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REVIEW ARTICLE

Treatment of ankle osteoarthritis: arthrodesis versus total ankle replacement

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Abstract While ankle arthrodesis has remained the gold standard treatment for symptomatic primary, secondary, and posttraumatic ankle arthritis, more recently, total ankle replacement (TAR) has seen considerable improvement in terms of biomechanics, function, and complication rates. However, while in the long-term degeneration of the adjacent joints is almost always found on radiographs after ankle arthrodesis, the longevity of TAR is still insufficient and does not match that of total knee and hip joints. The current review article focuses on the treatment of ankle arthritis by means of arthrodesis and TAR.

Keywords Osteoarthritis · Ankle arthrodesis · Total replacement

Introduction

Longstanding symptomatic ankle arthrosis can be very debilitating. Treatment modalities encompass both conservative and surgical measures. Conservative treatment includes medication, bracing, orthotic management, shoe modifications, and intraarticular application of steroids [1, 2]. Once conservative measures have failed, surgery should be considered. Established surgical strategies involve simple debridement, corrective osteotomies, arthrodesis, and total ankle replacement (TAR). While the use of supramalleolar osteotomy for the treatment of asymmetric ankle arthritis has been shown to be a viable treatment, especially for asymmetric osteoarthritis of the ankle [3–7], arthrodesis and TAR have become the most important surgical treatment strategies. Ankle distraction arthroplasty [8–10] and allograft TAR [11] have been investigated, but the insufficient data and high failure rates of these procedures preclude their use as treatment in the first line.

Since its first description more than 100 years ago, ankle arthrodesis has become the so-called gold standard to treat symptomatic arthritic ankle disease. Current techniques of arthrodesis provide good short- to long-term outcomes. However, more recently, the reliability of long-term outcomes after ankle arthrodesis has been questioned. In addition, a more profound understanding of ankle biomechanics has led to the development of modern TAR designs, which, in turn, challenge the idea that arthrodesis is the treatment of choice.

Epidemiology and pathophysiology of ankle osteoarthritis

The true prevalence of ankle arthritis is still difficult to determine and, to date, no clear information exists, except of rough extrapolations [12]. Based on reports from clinical practice, the prevalence of symptomatic degenerative ankle disease is assumed to be nine times lower than that at the knee or hip [12–14]. More recently, Valderrabano et al. [15] found, in 78% of cases, trauma to be the main cause for ankle osteoarthritis. Among them, malleolar fractures are the predominantly found cause, followed by chronic ankle instability. Similar values were previously reported by Saltzman et al. and Brown et al. [12, 16]. Secondary osteoarthritis as a sequel of rheumatoid arthritis, hemochromatosis, residual clubfoot deformity, avascular necrosis of the

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talus, osteochondral lesions, and postinfectious conditions account for approximately 13% of cases. Primary osteoarthritis occurs only in 7–9% [16, 17].

General biomechanical and biologic aspects of the ankle joint

The exact biological mechanisms of cartilage degeneration continue to be a subject of constant research. It is known and resembles logic that, in degenerative disease, the biochemical and biomechanical nature of the osteoarthritic articular cartilage is altered [17]. It begins with deterioration of the articular cartilage secondary to progressive destruction of the collagen network and loss of cartilage molecules, including proteoglycans. At an ultrastructural level, the cartilage becomes altered and the mechanical properties weakened [18]. In an attempt to repair the damage to the cartilaginous surface, chondrocytes start to dedifferentiate and begin to produce inappropriate matrix molecules (catabolic cytokines and matrix proteases), which lead to further degradation of the cartilage [19, 20]. Additionally, the subchondral bone becomes dense. Radiographically, subchondral sclerosis suggests increased bone density. It remains unclear whether these subchondral changes are the result of alterations in the articular cartilage itself or whether they are the vehicles for such changes [21–23].

The ankle joint is a highly constrained articulation which is comprised of three important bones (tibia, talus, and fibula) that provide stability, together with the tendons, ligaments, and syndesmoses [24, 25]. Tendons and ligaments provide dynamic stabilization and control of the joint. The greatest tibiotalar and tibiofibular contact is achieved during mid-stance-phase and averages 7 cm^2 [26]. The coronary tibiotalar angulation averages 93° and is important to know when considering reconstructive surgery at the ankle. Under weight-bearing conditions, the congruency of bones provides 100% of stability for eversion and inversion, but only 30% of rotational stability [27, 28]. The ligamentous complexes predominantly control rotatory stability and antero-posterior tibiotalar shifting. The strongest part of the tibial plafond is found posteromedially. However, depending on the amount of subchondral bone resection, the compressive resistance of the bone could be reduced by 30–50% [26]. A resection of the distal tibia by 1 cm reduces the compressive resistance by 90%. The role of bony and ligamentous stabilizers of the ankle and subtalar joints depends on the load and position of the foot and ankle in space. They provide proprioception, stabilization, and limitation of non-physiologic motion about the lateral ankle [28].

Motion at the ankle is multiplanar and linked to the tibia. The complex and dynamic configuration of the rotational axis of the ankle joint might be responsible for some implant failures at the ankle. Several studies, using different types of methodology, tried to identify the direction of axis, all of them confirming a shift of the instant center of rotation from posterior inferior to anterior superior [25, 29, 30]. It is important to realize that the ankle joint is not a simple hinge joint and this fact should be kept in mind when designing future TAR. The course of movement within the ankle joint is predominantly from plantarflexion (range 23°–56°) to dorsiflexion (range 13°–33°), but contains mild degrees of internal (1.9 ± 4.12°) and external rotation (7.2 ± 3.8°) [31–38]. For normal gait, an average dorsiflexion of 10° and plantarflexion of 15° is needed. In contrast to the ankle joint, the subtalar joint follows more complex kinematics. The calcaneus rotates around the interosseous ligament, resulting in a screw-like motion associated with translation and rotation. According to Inman et al. [38–41], motion at the subtalar joint is triplanar, comprised of inversion (calcaneus turns inward) and eversion (calcaneus turns outward). As stated by Hintermann and Nigg [32], inversion is accompanied by a mandatory external rotation of the leg. In the intact hindfoot, this rotation takes place at the subtalar joint, whereas in the injured ankle joint without stabilizing ligaments, this rotation is happening at the ankle joint [42, 43].

Pathophysiology

The infrequency of primary osteoarthritis of the ankle might be the result of the high congruency, stability, and constrained nature of the ankle joint. In addition, tensile properties and metabolic characteristics or both could contribute to the resilience of the articular cartilage. It has been found that a highly congruent joint has a very thin cartilage surface [44]. The thin articular cartilage, in turn, and the relatively small contact area result in high peak contact stresses, making the cartilage more susceptible to posttraumatic osteoarthritis [20, 45]. In particular, the thinner and stiffer articular cartilage of the ankle may be less able to adapt to articular surface incongruity and increased contact stresses than the thicker articular cartilage of the hip or knee.

As a sequel to injury and damage of the articular cartilage and subchondral bone, the articular surface creates incongruencies [46]. As a result, joint stability is impaired. It is very likely that posttraumatic ankle osteoarthritis results from elevated contact stresses that exceed beyond the capacity of the joint to repair itself or adapt. In secondary osteoarthritis like neuropathies or necrosis of the talus, also, an incongruity of the articular surface is caused.

The reason for this is found in a loss of proprioception and protective sensation that leads to undetected ligamentous or articular surface injuries that create localized regions of increased contact stress. Progressive joint degeneration and destruction occurs.

Interestingly, in practice, there are patients who develop progressive joint degeneration without apparent articular surface damage, alteration of joint anatomy, or instability. In contrast, there are patients with articular surface incongruity or joint instability that do not develop progressive joint degeneration. Thus, the pathogenesis of ankle osteoarthritis is more complex than it appears, but, also, the treatment strategies must be individually tailored based on pathology and patient needs.

Ankle arthrodesis

The first description of ankle arthrodesis is attributed to Albert in 1879, who reported on the fusion of both knees and ankles in a 14-year-old boy suffering from severe palsy of the lower extremity due to poliomyelitis. The use of ankle arthrodesis as a treatment for posttraumatic osteoarthritis began in the 1930s. The classic ankle fusion was done by removal of the degenerated bone and interposition of cancellous bone, which was then followed by long-term cast immobilization. Charnley [47] introduced the concept of axial compression along the arthrodesis zone, resulting in direct fusion of vital bones without the need of a graft. As a result, the fusion rates were improved. Based on promising results by means of external fixation to achieve arthrodesis of the knee, he continued to use the technique to fuse the ankle in a series of 19 cases. Failure was found in four patients.

Adequate fusion rates are obtained by creating large contact areas of well vascularized bone surfaces, which are rigidly fixed, thus, minimizing shear forces at the fusion site. Larger approaches facilitate exposure and the achievement of adequate bone congruency, as well as easier handling of the fixation. However, aggressive soft tissue and periosteal stripping may compromise local bone perfusion [48]. This has been shown to be relevant when using the transfibular approach. Furthermore, extensile approaches carry a higher risk of impaired wound healing, infection, or injury to the neurovascular structures. Nevertheless, exposition of the site needs to be sufficient in order to correct any misalignment and to position the joint into the desired plantigrade orientation. No surgical technique can be considered as the "best" procedure. The choice of technique for ankle arthrodesis depends on the surgeon's preference and experience, and should properly fit with the patient's needs. The choice also depends on the morphology of the ankle to be fused (amount of misalignment, available bone stock, and quality), the soft tissue conditions (perfusion, prior surgical approaches), the presence of any neural damage, and additional risk factors for non-union or other complications (history of open fracture, infection, evidence of avascular necrosis, immunodepressive disease including diabetes, alcohol, drug, or nicotine abuse, and, maybe, expected compromise through soft tissue tension after the correction of severe hindfoot deformity).

Indications for ankle arthrodesis include:

- Posttraumatic or idiopathic ankle arthritis
- Posttraumatic misalignment of the ankle
- Chronic instability associated with ankle arthritis
- Misalignment due to paralysis
- Postinfectious joint destruction
- Secondary ankle arthritis
- Failed TAR

Contraindications for ankle arthrodesis include:

- Poor soft tissue conditions or coverage
- Acute purulent infection
- Total avascular necrosis of the talus
- Severe peripheral arterial occlusive disease

The following sections discuss the surgical techniques for an isolated fusion of the ankle which we favor for different degrees of complexity.

Arthroscopically assisted or mini-open approaches

In case of minimal deformity, a mini-open or arthroscopically assisted procedure by means of percutaneous screw fixation can be considered [49, 50]. Due to the technical difficulty and learning curve of arthroscopic approaches, we prefer a mini-open approach as described by Miller et al. and Paremain et al. [48, 49] (Fig. 1). The advantages of the procedure consist of minimizing morbiditiy, including wound dehiscence, wound infection, or neural damage, along with only minor disruption of bone perfusion at the fusion site. In contrast to arthroscopic techniques, the preparation of articular surfaces is not performed with a burr, thus, limiting thermal necrosis. The major disadvantage of the mini-open technique is impaired visualization of the posterior part of the ankle. Arthroscopic procedures have been shown to achieve fusion rates between 89 and 100% [50–52], while the mini-open technique shows rates ranging from 97 to 100% [48, 49].

Open anterior screw arthrodesis

When better visualization of the ankle joint surfaces is needed, as, for example, in cases with greater ankle deformity or anterior subluxation of the talus, an open approach is preferable. It is necessary to obtain an

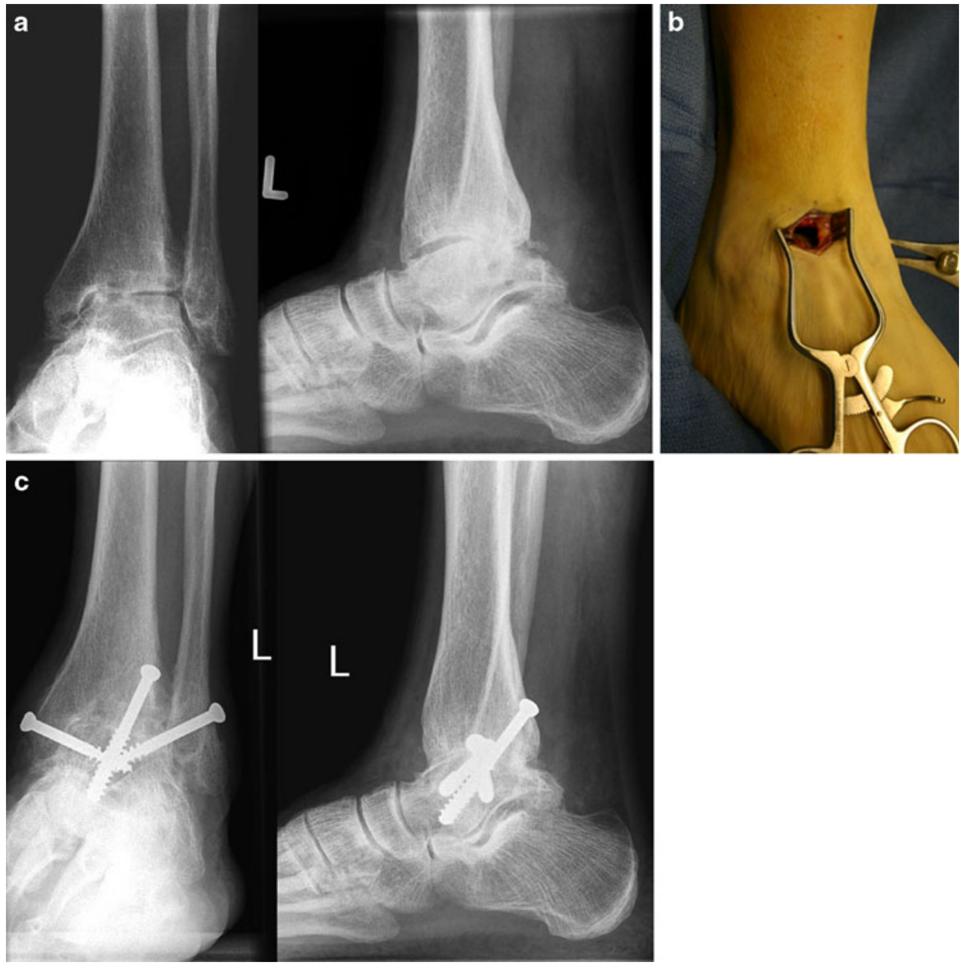

Fig. 1 Depicted are images of a patient who has been treated by means of the mini-arthrotomy ankle fusion technique. **a** The preoperative radiographs of the ankle joint. **b** The ankle joint is approached through mini-incisions anteriomedially and anterolaterally. **c** The postoperative radiographs of the same patient 1 year after arthrodesis

anatomic reduction in order to correct the length of the lever arm of the hindfoot. For this purpose, we use the technique as described by Grass and Zwipp in 1998 [53] (Fig. 2). Using this technique, Zwipp et al. [54] reported of minor complications, with 5% of wound dehiscence or wound edge necrosis and 3% of postoperative hematoma requiring single drainage. Fusion rates were as high as 99%.

Surgical technique

An 8-cm longitudinal anterior approach medial to the anterior tibial tendon is performed while protecting the anterior tibial vessels and deep peroneal nerve. The joint surfaces are debrided from the remnant cartilage. Depending on a need for the correction of a defect or in order to avoid excessive limb shortening, an autologous graft could be interposed. Persistent equinus of more than 10° is addressed by percutaneous or open Achilles tendon lengthening. The fixation is achieved with four lag screws. The first two are placed parallel from the anterior aspect of the tibia distally angulated 70–80° posteriorly into the talar body. This mode of screw placement makes use of the principle of tension banding together with the Achilles tendon. A third, mechanically important, screw is inserted through a separate small skin incision from the posterior aspect of the medial malleolus and driven anteriorly into the talar head. A forth screw is placed from the lateral malleolus into the talar body.

Anterior plate arthrodesis

In the presence of significant talar bone loss, often associated with poor bone quality, as, for example, in the setting of salvage of a failed TAR or correction of severe deformity, screw fixation is unlikely to provide sufficient primary stability to achieve adequate bony fusion. Therefore, more stable constructs have been introduced using plate fixations [55–58]. We use an anterior double-plating system (Tibiaxys^{TM}, Integra, Plainsboro, NJ/Newdeal, Lyon, France) developed to increase primary stability and compression between the tibia and the talus (Fig. 3). One major advantage of anterior double-plating is the use of the tension band mechanism through the Achilles tendon while

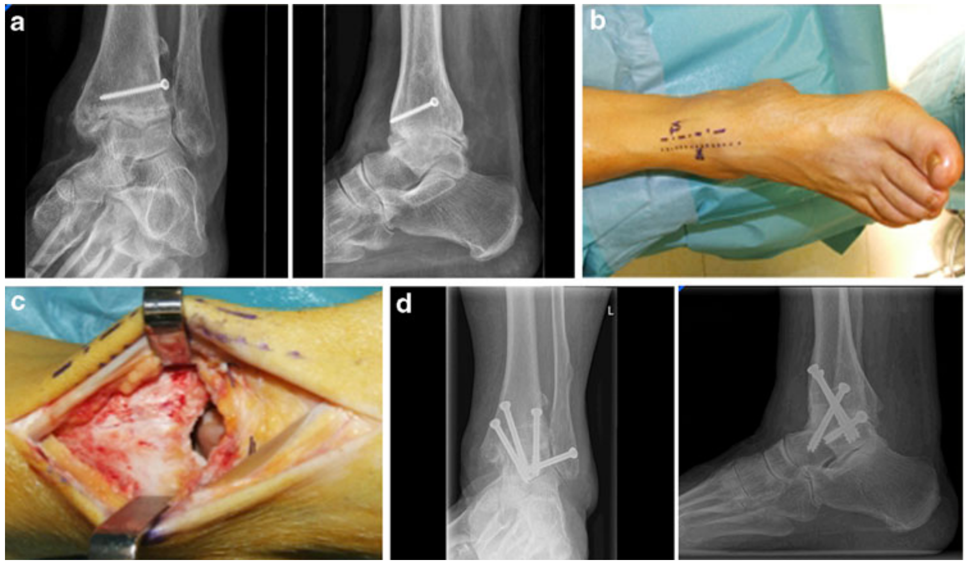

Fig. 2 **a** Illustrated are the preoperative radiographs of an obese female patient some years after initial trauma. Note the progressed arthritis of the ankle joint. **b** The ankle joint is approached through an anterior incision. **c** The skin is opened and the joint accessed. Note the larger anterior osteophytes. The joint is then debrided and prepared for fusion. **d** The postoperative radiographs of the same patient 1 year after fusion

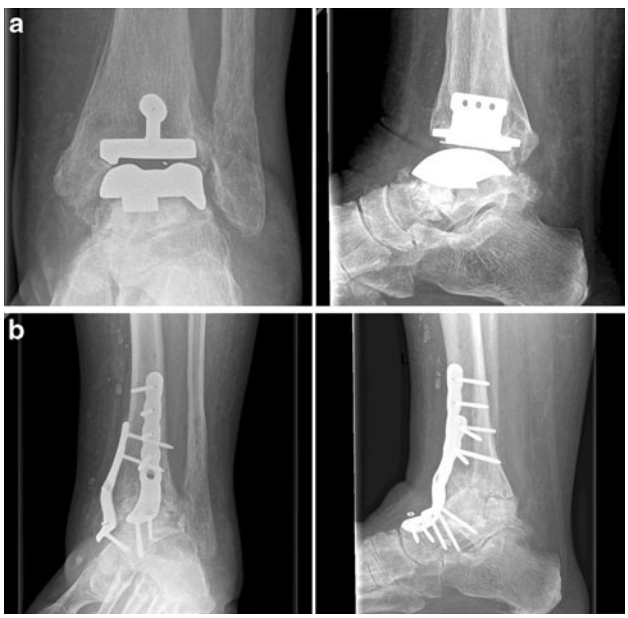

Fig. 3 **a** The preoperative radiographs of an elderly female patient who has been treated by total ankle replacement (TAR). Shortly after implantation, the patient complained about pain. Several further interventions followed the initial procedure in order to halt failure. However, failure could not be prevented. Thus, she was considered to be converted to ankle fusion. **b** Fusion was achieved by explantation of all components, subsequent filling of the bone defect by means of an allograft, and iliac crest autograft and fixation through anterior double-plating. The images present the same patient 8 months after surgery

avoiding massive insertions of larger screws into the talar body. The contact surfaces are increased, ensuring better fusion. In the series published by Plaass et al. [55], bony fusion was achieved in all of 29 patients, including 16 ankles with osteoarthritis and poor bone quality, four patients with non-union of an ankle arthrodesis, and nine failed ankle arthroplasties. Minor complications were seen in only two patients.

Surgical technique

Similar to the four-screw arthrodesis described above, an anterior longitudinal approach is used. Preparation of bony surfaces is performed and, after having reached the desired plantigrade position, temporary K-wire fixation is done. The lateral plate is fixed first to the talar head and neck using multiplanar interlocking screws. Maximal compression of the arthrodesis site can now be achieved with a compression device and a monocortical tibial screw after removal of the K-wire. With the insertion of interlocking screws, the plate pushes the talus against the medial malleolus. The second plate is then fixed anteriomedially in an angle of approximately 70° to the lateral plate onto the tibia and the talus. Completion is achieved after the placement of an oblique screw through each of the two plates to reach the posterior aspect of the talus under fluoroscopic control.

External ring fixator arthrodesis

Charcot neuroarthropathy represents a complex clinical situation where ordinary screw fixation might not be sufficient to achieve fusion. Similar complex conditions can be encountered after septic arthritis of the ankle joint or when trying to salvage the hindfoot after failed prior surgery. Surgical strategies deal with severe misalignment, poor bone stock, and critical soft tissue conditions and/or poor perfusion. Ogut et al. [59] were able to show in a cadaver study that, in the context of suboptimal bone quality or complex ankle pathology, an external ring fixation can reach similar primary stability as screw fixation. The advantage of external fixation is the potential of secondary adjustment of alignment and joint compression after the initial surgery. External ring fixation needs precise care during the postoperative period and might be time-consuming for the surgeon. Drawbacks are the high rates of pin track infections and poor patient comfort, but in these complicated situations, viable limb-saving alternatives are scarce. Reports on the outcomes of the Ilizarov ring or comparable external fixation techniques for ankle fusion are rare, with the ones available accounting for fusion rates between 80 and 100% [60–65].

TAR

Lord and Marotte in 1970 were first to implant an unconstrained cemented artificial ankle joint and were followed by other authors who used different types of implants [26, 66]. However, highly constrained designs and cemented fixation resulted in high shear stresses along the bone–cement–implant surfaces with poor osseous integration. Because of the high failure rates of first-generation implants, TAR was almost abandoned. Recently, a more profound understanding of ankle biomechanics and design of TAR has led to the evolution of second- and third-generation prostheses, which show promising mid- and long-term results. During normal gait, the ankle joint is loaded with a force of approximately six times body weight. In a degenerated ankle joint, this force is reduced down to three times body weight. However, it is assumed that, when TAR is considered, the strength of bone should be at least three times higher than that under normal conditions to compensate for the forces exerted under higher performance activities in order to avoid any subsidence of the components [67]. Thus, proper fixation techniques are needed. Besides this, the polyethylene should be preserved as long as possible in order to avoid premature wear. Polyethylene wear depends on geometry, strength (ultrastructure), and alignment of the components [68]. There is no information about the adequate thickness of polyethylene that should be used in TAR. The optimal polyethylene should be thin and strong, without the risk of impairing bony strength at the bone–implant–interface. In general, an adequate prosthesis should be shaped as anatomically as possible and mimic the kinetics and kinematics of a normal joint in order to minimize the risk of early failure [69, 70]. For this purpose, a TAR should maximize conformity and optimize constraint. The high conformity of bearing surfaces avoids peak pressures and wear [71]. In contrast, an artificial ankle joint needs sufficient constraint in order to provide enough stability but without increasing shear stresses at the bone–implant interface. Contemporary three-component TAR designs are more anatomical, with improved biomechanical performance and use biologic integration of the components. The surfaces are covered with calcium-hydroxyapatite, and sometimes combined with porous coating of the component. The advantages of an anatomic design and biologic cementless fixation include: less extensive resections of the tibia and the talus, smaller sizes of implants, reduction of body wear, avoidance of heat destruction of the soft tissues and bones. Those advantages provide the possibility of revision TAR, but, also, easier conversion into ankle arthrodesis after failed primary total ankle arthroplasty.

General requirements and indications for TAR include [27]:

- Primary osteoarthritis, secondary osteoarthritis, and posttraumatic osteoarthrosis
- Adequate bone quality, ligamentous stability
- Proper vascular status and immunological conditions
- Well-aligned hindfoot with sufficient preoperative range of motion

Relative contraindications comprise:

- Status after major trauma (open ankle fractures, fracture dislocations of the talus, segmental bony defects)
- Eradicated infection
- Avascular necrosis of the talus (25–50% involvement)
- Severe osteopenia or osteoporosis
- Longstanding steroid treatment (either systemic or local)
- Diabetes mellitus
- Moderate physical demands

Absolute contraindications include:

- Neuropathic feet
- Active joint infections
- Major avascular necrosis of the talus (>50% involvement)
- Severe hypermobility of the joints and hyperlaxity
- Periarticular compromise of the soft tissues
- High physical demands

Comparison of results after ankle arthrodesis and TAR

The different demographics, indications, and patient-based characteristics between patients who undergo ankle arthrodesis and those who undergo total ankle arthroplasty make a direct comparison impossible. However, it might be useful to review some essential and recent literature to identify the results achieved with either technique. Only a few studies have attempted to directly compare total ankle arthroplasty with ankle arthrodesis. Most articles compare revision rates, functional outcomes, and biomechanical alterations and radiographic changes of adjacent joints of each of the procedures and try to draw conclusions regarding their effectiveness.

Among all complications regarding ankle arthrodesis, non-union and adjacent joint arthritis are the most dominant. The latter is thought to be less frequently occurring after TAR. Current techniques of ankle arthrodesis and the supplementary use of stimulating growth factors achieve fusion of up to 100% [72]. However, SooHoo et al. [73] calculated the raw revision rate to be 11% in ankle arthrodesis. Although it has been shown that successful unilateral fusion of the ankle in a plantigrade position yields high patient satisfaction and an acceptable functional outcome, there is no question that the sacrifice of the ankle joint will lead to altered hindfoot mechanics. In order to compensate for the loss of ankle mobility, a hypermobility in dorsalextension and plantarflexion of the Chopart joint of up to 21° occurs [74]. Due to the abnormal mechanical loading in the other joints, osteoarthritis as a long-term sequel will occur. Gait analysis reveals significant decreases of sagittal, coronal, and transverse motion at the hindfoot and forefoot after ankle arthrodesis during stance and swing phase [75–78]. In addition, cadence and stride length are decreased. An important work by Valderrabano et al. [75–77] showed that the range of motion is closely replicated to normal joint conditions by TAR and that ankle arthrodesis reduces the range of motion substantially in all three planes. In conclusion, the reduction of the range of motion in ankle arthrodesis increases stress in adjacent structures. While there are no substantial differences of adjacent joint arthritis among patients with TAR and ankle arthrodesis in the short term, long-term outcomes after arthrodesis have been questioned based on the fact that progressive degeneration of the adjacent joints (especially of the talonavicular and subtalar joint) will ultimately occur. According to Coester et al. [79], the rates of adjacent joint arthritis have been reported to reach values of up to 91% after a mean follow-up time of 22 years (range 12–24). However, although adjacent joint arthritides in patients are almost always evident on long-term radiographs, this does not necessarily mean that they imperatively need subsequent fusion. SooHoo et al. [73] found a significantly lower rate of subtalar fusion in patients with TAR (0.7%) after 5 years when compared with ankle arthrodesis (2.3%). This could support the assumption that the more the range of motion at the ankle is preserved, as, for example, after TAR, the more protected the subtalar joint. However, the raw subtalar fusion rate 5 years after ankle arthrodesis still remains low. No significant differences in the risk of triple arthrodesis or tarsometatarsal fusion were found between both arthrodesis and TAR. Midtarsal fusion as a sequel to surgery was only found in patients who underwent ankle arthrodesis. Even though high rates of satisfaction after ankle arthrodesis have been reported in the literature, patients must be aware of the potential complications and the probable need of prolonged immobilization or revision surgery. Furthermore, preoperative information of possible limb-shortening and need for modified orthopedic shoewear is mandatory.

In a meta-analysis evaluating intermediate and long-term clinical outcomes after TAR and ankle arthrodesis, Haddad et al. [80] reported on good to excellent outcomes in 78% for the former and 73% for the latter group. More recently, in a retrospective 2–6 years follow-up study performed by Saltzman et al. [81], the overall outcome after TAR (i.e., SF-36 and AOS disability scale) was found to be superior in the TAR group when compared to those in the arthrodesis group. The reason for this difference was attributed to the fact that patients who had had an ankle arthrodesis were suffering from posttraumatic rather than degenerative ankle arthritis.

One major drawback of TAR is the low survival rate and the higher failure and revision rates. Raw revision rates have been reported to average 23% after 5 years for TAR [73]. Although there are studies on the long-term survival rates after TAR, they have mainly been done by the inventors of specific designs. For example, Knecht et al. [82] found a 10-year survival rate of 85% for the Agility implant. Buechel et al. [83] reported a 12-year survival rate of 92% for the Buechel–Pappas design and Kofoed reported a 12-year survival rate of 95% for the uncemented STAR design [84]. However, these data should be interpreted with caution. Fevang et al. evaluated the 5- and 10-year-survival rates based on the Norwegian Joint Registry. They found a 5-year survival rate of 89% and the 10-year survival rate was 76% [85]. Almost half of the patients suffered from rheumatoid arthritis. An independent and more objective study performed by Henricson et al. [86] assessed the mid- and long-term survival and complication rates among different TAR designs based on data retrieved from the Swedish Ankle Arthroplasty Register. They found a lower overall 5-year survival rate of 78% and a 10-year survival rate of 62%. Stratification according to the underlying pathology revealed that patients with rheumatoid arthritis had a higher 5-year survival rate (82%) than those with idiopathic (80%) or posttraumatic arthritis (70%). Their results are in contrast to others who reported 5-year survival rates of up to 94% [87, 88]. One of the discussed reasons for the fewer good results in patients with posttraumatic arthritis is that, besides osseous and cartilaginous lesions, the traumatic injury induces alterations of the soft tissues (i.e., scarring), resulting in decreased elasticity. The most frequent reason for failed total ankle arthroplasty is aseptic loosening followed by

Table 1 The table lists a group of total ankle replacement (TAR) designs that are frequently used in the United States, Europe, and Asia (modified after Hintermann [26])

Authors	TAR	*n*	PTA (%)	PRA (%)	SA (%)	Follow-up	Satisfaction (%)	Loosening (%)	Revision (%)
Hintermann et al. [93]	HINTEGRA	122	75	13	12	28	84	2	7
Valderrabano et al. [99]	STAR®	68	71	13	16	44	97	13	34
Knecht et al. [82]	AGILITY™	132	46	29	25	108	90	76	35
Tanaka and Takakura [100]	TNK 3^{d} G	70	39	0	31	63	71	24	4
Bonnin et al. [101]	Salto	98	69	0	29	35	n.a.	2	6
Buechel et al. [102]	Buechel–Pappas	75	73	5	12	60	88	11	6
Wood et al. [94]	MOBILITY™	100	73	0	27	43	97	n.a.	5

technical errors, instability, and infection [89]. Gougoulias et al. [90] performed a systematic literature research regarding TAR. They considered revision, arthrodesis, or amputations as the endpoints of their study and calculated the failure rate to be 9.8%. Amputations, however, were very rare procedures. The overall rate for superficial infections averaged 8% and that for deep infections averaged 0.8%.

While the results of cemented and uncemented first-generation TAR designs were limited and disappointing, contemporary anatomic and biomechanically sound third-generation three-component designs with menisceal bearing show promising results (Table 1). Espinosa et al. [91] performed a biomechanical study and finite-element-model analysis and found a better tolerance of a congruent mobile bearing design with regard to misalignment and more even pressure distribution within the ankle joint when compared to a two-component design with fixed bearing. Valderrabano et al. [75–77] were able to show that a more anatomical design of TAR better replicates normal ankle joint range of motion. Recently published short- and mid-term data of the HINTEGRA® (Newdeal SA, Lyon, France), a highly anatomical design, showed revision rates of about 7% [92, 93] (Fig. 4). This rate is far below the 23% revision rate as identified by SooHoo et al. [73] and even lower than the rough estimate of the revision rate for arthrodesis (11%). More sophisticated techniques and instruments combined with the great experience of a surgeon can yield very low infection rates (3% superficial and 1% deep). Hintermann reported loosening of the talar component to occur in 5.5% of cases. However, almost no loosening of the tibial component was observed (0.7%). Wood et al. reported on the short-term results of the first 100 MOBILITY™ TAR (DePuy Orthopaedics, Inc., Warsaw, IN, USA) [94]. Their revision rate was even lower (5%) than that reported by Hintermann et al. However, 10-year survival rates of the HINTEGRA® or MOBILITY™ TAR are currently not available. Long-term studies still are needed to prove whether those designs show any superior behavior and outcome when compared to the presently available two- and three-component TAR. The direct comparison between HINTEGRA® and MOBILITY™ could not reveal any difference regarding the complication rates [95]. Both designs preserve enough bone stock and offer an easy way of conversion into arthrodesis. The HINTEGRA® design also offers the possibility of revision arthroplasty. However, in case of failed TAR, revision arthroplasty has not yet been shown to be a reliable option, leaving arthrodesis as the preferred management [96–98].

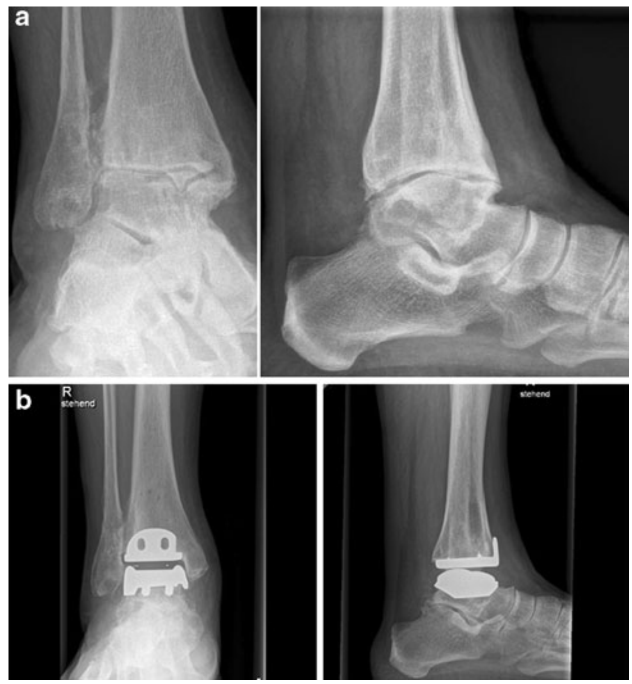

Fig. 4 **a** Preoperative radiographs of a female patient suffering from idiopathic ankle osteoarthritis. **b** The same patient 1 year after the implantation of a HINTEGRA® TAR

Summary

Ankle arthrodesis has remained the gold standard for the treatment of ankle arthritis. While patients show good-to-excellent outcomes after unilateral ankle fusion and acceptable gait function in the short- and mid-term, it must be pointed out that biomechanics are altered and, thus, function too. In the long-term, deterioration of the adjacent joints occurs as an inevitable consequence, with a greater risk of secondary arthritis in the hind- and mid-foot area. An alternative treatment that could preserve ankle motion and prevent adjacent joint arthritis would be of advantage. Based on current data in the literature, in the near-future, arthrodesis has to face a serious rival: TAR.

During the last two decades, TAR has seen significant changes in terms of improved anatomical design, biomechanical behavior, and instrumentation, resulting in improved short- and mid-term outcomes. There is an increasing demand for TAR from patients suffering from symptomatic ankle disease. While not every patient qualifies for TAR, it should be seen as viable alternative treatment for those with ankle arthritis. Although modern three-component designs of TAR show promising findings in the short- and mid-term, long-term results are still needed. The longevity of implants, however, is limited and the results of TAR are still inferior to those found for total knee and hip. Besides this, the experience and the number of TAR performed by a surgeon seems to play an important role in determining the future outcome. Surgeons and patients have to deal with the risk failure and must be aware of the fact to perform either revision TAR or conversion into arthrodesis.

Conflict of interest None.

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