

Ankle Arthrodesis – a Review of Current Techniques and Results

Artrodéza hlezna – přehled současných technik a výsledků

E. MANKE¹, N. YEO ENG MENG², S. RAMMELT¹

¹ University Center of Orthopaedics & Traumatology, University Hospital Carl Gustav Carus, Dresden, Germany

² SingHealth Duke National University of Singapore, Academic Medical Centre, Singapore

SUMMARY

Ankle arthrodesis continues to be the golden standard in the treatment of end-stage ankle arthritis. Meticulous soft tissue handling, correct positioning of the foot, and stable fixation are crucial for obtaining a favorable result. With current techniques, mostly internal fixation with screws or plates, union rates between 87 and 100% are reported. Adjacent joint arthritis remains a concern in long-term follow-up, but does not always become symptomatic. It is pre-existing in a substantial number of cases and associated with fusion in less than optimal position, particularly equinus. With arthroscopic arthrodesis techniques, wound complications and scarring can be further reduced while obtaining similar fusion rates and equivalent, if not better, functional results when compared with open techniques.

Key words: ankle, hindfoot, fusion, screws, plate, anterior approach, transfibular.

INTRODUCTION

It is estimated that about 1% of the world's adult population suffers from osteoarthritis of the ankle (62). The main etiology of ankle arthritis is trauma making up over 70% of cases in larger clinical studies (70, 78). The most common underlying injuries are malleolar fractures, ligament lesions, and fractures of the tibial pilon. Secondary ankle arthritis results from rheumatoid arthritis, hemochromatosis, hemophilia and neurogenic osteoarthropathy. Primary osteoarthritis is seen in about 10% of cases. The majority of patients with ankle arthritis of any origin has varus malalignment (74, 78). End-stage ankle arthritis results in considerable mental and physical disability that is at least as severe as that associated with end-stage hip arthritis (22).

Post-traumatic ankle arthritis is an extremely disabling condition, especially in younger patients. Despite advancements in total ankle arthroplasty, survivorship of ankle replacements still lags behind that of knee and hip replacements. As such, ankle arthrodesis remains the gold standard for younger, active patients with end-stage ankle arthritis.

The term "arthrodesis" was coined by the Austrian surgeon Eduard Albert in 1878, when he surgically fused of both knees and ankles in a 14-year-old child with severe palsy of the lower extremities (2). While at the end of the 19th century and the beginning of the 20th century, ankle and subtalar arthrodeses were used predominantly for paralytic foot deformities, in the 1930s, ankle fusion was increasingly used for surgical reconstruction of painful malunited malleolar fractures (32). Historically, complication rates between 9 and 60%, nonunion rates between 5% and 37%, and limitations of the activities of daily life or occupation in 33 to 50% of patients have been reported after ankle arthrodesis (1, 36, 54,

85). These studies looked at historical techniques and thus included a high proportion of patients who had been treated with external fixation, were fused in equinus or varus malalignment, and those who underwent simultaneous fusion of adjacent joints. More recent series that employed screw fixation and strived for fusion in neutral position of the ankle reported substantially better functional outcomes and union rates between 87% and 100% (86).

Over the last 25 years, total ankle replacement has evolved as a viable treatment alternative to arthrodesis in end-stage ankle arthritis. With proper technique and patient selection, the complication rates and medium-term functional outcomes of both procedures seem to be similar. Patients after total ankle replacement showed a greater mean overall sagittal movement in comparison to patients after ankle fusion. Ankle fusion predisposes to degenerative changes of adjacent joints with development of peritalar and midfoot arthritis due to a relative increase of talonavicular movement (46). Aseptic loosening is the most frequent reason for failure after total ankle replacement (28, 42, 60).

SURGICAL APPROACHES AND TECHNIQUES

The surgical approach and technique for ankle arthrodesis is highly variable. More than thirty different techniques for tibiotalar arthrodesis have been described in literature (16). Selection of the exact approach should be based on the advantages and pitfalls of each fixation strategy as well as taking into consideration patient factors and the underlying pathology. Both internal and external fixation techniques have been well described in the literature. Advantages of internal fixation include

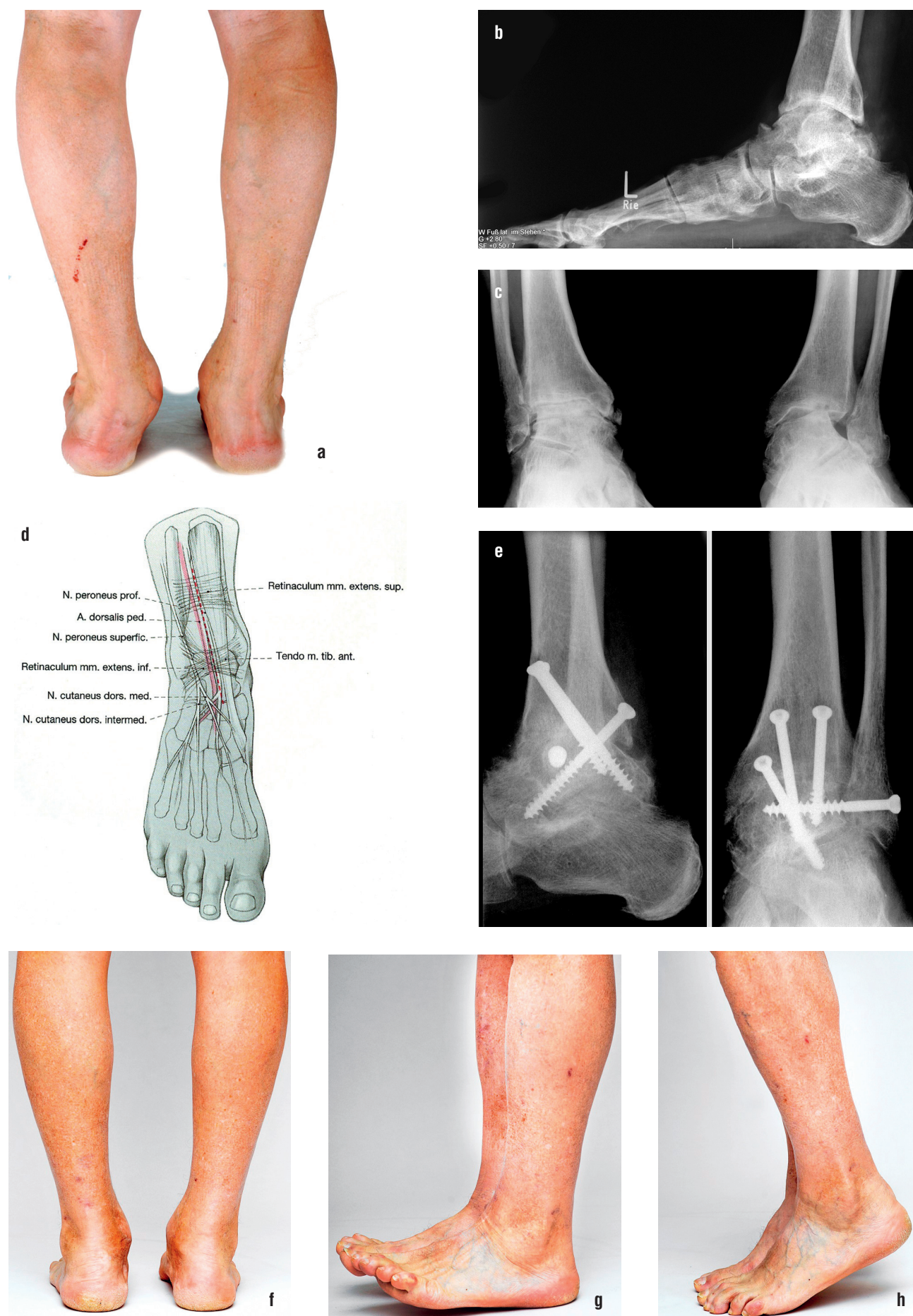




Fig. 1. (a–c) Severe valgus osteoarthritis in 55 an old male patient with chronic lateral ankle instability. (d) Ankle fusion was carried out via an anteromedian approach (15). (e) Internal fixation is achieved with four screws. (f) At 5 years follow-up the patient is painfree and the ankle is well aligned. (g–h) There is compensatory sagittal motion in the mid-tarsal and tarsometatarsal joints. (i–j) Radiographs at 5 years show solid fusion of the ankle in physiological alignment and no signs of adjacent joint arthritis.



ease of application, reduced rates of nonunion, infection and neutralisation of biomechanical forces (51, 56, 76). However, there are certain scenarios where external fixation confers significant advantages. These include situations where there is an active deep infection or osteomyelitis, a compromised soft tissue envelope around the ankle, insufficient bone stock to adequately support implants or if there is a bone defect requiring simultaneous tibial lengthening with distraction osteogenesis (17, 85). Otherwise, current recommendations still favour internal compression techniques using screw or plate constructs (86).

External fixation

Historically, the results of compressive arthrodesis of the ankle joint using external fixators was poor due to high rates of nonunion. This was until Charnley described in 1951, the concept of combining open surgical debridement of the ankle joint with compression arthrodesis via one pin through the tibia and one pin through the neck of the talus with connecting bars across the two pins. Patients were allowed to bear weight postoperatively with the frame and he reported relatively high union rates with this technique (6). Subsequently, the monolateral, hybrid, Calandruccio and Ilizarov multiplanar ring external fixators were described to achieve arthrodesis of the ankle joint (17, 80). Advocates of this technique point to the ability to adjust the amount of compression and alignment postoperatively.

The combination of dynamic axial compression and ability to resist bending, shear and torsional forces allows for the option of early weight-bearing. This is an ideal option in cases of complex ankle arthrodesis. It may be performed in patients with poor bone stock, significant soft tissue trauma, in the presence of active

infection and anticipated patient noncompliance with postoperative weight-bearing restrictions. Thordarson et al. reported that screws provided better resistance to torsional loading in specimens with higher bone quality whereas external fixation provided better resistance to torsion in specimens with lower bone quality (76). This further highlights the potential advantage of external fixation techniques in patients with inadequate bone stock at the arthrodesis site due to previous infection, avascular necrosis or trauma.

More recently, Easley et al. reported an 85% fusion rate with use of a ring fixator for revision and re-revision cases of ankle arthrodesis (14). Morasiewicz et al. achieved a fusion rate of 100% in patients with Ilizarov fixator in comparison to 85% fusion rate in internal fixation. They did not find a significant difference between internal and external stabilization of the ankle joint using the Ilizarov fixator regarding the period of hospitalization, function (FAAM functional score) and complication rate. In the group of Ilizarov external stabilization VAS pain level was even significantly lower postoperatively than after internal fixation (53). A relative contraindication to external fixation includes patients with existing ipsilateral knee arthroplasty due to the risk of periprosthetic infections from potential pin tract infections.

Internal fixation

The most widespread operative strategy for achieving ankle arthrodesis is internal fixation. It has been shown to give excellent outcomes in terms of achieving rigid fixation and bony union with minimal complications. Advantages of internal fixation include the ready availability of screws, relatively low cost, ease of application and documented clinical efficacy under favourable clinical conditions (34, 86).

Ankle arthrodesis can be achieved via both arthroscopic and open techniques. Open techniques include the anterior, lateral transfibular and mini-open approaches.

Open techniques

Anterior approach

An anterior approach allows a complete exposure of the ankle joint and easy correction of deformities (Fig. 1). It is useful when the talus has been displaced laterally or medially under the tibia in the coronal plane. It is also indicated when previous surgery has been performed through an anterior approach. This approach provides excellent exposure of the ankle joint for arthrodesis (9, 86).

The patient is placed supine on the operating table with a thigh tourniquet and a bump under the ipsilateral buttock to maintain the leg in neutral rotation. A standard longitudinal anterior incision is made midway between the malleoli, starting 7.5 cm above the ankle joint and carried to the neck of the talus to give a wide exposure of the joint. The extensor retinaculum is incised in a zig zag fashion to facilitate reapproximation during closure (15). Care should be taken to preserve the medial dorsal cutaneous nerve which may cross over the distal incision medially and to identify the neurovascular bundle just lateral to the extensor hallucis longus tendon in the deep plane. The neurovascular bundle is retracted laterally together with extensor hallucis longus and extensor digitorum longus tendons and the tibialis anterior tendon is retracted medially. The ankle joint capsule is then incised and detached from the tibia and talus using sharp dissection to expose the ankle joint.

All existing osteophytes are then resected. A generous debridement and removal of all sclerotic and nonviable bone is performed using curved osteotomes, curettes and a rongeur. A laminar spreader is placed between the tibia and talus first laterally, then medially to allow complete debridement of the posterior aspect of the ankle, medial and lateral gutters. The tourniquet is then deflated to ensure that a bleeding cancellous bone surface was exposed. In cases where significant bone defects were present, autologous iliac crest bone block is harvested and grafted and additional cancellous bone chips are interposed.

A roll of sheets below the distal tibia served as a fulcrum for forced reduction of the foot with respect to the tibial axis to avoid anteversion of the talus. The ankle joint was then reduced, aiming for 5-8 degrees of valgus, 5-10 degrees of external rotation, neutral dorsiflexion/plantarflexion and the talus is centered below the tibia in both anteroposterior and lateral planes (5, 15, 16, 37, 86). The ankle is then fixed temporarily with K-wires.

Numerous fixation techniques have been described in the literature. These include compression screws in various configurations and lateral, anterior or posterior plating techniques. Additional screws may be placed through the medial or lateral malleoli or both. Crossed screws have been shown to form a stronger construct than parallel screws but may prevent compression if not done sequentially. Some authors have advocated the 'home-run' screw as being the most important. It is placed from the posterior malleolus into the talar neck and head (13, 15, 59, 67, 68, 86).

Zwipp et al. reported a 99% union rate and excellent clinical outcomes at midterm followup using a four screw technique (86). Four 6.5mm cancellous lag screws were used. Two screws were inserted parallel from the anterior aspect of the tibia into the body of the talus and countersunk to achieve adequate purchase of the bone and compression. The third, mechanically most important, screw was inserted through a posteromedial stab incision approximately 3 cm proximal to the tip of the medial malleolus. The screw was inserted into the anterolateral portion of the talar head. The fourth screw was inserted percutaneously from the posterolateral aspect of the distal fibula approximately 1.5 cm proximal to the tip of the lateral malleolus into the dorsal portion of the talar body. In the presence of bone defects or osteopenic bone, fully threaded 6.5mm screws were used. If a manifest syndesmotic instability was present at the time of fusion, a fifth screw was introduced as a tibiofibular set screw approximately 1.5 cm above and parallel to the tibial plafond (15, 85, 86). Other variations of the four screw technique have been employed successfully (33, 34, 68, 79).

Various plating techniques have also been described in the literature. These include single or double anterior plating with or without compression screws across the joint, lateral and posterior plating (27, 73, 84). Plating techniques have been shown to have superior biomechanical properties in terms of primary stability and stiffness versus cross screw constructs. It also minimizes any hardware across the fusion site, maximizing the surface area for healing (4, 21, 63). Posterior plating may be useful in cases of critical soft tissue conditions around the ankle and if ankle fusion has to be combined with subtalar fusion (27). Anterior plate fixation seems to be a convenient and effective way of ankle arthrodesis with low complication rate, short healing time and rapid recovery (21). A high union rate of 93.8% in a high-risk patient cohort (necrosis of the talus, severe segmental bone defect, smoking, inflammatory arthropathy, coronal deformity greater than 15 degrees, diabetes mellitus, septic nonunion, failed ankle arthrodesis and BMI greater than 35) was shown by Steginsky et al. (73). Disadvantages of anterior plating include potential concerns for a stress fracture proximal to the plate and hardware irritation (73). Clifford et al. recently reported superior stiffness when a compression screw was added to a plate construct placed on the compression side of loading (7). However, whether this translates to clinical outcomes has yet to be adequately evaluated.

Lateral transfibular approach

The lateral approach (Fig. 2) is useful when the foot is translated forward due to a malunited anterior pilon fracture or when a plate on the lateral malleolus needs to be removed. It is often performed with an onlay fibular autograft. This further increases the stability of the construct, compensates for bone loss and adds a strut of living bone that bridges the fusion site without the donor site morbidity of an iliac crest autograft. A further advantage is the full overview over the talar dome from lateral



Fig. 2. (a, b) Varus osteoarthritis, drop-foot and lateral shift of the talus due to chronic syndesmotic instability in a 59-year-old female patient 25 years after ankle fracture-dislocation treated operatively. The patient reports increasing pain over the last 5 years (c, d) Corrective arthrodesis with 5 screws includes tibiofibular fusion via a transfibular approach and additional Achilles tendon lengthening to achieve a plantigrade position of the foot. At 6 weeks the fusion has consolidated.

with the possibility to remove posterior osteophytes that also impinge on the subtalar joint (40). On the other hand, an additional small medial approach will be necessary to debride the medial facets of the tibia and talus.

The patient is placed supine on the operating table with a bump under the ipsilateral buttock to rotate the limb internally and facilitate visualisation of the lateral aspect of the foot. A thigh tourniquet is utilised. A longitudinal lateral incision is made over the anterior margin of the fibula extending down to its distal end. Care should be taken at the proximal end of the incision not to injure the superficial branch of the peroneal nerve. The skin flaps are elevated and the periosteum is incised longitudinally. Limited stripping of the periosteum is performed to expose the lateral and anterior portions of the distal fibula and to view the anterior inferior tibiofibular ligament inferiorly. The lateral ankle ligaments are released from their fibula origins. Care should be taken to preserve the fibular periosteum laterally and posteriorly to preserve its vascularity. The fibula is transected trans-

versely 2 cm above the tibial plafond and rotated posteriorly, providing access to the lateral fibulotalar joint and the syndesmosis.

The tibiofibular joint is debrided with a rongeur and the ligamentous attachment between the tibia and fibula removed along with osteophytes and fibrous tissue. The fibula is then sectioned and split longitudinally in the sagittal plane and the medial cortex with its fibula articular facet excised. If the fibula is rather small, the medial facet is just debrided to facilitate fusion. This leaves a corticocancellous strut graft which will be fastened to the arthrodesis site at the end of the procedure. The lateral talus and tibia are then prepared for arthrodesis with the aid of a laminar spreader to facilitate exposure. If the medial aspect of the joint is difficult to access from this incision, a secondary anteromedial incision may be utilised. This provides excellent visualisation of the medial gutter and medial tibiotalar joint.

The ankle is then reduced in the optimal position and fixed with three compression screws. Staples may be

used to bridge the fusion site and further augment the fixation. The fibula onlay graft is now positioned and compressed to the lateral side of the fusion site using two compression screws. One screw compresses the fibula into the distal tibial metaphysis and a second screw compresses the fibula into the lateral talar facet (12, 30, 48, 82). In case of a severe valgus deformity, the distal fibula can be used as a graft (68).

Comparing the anterior and lateral approaches, there were no significant differences of pre- and postoperative VAS, AOFAS, union rate and postoperative alignment. With both approaches, comparably good results were achieved (40).

Mini-open approach

Gallie first described performing an ankle arthrodesis through smaller anteromedial and anterolateral incisions. In his technique, bone grafts were placed into the medial and lateral gutters of the ankle after cartilage was removed via curettage. This was found to be useful in rheumatoid patients where the joints were symptomatic but had minimal deformity. The screws were then inserted percutaneously under fluoroscopic guidance (20).

Arthroscopic arthrodesis

Arthroscopic ankle fusion has gained in popularity in selected patient groups over the last few decades. In 2012, Goldberg et al. reported that 48% of foot and ankle surgeons in the United Kingdom preferred the arthroscopic technique when performing an ankle arthrodesis (25).

This is a minimally invasive procedure with several advantages over the traditional open technique. This technique involved minimal soft tissue disruption and consequently less early postoperative pain (48). It has been shown to result in less morbidity, faster return to activity, reduced overall cost of treatment and reduced length of hospital stay (1.4 days longer with open procedures) if necessary (55, 61, 83). In addition, multiple studies have shown that it leads to higher and faster fusion rates than open procedures, likely because of decreased soft tissue stripping and preservation of blood supply (23, 35, 58, 65, 81). A systematic review of the literature and meta-analysis of outcomes of arthroscopic and open ankle fusions showed no significant differences between the two groups in terms of infections rate, overall complication and operation time (35). For arthroscopic procedures, the complication rate varies from 0–40% whereas in open procedures it ranges from 20–56% (81).

Relative contraindications to arthroscopic ankle fusion include patients with severe arthritic changes and significant ankle malalignment in the coronal plane. Multiple studies advocate arthroscopic technique only for ankles with less than 15 degrees of varus or valgus (71). Authors have cautioned against performing arthroscopic arthrodesis in these patients, citing inability to achieve optimal stable reduction and fixation (55, 59). However, Townshend et al. report good results in patients with coronal plane deformities as large as 30 and 36 degrees.

They believe that large coronal plane deformities are frequently the result of talar tilting within the ankle mortise with little deformity in the actual tibia or talus (35, 77). The use of arthroscopic arthrodesis for larger coronal plane deformities was supported by Gougoulas et al. who compared the outcomes of arthroscopic arthrodesis in patients with <15 degrees of deformity and >15 degrees (up to 45 degrees) of deformity. The outcomes were similar, with good results in 79% and 80% of the patients, respectively, and good correction in both groups (26). Quayle et al. achieved deformity correction in the majority in ankles with severe coronal plane deformity over 10 degrees with no statistically difference to the open group (65). Schmid et al. compared 62 patients with arthroscopic ankle fusion and 35 patients with open procedure. Preoperative deformity was the same regarding sagittal alignment and coronal alignment. Only tibial deformity measured by the tibial plafond angle was less in the arthroscopic group and more often addressed by an open procedure. Follow-up of patients after 12 months showed an identical radiological outcome in both groups with proper alignment in coronal and sagittal plane as measured by lateral talar station (71).

Ankle arthroscopy requires the establishment of safe and functional portals. Arthroscopic ankle fusion is performed in the supine position. Anterior arthroscopy uses standard portals based on the medial and lateral sides of the joint, the anteromedial and anterolateral portals. Medial and lateral accessory portals can be created next to the tip of the medial malleolus and the tip of the lateral malleolus to assist in debridement of the gutters. Accessory portals can be placed above the primary portals, allowing triangulation from above and below and also through a posteromedial portal to access the posterior aspect of the ankle joint from a supine position (3).

The patient is placed supine on the operating table and a thigh tourniquet is applied. A non-invasive ankle distractor is applied and standard anteromedial and anterolateral portals are created. The anteromedial portal is placed in the medial side of the ankle, just medial to the tibialis anterior tendon at the level of the joint line. The soft spot on the medial side of the ankle is palpated while the ankle is dorsiflexed and plantar flexed. The portal is marked and the skin is incised with an incision that goes just deep to the dermis. Deep dissection is carried out blunt with scissors or clamp. The joint is penetrated and the joint line is palpated with a blunt instrument. The arthroscope can then be placed across the anterior ankle in dorsiflexion or over the top of the talus while the ankle is distracted. The anterolateral portal is palpated on the lateral side of the ankle lateral to the extensor tendons. The terminal branches of the superficial branch of the peroneal nerve can be seen through the skin and visualized using diaphanoscopy. As these are variable in position their presence should always be considered as being close to the portal and all deep dissection done blunt. Once second portal is established, the instruments used for debridement are placed across the anterior ankle in dorsiflexion or over the top of the talus with the joint being distracted.

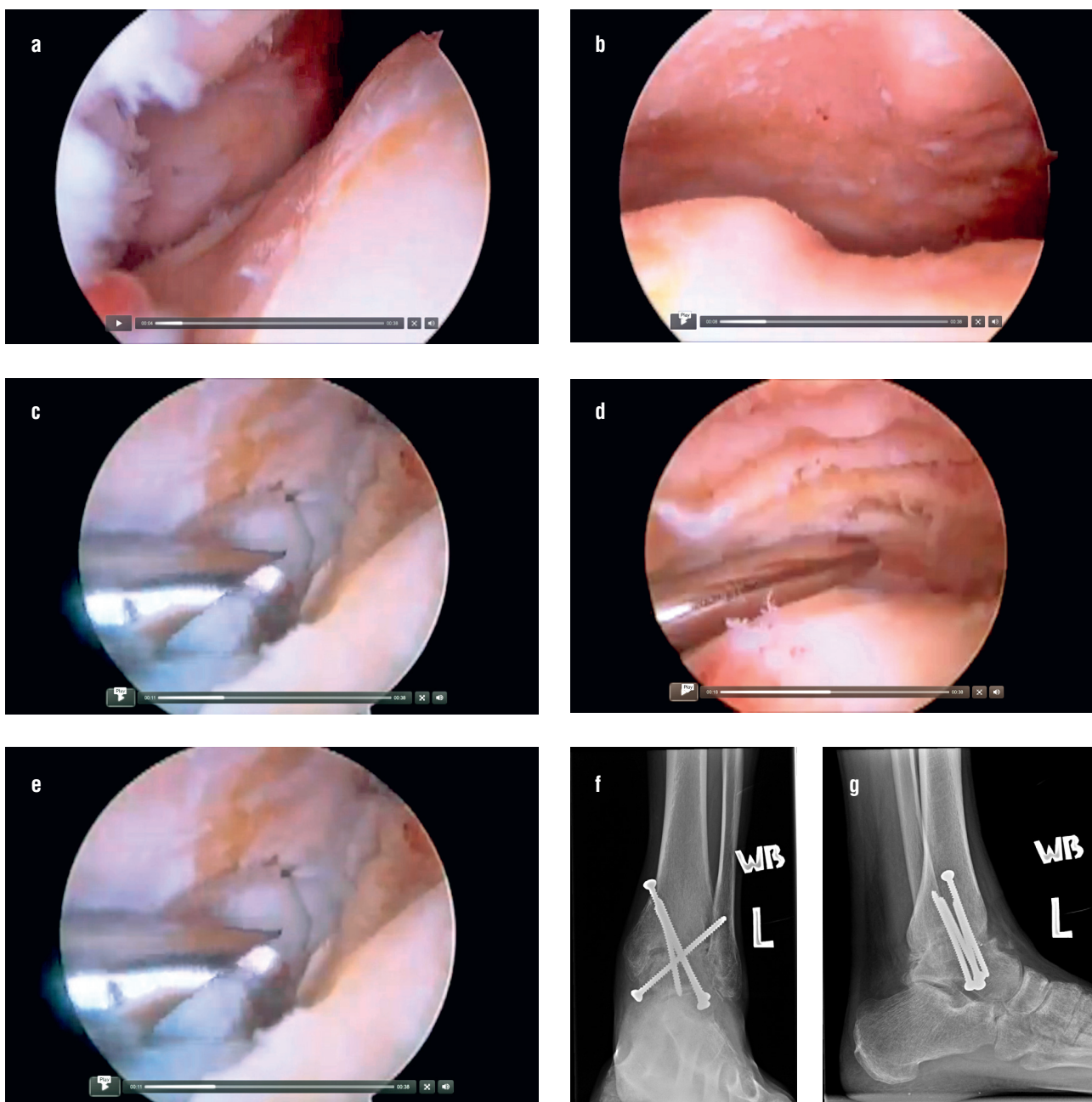


Fig. 3. (a) Arthroscopic view of the lateral gutter and (b) talar dome in an osteoarthritic ankle. (c) Removal of residual cartilage at the lateral gutter and (d) talar dome is achieved with a shaver. (e) Bleeding from the subchondral bone indicates adequate debridement. (f, g) Postoperative images after arthroscopic ankle fusion and percutaneous screw fixation.

In arthroscopic ankle fusion the medial malleolar portal can be very helpful as an accessory instrument portal. With the arthroscope in the anterior medial or anterior lateral portal looking down into the medial gutter, a burr is used to resect osteophytes from the medial malleolus and talar neck (Fig. 3). A shaver can be used to remove any remaining soft tissue impingement. A low anterior medial portal can also be used to remove the cartilage from the medial talus and corresponding joint surface of the medial malleolus. The portal is established just inferior and anterior to the tip of the medial malleolus. A small skin incision is made and a blunt instrument placed into the ankle joint. The instruments are then

inserted. In analogy to the medial side, an additional lateral malleolar portal is an effective way of approaching the lateral gutter. The incision is made just inferior and anterior to the lateral malleolus.

Initial visualisation may be impaired by anterior joint synovitis. All inflamed synovium and scar tissue should be aggressively debrided with a shaver as they may impair mobilisation and reduction of the joint surfaces. An arthroscopic burr is then used to remove all articular cartilage. As detailed above, the accessory medial and lateral portals allow access to the gutters and the posteromedial portal can be useful to access the posterior talar dome and tibial plafond. In most posttraumatic

Table 1. Main findings in relevant studies during the last decade employing ankle arthrodesis

First author	Number of ankles followed	Method of fixation	Average followup (years, months)	Union rate (%)	Wound healing problems (%)	Deep infection rate (%)	Functional outcome assessment (score with a maximum of 100)	Alignment, remarks
Zwipp et al. [86]	72	standard screw technique	5 y 11m	98.9	5.3	0	84.7 (AOFAS)	varus malalignment in one case (1.3%)
Morasiewicz et al. [53]	47	external fixation with Ilizarov fixator (n=21), internal fixation with cannulated screws (n=26)	>24 m	Ilizarov 100 Screws 85	Ilizarov 61,5 Screws 13,35	-	Ilizarov 79,38 (FAAM) Screws 70,11 (FAAM)	-
Goetzmann et al. [24]	111	internal fixation with two vs. three screws	12 m	87,4 (84 vs 94,4)	5	5	-	coronal malalignment >5° in 7,1% of non-united ankles, in 12,3% of united ankles lateral malalignment >5° in 21,4% of non-united ankles, in 20,6% of united ankles
Kerkhoff et al. [38]	185	internal fixation with two screws via lateral approach and osteotomy of the fibula	8 y	90,8	5,4	1,6	70 (FAAM ADL)	frontal tibiotalar angle 88,2° lateral tibiotalar angle 106,1°
Leeuw et al. [45]	40	posterior arthroscopic arthrodesis with screws	42 m (24-66m)	100	-	0	63 (FAAM ADL)	reoperation in 3 patients with mal-placement of screws
Schmid et al. [71]	97	62 arthroscopic vs. 35 open ankle fusions via screws	4,5 y vs. 4,1 y	-	-	-	-	medial tibiotalar angle 89,3° vs. 88,3° lateral tibiotalar angle 111,2° vs. 110,4°
Quayle et al. [65]	79	29 open ankle fusion vs. 50 arthroscopic fusions	48 m vs. 39 m	83 vs. 98	0,3 vs. 0,5	0 vs. 0,5	-	postoperative coronal alignment within 5° achieved in 97 vs. 96%; 2 arthroscopic operations converted to open
Malerba et al. [49]	12	isolated tibiotalar fusion via two screws (n=6) vs. combined tibiotalarocalcaneal fusion via compressive intramedullary nail (n=6)	70 m	-	-	-	57,2 vs. 62,5 (AOFAS)	Gait analysis without differences in time-distance parameters, arthritic degeneration subtalar in isolated fusion group, talonavicular and Lisfranc in combined fusion
Pedowitz et al. [60]	68	total ankle arthroplasty (TAA, n=41) vs. tibiotalar arthrodesis via anterior approach and tibiotalar fusion with three screws (TTF, n=27)	33,66 m vs. 40,26 m	-	-	-	82,19 vs. 71,67 (FAAM ADL)	TAA greater mean overall sagittal movement (34,2° vs 24,3°), TTF: arc of movement from the midfoot, TAA: 23,7° from tibiotalar joint, 10,5° from midfoot, TAA more normal mean movement across midfoot, increased movement distal to the tibiotalar joint basis for development of peritalar and midfoot arthritis after ankle arthrodesis
Saltzman et al. [69]	71	total ankle replacement (n=42) vs. ankle fusion (screws vs. plate and screws vs. external fixation n=29)	4,2 y	90 (ankle fusion group)	4,7 vs. 3,4 (FU incomplete)	-	39,9 vs. 38,9 (SF-36 PCS)	arthroplasty group with better pain relief postoperatively and preservation of motion but with more complications that required further surgery
Lee et al. [44]	23	ankle fusion using 2 retrograde screws	41 m	95,7	0	0	71 (AOFAS)	suboptimal postoperative ankle alignment: 2,7° varus, 6,7° plantar flexion and 2,9° internal rotation, progressive arthritis subtalar (n=2) or subtalar and talonavicular (n=2)
Kim et al. [40]	60	anterior approach via fixation with two screws (n=38) vs. lateral approach via osteotomy of the fibula, two screws and fibula onlay bone graft (n=22) for ankle fusion	-	89,5 vs. 95,4	-	-	58,3 vs. 60,7 (AOFAS)	no significant difference VAS, AOFAS, bone union, no difference in postoperative alignment, union rate, comparable good results
Woo et al. [81]	76	arthroscopic (n=28) vs. open ankle arthrodesis (n=56)	24 m	100	-	0 vs. 7,1	78,9±18,9 vs. 68,9±24,7 (AOFAS)	arthroscopic method associated with less perioperative pain, shorter length of stay, fewer complications and followup operations
Coughlin et al. [10]	13	lateral compression locking plate with single compression screw across joint	8.6 m	100	1	0	71 (AOFAS)	fibula osteotomy performed

Townshend et al. [77]	60	open: transfibular approach (n=30) arthroscopic: 2–3 screws (n=30)	24 m	97	2	0	Ankle Osteoarthritis Scale (AOS) Open 29.2 Arthro 17.2	1 non-union in each group requiring revision 1 delayed wound healing in each group 2 required removal of symptomatic implants (both in arthroscopic group)
Daniels et al. [11]	107	rigid internal fixation with compression	4.8 y	93	-	-	Ankle Osteoarthritis Scale (AOS) 33.6 (Pre-Op 53.4)	COFAS Multicentre Study Included both open & arthroscopic fusions, did not report minor wound complications, 1 amputation
Nielsen et al. [57]	107	Rigid internal fixation with compression screws (arthroscopic n=58; open n= 49)	1 y	90	4	2	-	nonunions (8 open 3 arthro) Infections (4 open 2 arthro; of which 2 deep infections were in open group)
Gharehdaghi et al. [21]	12	anterior plating	2 y	100	0	0	MOXFQ score 38 Preop 69	all required hardware removal at 1y

osteoarthritic ankles the anterior part of the joint has the least remaining cartilage. The posterior arthroscopic approach allows a proper removal of the remaining cartilage in the posterior part of the ankle joint (45). Curettes are then used to debride any articular cartilage and underlying sclerotic bone. The tourniquet is deflated to confirm adequate bleeding of the bone surfaces.

As with open arthrodesis techniques, the ankle joint is brought into the optimal position for fusion and fixation is accomplished with percutaneous placement of multiple screws. Cannulated compression screws of 6.5mm diameter or larger are usually preferred. Multiple screw configurations have been described in the literature including cross screw constructs and the 'home run' screw. This is detailed in the 'Open Technique' section. The use of at least three screws is preferred in arthroscopic fusions. The non-union rate was reduced from 16% with two screws to 5.6% with three screws in arthroscopic procedures. Furthermore patients with three screws had a shorter time to union (24).

POSTOPERATIVE MANAGEMENT

The postoperative regimen can vary depending on bone quality, the amount of bone grafting, regional practices and surgeon preference. Patients are typically placed on a well padded cast for the initial two weeks post surgery. Sutures are removed at two weeks and the cast changed. The second cast is removed at six week post surgery and radiographs are taken at this time point. If there is radiographic evidence of interval fusion as defined by the presence of continuous bone trabeculae across the former joint line, the patient is placed in a walker boot and progressive weightbearing is commenced. At three months post surgery, the patient may start to return to his regular footwear. In the absence of radiographic bony fusion at six weeks, the patient may be converted to a walker boot but kept non-weightbearing till there is clinical and radiographic evidence of fusion, or till the patient fulfills the criteria for nonunion (usually at 6 to 8 months) and requires a revision procedure.

In the authors' preference, patients are kept non-weightbearing in a splint in neutral position for 5–7 days.

Range of motion exercises and isometric muscle contractions are carried out beginning the 2nd postoperative day. If the patients are reliable, they are mobilized with partial weightbearing of 20 kg (i. e. the weight of the leg on the ground without pressure) in a removable boot / walker which is only taken off for foot care. Gradual transition to full weight-bearing is initiated upon radiographic union at 6–12 weeks postoperatively.

A systematic review of Potter et al. included 60 studies to compare the outcome of different postoperative regimens to determine the evidence for weightbearing following ankle arthrodesis. Patients were divided into four groups based on duration of non-weightbearing postoperatively (group A: 0–1 weeks, group B: 2–3 weeks, group C: 4–5 weeks, group D: >6 weeks). Immobilization methods included casts, boots, splints and braces. The authors concluded that outcomes following ankle arthrodesis appeared to be similar regardless of the duration of postoperative non-weightbearing. Union rate was comparable in all groups (group A: 93.2%, group B: 95.5%, group C 93%, group D: 93%). The shortest time to union was seen in the group with the shortest non weight-bearing (group A: 10.4 weeks, group B: 14.5 weeks, group C 12.4 weeks, group D: 14.4 weeks). The authors assumed that early weightbearing may promote a faster union as micromovements in transverse plane between adjacent bone surfaces stimulate bone formation. However, a formal meta-analysis with statistical outcomes is difficult because of heterogeneity between the groups and reviewed studies (64).

RESULTS AND COMPLICATIONS

Ankle arthrodesis has been performed for more than a century and affords a predictable and reliable method to relieve the symptoms of end stage arthritis. Early reports in the literature suggested nonunion rates following ankle arthrodesis between 9 and 60% and nonunion rates between 5 and 37%, but it should be noted that most of these procedures were performed with no fixation at all, less stable fixation techniques (mostly external fixation) and without bone grafting (36, 41, 51, 54). Many of these procedures were performed on poor sur-

gical candidates including patients with deep joint infections and sensory neuropathy (1, 18, 54). More recent data from the last 20 years suggest good to excellent outcomes with union rates of between 90–99% (8, 28, 66, 84, 86). These studies employed contemporary techniques of rigid screw fixation and strived for fusion in the neutral position of the ankle, thus resulting in substantially better functional outcomes and nonunion rates between 0 and 13%. A summary of the reported results from studies published over the last 10 years is provided in Table 1.

In the largest systemic review to date, Haddad et al. in 2007 reviewed 39 papers on ankle arthrodesis totalling 1262 ankle arthrodesis procedures using a variety of techniques. Inclusion criteria were primary procedures with at least 10 patients and minimum of 2 years follow-up. The tabulated results showed 68% good to excellent outcomes and a 10% nonunion rate (28). In a prospective, comparative multicentre study, Daniel et al. compared the intermediate term results of Total Ankle Arthroplasty and Ankle Arthrodesis in a patient cohort drawn from the Canadian Orthopaedic Foot and Ankle Society Database. They reported a revision rate of 7% in the ankle arthrodesis group. This was in keeping with registry data which reported a 3–15% revision rate in ankle arthrodesis patients (11, 42).

Ankle arthroplasty has evolved as an alternative treatment option for end-stage ankle arthritis. The question whether ankle arthrodesis is equivalent or superior to ankle arthroplasty is beyond the scope of this review. It is generally agreed upon the ankle fusion and arthroplasty have overlapping indications. Several systematic reviews failed to show superiority of either procedure while ankle arthroplasty is associated with a lower rate of adjacent joint arthritis but a higher overall revision rate (39, 43, 47, 52). The decision to choose the one or the other procedure should be made on an individual patient basis.

Results of arthroscopic arthrodesis have been promising so far. They have been shown to result in significantly less morbidity, shorter surgical and tourniquet times, less blood loss, shorter length of hospital stay, faster fusion rates and better improvement of outcome scores compared with open arthrodesis for up to 2 years after surgery (23, 58, 77). It should be noted that there is a learning curve in mastering this technique and conversion to open procedure is occasionally necessary to achieve the technical outcome required.

Complications related to ankle arthrodesis include delayed wound healing, infection, neurovascular injuries, complex regional pain syndrome, venous thromboembolic events, nonunion, malunion and adjacent joint arthritis. Most early complications can be avoided with careful patient selection, recognition of high-risk patients, careful dissection and meticulous soft tissue handling. A common complication unique to arthroscopic ankle surgery is superficial peroneal nerve injury at the anterolateral portal site. This, again, may be avoided by meticulous technique during portal creation.

Coester et al. reported on 23 patients who underwent isolated ankle arthrodesis for painful post traumatic arthritis of the ankle and were followed up for a mean of 22 years (8). 84% of patients complained pain after a minimum follow up of 10 years in a study of Gaedke et al. (19). Prevalences of osteoarthritis ranged from 24–100% in subtalar joint and 18–77% in the Chopart joint. Zwipp et al. reported a prevalence of talonavicular osteoarthritis in 18% at an average of 6 years following ankle arthrodesis in a four screw technique. The subtalar, calcaneocuboid, talonavicular, tarsometatarsal, naviculocuneiform, and first metatarsophalangeal joints on the ipsilateral side all revealed a significantly increased level of osteoarthritis compared with those joints on the contralateral side. This is in keeping with the results of multiple authors who report evidence of adjacent joint disease an average of 4.4–8 years after surgery (29, 50). However, in a substantial number of patients adjacent joint arthritis will already be present at the time of fusion due to long-standing malfunction of the ankle joint with consecutive eccentric loading of the adjacent joints (72, 86). The correlation between radiological findings and functional limitation and pain remains unclear because none of the studies could show a correlation between quality of life and the radiological grade of osteoarthritis at the subtalar and the Chopart joint (19). Furthermore, it is assumed that less favourable outcomes and high rates of adjacent joint arthritis in historical and long-term studies result from fusion in malalignment in numerous cases, as has been verified in a thorough literature review (86). Several clinical studies have reported a correlation between radiographic alignment of the fused ankle and functional outcome (1, 54, 56, 74). The best position for ankle arthrodesis was neutral flexion of the foot in the sagittal plane, neutral to slight valgus (5°) in the coronal plane, and 5° to 10° external rotation in the horizontal plane with the talus centered exactly below the tibia. These recommendations from clinical outcome studies could be substantiated a wealth of studies employing further measurements like gait analyses and pressure measurements of the subtalar joint (5, 31, 68, 75, 86).

CONCLUSIONS

In conclusion, surgical techniques for arthrodesis of the ankle joint have come a long way since the first reports from the 19th century. Our understanding of the biology of bony fusion and the development of advanced surgical techniques including the advent of arthroscopic surgery have improved the clinical outcomes and reduced the complication rate of this procedure. Arthroscopy is an essential tool in the armamentarium of the modern foot and ankle surgeon. There is a growing body of literature that suggests that, in selected patients, arthroscopic ankle arthrodesis provides superior outcomes to the traditional open technique. However, regardless of surgical approach employed, it is rigid internal fixation of an optimally reduced and compressed tibio-talar joint that is key to achieving excellent outcomes in arthrodesis surgery.

References

1. Abdo RV, Wasilewski SA. Ankle Arthrodesis: a long term study. *Foot Ankle*. 1992;13:307–312.
2. Albert E. Zur Resektion des Kniegelenkes. *Wien Med Press* 1879;20:705–708.
3. Allegra F, Maffulli N, Cerza F, Delianni E. Postero–medial approach procedure in the supine position for a one step anterior and posterior ankle arthroscopy. *Sports Med Arthrosc*. 2009;17:185–189.
4. Betz MM, Benninger EE, Favre PP, Wieser KK, Vich MM, Espinosa N. Primary stability and stiffness in ankle arthrodeses—Crossed screws versus anterior plating. *Foot Ankle Surg*. 2013;19:168–172.
5. Buck P, Morrey BF, Chao EY. The optimum position of arthrodesis of the ankle. A gait study of the knee and ankle. *J Bone Joint Surg Am* 1987;69(7):1052–1062.
6. Charnley J. Compression arthrodesis of the ankle and shoulder. *J Bone Joint Surg Br*. 1951;33:180–191.
7. Clifford C, Berg S, McCann K, Hutchinson B. A biomechanical comparison of internal fixation techniques for ankle arthrodesis. *J Foot Ankle Surg*. 2015 Mar–Apr;54(2):188–91.
8. Coester LM, Saltzman CL, Leopold J, Pontarelli W. Long-term results following ankle arthrodesis for post-traumatic arthritis. *J Bone Joint Surg Am*. 2001;83:219–228.
9. Colonna PC, Ralston EL. Operative approaches to the ankle joint. *Am J Surg*. 1951;82:44.
10. Coughlin MJ, Nery C, Baumfeld D, Jastifer J. Tibiotarsal compression arthrodesis using a lateral locking plate. *Rev Bras Ortop*. 2015;47:611–615.
11. Daniels TR, Younger AS, Penner M, Wing K, Dryden PJ, Wong H, Glazebrook M. Intermediate–term results of total ankle replacement and ankle arthrodesis: a COFAS multicenter study. *J Bone Joint Surg Am*. 2014;96:135–142.
12. Dereymaeker GP, Van Eygen P, Driesen R, Ferm A De. Tibiotalar arthrodesis in the rheumatoid foot. *Clin Orthop Relat Res*. 1998;349:43–47.
13. Dohm MP, Benjamin JB, Harrison J, Szivek JA. A biomechanical evaluation of three forms of internal fixation used in ankle arthrodesis. *Foot Ankle Int* 1994;15(6):297–300.
14. Easley M, Looney C, Wellman S, Ison J. Ankle arthrodesis using ring external fixation. *Tech Foot Ankle Surg*. 2006;5:150–163.
15. Endres T, Grass R, Rammelt S, Zwipp H. Ankle arthrodesis with four cancellous lag screws. *Oper Orthop Traumatol*. 2005;17:345–360.
16. Ferguson Z, Anugraha A, Janghir N, Pillai A. Ankle arthrodesis: A long term review of the literature. *J Orthop*. 2019;16:430–433.
17. Fragomen AT, Borst E, Schachter L, Lyman S, Rozbruch SR. Complex ankle arthrodesis using the Ilizarov method yields high rate of fusion. *Clin Orthop Relat Res*. 2012;470:2864–2873.
18. Frey C, Halikus NM, Vu–Rose T, Ebramzadeh E. A review of ankle arthrodesis: predisposing factors to non-union. *Foot Ankle Int*. 1994;15:581–584.
19. Gaedke IE, Wiebking U, O'Loughlin PF, Krettek C, Gaulke R. Clinical and radiological mid- to long-term outcomes following ankle fusion. *In Vivo*. 2018;32:1463–1471.
20. Gallie WE. Arthrodesis of the ankle joint. *J Bone Joint Surg Br*. 1948;30:619–621.
21. Gharehdaghi M, Rahimi H, Mousavian A. Anterior ankle arthrodesis with molded plate: technique and outcomes. *Arch Bone Jt Surg*. 2014;2:203–209.
22. Glazebrook M, Daniels T, Younger A, Foote CJ, Penner M, Wing K, Lau J, Leighton R, Dunbar M. Comparison of health-related quality of life between patients with end-stage ankle and hip arthrosis. *J Bone Joint Surg Am*. 2008;90:499–505.
23. Glick JM, Morgan CD, Myserson MS, Sampson TG, Mann JA. Ankle arthrodesis using an arthroscopic method: Long-term follow-up of 34 cases. *Arthroscopy*. 1996;12:428–434.
24. Goetzmann T, Molé D, Jullion S, Roche O, Sirveaux F, Jacquot A. Influence of fixation with two vs. three screws on union of arthroscopic tibio–talar arthrodesis: comparative radiographic study of 111 cases. *Orthop Traumatol Surg Res*. 2016;102:651–656.
25. Goldberg AJ, Macgregor A, Dawson J, Singh D, Cullen N, Sharp RJ, Cooke PH. The demand incidence of symptomatic ankle osteoarthritis presenting to foot & ankle surgeons in the United Kingdom. *Foot (Edinb)* 2012;22:163–166.
26. Gougoulis NE, Agathangelidis FG, Parsons SW. Arthroscopic ankle arthrodesis. *Foot Ankle Int*. 2007;28:695–706.
27. Gutteck N, Lebek S, Zeh A, Gradl G, Delank KS, Wohlrab D. Ankle arthrodesis with an posterolateral approach using a polyaxial angle stable Talarlock® plate. (German) *Oper Orthop Traumatol*. 2013;25:615–623.
28. Haddad SL, Coetzee JC, Estok R, Fahrback K, Banel D, Nalysnyk L. Intermediate and long term outcomes of total ankle arthroplasty and ankle arthrodesis. A systematic review of the literature. *J Bone Joint Surg Am*. 2007;89:1899–1905.
29. Hallock H. Arthrodesis of the ankle joint for old, painful fractures. *J Bone Joint Surg Am*. 1945;27:49–58.
30. Hansen ST. Functional Reconstruction of the Foot and Ankle. Philadelphia, Lippincott, 2000;pp. 283–292.
31. Hefti FL, Baumann JU, Morscher EW. Ankle joint fusion: determination of optimal position by gait analysis. *Arch Orthop Trauma Surg*. 1980;96:187–195.
32. Henderson MS, Stuck WG. Fractures of the ankle: recent and old. *J Bone Joint Surg Am*. 1933;15:882–888.
33. Hendricks RP, Kerkhoffs GM, Stufkens SA, van Dijk CN, Marti RK. Ankle fusion using a 2-incision, 3-screw technique. *Oper Orthop Traumatol*. 2011;23:131–134.
34. Holt ES, Hansen ST, Mayo KA, Sangeorzan BJ. Ankle arthrodesis using internal screw fixation. *Clin Orthop Relat Res*. 1991;268:21–28.
35. Honnenahalli Chandrappa M, Hajibandeh S, Hajibandeh S. Ankle arthrodesis—Open versus arthroscopic: a systematic review and meta-analysis. *J Clin Orthop Trauma*. 2017;8(Suppl 2):S71–S77.
36. Johnson EW, Boseker EH. Arthrodesis of the ankle. *Arch Surg*. 1968;97:766–773.
37. Katcherian DA. Treatment of ankle arthrosis. *Clin Orthop Relat Res* 1998;349:48–57.
38. Kerkhoff YRA, Keijsers NLW, Louwerens JWK. Sports participation, functional outcome, and complications after ankle arthrodesis: midterm follow-up. *Foot Ankle Int*. 2017;38:1085–1091.
39. Kim HJ, Suh DH, Yang JH, Lee JW, Kim HJ, Ahn HS, Han SW, Choi GW. Total ankle arthroplasty versus ankle arthrodesis for the treatment of end-stage ankle arthritis: a meta-analysis of comparative studies. *Int Orthop*. 2017;41:101–109.
40. Kim JG, Ha DJ, Gwak HC, Kim CW, Kim JH, Lee SJ, Kim YJ, Lee CR, Park JH. Ankle arthrodesis: comparison of anterior approach and transfibular approach. *Clin Orthop Surg*. 2018;10:368–373.
41. Kitaoka HB, Anderson PJ, Morrey BF. Revision of ankle arthrodesis with external fixation for malunion. *J Bone Joint Surg Am*. 1992;74:1191–1198.
42. Lebek G, Klaus H, Schlichtherle R, Williams A, Agreiter M. Revision rates after total ankle arthroplasty in sample-based clinical studies and national registries. *Foot Ankle Int*. 2011;32:740–745.
43. Lawton CD, Butler BA, Dekker RG 2nd, Prescott A, Kadakia AR. Total ankle arthroplasty versus ankle arthrodesis—a comparison of outcomes over the last decade. *J Orthop Surg Res*. 2017;12:76.
44. Lee HJ, Min WK, Kim JS, Yoon SD, Kim DH. Transfibular ankle arthrodesis using burring, curettage, multiple drilling, and fixation with two retrograde screws through a single lateral incision. *J Orthop Surg (Hong Kong)*. 2016;24:101–105.
45. Leeuw PA, Hendrickx RP, van Dijk CN, Stufkens SS, Kerkhoffs GM. Midterm results of posterior arthroscopic ankle fusion. *Knee Surg Sports Traumatol Arthrosc*. 2016;24:1326–1331.
46. Lenz AL, Nichols JA, Roach KE, Foreman KB, Barg A, Saltzman CL, Anderson AE. Compensatory motion of the subtalar joint following tibiotalar arthrodesis: an in vivo dual–fluoroscopy imaging study. *J Bone Joint Surg Am*. 2020;102:600–608.
47. Li Y, He J, Hu Y. Comparison of the efficiency and safety of total ankle replacement and ankle arthrodesis in the treatment of osteoarthritis: an updated systematic review and meta-analysis. *Orthop Surg*. 2020;12:372–377. (Epub ahead of print)
48. Maenpaa H, Lehto MU, Belt EA. Why do ankle arthrodeses fail in patients with rheumatic disease? *Foot Ankle Int*. 2001;22:403–408.

49. Malerba F, Benedetti MG, Uselli FG, Milani R, Berti L, Champlon C, Leardini A. Functional and clinical assessment of two ankle arthrodesis techniques. *J Foot Ankle Surg.* 2015;54:399–405.
50. Mazur JM, Schwartz E, Simon SR. Ankle arthrodesis. Long-term follow-up with gait analysis. *J Bone Joint Surg Am.* 1979;61:964–975.
51. Moeckel BH, Patterson BM, Inglis AE, Sculco TP. Ankle arthrodesis. A comparison of internal and external fixation. *Clin Orthop Relat Res.* 1991;268:78–83.
52. Morash J, Walton DM, Glazebrook M. Ankle arthrodesis versus total ankle arthroplasty. *Foot Ankle Clin.* 2017;22:251–266.
53. Morasiewicz P, Dejneke M, Orzechowski W, Urbański W, Kulej M, Dragan SL2, Dragan SF, Pawik Ł. Clinical evaluation of ankle arthrodesis with Ilizarov fixation and internal fixation. *BMC Musculoskelet Disord.* 2019;20:167.
54. Morrey BF, Wiedemann GP. Complications and long term results of ankle arthrodesis following trauma. *J Bone Joint Surg Am.* 1980;62:777–784.
55. Myerson MS, Quill G. Ankle arthrodesis: a comparison of an arthroscopic and an open method of treatment. *Clin Orthop* 1991;268:85–95.
56. Nasson S, Shuff C, Palmer D, Owen J, Wayne J, Carr J, Adelaar R, May D. Biomechanical comparison of ankle arthrodesis techniques: crossed screws vs. blade plate. *Foot Ankle Int.* 2001;22:575–580.
57. Nielsen LL, Linde F, Jensen NC. The outcome of arthroscopic and open surgery ankle arthrodesis: a comparative retrospective study on 107 patients. *Foot Ankle Surg.* 2008;14:153–157.
58. O'Brien TS, Hart TS, Shereff MJ, Stone J, Johnson J. Open versus arthroscopic ankle arthrodesis: A comparative study. *Foot Ankle Int.* 1999;20:368–374.
59. Ogilvie-Harris DJ, Fitsialis D, Hedman TP. Arthrodesis of the ankle: A comparison of two versus three screw fixation in a crossed configuration. *Clin Orthop Relat Res.* 1994;304:195–199.
60. Pedowitz DI, Kane JM, Smith GM, Saffel HL, Comer C, Raikin SM. Total ankle arthroplasty versus ankle arthrodesis: a comparative analysis of arc of movement and functional outcomes. *Bone Joint J.* 2016;98-B:634–640.
61. Peterson KS, Lee MS, Buddecke DE. Arthroscopic versus open ankle arthrodesis: a retrospective cost analysis. *J Foot Ankle Surg.* 2010;49:242–247.
62. Peyron JG. The epidemiology of osteoarthritis. In: Moskowitz R, Howell D, Goldberg V, Mankin H (eds). *Osteoarthritis. Diagnosis and treatment.* Saunders, Philadelphia, 1984, pp 9–27.
63. Plaass C, Knupp M, Barg A, Hintermann B. Anterior double plating for rigid fixation of isolated tibiotalar arthrodesis. *Foot Ankle Int.* 2009;30: 631–639.
64. Potter MJ, Freeman R. Postoperative weightbearing following ankle arthrodesis – a systematic review. *Bone Joint J.* 2019;101-B:1256–1262.
65. Quayle J, Shafafy R, Khan MA, Ghosh K, Sakellariou A, Gougoulas N. Arthroscopic versus open ankle arthrodesis. *Foot Ankle Surg.* 2018;24:137–142.
66. Raikin SM, Rampuri V. An approach to the failed ankle arthrodesis. *Foot Ankle Clin.* 2008;13:401–416.
67. Raikin SM. Arthrodesis of the ankle: arthroscopic, mini-open and open techniques. *Foot Ankle Clin.* 2003;8:347–359.
68. Rammelt S, Zwipp H, Hansen ST. Posttraumatic reconstruction of the foot and ankle. In: Browner BD, Jupiter JB, Krettek C, Anderson PA (eds.). *Skeletal trauma, 6th Edition,* Elsevier Saunders, Philadelphia, 2019, pp 2641–2690.
69. Saltzman CL, Kadoko RG, Suh JS. Treatment of isolated ankle osteoarthritis with arthrodesis or the total ankle replacement: a comparison of early outcomes. *Clin Orthop Surg.* 2010;2:1–7.
70. Saltzman CL, Salamon ML, Blanchard GM, Huff T, Hayes A, Buckwalter JA, Amendola A. Epidemiology of ankle arthritis: report of a consecutive series of 639 patients from a tertiary orthopaedic center. *Iowa Orthop J.* 2005;25:44–46.
71. Schmid T, Krause F, Penner MJ, Veljkovic A, Younger ASE, Wing K. Effect of preoperative deformity on arthroscopic and open ankle fusion outcomes. *Foot Ankle Int.* 2017;38:1301–1310.
72. Sheridan BD, Robinson DE, Hubble MJ, Winson IG. Ankle arthrodesis and its relationship to ipsilateral arthritis of the hind- and mid-foot. *J Bone Joint Surg Br.* 2006;88:206–207.
73. Steginsky BD, Suhling ML, Vora AM. Ankle arthrodesis with anterior plate fixation in patients at high risk for nonunion. *Foot Ankle Spec.* 2020;13:211–218.
74. Takakura Y, Tanaka Y, Sugimoto K, Akiyama K, Tamai S. Long-term results of arthrodesis for osteoarthritis of the ankle. *Clin Orthop Relat Res.* 1999;361:178–185.
75. Thomas R, Daniels TR, Parker K. Gait analysis and functional outcomes following ankle arthrodesis for isolated ankle arthritis. *J Bone Joint Surg Am.* 2006;88:526–535.
76. Thordarson DB, Markolf K, Cracchiolo A. Stability of an ankle arthrodesis fixed by cancellous-bone screws compared with that fixed by an external fixator. A biomechanical study. *J Bone Joint Surg Am.* 1992;74:1050–1055.
77. Townshend D, Di Silvestro M, Krause F, Penner M, Younger A, Glazebrook M, Wing K. Arthroscopic versus open ankle arthrodesis: A multicenter comparative case series. *J Bone Joint Surg Am.* 2013;95:98–102.
78. Valderrabano V, Horisberger M, Russell I, Dougall H, Hintermann B. Etiology of ankle osteoarthritis. *Clin Orthop Relat Res.* 2009;467:1800–1806.
79. Wheeler J, Sangeorzan A, Crass SM, Sangeorzan BJ, Benirschke SK, Hansen ST. Locally generated bone slurry accelerated ankle arthrodesis. *Foot Ankle Int.* 2009;30:686–689.
80. Williams JE Jr, Marcinko DE, Lazerson A, Elleby DH. The Calandruccio triangular compression device: a schematic introduction. *J Am Podiatr Assoc.* 1983;73:536–539.
81. Woo BJ, Lai MC, Ng S, Rikhray IS, Koo K. Clinical outcomes comparing arthroscopic vs open ankle arthrodesis. *Foot Ankle Surg.* 2019;26:530–534.
82. Yajima H, Kobata Y, Tomita Y, Kawate K, Sugimoto K, Takakura Y. Ankle and pantalar arthrodesis using vascularized fibula grafts. *Foot Ankle Int.* 2004;25:3–7.
83. Zvijac JE, Lemak L, Schurhoff MR, Hechtman KS, Uribe JW. Analysis of arthroscopically assisted ankle arthrodesis. *Arthroscopy.* 2002;18:70–75.
84. Zwipp H. Arthrodesis of the Ankle. *Acta Chir Orthop Traumatol Cech.* 2017;84:13–23.
85. Zwipp H, Grass R, Rammelt S, Dahlen C. [Arthrodesis—non-union of the ankle. Arthrodesis failed] (in German). *Chirurg.* 1999;70:1216–1224.
86. Zwipp H, Rammelt S, Endres T, Heineck J. High union rates and function scores at midterm followup with ankle arthrodesis using a four screw technique. *Clin Orthop Relat Res.* 2010;468:958–968.

Corresponding author:

Stefan Rammelt, MD, PhD
 Professor, Head of the Foot & Ankle Section
 University Center of Orthopaedics & Traumatology
 University Hospital Carl Gustav Carus
 Fetscherstrasse 74
 01307 Dresden, Germany
 E-mail: stefan.rammelt@uniklinikum-dresden.de