

# Fractures of the Calcaneus: Current Treatment Strategies

## Zlomeniny patní kosti: současná koncepce léčení

S. RAMMELT, H. ZWIPP

University Center for Orthopaedics and Traumatology, University Hospital Carl-Gustav Carus, Dresden, Germany

### SUMMARY

Displaced, intra-articular fractures of the calcaneus represent a surgical challenge and the ideal choice of treatment remains a subject of continued debate. Open reduction and stable internal fixation without joint transfixation has been established as the standard treatment for most of these fractures with good to excellent results in more than two thirds of patients in larger clinical series. 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, but wound healing problems cannot be completely avoided despite meticulous soft tissue handling. Percutaneous and less invasive procedures have successfully lowered the rates of wound complications but exact anatomic reduction remains an important issue. Care must be taken not to overlook atypical fractures like sustentacular fractures and fracture-dislocations of the calcaneus that are treated with a small medial or curved epimalleolar lateral approach, respectively. The use of bone grafting or bone substitutes for defect filling appears not necessary in most cases. Prognostic factors that can be influenced by the surgeon are anatomical reduction of the overall shape of the calcaneus and congruity of the subtalar joint which should both be controlled intra-operatively. Treatment results are adversely affected by severity of injury, open fractures, bilateral fractures, a high body mass index and smoking. Early, stable soft tissue coverage with pedicled or free flaps appears to lower infection rates and improve the functional results after open fractures. Calcaneal malunions and nonunions are disabling conditions resulting from either non-operative treatment or inadequate reduction and fixation of displaced fractures. Deformity correction is tailored to the type of deformity and individual patient needs. Treatment options include lateral wall decompression, *in situ*- or corrective subtalar arthrodesis and calcaneal osteotomies accompanied by soft tissue-balancing.

**Key words:** calcaneus, fracture, subtalar joint, internal fixation, sustentaculum, fracture-dislocation, malunion.

### INTRODUCTION

Few issues have generated as much controversy in traumatology as the treatment of displaced, intra-articular calcaneal fractures, and they continue to do so today. The reasons for that are manifold. Calcaneal fractures display a wide range of injury patterns with about 80% being intraarticular and their operative management is challenging with a considerable learning curve for the surgeon (46, 58, 72). The soft tissue cover around the calcaneus is delicate with a vulnerable layer of skin over the lateral calcaneal wall that is prone to wound healing problems and a unique plantar skin that cannot be replaced with adequate tissue once it is avulsed or severely damaged (2, 19). A substantial proportion of calcaneal fractures result from axial impact inflicting a great number of young male industrial workers thus having a considerable socio-economic impact (60). Axial impaction also results in a primary cartilage damage that may lead to posttraumatic arthritis irrespective of the kind of treatment. On the other hand, we are witnessing an increasing number of low-velocity injuries in the elderly population with osteoporosis or diabetes that are challenging to treat and prone to complications (29).

From a historical perspective, the treatment concepts for calcaneal fractures have witnessed numerous changes over the last 150 years (52). One of the first to propose internal fixation with a nail was Carl Gussenbauer from Prague in 1888 (27). Over the last 20 years a large number of clinical studies have described the operative treatment of displaced, intraarticular calcaneal fractures (56). Conclusions on the best treatment are difficult because of diverse operative strategies and outcome measurements. Several studies have shown that only anatomic reconstruction of the calcaneal anatomy and meticulous restoration of joint geometry will lead to acceptable functional results and merit the effort of operative treatment with its possible complications (38, 50, 58, 71). On the other hand, the occurrence of postoperative complications like wound edge necrosis, soft tissue and bone infection as well as arthrofibrosis and stiffness of the subtalar joint, are a matter of concern. Therefore several percutaneous and minimally-invasive treatment methods have evolved over the last years (20, 53, 67–70). This article provides a critical overview of current strategies in the treatment of these challenging injuries.

## SURGICAL ANATOMY AND PATHOMECHANICS

The calcaneus is the largest and most irregularly shaped bone of the foot. It represents the posterior part of the longitudinal arch and the lateral column of the foot. Through the action of the Achilles tendon, the plantar fascia, the extrinsic and intrinsic foot muscles it acts as a strong lever arm under static and dynamic conditions.

The calcaneus has a thick cortical shell at the medial wall, especially the sustentaculum tali, and at the tuberosity. A thin cortex covers the lateral wall that is prone to bulging with compression fractures. The trabecular architecture displays a vaultlike pattern reflecting the forces transmitted through it during standing and walking (Fig. 1). The trajectories leave a “neutral triangle” at the calcaneal neck that is frequently impacted during fractures. A dense portion of the cancellous bone is situated below the posterior facet of the subtalar joint and therefore named “thalamus calcanei”. The posterior edge of the tuberosity and the subtalar joint form an angle between 25 and 40° (Böhler’s angle), that is an important measure of the anatomical shape of the calcaneus and the quality of reduction after displaced fractures (7). The subtalar joint and superior cortex of the anterior process form Gissane’s crucial angle along the calcaneal neck that has a normal value of 120 to 145° in the lateral view.

The calcaneus articulates with the talus via three joint surfaces (Fig. 1b). The posterior facet of the subtalar joint is the largest and involved in almost 90% of all intra-articular calcaneal fractures (72). The posterior facet is separated from the anterior and middle facets of the subtalar joint by the calcaneal sulcus which is forming the bottom of the canalis tarsi medially and

the sinus tarsi laterally with the talocalcaneal interosseous ligament complex. The medial facet covers the sustentaculum tali and is merged with the anterior facet on the superomedial aspect of the anterior process in about 20% of all cases. The joint surface to the cuboid is slightly saddle-shaped and involved in about two thirds of all intra-articular calcaneal fractures (71). The subtalar and calcaneocuboid joints are part of the triple joint complex and therefore essential for the three-dimensional movement of the hindfoot with respect to the midfoot during shock absorption, propulsion and adaption of the foot to uneven ground. Malfunction of the subtalar joint secondary to malunited calcaneal fractures has a marked effect on global foot function with pronounced difficulties and pain on uneven ground, ladders and stairs (51).

The vertical axis of the calcaneus lies laterally to that of the talus and the longitudinal axes of the talus and the calcaneus form an angle of about 25–30° in the horizontal plane. Therefore with axial loading the sustentaculum tali is sheared off the main body of the calcaneus carrying the posterior facet of the subtalar joint and the tuberosity. Consequently, the primary fracture line runs sagittally through the calcaneus and mostly through the posterior facet of the subtalar joint. The thin lateral wall bulges and thus leads to impingement of the peroneal tendons and, with massive impaction, even of the distal fibula (“abutment”). In cases of fracture-dislocations the whole calcaneal tuberosity is displaced laterally and towards the fibular tip, frequently producing an irregular distal fibular fracture with avulsion of the superior peroneal retinacle (74). These injuries are frequently overlooked or misinterpreted as “Weber A” fibular fractures because they do not display the typical features of calcaneal fractures as outlined below.

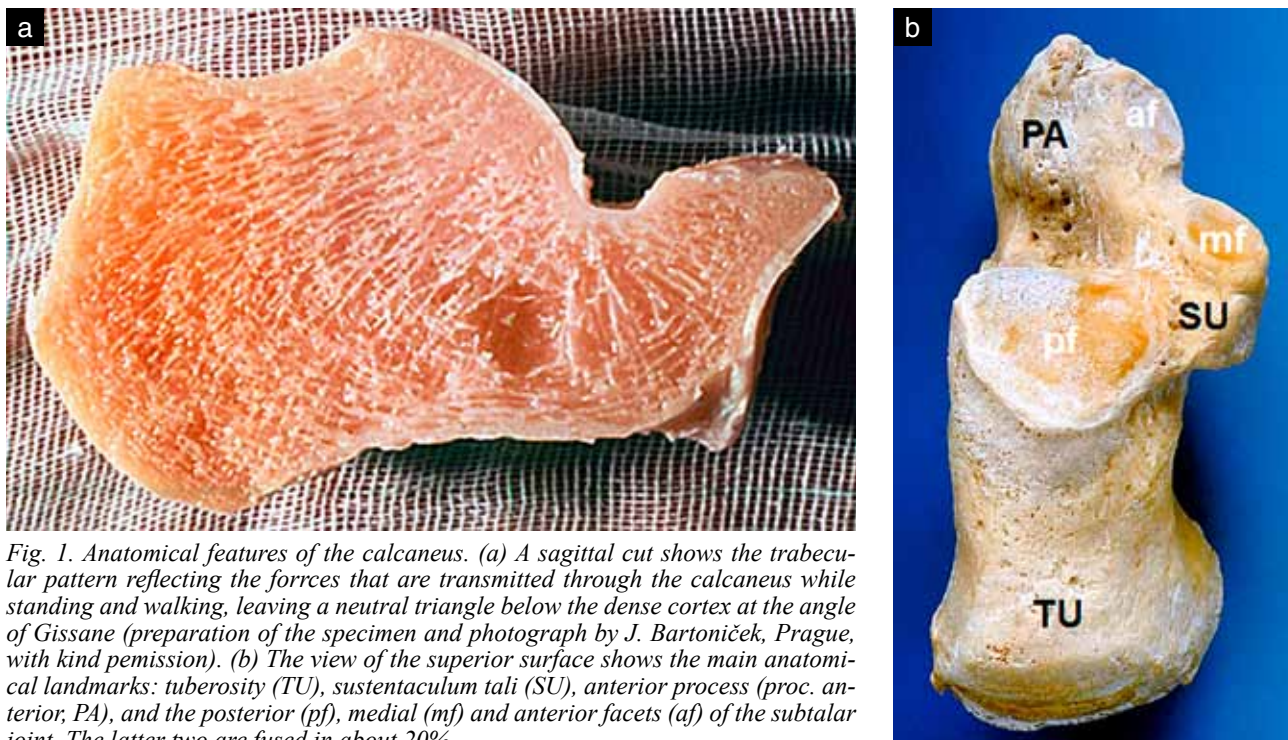


Fig. 1. Anatomical features of the calcaneus. (a) A sagittal cut shows the trabecular pattern reflecting the forces that are transmitted through the calcaneus while standing and walking, leaving a neutral triangle below the dense cortex at the angle of Gissane (preparation of the specimen and photograph by J. Bartoniček, Prague, with kind permission). (b) The view of the superior surface shows the main anatomical landmarks: tuberosity (TU), sustentaculum tali (SU), anterior process (proc. anterior; PA), and the posterior (pf), medial (mf) and anterior facets (af) of the subtalar joint. The latter two are fused in about 20%.

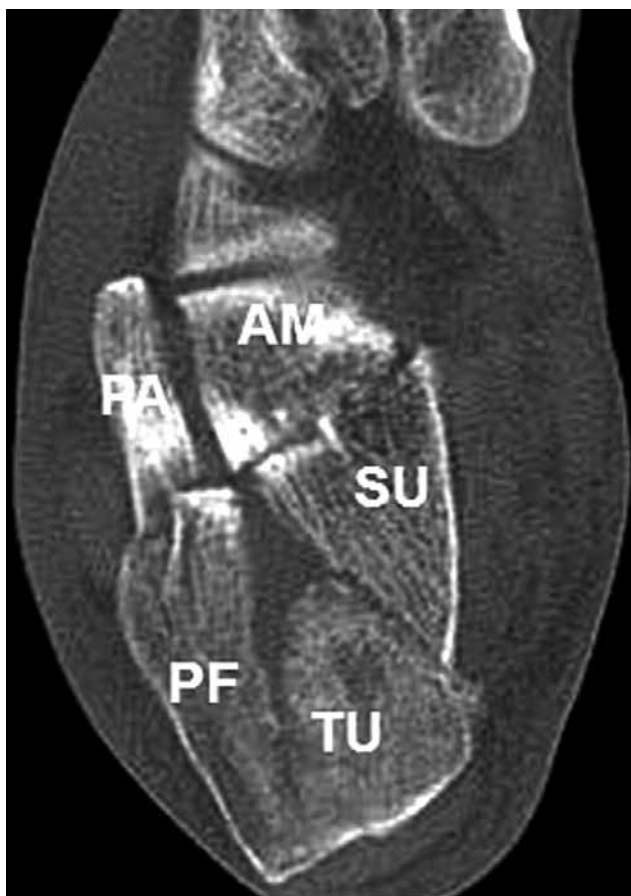


Fig. 2. Up to five reproducible major fragments can be typically observed in calcaneus fractures: the tuberosity fragment (TU), sustentacular fragment (SU), posterior facet fragment (PF), anterior process fragment (PA) and an anteromedial fragment (AM). These fragments, together with the number of involved fragments and severity of soft tissue damage form the basis of fracture classification (127).

Depending on the energy of the impact and position of the foot at the time of injury, secondary fracture lines develop. These lines also follow reproducible patterns, beginning at Gissane's angle and the posterior aspect of the subtalar joint (17). In "joint depression type" fractures the fracture line runs downward posterior to the impacted posterior facet resulting in a depressed and tilted facet fragment. In the lateral radiographic projection this results in a double contour at the subtalar joint. In "tongue type" fractures the fracture exits through the superior part of the tuberosity, producing in a large fragment which is pulled upwards by the Achilles tendon giving it a tongue-like appearance. Isolated avulsion of the superior aspect of the tuberosity by the Achilles tendon may lead to an extra-articular "beak fracture" both in adolescents and osteoporotic or diabetic patients (29, 60). Irregular fracture patterns after inadequate trauma are highly suspicious for Charcot osteoarthropathy or rheumatoid disorders.

The fracture lines also regularly extend anteriorly and frequently involve the (antero)medial subtalar and calcaneocuboid joints. With the split of the anterior process fragment a maximum of 5 reproducible main fragments results that provides the basis for fracture classification and treatment planning (Fig. 2). Isolated fractures of the anterior calcaneal process result from abduction forces through the midtarsal (Chopart's) joint and therefore further bony and ligamentous injuries at the Chopart joint should be ruled out.

## DIAGNOSIS

The clinical examination focuses on pain, swelling, hematoma and deformity at the hindfoot (Fig. 3). Ac-



Fig. 3. (a) Clinical presentation of bilateral calcaneal fractures with hematoma and marked soft tissue swelling around the heels. (b) Compartment syndrome has to be ruled out clinically or, in unconscious patients, with direct multi-stick measurements.





*Fig. 4. Radiographic imaging: If the lateral radiograph shows a calcaneal fracture (a), CT scanning is carried out to show the exact fracture pathoanatomy and joint involvement (b–d) in order to plan the adequate treatment.*

tive or passive inversion and eversion of the foot is painful. The heel is tender to palpation. Blister formation may develop within a few hours and may indicate pressure from the inside by hematoma or displaced fragments. In particular, a grossly displaced posterior tuberosity fragment as seen in tongue type and beak

fractures, may rapidly progress into full-thickness skin necrosis over the insertion of the Achilles tendon, i. e. a region where soft tissue coverage is particularly challenging. Progressive soft tissue swelling and pain that does not resolve with rest, elevation and ice is highly indicative of a compartment syndrome. In

unconscious patients, pathological pressures have to be ruled out with multi-stick invasive measurements. Repeat clinical examinations have been suggested to not overlook calcaneal fractures in polytraumatized or multiply injured patients after high-velocity injuries (52).

Standard radiographs for a suspected calcaneal fracture include axial and lateral projections of the hindfoot. Anteroposterior radiographs of the ankle show the amount of fibulocalcaneal abutment and talar tilt in fracture-dislocations. If a displaced fracture is seen, lateral views of the unaffected calcaneus are useful to measure the individual normal values of Böhler's and Gissane's angles. Oblique views of the subtalar joint (Brodén series) that show the extent of damage to the subtalar joint are useful for intra-operative assessment of joint reconstruction (58). The foot is placed in neutral flexion and internal rotation of 45°, while the tube is angled 10 to 40°, the former showing the posterior, the latter the anterior portion of the subtalar joint. If an intra-articular fracture is suspected, CT scanning is carried out to precisely analyze the fracture morphology and joint involvement (Fig. 4) to determine the treatment strategy.

## CLASSIFICATION

Present classification systems are CT-based. The most widely used has been introduced by Sanders (58). It is based on the amount of displaced fracture lines in the posterior facet of the subtalar joint in the coronal CT scans which has been shown to be of prognostic relevance. Extra-articular and non-displaced fractures are classified type I, one displaced fracture line as type II, two as type III and three or more as type IV. Laterally situated fracture lines are encoded with the letter A, intermediate with B, and medial ones with the letter C.

Zwipp (72) introduced a 12-point fracture scale, that reflects the number of main fragments (2–5) and involved joint surfaces (0–3) as well as the degree of soft tissue trauma and accompanying fractures of adjacent bones (additional 1–4 points) (for main fragments see Fig. 2). This classification has also proved to be of prognostic value in a greater patient population (56, 71).

## INDICATIONS FOR SURGERY

There is no general consensus on the indications for surgical treatment of calcaneal fractures. Most authors agree that, in the absence of local or systemic contraindications, displaced intra-articular fractures should be reduced anatomically to avoid painful hindfoot deformities and posttraumatic arthritis of the subtalar joint (3, 56, 58, 74). It has been shown repeatedly that even small step-offs of 1–2 mm in the posterior facet of the subtalar joint are associated with a significant load redistribution at the subtalar joint in biomechanical experiments (61) and inferior functional results in clinical series (6, 8, 10, 45, 50, 58). We therefore recommend surgical reduction of

calcaneal fractures with a joint displacement of more than 1 mm. Extra-articular fractures with a substantial hindfoot varus or valgus deformity of more than 10 degrees and those with significant flattening, broadening or shortening of the heel should also be reduced, preferably via small or percutaneous approaches. We also recommend reduction of a displaced medial process of the tuberosity to avoid plantar heel pain over the displaced fragment (60).

Internal fixation is usually performed within 1 to 2 weeks after the injury, when the initial hematoma and swelling have decreased markedly. However, if surgery is delayed beyond two weeks after the trauma, beginning fibrous union and soft tissue shrinking will render anatomic reduction more difficult, especially with markedly displaced fractures, thus increasing the risk of wound healing problems and infection (50, 65). Therefore, if internal fixation appears impossible within two weeks (e. g. in polytraumatized patients), initial percutaneous reduction and temporary fixation with a medially applied external fixator is advocated to minimize soft tissue shrinkage and facilitate open reduction beyond 2 weeks (52, 72).

Systemic contraindications to open reduction and internal fixation include severe neurovascular insufficiency, poorly controlled insulin-dependent diabetes mellitus, non-compliance (e. g. substance abuse), and severe systemic disorders with immunodeficiency and/or a poor overall prognosis. Higher patient age is not a contraindication to surgery, because favourable results can be obtained in active patients beyond 65 years of age (23, 56). Treatment is rather tailored to the functional demand, comorbidities and compliance of the patients (52).

Non-operative treatment is generally preferred in non- or minimally displaced fractures and in the presence of local or systemic contraindications to surgery as outlined above (58, 72). Initially, the affected foot is treated with ice, rest and elevation for 3–4 days ankle and subtalar range of motion exercises are initiated. Patients are then gradually mobilised in their own shoes with partial weight-bearing of 20 kg on the affected foot. Full weight-bearing is achieved after 6–10 weeks, depending on the type of fracture and bone quality.

## OPERATIVE TREATMENT

### Emergency procedures

Open fractures, closed fractures with impending compartment syndrome and with severe incarceration of the soft tissues by displaced bony fragments are treated as emergencies. The extra-articular tongue-type ("beak") fractures with severe displacement of the superior margin of the calcaneal tuberosity belong to the latter group and are notorious for rapid development of skin necrosis over the dorsal aspect of the heel if not reduced immediately (22, 52, 60).

According to the general surgical treatment principles, open fractures are subjected to early, aggressive debridement of all heavily contaminated and avital tissue

followed by copious lavage. Gross reduction is achieved by percutaneous leverage and direct manipulation of the displaced main fragments through the existing wound. The fragments are fixed temporarily with K-wires introduced percutaneously through the tuberosity into the talus and/or the cuboid, supplemented by a tibiometatarsal external fixator to assist soft tissue consolidation. Alternatively, a medial three-point external fixator is applied with the pins introduced into the calcaneal tuberosity, the talar head and the navicular or medial cuneiform. Traction on the pins restores the overall geometry of the calcaneus until definite internal fixation via a lateral approach becomes feasible. If wound closure cannot be achieved without tension because of severe swelling or loss of skin, vacuum-assisted wound closure or artificial skin substitute is used for temporary wound coverage. A second look is scheduled at 48 to 72 hours after the first surgery and after repeated debridement and irrigation the type of definite soft tissue coverage is determined. If secondary suture is not feasible, smaller sized and partial thickness defects may be covered with split thickness skin grafting. Full thickness soft tissue defects, especially those with underlying bone, cartilage, or tendons, require a pedicled or free fasciocutaneous or myocutaneous flap.

Compound injuries with multi-level fractures, transcalcaneal talonavicular dislocation and plantar medial open wounds have a guarded prognosis with high rates of infection, posttraumatic arthritis and functional restrictions in cases of limb salvage (2, 19, 30). Early amputation should be considered individually if functional reconstruction does not appear feasible in order to avoid protracted courses and multiple reoperations (16).

Acute compartment syndrome of the foot is seen in 1 to 10% of calcaneal fractures (43, 66). Fasciotomy is warranted with pressures exceeding 30 mm Hg, as in the forearm and leg (43). In the authors' preference this limit has been lowered to 25 mm Hg, 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 (72). The clinical relevance of isolated pressure elevation within the deep calcaneal compartment containing the quadratus plantae muscle and the lateral plantar nerve as seen in cadaver injection studies is not entirely clear. Some authors ad-



Fig. 5. (a–d) Percutaneous reduction and screw fixation of a less severe intra-articular calcaneal fracture (Sanders type II). Anatomic reduction of the posterior facet is determined either with subtalar arthroscopy or 3D fluoroscopy.

vocate the release of the deep calcaneal compartment by a separate hindfoot incision similar to that used for a plantar fascia release (39, 58).

In closed calcaneal fractures with severely displaced fragments and threatening breakdown of the soft tissues, percutaneous reduction and temporary external and K-wire fixation is indicated for soft tissue protection, if no immediate internal fixation is feasible. Gross reduction and triangular external fixation from medial is also indicated in severely displaced calcaneal fractures in polytraumatized patients (52). This measure will counteract soft tissue contracture and allow postponement of definite internal fixation until the patient's overall condition has improved.

### Minimally-invasive procedures

Minimally-invasive fixation of calcaneal fractures significantly reduces the risk of soft-tissue complications (34, 35, 44, 53). Apart from temporary percutaneous fixation for patients with a critical overall condition or contraindications to extensile approaches (28, 52), it is extremely useful in properly selected patients with less severe fracture patterns (Fig. 5). Many authors consider percutaneous reduction and screw fixation in cases of extraarticular and simple intraarticular fractures with the posterior facet being displaced as a whole as in Sanders Type IIC fractures (53, 67). These techniques can be applied also to intraarticular fractures with just one displaced fracture line across the subtalar joint (i. e. Sanders Types IIA and IIB) with proper control of the articular reduction with subtalar arthroscopy or three-dimensional fluoroscopy (25, 70). Several authors perform percutaneous reduction and fixation in all types of calcaneal fractures (20, 64). This carries, however, the risk of inadequate reduction of the calcaneal shape and the subtalar joint as well as loss of fixation (53).

For percutaneous reduction the patient is placed on the noninjured side on a radiolucent operating table. A 6.5 mm Schanz screw with handle is introduced via a posterior stab incision into the superior aspect of the tuberosity. This percutaneous reduction technique has been described first by Westhues (69) and later popularized in the English-speaking literature by Essex-Lopresti (29). Gross reduction of the calcaneal shape is achieved with downward movement of the handle of the Schanz screw to realign the tuberosity fragment with the sustentacular fragment (67). Varus or valgus malalignment is reduced with lateral or medial movement of the handle respectively (71). Reduction is controlled fluoroscopically and held temporarily with percutaneous K-wires. If the posterior facet is displaced as a whole, like in Sanders Type IIC fractures, this maneuver alone is sufficient to achieve anatomical reduction (53, 67).

In tongue type fractures with a displaced fracture through the subtalar joint (Sanders Types IIA and IIB) the Westhues maneuver will also reduce the intra-articular fracture component. A curved reduction clamp set between the sustentaculum and the lateral calcaneal wall is very helpful in obtaining compression between

the main fragments. In joint-depression fractures, the separate lateral posterior facet fragment has to be manipulated percutaneously with either a sharp elevator, Kirschner wires, or a pestle introduced percutaneously. The fragments are fixed temporarily with K-wires and anatomic reduction of the posterior facet of the subtalar joint is controlled either arthroscopically or with 3D fluoroscopy. The standard portals are employed for subtalar arthroscopy (4). Mostly, the anterior lateral portal is used to visualise the joint while the posterior lateral portal and sometimes an additional middle portal are utilized to remove debris and fibrous adhesions from the joint and the fracture plane, if necessary. If a remaining step-off is seen, the K-wires are retracted and the fine reduction of the posterior calcaneal facet is repeated. Fixation is achieved with screws that are introduced via stab incisions. One or two screws are placed parallel to the joint into the thalamic portion and are aimed towards the sustentaculum tali to obtain maximum stability and compression across the primary fracture line (Fig. 5). Correct screw position is controlled with fluoroscopy, preferably in a 3D mode.

### Open reduction and internal fixation

#### Selection of approaches

The majority of complex, displaced, intra-articular fractures of the calcaneus can be effectively treated via an **extensile lateral approach** (3). This approach allows good visualisation of the fractured posterior facet, the sinus tarsi and the anterior process including the calcaneocuboidal joint while respecting the course of the peroneal tendons, the sural nerve and the lateral calcaneal artery (21).

The **direct lateral approach** (24) starts at the tip of the fibula and runs directly over the subtalar joint and sinus tarsi parallel to the peroneal tendons in a slightly curved manner. This approach requires less soft-tissue dissection as compared to the extensile lateral approach. However, it cuts directly through the angiosome of the lateral calcaneal artery and may lead to scarring of the peroneal tendons and the sural nerve. Recently, small direct lateral approaches directly above the angle of Gissane (**sinus tarsi approach**) have gained increasing popularity for less invasive reduction and fixation of calcaneal fractures (26, 44, 68, 75). These small approaches may also be helpful if an attempted percutaneous reduction proves impossible and direct access to the joint is required (53). The incision lies obliquely directly over the sinus tarsi and has a length of about 4 to 5 cm (Fig. 6). The peroneal tendons are identified, mobilized within their sheaths and held away with a soft strap. The subtalar joint is accessed directly from the sinus tarsi and cleared from hematoma and small debris. The main fragments are manipulated percutaneously like described above, but the joint fragments can be manipulated directly through the approach. Definite fixation is achieved with percutaneous screws or bolts, an intramedullary nail with locking screws, or a small plate that is sled in through the ap-



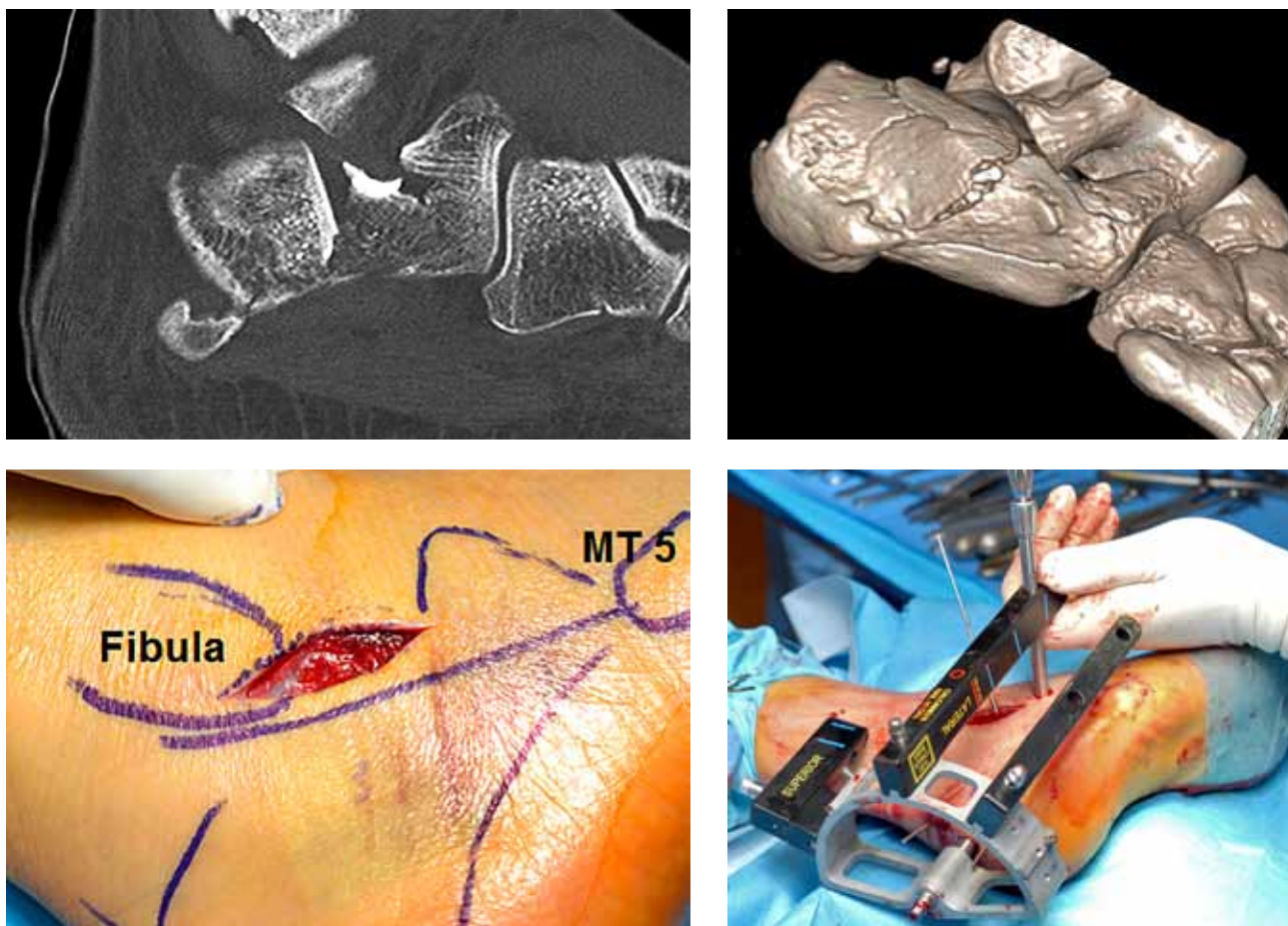


Fig. 6. (a–b) Less invasive fixation of a Sanders II calcaneal fracture with deep impaction of the posterior facet fragment. (c) Anatomic joint reduction is controlled via a sinus tarsi approach and the fracture is stabilized with an intramedullary implant (C-Nail, Medin, Nové Město na Moravě). (d–e) Percutaneous interlocking of the nail is performed via an aiming device. (f–i) Postoperative radiographs and CT scanning demonstrate exact screw placement in the sustentaculum tali, providing maximum stability (i). (The C-Nail was developed in co-operation with M. Pompach, Pardubice).

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proach and tunnelled beneath the peroneal tendons (13, 26, 68, 75).

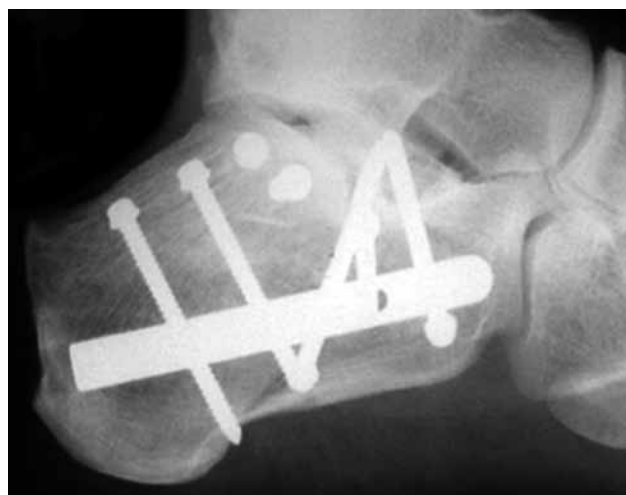
An extension of the direct lateral approach (**dislocation approach**) is used in the authors' practice in cases of fracture dislocations with direct compression of the fibular tip by the tuberosity fragment and subsequent dislocation of the peroneal tendons (74). The incision allows access to the displaced tuberosity and lateral joint fragment from above. It starts over the lateral malleolus, thus allowing fixation of an accompanying fibular fracture and reattachment of the peroneal retinacle after fracture reduction and rerouting of the tendons (Fig. 7). Care has to be taken to identify and protect the peroneal tendons which are dislocated into the subcutaneous tissue in front of the lateral malleolus. They are held away with a soft strap and the torn retinacle is secured with sutures. The tuberosity fragment carrying most of the subtalar joint is mobilized with a Schanz screw introduced into the tuberosity. The main sagittal fracture line is cleared from hematoma and debris and the tuberosity fragment is reduced stepwise to the sustentaculum fragment that carries the medial facet of the subtalar joint. A curved reduction clamp is most useful in these cases.

The fragments are fixed with compression screws inserted from laterally into the sustentaculum tali. In cases of highly unstable fractures and comminution extending into the anterior process, plate fixation is preferred and a second, medial approach may be needed (74).

A **medial approach** (40) halfway between the medial malleolus and the sole of the foot was designed to directly buttress the displaced medial wall of the calcaneus with an anti-glide plate (72). With this approach, however, the posterior facet of the subtalar joint and the calcaneocuboid joint cannot be visualized and reduced directly. Furthermore there is a sizeable risk of damage to the posterior tibial neurovascular bundle. The medial approach may be useful in two-part, extra-articular fractures or in addition to a lateral approach in complex fracture-dislocations (72).

In the authors' practice, a small medial approach directly over the sustentaculum tali (**sustentacular approach** (72)) is preferred over the classical McReynolds approach in cases of isolated fractures of the sustentaculum tali (15) or in addition to the extended lateral approach with fragmentation of the medial joint facet in more complex intra-articular fractures (52, 74). The





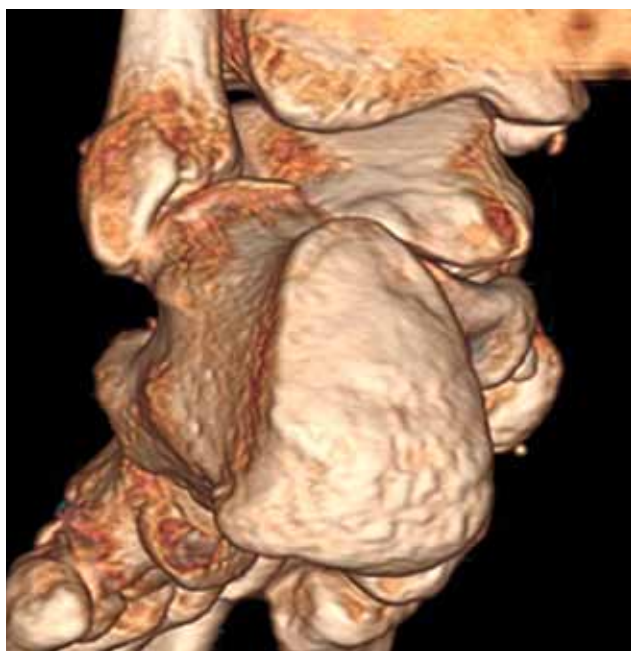
horizontal incision of about 3 cm lies directly over the palpable sustentaculum approximately 1.5 cm below and 1 cm anterior to the tip of the medial malleolus (Fig. 8). The nearby posterior tibial and flexor digitorum longus tendons are held away with vessel loops. The neurovascular bundle is held away plantarly with the flexor hallucis longus tendon and need not be exposed. After reduction of the medial joint facet under direct vision, the sustentaculum is usually fixed with long 3.5 mm compression screws, which are introduced along its axis into the calcaneal body (15, 52).

#### Open reduction and fixation technique via the extended lateral approach

For the **extended lateral approach**, the patient is placed on a radiolucent table in a lateral decubitus position on the noninjured side with the injured foot on a pad. The incision is L-shaped over the lateral aspect of the heel on about two thirds of the distance between the palpable tip of the fibula and the Achilles tendon posteriorly and the heel inferiorly (Fig. 9). The sural nerve has to be respected in the most proximal and distal part of the approach, while the incision can be carried out directly

to the bone in the central aspect of the approach. From there a full-thickness fasciocutaneous flap is created up to the subtalar joint. The peroneal tendons have to be detached carefully from the peroneal tubercle where they are held by a separate retinacle. The tendons are gently mobilized within their sheaths and protected within the flap. To achieve a good overview over the injured subtalar joint, two K-wires are introduced into the lateral process of the talus to hold the soft tissue flap away cranially. The anterior process and the calcaneocuboid joint are visualised in the anterior part of the incision with the peroneal tendons and the sural nerve held plantarly with a soft strap. In analogy to the subtalar joint, the skin flap may be held away from the calcaneocuboid joint with one or two K-wires inserted into the cuboid.

For most types of calcaneal fractures direct manipulation of the tuberosity fragment is very useful. A 6.5 mm cancellous Schanz screw with handle is introduced via a stab incision into the tuberosity from posterior or lateral. Movement of the handle loosens the tuberosity and the impacted intra-articular fragments and allows a better visualization of the fractured subtalar joint. The



bulged lateral calcaneal wall is folded away and a separate lateral joint fragment is retracted inferiorly and secured with a suture. To gain access to the entire subtalar joint, fragments of the anterior process that are displaced upward must be held away temporarily at the angle of Gissane. The subtalar joint is reduced stepwise from medial to lateral. Reduction starts with the sustentacular fragment that is either angulated, translated medially, or fractured in 42% of intra-articular calcaneal fractures (4). The sustentacular fragment is reduced congruently to the medial facet of the talus if tilted or shifted and may be fixed with a 2.0 mm K-wire introduced from plantar if grossly unstable (74). In cases of comminuted fractures of the sustentaculum, an additional direct approach

is carried out as described above, to anatomically reduce the medial facet (43).

To achieve reconstruction of the medial wall and enable anatomic reduction of the articular fragments, the tuberosity fragment is pulled downward and medially beneath the sustentacular fragment. To achieve this, an elevator is introduced a lever between these two fragments (60, 75). The fragments are fixed to each other with one or two K-wires and reduction of the medial wall is controlled fluoroscopically. If the tuberosity fragment is not reduced adequately, articular reduction may not be possible and tilting of the main articular fragments may occur resulting in persistent incongruities. If intermediate joint fragment(s) are present, these are then reduced



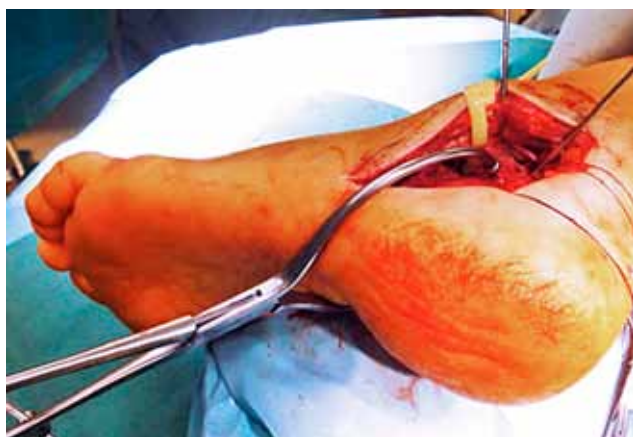


Fig. 7. (a-c) Fracture-dislocation of the calcaneus with wind craniolateral displacement of the tuberosity fragment causing a direct fracture to the distal fibula and peroneal tendon dislocation. (d) The dislocated peroneal tendons, the fractured tip of the fibula, and the displaced tuberosity fragment carrying the posterior joint facet are visualized via a curved epimalleolar lateral ("dislocation") approach. (e) The main fragments are reduced with an overriding curved reduction clamp. The avulsed superior peroneal retinacle is reattached. (f-g) Definite fixation is achieved with lag screws.

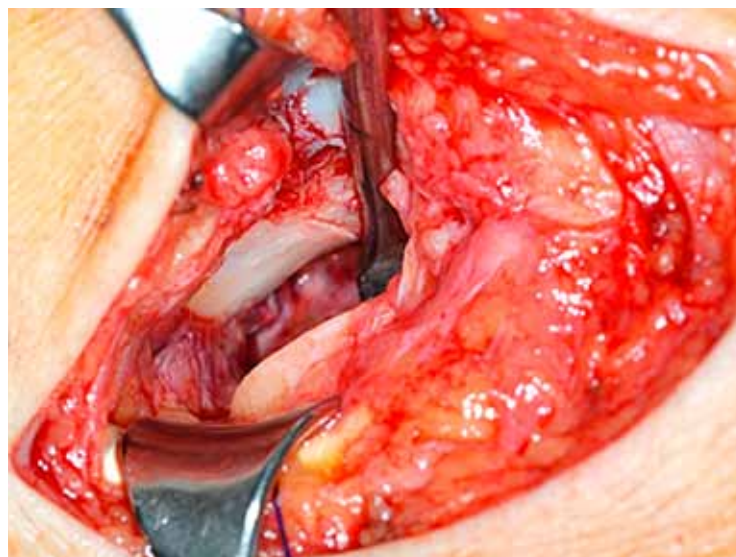
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and fixed to the sustentacular fragment with one or two K-wires that are drilled through the medial cortex and the skin in a way that they are flush with the intermediate fragment on the lateral side (see Fig. 9 a-b). Small intermediate fragments with intact cartilage cover may alternatively be fixed with "lost" K-wires or absorbable pins. Finally, the depressed lateral portion of the posterior facet is reduced to the medial fragment(s) using the inferior articular surface of the talus as a template and the K-wires are drilled back into this fragment from medial. If the lateral joint fragment is part of a tongue fragment extending to the posterior wall of the tuberosity, anatomic reduction of this fragment at the joint level may be impossible because of soft-tissue restraints. In these cases,

an osteotomy through the "tongue" fragment, turning it into a separate "joint depression" fragment, makes exact reduction of the posterior facet possible (59).

Intra-operative control of the reduction of the subtalar joint is of great importance when treating displaced intra-articular fractures operatively. To visually check the joint surface, any K-wires crossing the subtalar joint have to be removed at that point and the heel is brought into a slight varus position. Because of the curved articular surface, fractures that are situated far medially and fractures with multiple fragmentation of the subtalar joint may not be assessed reliably with direct vision. In these cases the quality of joint reduction of the subtalar should be checked either by open subtalar arthroscopy



(49) or intraoperative 3D fluoroscopy (25). Depending on the fracture anatomy a small diameter arthroscope (2.7 mm, 30°) is introduced into the exposed subtalar joint from the angle of Gissane or from the posterior margin of the joint thus resembling the classical anterior and posterior lateral portals (49, 75). The joint is inspected for remaining incongruities and loose fragments. If an intra-articular step-off is found, the K-wires are removed and joint reduction can be corrected immediately thus preventing painful postoperative conditions or the need for further surgery (Fig. 10). The same is true for K-wires and screws introduced from the lateral aspect of the calcaneus into the sustentaculum that may protrude into the joint. In clinical studies, arthroscopy and 3D fluoroscopy detected relevant irregularities or screw malpositioning within the subtalar joint that had been judged as being uneventfully with conventional fluoroscopy in more than 20% of cases (25, 49). After ensuring exact reduction, a screw may be inserted parallel to the joint into the sustentaculum to stabilize the articular portion of the calcaneus. In highly unstable fractures necessitating K-wire transfixation of the subtalar joint, control of the joint congruity is carried out after screw and plate

fixation at the end of the surgery. If incongruities are detected at that stage, the subthalamic screws have to be removed and reduction repeated.

The reconstructed subtalar joint block is then reduced to the tuberosity fragment. After having restored the medial wall as described above this is a mere fine reduction avoiding residual loss of heel height and any varus or valgus deformity of the tuberosity by using the inserted Schanz screw as a lever. The fragments are fixed temporarily with K-wires.

In many cases, reduction of the whole posterior part of the calcaneus will also have at least partially restored calcaneocuboid alignment. The anteromedial facet of the subtalar joint (if fractured) and the calcaneocuboid joint surface are visualized via the anterior part of the approach. With remaining incongruities, especially depressed joint fragments in the calcaneocuboid joint, the joint surfaces are reduced starting from medial to lateral using the joint facet of the cuboid as a template. The reduced fragments are temporarily held with K-wires introduced into the subchondral bone in a manner that they are not interfering with later positioning of the plate. Finally, the reconstructed anterior process is brought into



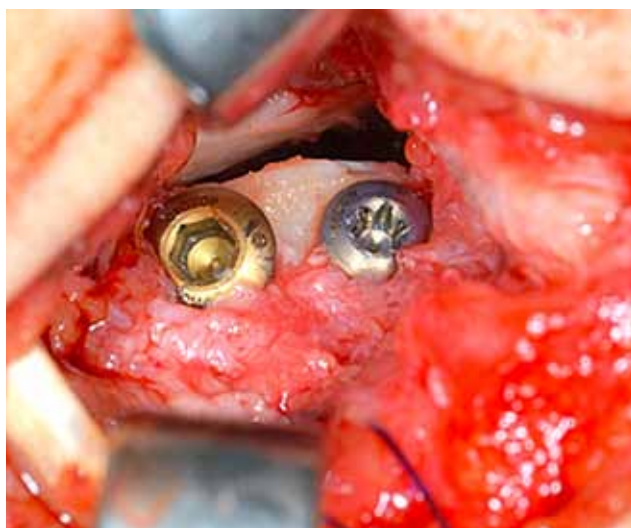
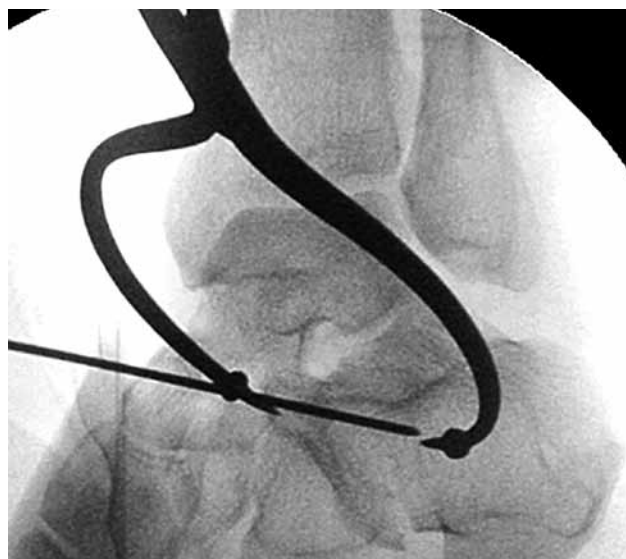


Fig. 8. (a–c) Fracture of the sustentaculum tali with depression of the medial facet of the subtalar joint. (d–g) Reduction and fixation is achieved via a small medial approach directly over the sustentaculum. (h–i) Lateral and axial radiographs at 18 months follow-up (taken from Dürr, C., Zwipp, H., Rammelt, S.: *Fractures of the sustentaculum tali. Oper. Orthop. Traumatol.*, 25: 569–578, 2013 with kind permission from Springer Science and Media).

a	b	e	f
c	d	g	h
		i	

alignment with the posterior part of the calcaneus thus recreating the crucial angle of Gissane where reduction of the primary coronal fracture can be reliably controlled at the strong cortical bone. The fragments are held with additional K-wires introduced along the longitudinal axis of the calcaneus. The bulged lateral calcaneal wall is now folded back and must fit with the other fragments along the secondary fracture lines. Restoration of the anatomical shape of the calcaneus is controlled fluoroscopically.

Elevation of the depressed lateral (thalamic) portion of the posterior facet frequently leaves a bony defect





Fig. 9. (a) Open reduction of a Sanders Type III calcaneal fracture (same patient as in Fig. 4) via the extended lateral approach. (b) The posterior facet is reduced step-wise from medial to lateral and held temporarily with K-wires that penetrate the medial skin to fix the intermediate joint fragment to the medial fragment. (c) The lateral fragment is then reduced to the intermediate fragment and the K-wire is driven back laterally. The anterior process is typically displaced cranially and its reduction is controlled at the crucial angle of Gissane.

resulting from impaction of this fragment into the weak cancellous bone at the neutral triangle. The need of defect filling either with bone grafting from the ipsilateral iliac crest or with bone substitutes is not substantiated by clinical evidence. Injection of an injectable calcium phosphate cement has resulted in superior compressive strength of plate fixation in cadaver experiments, earlier weight-bearing and less collapse of Böhler's angle after one year in clinical studies (33, 62). On the other hand, reported complications related to the use of bone cement include sinus formation, cement loosening, wound edge necrosis, and infection (62). Injectable bone cements might have a role in the percutaneous treatment of depressed calcaneal fractures to avoid secondary displacement after screw fixation, but sufficient numbers and adequate follow-up from clinical studies is still lacking (13). Based on the available data currently and our recent experience, we do not advocate the use of bone substitutes in the fixation of calcaneal fractures.

For internal fixation most authors use a single lateral plate that displays the anatomical features of the calcaneus, providing support to the tuberosity, the thalamic

portion with the posterior joint facet and the anterior process (3, 6, 56, 58, 60, 71). Generally, a minimum of two screws should be directed into the sustentaculum tali, the tuberosity, and the anterior process (Fig. 11). The exact number and position of screws depend on the individual fracture pattern and bone quality. One or two additional screws may be placed freely outside the plate in order to obtain ideal positioning into the sustentaculum tali, a severely displaced anterior process or anterior facet fragment. Several biomechanical studies have failed to show a superior stability of locking vs. unlocking calcaneal plates, although the modes of failure are different (48, 94). If an interlocking plate is used, one or two conventional screws should be placed first to bring the plate close to the bone thus increasing stability by friction and avoiding soft tissue impingement from plate protrusion (31). Screw placement within the plate can be facilitated with the use of polyaxially locked plate designs.

Some authors advocate primary subtalar fusion in the cases of highly comminuted fractures (Sanders Type IV) when restoration of the joint appears impossible (58). After reconstruction of the outer calcaneal shape and internal



fixation as described above, all remaining cartilage is removed from the joint surfaces and arthrodesis is achieved with autologous bone graft and one or two 6.5 to 8.0 mm cancellous bone screws (58). In a recent prospective-randomized trial, primary fusion was not superior to open reduction and internal fixation in Sanders Type IV fractures (11). In our experience, patients with Sanders Type IV fractures have inferior long-term outcome compared to those with Sanders Type II and III fractures but the rate of secondary subtalar fusion is not different in these 3 groups (56). We therefore perform primary fusion only in selected cases of near complete loss of the articular surface or compound injuries with severe soft tissue damage warranting further measures (74). If painful subtalar arthritis develops after primary internal fixation and consolidation of bone and soft tissue, fusion can then be done in situ which is easier to achieve and associated with less complications and better clinical outcome than corrective arthrodesis for malunited calcaneal fractures that have been treated conservatively at first presentation (48, 51).

## POSTOPERATIVE CARE AND REHABILITATION

Postoperatively, a lower leg splint or cast is applied for 5–7 days until soft tissue swelling has resided. From the first postoperative day on the patient is instructed to press the sole of the injured foot against the cast regularly in order to improve venous outflow. The splint or cast is removed for wound care and physical therapy that includes active and passive range of motion exercises in the ankle, subtalar and mid-tarsal joints starting at the second postoperative day. In addition, continuous passive motion of the subtalar joint is initiated. Patients are restricted to partial weight-bearing of about 20 kilograms in their own shoes for 6 to 12 weeks, depending on the fracture pattern and bone quality. Hard labour and sports is allowed as tolerated after 4–6 months. Implant removal one year after plate fixation is only advocated in

cases of protruding hardware or massive arthrofibrosis with limited range of motion (Fig. 12). In the authors' preference, hardware removal is combined with extra- and intra-articular arthrolysis and debridement employing subtalar arthroscopy (49).

After percutaneous or minimally-invasive screw fixation of less severe calcaneal fractures, no splint is applied and physical therapy is initiated immediately after surgery (53). Partial weight-bearing in the patient's shoe is recommended for 6–8 weeks. In patients with multiple injuries the postoperative regimen is tailored to the individual fracture pattern.

## COMPLICATIONS

### Soft tissue problems

The development of wound healing problems is a particular concern after open reduction and internal fixation of calcaneal fractures via lateral approaches. Superficial wound edge necrosis occurs in between 2 and 20% of all cases after osteosynthesis via an extended lateral approach (1, 3, 5, 49, 65, 71, 75). The percentages with direct lateral approaches including a sinus tarsi approach lie between 0 and 15%, however the distinction between both is not always clear from the descriptions (13, 18, 24, 34, 44, 68). Considerably lower numbers between 0 and 6% are reported with percutaneous fixation (35, 53, 63, 70). Superficial skin breakdown usually responds to local wound care, antiseptic dressings and immobilisation. In less than 5% of cases a wound haematoma occurs. If it does not regress with elevation, rest and antiphlogistics, aspiration or surgical revision is indicated (56, 72). Injury to the sural nerve may occur in about 10% of cases. It mostly causes hypesthesia or dysesthesia over the lateral aspect of the foot that may subside with time. Treatment is observational. Only in cases of painful neuroma formation excision is advised (60).

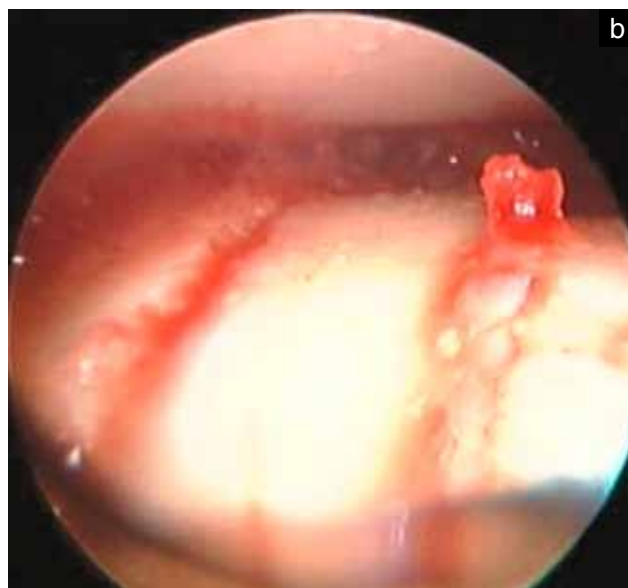


Fig. 10. (a-b) Anatomic reduction of the multiply fractured joint is controlled with open intra-operative subtalar arthroscopy and small residual step-offs in the subtalar joint are corrected immediately.

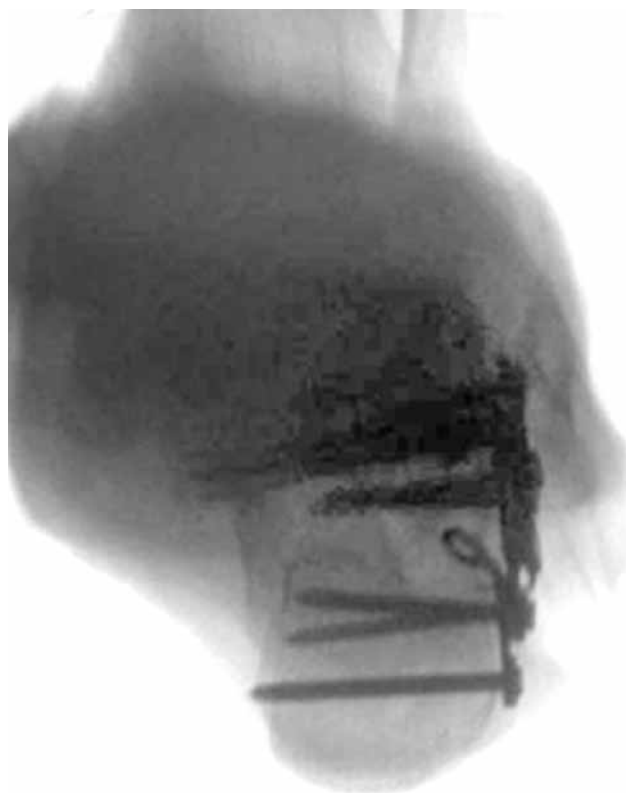
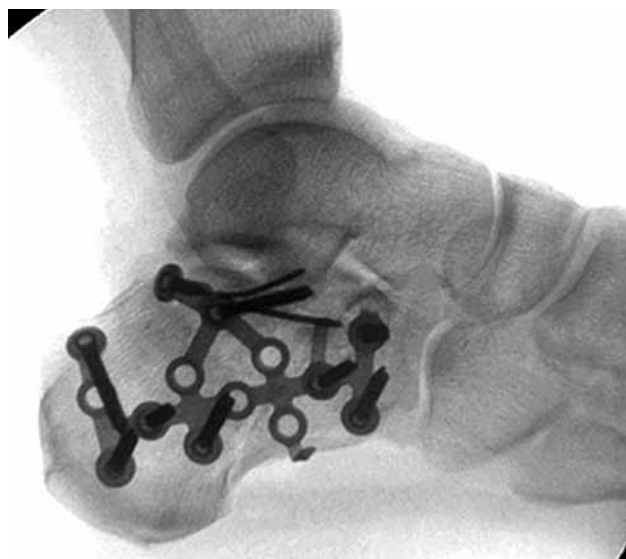
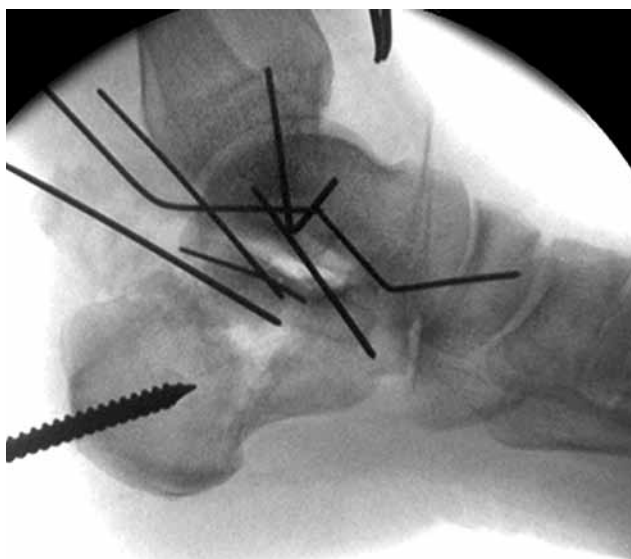


Fig. 11. (a–d) After open reduction and temporary K-wire fixation, the fracture is definitely stabilized with a lateral plate. The multifragmentary posterior facet warrants fixation with an additional subchondral “lost” K-wire.

a/b  
c/d

## Infections

Deep infections of the soft tissues and bone are the most serious complications after operative treatment of calcaneal fractures. The reported postoperative infection rates vary between 1.3 to 7 per cent after open reduction and internal fixation with a lateral plate (3, 6, 49, 56, 58, 71, 75). Risk factors include open fractures, delay of surgery beyond 14 days after the injury, the number of people in the operating room, a high body mass index, diabetes, and smoking (1, 14, 30, 49, 65). Specifically, open fractures are associated with an up to fivefold increased risk of wound complications and infections as compared to closed fractures (30, 49) but this complication can be mini-

mized with staged treatment (2, 41) and early, stable soft tissue coverage of open calcaneal fractures (9). Treatment consists of radical, repeated debridement of all infected and necrotic tissue and irrigation. In most cases the plate has to be removed and the fracture – if not yet consolidated – is fixed with screws. Temporary placement of antibiotic PMMA-beads and vacuum-assisted wound closure are useful adjuncts, especially if debridement leaves a considerable defect. Intravenous antimicrobial therapy is initiated with the first debridement and adjusted to the results of intra-operative specimen culture. If chronic calcaneal osteomyelitis develops, subtotal or total calcaneal osteomyelitis is inevitable (72).



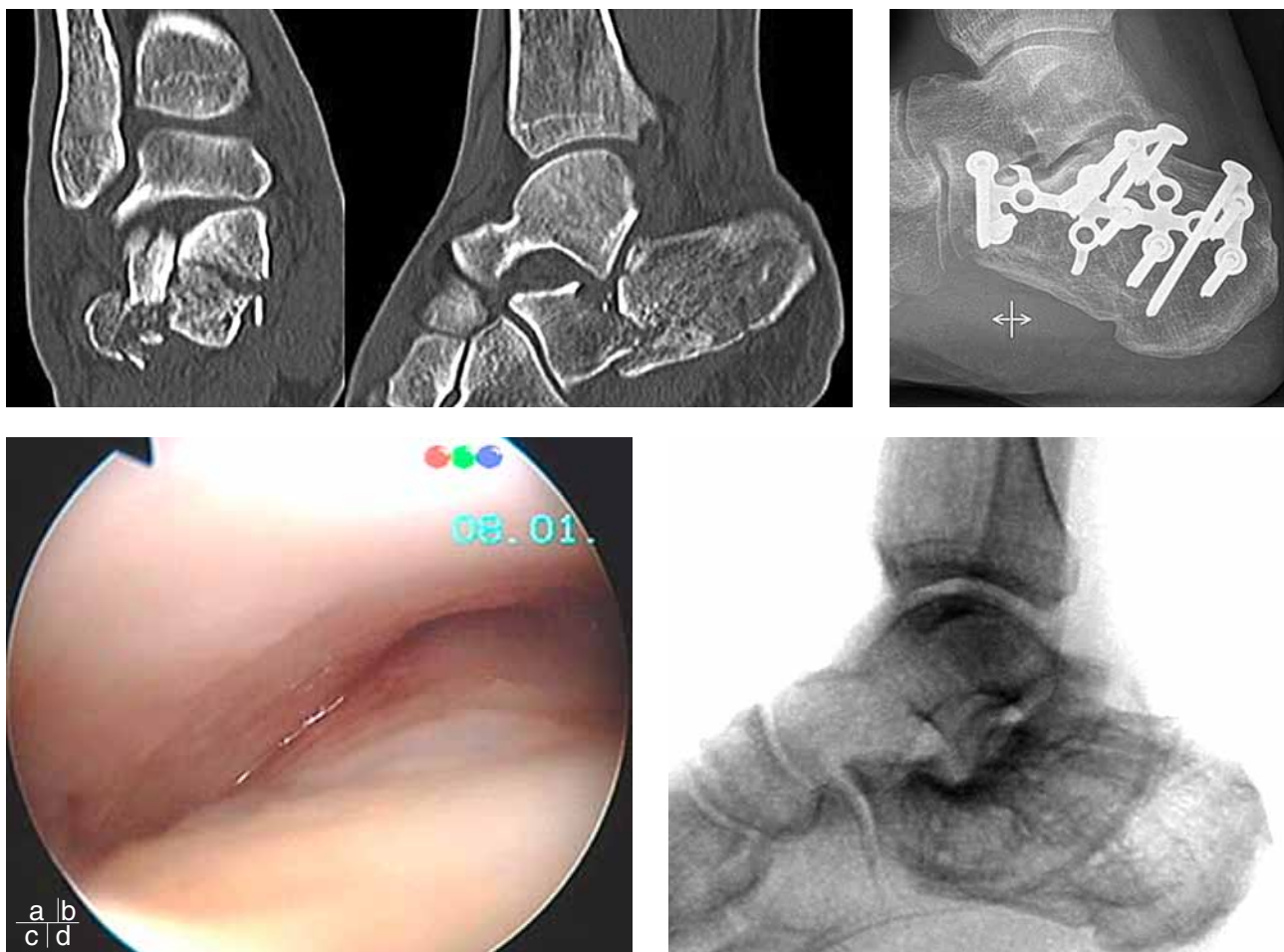


Fig. 12. (a–b) A 32-year-old patient presents 2 years after open reduction and internal fixation of a Sanders Type III calcaneal fracture. He has few residual complaints but marked loss of subtalar motion. (c–d) Hardware removal is combined with extra- and intra-articular arthrolysis. Subtalar arthroscopy at the time of hardware removal reveals good cartilage quality and congruity at the subtalar joint. The former fracture lines are covered with fibrocartilage.

Table 1. Classification of calcaneal malunions – modified after Zwipp & Rammelt (73)

Type		Quality	
0	any deformity without subtalar arthritis	A	solid malunion
I	subtalar joint arthritis	B	nonunion
II	additional hindfoot varus/valgus	C	necrosis
III	additional loss of height		
IV	additional lateral translation of the tuberosity		
V	additional talar tilt at the ankle joint		

## Malunions

Non-operative management and inadequate reduction or fixation of displaced intra-articular calcaneal fractures regularly results in painful malunions or nonunions with severe functional deficits (12, 51, 60). Residual step-offs in the subtalar joint or severe cartilage damage the time of the injury regularly lead to posttraumatic arthritis of the subtalar joint. The chronic deformities seen after calcaneal fractures are a consequence of the primary fracture pathoanatomy with loss of calcaneal height, broadening of the heel, hindfoot varus or valgus malalignment, lateral shift of the heel with fracture-dislocations and even talar tilt within the ankle mortise (55, 57). These bony deformities in

turn lead to a number of soft tissue problems like painful callosities or ulcerations around overloaded portions of the hindfoot, impingement and/or subluxation of the peroneal tendons at the displaced lateral calcaneal wall, flexor hallucis longus entrapment along the medial wall or sustentaculum tali, direct fibulocalcaneal abutment (especially in malunited fracture-dislocations), sural or posterior tibial neuritis, and claw toes from unrecognized compartment syndrome (55, 57, 58, 74). Therefore, correction of the bony malunion is regularly supplemented by soft tissue balancing. These procedures include Achilles tendon lengthening, tenolysis of the peroneal tendons and reconstruction of the superior retinaculum, flexor-to-extensor transfer at the lesser toes,

tenolysis and/or lengthening of the flexor hallucis longus tendon.

Symptomatic malunions require precise preoperative assessment of the deformity before surgical correction of the in order to salvage foot function (Table 1):

In the absence of subtalar arthritis (Type 0 malunion), a joint-preserving corrective osteotomy may be carried out in carefully selected, compliant patients with good bone quality. This is the case for the rare, extra-articular malunions and intra-articular malunions with still viable cartilage. In our experience the latter is rare, because the subtalar joint deteriorates rapidly with remaining step-offs in the posterior facet because of eccentric loading (90). With a purely lateral exostosis, decompression of the lateral wall and exostosectomy have reportedly lead to good results.

Type I malunions with painful subtalar arthritis are treated successfully with subtalar in situ fusion, which may be accompanied by decompression of the lateral wall in case of a painful exostosis. Both procedures may be carried out arthroscopically if no implant removal is indicated.

Type II malunions are treated with corrective subtalar fusion. Varus or valgus malalignment is corrected either by asymmetric joint resection or introduction of wedge-shaped bone blocks into the joint space in cases of mild deformities (72). With considerable varus deformity (roughly more than 15°), an additional lateral closing wedge osteotomy through the tuberosity is carried out (55).

Type III malunions with additional loss of height are corrected with a subtalar distraction bone block arthrodesis to reestablish heel height and relieve the subsequent anterior tibiotalar impingement (12, 51). With severe malalignment of the tuberosity, an additional corrective osteotomy may be required.

Type IV malunions represent malunited fracture-dislocations of the calcaneus with the tuberosity fragment directly impinging on the distal fibula, sometimes producing a direct lateral malleolar fracture and almost inevitably leading to chronic peroneal tendon dislocation. All elements of this three-dimensional deformity can be corrected by an osteotomy along the former fracture plane and additional subtalar fusion with bone grafting in case of a remaining defect (55, 57).

Type V malunions with talar tilt in the ankle mortise secondary to a complex calcaneal deformity require revision of the ankle joint via an additional anterior approach with careful debridement of all ingrown tissue followed by stepwise realignment of the talus and calcaneus and corrective subtalar fusion, mostly via bilateral approaches (72).

Solid malunions (subgroup A) require a formal osteotomy and solid internal fixation. In case of nonunions (subgroup B) correction is preceded by debridement of the fibrous pseudoarthrosis and supplemented by cancellous bone grafting. Avascular necrosis (subgroup C) of the calcaneus is rare and requires radical debridement of all necrotic tissue followed by bone grafting.

## RESULTS

Clinical series with more than 100 patients and followed for more than one year showed good to excellent results with open reduction and lateral plate fixation in 60 to 85 per cent of cases using different outcome criteria (5, 8, 49, 71). Three studies with larger patient cohorts (47 to 127 patients) report function at 8 to 12 years after operative treatment (38, 46, 56). Negative prognostic factors that have been identified in several studies include the original fracture pattern as represented by a higher Zwipp or Sanders classification, open and bilateral fractures, eligibility for workers' compensation, high workload (6, 8, 10, 45, 49, 56, 58, 65, 71). There is still insufficient evidence from prospective-randomized trials as to the best available treatment, but from the largest existing study several patient cohorts can be identified that benefit from operative treatment such as women, men under 50 years of age, and patients with a light workload. The need of secondary subtalar fusion is increased sevenfold after non-operative treatment (10). More data from studies with larger patient cohorts and longer follow-up are needed to assess the value of less invasive approaches and fixation techniques. The short-term results are promising.

Positive prognostic factors that may be influenced by the surgeon are reconstruction of Böhler's angle, subtalar joint reduction within 2 mm, and surgeon experience (3, 6, 10, 24, 32, 36, 38, 45, 49, 58, 71). Higher patient age does not appear to negatively affect outcome after operative treatment of calcaneal fractures (23, 56). The rates of secondary subtalar fusion for symptomatic post-traumatic arthritis range between zero (42) and 14% (8, 58) with most authors reporting between 2 and 6% (56).

In conclusion, fractures of the calcaneus require an individualized treatment approach and precise preoperative planning. Undisplaced and slightly displaced extra-articular fractures are treated non-operatively. Displaced extra-articular and selected intra-articular fractures may be treated with percutaneous reduction and fixation with excellent results. Percutaneous reduction and fixation is also helpful as a temporary measure in more severe fracture patterns with critical soft tissues or a critical overall condition of the patient. Open fractures and closed fractures with compartment syndrome or severe soft tissue incarceration resulting from internal fragment pressure are treated as emergencies. In the absence of contraindications the majority of displaced, intra-articular fractures are best treated by open reduction and internal fixation. Selected, less invasive approaches and novel fixation techniques have to potential to minimize soft-tissue complications while ensuring anatomic reduction and stable internal fixation. Non-operative treatment of severely displaced fractures or failure to achieve anatomic reduction with surgical treatment regularly results in painful malunions with rapidly evolving subtalar arthritis. Symptomatic malunions and nonunions are treated according to their respective pathoanatomy with correction of the deformity including corrective osteotomy, fusion, and soft tissue balancing.

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#### Corresponding author:

Prof. Dr. Stefan Rammelt

University Center for Orthopaedics and Traumatology

University Hospital Carl-Gustav Carus

Fetscherstrasse 74

01307 Dresden, Germany

E-mail: stefan.rammelt@uniklinikum-dresden.de