8  Clinical example of open reduction and internal fixation of an intra-articular calcaneal fracture—Sanders type IIIB and IIIC, five fragments/two joints (a—d) with the AO calcaneus plate and two additional screws introduced into the thalamic portion and directed towards the sustentaculum tali (e and f). Joint congruity is checked with an intra-operative Brodén view (f) and subtalar arthroscopy (g). Follow-up at 1 year with clinical examination (h) and weight-bearing radiographs (i and j) shows exact axial alignment. CT after hardware removal reveals the restored shape (k) and joint congruity (l).
Figure 8. (Continued).
developed by the AO Foot and Ankle Expert Group that should obviate the need for bone grafting even in highly unstable fractures (Fig. 9).

Primary subtalar arthrodesis

Anatomical reconstruction of the calcaneal shape and especially of the joint surfaces may be impossible in highly comminuted fractures (Sanders type IV). Some authors advocate primary subtalar arthrodesis in these cases.18,86 This procedure must be combined with reconstruction of heel height and width in order to achieve a plantigrade foot. After reconstruction of the anatomical shape of the calcaneus and plate fixation as described earlier, all remaining cartilage is removed from the joint surfaces and arthrodesis is achieved with autologous bone graft and one or two 6.5–8.0 mm transarticular cancellous bone lag screws.87 Alternatively, secondary arthrodesis may be performed after primary standard osteosynthesis, if painful subtalar arthritis develops, since asymptomatic ankylosis may occur as well.84 In any case, primary open reduction reduces soft tissue strain and facilitates any arthrodesis procedure that may be performed in situ117 and leads to better results as compared with primary conservative treatment.100

Postoperative care

Independently of the surgical approach, postoperative rehabilitation aims at early mobilisation of the patient. The protocol includes active and passive range of motion exercises in the ankle, subtalar and Chopart joints and isotonic and isometric exercises of the leg accompanied by continuous passive motion, beginning at the second postoperative day.113 Patients are restricted to partial weight-bearing in their own shoes for 6–12 weeks, depending on the severity of the fracture. Hardware removal approximately 1 year after placement of a lateral plate is optional (Fig. 8). Since postoperative adhesions and arthrofibrosis are frequently

Figure 9  Example of an intra-articular calcaneus fracture (a) fixed with an interlocking calcaneal plate (b–d).
seen after severe injuries, this procedure may be combined with subtalar arthroscopy and arthrosis, including intra- and extra-articular debridement of the subtalar joint. Arthroscopic grading of the subtalar joint is closely correlated with the clinical results and helpful in decision-making for subtalar arthrodesis.

Complications

Injuries to the cutaneous nerves most frequently afflict the sural nerve laterally and the posterior tibial nerve medially. These lesions usually result in hypaesthesia and are treated conservatively, except for neuroma formation, for which excision is advised. The most frequently observed postoperative complication is superficial wound edge necrosis, which is seen in up to 14% of cases after standard osteosynthesis via an extended lateral approach, and up to 27% with a bilateral approach. Superficial breakdown of the wound margins usually heals spontaneously with local wound care and immobilisation. Wound haematoma occurs in about 5% and can be treated initially with leg elevation and ice packs. If there is no rapid regression, aspiration or surgical evacuation are indicated to prevent skin necrosis or abscess formation. The application of a collagen-sponge over the lateral wall of the calcaneus after internal fixation may reduce bleeding from the cancellous bone. Wound abscesses should be excised immediately, and systemic antibiotics are applied. Deep infections occur in 1.3–7%. Some authors who did not discriminate between superficial wound breakdown and deep infections have reported on an overall 3–25% of “wound problems”. Radical debridement and aggressive antimicrobial therapy are mandatory in cases of deep infections. Mostly, the plate has to be removed and the calcaneus may be fixed with screws. If chronic calcaneal osteomyelitis develops, subtotal or total calcaneectomy is inevitable. Soft tissue coverage with local or free flaps has to be considered in order to control infection and to avoid protracted courses.

Open fractures, delayed surgery—In particular beyond 14 days after injury, high body mass index and smoking are important risk factors for the development of deep infections. In a series of patients with complex foot trauma, including calcaneal fractures, the infection rate after open fractures could be lowered considerably with early free or pedicled flap coverage. This “fix and flap” concept has been successfully applied to open tibial fractures and could also be useful for open foot fractures, to avoid the dreaded complications. Non-union is very rare after stable internal fixation and requires bone grafting and fixation with large cancellous screws.

Results of operative treatment

A multitude of clinical studies deals with the operative treatment of calcaneal fractures. It is still difficult to draw general conclusions because of the relatively low patient numbers in many of the studies, the lack of control groups and the different classification and outcome scores used by the various authors. In five larger clinical series of lateral plate osteosynthesis, including more than 100 patients classified consistently with CT, good to excellent results were observed in 60–85% of cases, using different outcome criteria.

Several retrospective clinical studies compare operative with non-operative treatment. While some show significantly better functional results after open reduction and internal fixation, others did not find significant differences between the treatment groups. Two of the latter, however, showed improved outcome in those sub-sets of patients in whom anatomical reduction could be achieved by operative treatment. One prospective, randomised study of 34 patients showed a clear superiority of open reduction and internal fixation done by a single surgeon, compared with conservative treatment. A prospective, randomised, multicentre trial with 424 enrolled patients gave more detailed information on patient sub-groups that benefit from operative treatment.

While the overall outcome measured with SF-36 and VAS was only slightly, insignificantly, higher, significantly less subtalar fusions were necessary after operative treatment. Also, patients who did not receive worker’s compensation and women scored significantly higher when treated operatively. Among those, who did not receive worker’s compensation, younger patients (less than 29 years old), patients with a moderately lower Böhler angle, a comminuted fracture, an anatomical reduction, or step-off less than 2 mm, scored significantly higher when treated surgically. In general, anatomical reduction of both the overall bone shape and the subtalar joint while respecting the soft tissue conditions, appears to be associated with a good functional outcome after displaced calcaneal fractures.

Calcaneal fractures in children are rare injuries, but have a considerable better prognosis than their adult counterparts due to the remodelling potential.
of the growing bone. The long-term results of the few available case series show good to excellent results in skeletally immature children with calcaneal fractures, even after displaced intra-articular fractures regardless of the type of treatment. In children and adolescents of more than 14 years, the treatment protocols should adhere to similar guidelines as in adults.

**Malunions after calcaneus fractures**

Calcaneal malunions regularly result from displaced fractures treated conservatively. The observed deformities are a direct consequence of the fracture pathology, as described earlier, and frequently lead to disabling conditions. Typical problems include painful subtalar arthritis, shortening and widening of the hindfoot, varus or valgus malalignment, impingement and/or subluxation of the peroneal tendons, fibulocalcaneal abutment, sural or posterior tibial neuritis, malposition of the talus with tibiotalar impingement and talar tilt leading to ankle arthritis, calcaneal malunions regularly result from displaced fractures regardless of the type of treatment. In children and adolescents of more than 14 years, the treatment protocols should adhere to similar guidelines as in adults. For more complex reconstructions CT-based planning software allowing virtual three-dimensional osteotomies, appears useful. Although significant improvement of foot function can be achieved, these corrective measures are essentially salvage procedures that do not restore normal foot function. Analysis of calcaneal malunions underlines the need for careful initial assessment of calcaneal fractures, as well as restoration of the anatomy and joint congruity in order to prevent painful and disabling deformities affecting the whole foot.

**Summary**

Assessment and treatment of calcaneal fractures have improved substantially over the last two decades. Open reduction and stable internal fixation, without joint transfixation, have been established as standard therapy for displaced fractures with good to excellent results in two-thirds to three-quarters of cases in larger clinical series. In the vast majority of cases, bone grafting is not necessary. Anatomical reduction of subtalar joint congruity and restoration of the overall shape of the calcaneus are important prognostic factors. The quality of joint reduction should be reliably proved intra-operatively either with Brodén views, high-resolution fluoroscopy or open subtalar arthroscopy. Treatment results are adversely affected by open fractures, delayed reduction after more than 14 days and individual risk factors, such as a high body mass index and smoking. Careful management of the soft tissues is equally important as fracture reduction. The extended lateral approach respects the neurovascular supply to the heel and allows a good exposition of the fractured lateral wall, the subtalar and calcaneocuboid joints in complex fractures. In selected, simple fracture patterns percutaneous screw fixation,
supplemented by arthroscopic control if necessary, is a good alternative with minimal affectation of the soft tissues. Open fractures, compartment syndrome and fractures with severe soft tissue compromise are emergencies. Early, stable soft tissue coverage, exploiting the full armamentarium of pedicled and free tissue transfer appears promising in improving the functional results and infection rates after open fractures. Whether new plate designs (oblique strut, interlocking screw holes) and subtalar arthrolysis at the time of hardware removal are effective in improving the final outcome remains to be elucidated in further studies. Calcaneal malunions after conservative therapy of displaced fractures are disabling conditions that can be treated successfully with a staged protocol according to the type of deformity. Treatment options include lateral wall decompression, in situ or correctional subtalar arthrodesis and calcaneal osteotomies along the former fracture line.

References


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