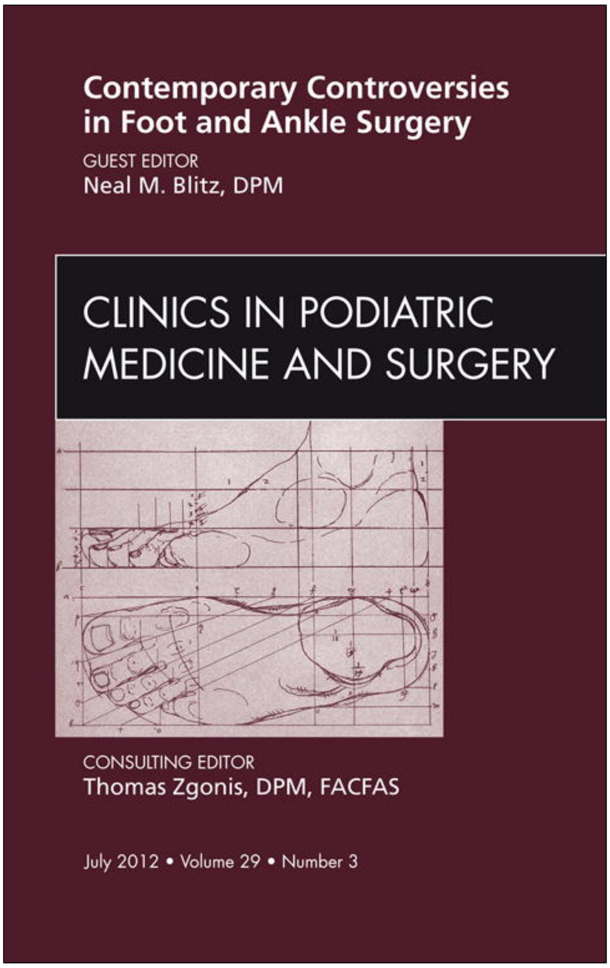
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# End-Stage Ankle Arthritis

## Arthrodiastasis, Supramalleolar Osteotomy, or Arthrodesis?

Lawrence A. DiDomenico, DPM[a,b,*], Nik Gatalyak, DPM[a]

**KEYWORDS**

• Ankle • Arthritis • Arthrodiastasis • Supramalleolar osteotomy • Arthrodesis

**KEY POINTS**

- End-stage ankle joint arthritis is a disabling and painful condition.
- A thorough history and physical and advanced imaging is paramount to an appropriate diagnosis of end-stage ankle arthritis.
- Osseous alignment is necessary to maintain a good long-term outcome.

## INTRODUCTION

One of the most challenging issues posed to foot and ankle surgeons is whether to perform a joint-sparing or a joint-destructive procedure for patients with end-stage ankle arthritis. Even more taxing for the foot and ankle surgeon is how to treat this condition in the younger patient population, in particular patients in their 20s, 30s, and 40s.

Patients who suffer with end-stage ankle arthritis have compromised quality of life. Nonsurgical treatment should be considered before surgery. The gold standard for end-stage ankle arthritis is currently ankle arthrodesis. With the advancements of AO fixation and plating technology, ankle arthrodesis has become a time tested and predictable joint destructive procedure. For years, foot and ankle surgeons have been looking for alternatives to ankle arthrodesis. The most common alternatives currently are the joint-sparing procedures, which consist of arthrodiastasis, total ankle replacements, total ankle allograft replacement, and supramalleolar osteotomies.

With reasonable reported outcomes in the literature, ankle arthrodiastasis provides foot and ankle surgeons another procedure option. Because the newer generations of ankle implants have a better anatomic design, coupled with significant successful

[a] Reconstructive Rearfoot & Ankle Surgical Fellowship, Ankle and Foot Care Centers, Ohio College of Podiatric Medicine, 8175 Market Street, Youngstown, OH 44512, USA; [b] St. Elizabeth Hospital, Youngstown, OH, USA
* Corresponding author. Reconstructive Rearfoot & Ankle Surgical Fellowship, Ankle and Foot Care Centers, Ohio College of Podiatric Medicine, 8175 Market Street, Youngstown, OH 44512.
*E-mail address:* ld5353@aol.com

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literature review, the implants are becoming increasingly popular as an alternative to ankle arthrodesis. Although not commonly performed, total ankle allograft transplant replacement has been sporadically reported in the literature as another possible substitute to ankle fusion. Supramalleolar osteotomies are performed to realign the distal tibia and improve foot and ankle function in those patients who suffer from end-stage ankle joint arthritis and juxta-articular tibial deformity.

## ARTHRITIS

Osteoarthritis is a degenerative disease of joints characterized by formation of osteophytes, subchondral sclerosis, subchondral cysts, loose bodies, and joint space narrowing.[1–3] It affects approximately 15% of the world's population, of which 1% is suffering with osteoarthritis of the ankle.[2] In the United States, arthritis is the leading cause of disability. About 21 million people reported having arthritis, and subsequent limitation of their work-related function has been found in 1 out of 3 of these people.[4] Daily function is significantly affected compared with the general population.[5] According to Glazebrook and colleagues,[3] end-stage ankle arthritis has a severe impact on pain, health-related quality of life, and function that is at least as severe as patients with end-stage hip arthritis. In general, patients with end-stage ankle arthritis experience greater emotional and mental distress than those who are experiencing end-stage hip arthritis.

The causes of osteoarthritis can be divided into 3 categories: primary, secondary, and posttraumatic. Primary osteoarthritis is idiopathic in nature with no obvious underlying abnormalities occurring 50% of the time, whereas secondary osteoarthritis occurs in patients with underlying conditions such as rheumatoid arthritis, hemarthroses, hemophilia, and postinfectious processes. Although primary osteoarthritis is the most common cause of hip and knee problems, the same is not observed in the ankle.[3,5–10] Primary osteoarthritis of the ankle affects older populations of patients. The primary group also has less pain and increased range of motion compared with secondary and posttraumatic osteoarthritis groups.[2,6,11] Valderrabano and colleagues[2] evaluated 406 ankles with symptomatic end-stage osteoarthritis. In their study, posttraumatic osteoarthritis of the ankle was seen in 78% of cases, secondary osteoarthritis in 19% of cases, and primary osteoarthritis in 9% of cases. Similar results were found by Saltzman and colleagues,[6] evaluating 639 ankles with 70% of cases occurring secondary to trauma of the ankle joint. Malleolar ankle fractures, ligamentous injuries causing ankle instability, pilon tibial fractures, tibial shaft fractures, talus fractures, osteochondritis dissecans, and severe combined fractures were the main causes of posttraumatic osteoarthritis of the ankle seen in both studies (**Fig. 1**).

## NONOPERATIVE CARE

Conservative treatments are limited for symptomatic end-stage ankle arthritis. Most therapies provide short-term improvement of symptoms and should be exhausted before consideration of surgical treatment options. Nonoperative, conservative treatment options include a combination of medications, injections, modification of activities, prescription of custom orthotic devices, and bracing.[12–14]

Nonsteroidal antiinflammatory drugs (NSAIDs) may help relieve pain of arthritic ankle joints. They should be given only short term and closely monitored for side effects. Altered kidney function tests as well as bleeding tendencies are the most common side effects associated with NSAIDs. A combination of corticosteroid-anesthetic intra-articular injection can be given to decrease joint pain and inflammation. Varied results have been reported for the duration of beneficial effects of the

**Fig. 1.** End-stage posttraumatic ankle arthritis.

injection. Side effects are uncommon but skin depigmentation and infections may be seen. Modification of activities may be beneficial. Patients' pain may be more manageable with changes in occupation to a sedentary job as well as a decrease in vigorous activities such as sports. Pain and inflammation can also be managed with bracing and change in shoe gear. Rocker-bottom sole, solid ankle cushion heel (SACH), lace-up ankle support braces, ankle-foot orthosis, and weight-bearing fiberglass or plaster cast can decrease inflammation and pain by restricting motion of the ankle joint. Patella tendon–bearing (PTB) braces have also been used with some success for treatment of ankle arthritis because they reduce pain and discomfort of the affected extremity by decreasing axial load (**Fig. 2**).[12–14]

## ARTHRODIASTASIS

The term arthrodiastasis comes from the Greek words arthro (joint), dia (through), and tasis (to stretch out). Distraction of the ankle joint has been used as an alternative to arthrodesis or arthroplasty. This procedure is advocated to reduce pain and increase motion of an arthritic joint without sacrificing the joint. It is indicated in younger patients with good bone stock and painful ankle joints who are not willing to have an ankle arthrodesis.[15,16]

The technique was first described by Judet in 1978 for treatment of osteoarthritis of the hip.[17] It was not until 1995 that van Valburg and colleagues[17] reported on the use of an arthrodiastasis technique for treatment of severe posttraumatic arthritis of the ankle joint. The Ilizarov external fixator was used for ankle distraction in 11 patients

**Fig. 2.** An ankle-foot orthosis. This is one of many types of ankle-foot orthosis that is often used to limit the motion of the ankle joint to treat end-stage ankle joint arthritis nonoperatively.

in combination with measurement of intra-articular hydrostatic pressure. The Ilizarov external fixator was applied for 3 months and the ankle joint was distracted 5 mm. Patients were able to be fully weight bearing just days after surgery. At 3 months, the fixator was removed and patients were transitioned into a cam boot. Clinical improvement of pain and mobility was observed at mean follow-up of 20 months and an increase in joint space was also noted on weight-bearing radiographs. During loading, the researchers observed an increase in intra-articular pressures of the distracted ankles.

After distraction of a joint, theoretically the cartilage has the potential to repair itself. It is thought that mechanical off-loading can prevent further damage to the articular cartilage. Once the joint is off-loaded, the chondrocyte repair process may begin with fluctuation in intra-articular hydrostatic pressure during weight bearing with the external fixator. Chondrocytes are able to repair by the cyclic changes in intra-articular fluid pressure within the joint.[15,18,19]

In 2002, Marijnissen and colleagues[20] published a large multicenter prospective study of 57 patients with a mean age of 44 years who underwent ankle distraction and ankle arthroscopy when necessary. Patients were followed on average of 2.8 years. Eleven of the 57 patients were excluded from the study because of short follow-up of less than 1 year and 13 patients withdrew from the study because of recurrent pain and required further treatment. Significant clinical improvement was seen in 38 patients at 1-year follow-up. More importantly, significant functional and clinical improvement was seen compared with the results at 1 year. A randomized study on 17 patients was also performed by the investigators. They evaluated 9 patients with ankle distraction with arthroscopic debridement as necessary compared with 8 patients with arthroscopic debridement alone. The results from the ankle distraction group were similar to their prospective study. In the debridement group, significantly less profound outcomes were observed and 3 of the 8 patients did not reach 1-year follow-up. The failures underwent joint distraction with satisfactory results. In this large multicenter study, significant improvement was observed using joint distraction.

Short-term results of joint distraction have proved to be satisfactory.

Ploegmakers and colleagues[21] performed a multicenter retrospective analysis of 27 patients with posttraumatic osteoarthritis. All patients were treated with Ilizarov ankle distraction. Of the 27 patients, 2 could not be traced and 3 patients incorrectly completed the questionnaire and could not be included in the study. Data was evaluated for these 22 patients with a mean age of 37 years and at least a 7-year follow-up. Six of these patients had remaining persistent pain and went on to arthrodesis. Sixteen patients were evaluated on the basis of pain, function, clinical status, and mobility at a mean 10-year follow-up. Sixteen of the 2-2, or 73%, of patients had significant improvement in all clinical parameters evaluated.

Ankle arthrodiastasis is performed using a circular external ring fixator. Application of a 2-ring block to the tibia is initially achieved. A talar wire is added to prevent distraction of the subtalar joint and is added to the foot plate in addition to the calcaneal wires. The distraction is then performed up to a total of 5 mm at a rate of 0.5 mm 2 times per day. Patients are also allowed to bear weight to tolerance for a recommended treatment duration of at least 3 months.

As with any surgical intervention, ankle arthrodiastasis has complications. The most common complications include soft tissue irritation and superficial infection at pin sites, which can lead to a more serious bone and joint infection. Care should be taken to avoid placing wires intra-articularly because this could cause a septic joint. Improper wire placement can damage neurovascular structures during surgery. Hardware failure can also occur and replacement or removal may be necessary. Overdistraction can lead to ligament tears/damage and fracture. Furthermore, patient noncompliance and psychological issues associated with the frame can become a challenge, therefore the surgeon needs to be prepared for a bailout of the procedure.

Contraindications consist of active infection, vascular impaired limb, poor soft tissue envelope, and significant planal deformities.

The data from multiple studies with large patient populations as well as long-term results show improvement of symptoms and function following ankle joint distraction in patients with severe posttraumatic osteoarthritis. Ankle joint distraction provides a viable joint-sparing treatment of ankle osteoarthritis. Most studies suggest that younger patients benefit more from ankle distraction, although Tellisi and colleagues[15] evaluated age as a predictor of results and showed that patients older than 60 years had more improvement. Even though relief or improvement of symptoms may be temporary, more definitive treatment, such as ankle arthrodesis, can be considered at a later date.

It is the experience of the authors that this provides a reasonable option for patients with end-stage ankle arthritis, in particular for younger patients. The authors suggest that this procedure be reserved for the right patient, and suggest that the patient be fully engaged in preoperative detailed demonstration and explanation of the procedure. In review of the authors experience, we think the condition surrounding joints contributes to the success or failure of the procedure (**Fig. 3**).

## ANKLE ARTHRODESIS

Ankle arthrodesis is a well-documented surgical treatment of end-stage ankle arthritis. It has been a preferred treatment of ankle arthritis because of its predictable

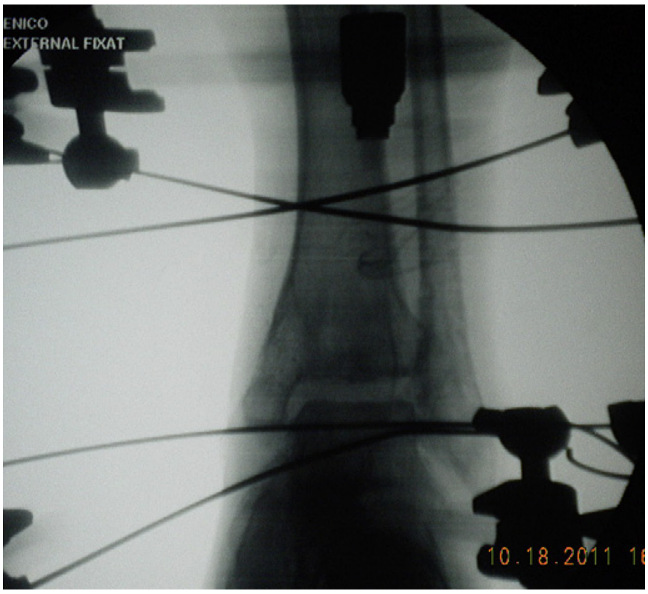


**Fig. 3.** Arthrodiastasis: an external fixator distracts the ankle joint. Intraoperative image shows 2 smooth wires in the tibia and 2 smooth wires in the talus.

outcomes. In 1879, Albert was the first to described ankle arthrodesis to treat paralytic ankle equinus.[14] More than 30 different techniques to improve the results of the procedure have been described since that time. Ankle arthrodesis is indicated when patients experience persistent pain secondary to the deformity that limits their daily function and after all conservative treatment options have failed.[13,14,22,23] Although still considered the gold standard, ankle arthrodesis for treatment of painful end-stage arthritis, clinicians must be aware of the biomechanical effects on the lower extremity and surrounding joints.

In earlier studies, surgeons experienced high nonunion rates and a higher need for revision surgery. Recent literature reports higher rates of fusion, although variability of fusion rates do exist. Studies report successful union rates of 81% to 99%.[22,24–27] High rates of nonunion have been associated with use of the external compression clamp that was popularized by Charley.[22,26,27] In contrast, in ankle arthrodesis, internal fixation has been associated with higher rates of union.[24,27–30] Morgan and colleagues[28] reviewed 101 ankle joint fusions with an average follow-up for patients of 10 years. An anterolateral surgical approach was used to gain access to the ankle joint and arthrodesis was achieved with screw fixation. A 95% fusion success rate was reported, which can be attributed to their emphasis on preparation of the joint to achieve bone-on-bone contact and use of internal fixation. Zwipp and colleagues[24] reported a fusion rate of 99% in 93 out of 94 patients using a 4-screw technique. Using an anterior fusion plate, Rowan and colleagues[27] achieved a 92% fusion rate in 31 out of 34 patients.

Following ankle arthrodesis, patients notice significant decrease in steps per minute, in addition to decreased stride length, but do not have a significant amount of pain compared with the control group. No significant difference in range of motion in the sagittal plane of the pelvis or the knee joint was seen but fusion of the ankle showed significant decrease in range of motion of the hindfoot and forefoot in all planes (sagittal, transverse, and frontal).[31] Buck and colleagues[32] studied the importance of position of ankle fusion and its affects on patterns of motion of the hindfoot and effect of different ground conditions. The recommended that the optimal position of the ankle joint is neutral flexion, $0^\circ$ to $5^\circ$ of valgus of hindfoot angulation and $5^\circ$ to $10^\circ$ of external rotation of the foot. A dorsiflexed position is better tolerated than a plantarflexed position of ankle fusion because it decreases sagittal plane motion of the foot and also causes genu recurvatum, producing an abnormal gait that is exaggerated with different ground conditions. Increased extension of the knee is also caused by anterior position of the talus on the tibia and during ambulation uphill. Varus hindfoot position produces a supinated foot type causing locking of the midtarsal joint, whereas arthrodesis in a slight valgus position allows greater motion in the foot. In the stance phase of gait, internal rotation of the foot decreases hindfoot motion and external positioning is indicated to decrease medial collateral ligament stress during toe-off.

Most patients who undergo ankle arthrodesis are satisfied with their results and would go through surgery again in the same circumstances.[25,28,30–33] However, they have long-term functional limitations secondary to pain in adjacent joints.[34] Early postoperative results show no significant changes in adjacent joints, but in one long-term study[35] and another by Coester and colleagues[34] there were significant arthritic changes in adjacent ipsilateral joints compared with the contralateral extremity. Patients had increased osteoarthritic changes in subtalar, talonavicular, and calcaneocuboid joints. In a long-term follow-up study on quality of life by Fuchs and colleagues,[33] 17 patients were followed up for at least for 20 years after ankle arthrodesis. Charnley compression clamps were used in 14 patients as an external fixator for ankle arthrodesis. Only half of the patients had minor restrictions of activities of daily living. Sixteen of the 17 patients were still working and 44% returned to their preinjured occupations, with others performing lighter duties. Similar results were found by Buck and colleagues.[32] Patients had increased physical limitations, emotional disturbance, and pain compared with the age-matched normal population. Significant correlation between functional outcome and radiographic osteoarthritic changes were seen in subtalar joints but not in midtarsal joints. A larger study of 107 subjects was performed by Slobogean and colleagues.[36] Their prospective study evaluated patients with ankle arthrodesis and ankle arthroplasty and their health state values using an SF-36 generic health-related quality of life instrument. The SF-36 uses 11 items to create 6 dimensions (SF-6D), namely physical function, role limitation, social functioning, bodily pain, mental health, and vitality. Patients were evaluated at baseline and at 1 year. They found no statistical difference in results at baseline or 1 year between the ankle arthrodesis or arthroplasty groups. Significant improvement in SF-6D scores were seen between baseline and 1-year follow-up of ankle arthrodesis and ankle arthroplasty groups. At 1-year follow-up, patients' SF-6D results approached age-matched and gender-matched US population norms.

Jung and colleagues[37] evaluated 12 cadaver limbs with an average age of specimen of 68 years (range 52–88 years). A 700-N load was tested on all cadaver specimens. The researchers measured joint contact pressures, peak pressure, and contact area in the talonavicular, subtalar, and calcaneocuboid joints before and after immobilization at neutral ankle axial loading and at tibiopedal dorsiflexion at different angles. Evaluation of different angles was meant to simulate late stance phase of the gait cycle. The results showed that there was significant increase in contact and peak pressures in talonavicular and calcaneocuboid joints between intact and fused ankles at different degrees of dorsiflexion. Comparison of the subtalar joint in intact and fused ankles showed no significant difference in contact or peak pressures but had an increase in contact surface area. Similar results were recorded by Suckel and colleagues[38] in 8 cadaver specimens. Further, an increase in peak pressures were seen at the talonavicular joints. These results suggest that increase in peak pressures at the talonavicular joint may lead to cartilage degeneration and long-term pain along the medial column.

Indications for ankle arthrodesis consist of osteoarthritis, rheumatoid arthritis, septic arthritis, isolated ankle joint Charcot arthropathy, paralytic/neuromuscular conditions, chronic ankle pain, end-stage ankle arthritis, chronic ankle instability, unsuccessful osteochondral defect repair, failed ankle arthroplasty, failed previous ankle arthrodesis, hemophilia, bone tumor, flat top talus, talar avascular necrosis, ankle deformity, and malalignment. Contraindications consist of acute infection and avascular limb.

The goals of an ankle arthrodesis is to reduce pain, improve function, reduce the deformity, provide stability and alignment, and create a plantigrade pain-free foot and ankle. In achieving these goals, the aim is to have the patient return to normal functional activity as much as possible. These activities include returning to a reasonable occupation, independence, and being as ambulatory as possible. Other considerations that need to be taken into account consist of the patient's age, weight, compliance, expectations, other medical conditions, and tobacco use. Because of the development of secondary arthritis, age must be discussed with patients. A young patient who undergoes an ankle arthrodesis may need to have a pantalar arthrodesis many years later. In nonneuropathic patients, this is a procedure the surgeon and patient should try to avoid at all cost.

Many approaches have been described. They consist of anterior, anterior-lateral, medial, lateral, transmalleolar, and posterior. It is the authors experience that the anterior and posterior approach allow the best ease of correction, especially with a frontal plane deformity. Each approach has its own benefit and downside. The posterior approach is favored when there is soft tissue compromise because the soft tissue envelope is thicker and rich in vascularity because of a low-lying flexor hallucis muscle below. Joint preparation can be performed as either curettage, joint resection, burring, or fish scaling. Each of these techniques has its own advantages and disadvantages too. It is the authors' experience that the curettage technique allows the least amount of shortening, provides excellent contour and inherent stability, with excellent bone-to-bone contact, therefore it is the technique of choice of the authors. Fixation options consists of internal fixation and external fixation. The internal fixation for the tibial-talar joint can be a choice of screws, staples, and plates. The authors' first choice is to use large cancellous screws combined with a locking plate and an onlay graft from the fibula as a biologic fixation. The authors highly recommend leaving the fibula intact because this allows patients and the surgeon the option of performing a takedown in the future. This method allows for the possibility of an ankle arthrodesis to be converted to an ankle replacement if needed (**Figs. 4–9**).

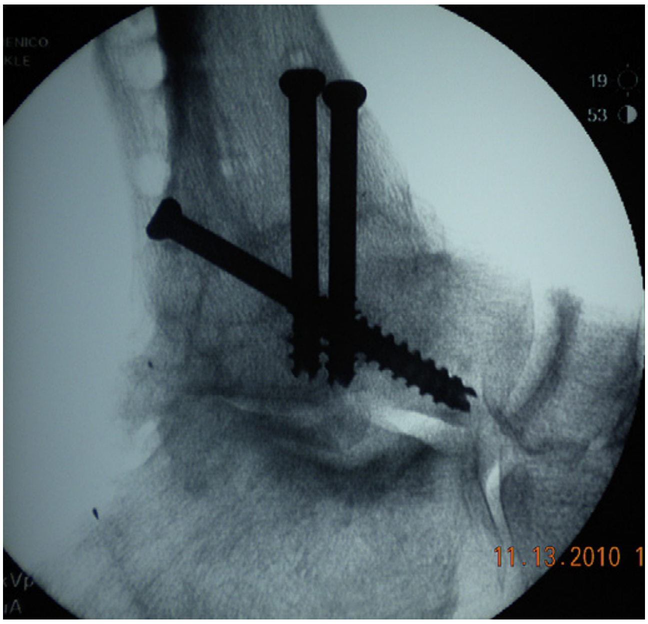


**Fig. 4.** An intraoperative image showing an ankle fusion fixated with 3 large cancellous screws.

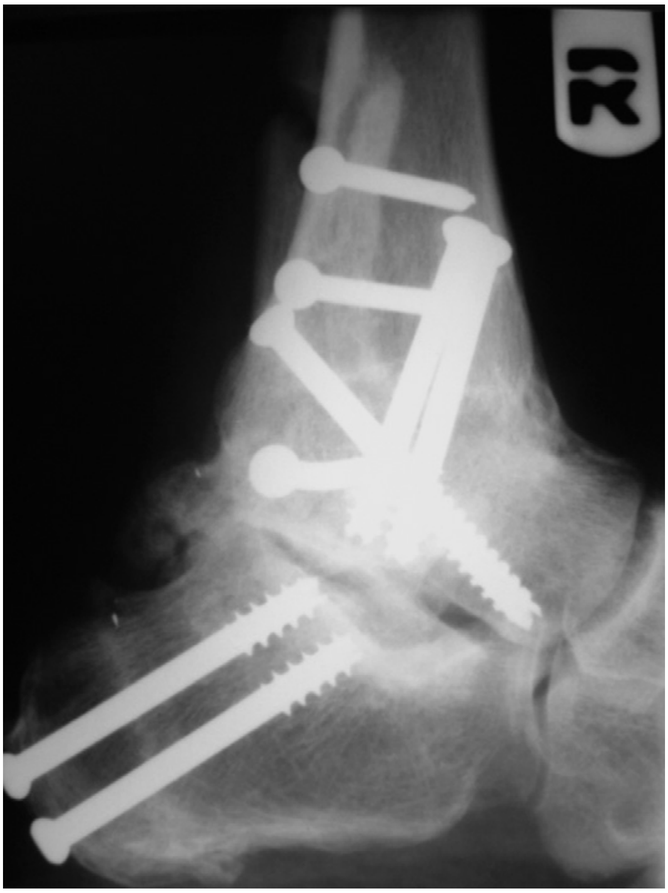


**Fig. 5.** A postoperative lateral view showing a tibial-talar arthrodesis that is constructed with 3 large cancellous screws at the tibial-talar joint and 3 fibula-tibia screws as a biologic fixation at the tibial-fibula interface.

A variety of complications following ankle arthrodesis have been documented. Neurovascular injury such as nerve damage and arterial/venous laceration sustained during the operation can be avoided with meticulous technique. Careful dissection and a well-planned longitudinal incision can also help minimize the risk to neurovascular complications. Skin complications have been reported 3% to 19% of the time. Most of the issues were superficial skin infections that were treated with oral antibiotics.[25–28] Morgan and colleagues[28] reported 1 deep infection and Rowan and colleagues[27] reported 2 out of 4 deep infections for which intravenous antibiotics were used and debridement preformed.

Rates of delayed union, nonunion, and malunion varied between different studies. Smoking and excessive soft tissue stripping have been associated with nonunion of any fracture or arthrodesis site. This group of patients is at a 4 times greater risk of developing nonunion than those who do not smoke. Nonunion occurs at lower rates when internal hardware has been used for fixation of ankle arthrodesis.[27–30] Malunion following this procedure can have significant effects on patients' gait cycle and can affect surrounding joints secondary to compensation.[32] Other complications consist of secondary arthritis of the subtalar joint and midtarsal joint, avascular necrosis, wound dehiscence, and malalignment. Additional complications such as stress fractures, below-knee amputation, and painful hardware have been reported.

## TOTAL ANKLE ARTHROPLASTY

The ankle joint is a complex universal joint that consist of an upper (tibial-talar) and lower (subtalar) ankle joint. The tibial-talar joint is only half of a more complex universal


**Fig. 6.** The use of 2 interfragmentary compression screws coupled with an anterior ankle arthrodesis locking plate.

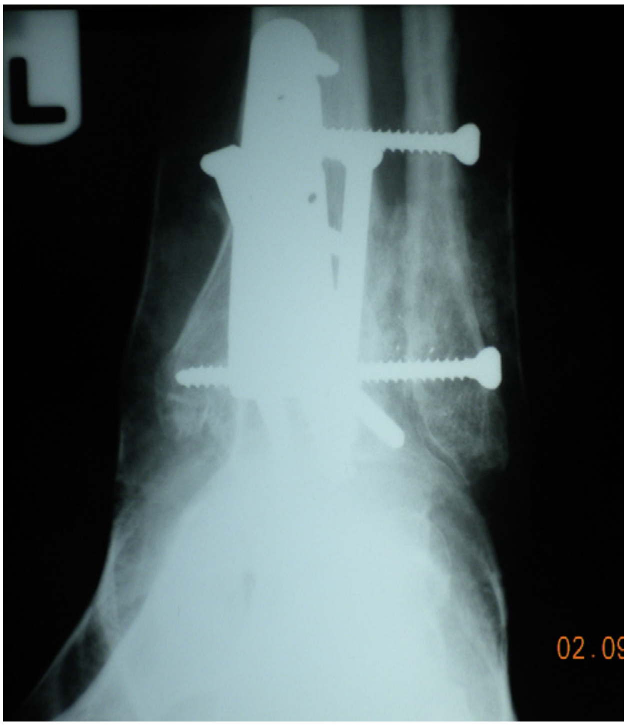


**Fig. 7.** An anterior-posterior radiograph following a tibial-talar and tibial-fibula arthrodesis using interfragmentary compression screws at the tibial-talar joint, an anterior ankle arthrodesis, and fibula-tibia syndesmosis fusion.

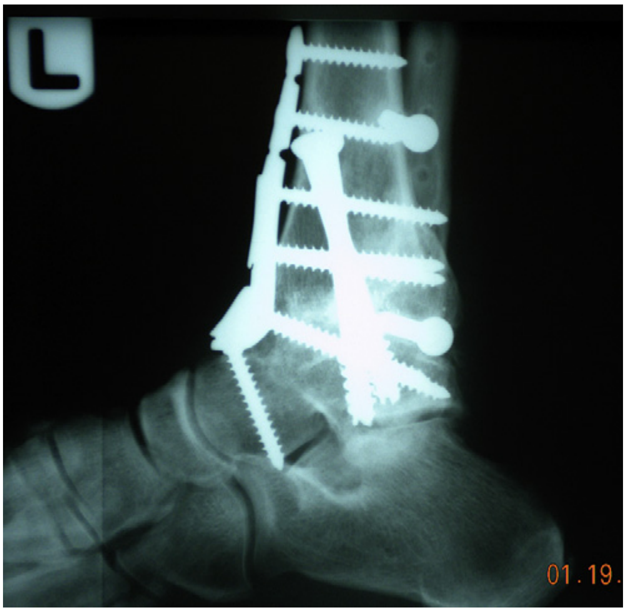


**Fig. 8.** A lateral radiograph following a tibial-talar and tibial-fibula arthrodesis using interfragmentary compression screws at the tibial-talar joint, an anterior ankle arthrodesis, and fibula-tibia syndesmosis fusion.

joint and works together with the other half—the subtalar joint. The problem with a total ankle replacement is that the only part being replaced is the tibial-talar joint. The anatomy of the subtalar joint is complex, therefore it is not replaceable. A normal subtalar joint allows the foot to be flexible, provides stability, and maintains alignment.

Ankle joint replacement works better in patients who are older and have less high-impact activity. Total ankle arthroplasty (TAA) is a viable alternative to ankle arthrodesis for treatment of patients with end-stage ankle arthritis. However, because of poor early results, ankle arthrodesis is considered to be the gold standard for treatment of ankle joint arthritis.[39–43] The initial implants had poor mechanical design, the physicians inserting the ankles had limited experience, therefore the performance of the early generations of ankle implants resulted in a negative stigma. Ankle fusion consequently remains the treatment of choice.

The new generation of ankle implants have better anatomic design, thus are becoming increasingly popular as an alternative to ankle arthrodesis. As a result of

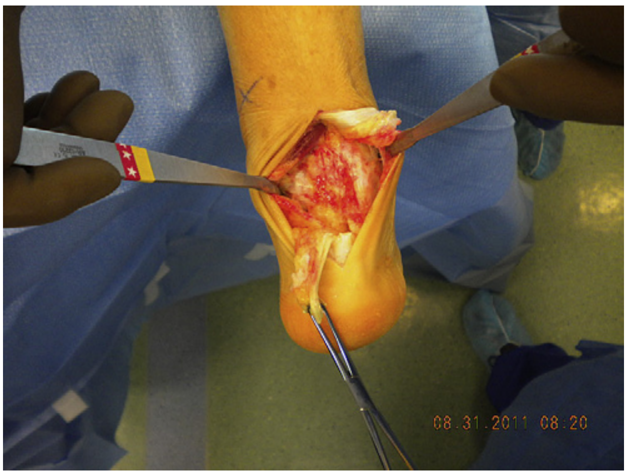


**Fig. 9.** A posterior approach can be used with a compromised medial, lateral, or anterior soft tissue envelope.

this increasing use of ankle implants, the merits of ankle replacement versus ankle arthrodesis continues to be one of the most debated topics in foot and ankle surgery. Consumers now have access to more information about their health care and, because of this, consumers are researching their options and tending to desire ankle replacement rather than ankle fusion. Patients are also living longer and are more active.

TAA was first performed by Lord and Marrotte in 1970.[10,41,44] The implant design was similar to those used for hip replacements. At a 10-year follow-up, only 7 patients had satisfactory results. First-generation implant design flaws led to a high revision rate. Subsidence and osteolysis was noted with these systems. Loosening of the implant components was seen in constrained designs at their cement-bone interface because normal triplane ankle motion was not addressed. Constrained ankle implant designs provide the greater stability and resistance to wear of polyethylene when surfaces are congruent. Incongruent surfaces in total ankle implants lead to higher stresses on the polyethylene piece, increasing its wear.[10,41,42,44] Because of high failure rates, newer generation implants were developed. They are grouped into 2-component or 3-component designs and as fixed-bearing or mobile-bearing designs.[41,44]

There are currently 5 ankle implants approved by the US Food and Drug Administration (FDA) , although many other systems are used in Europe. Only 1 of the 5 implants is a 3-component design. Agility LP Total Ankle System (DePuy), INBONE Total Ankle (Wright Medical), Salto Talaris Ankle (Tornier), and Eclipse Total Ankle (Integra Life-Sciences) are fixed-bearing, 2-component designs. Even though these implants have 3 pieces, the polyethylene component is fixed to the tibial piece and acts as a 2-component implant. They are considered to be fixed-bearing designs because the polyethylene piece has no independent movement. Scandinavian Total Ankle Replacement (STAR) (SBI) is the only cementless, 3-component, mobile-bearing system that is FDA approved.[39,41,44]

In 1984, Dr Frank Alvine designed the Agility ankle joint implant. Until 2007, it was the only total ankle replacement system that was FDA approved. It requires application of an external fixator to allow distraction of the joint during surgery. Arthrodesis across the syndesmosis is performed to improve stability and to provide support for the tibial component.[39,41,44] The INBONE system is unique. It has an intramedullary alignment system with a multipiece tibial stem. The Salto Talaris ankle implant is a mobile-bearing, 3-component system that is currently used in Europe. It has been redesigned to a 2-component system for use in the United States. In 1978, the STAR was designed as a 2-component, cemented, unconstrained system by Dr Hakon Kofoed. It was not until years later that it became a 3-component, cementless, mobile-bearing system. The STAR design enhances fixation to the tibia through 2 anchorage bars and allows minimal bone resection. The talar component has a longitudinal ridge that stabilizes the polyethylene component during ankle joint motion, and the flat proximal surface allows rotation at the polyethylene and tibial interface.[10,39,41,44]

Proper patient selection is important to achieve successful surgical results, although no absolute criteria have been set.[10,39–42,45] Indications consist of end-stage arthritis from posttraumatic arthritis, primary osteoarthritis, and rheumatoid arthritis. Multiple studies reviewed by Clare and colleagues[40] show that patients 50 years of age and older who underwent TAA had more favorable surgical results than younger patients. Ideal candidates are patients who have adequate bone stock, intact neurovascular status, neutral ankle alignment, intact deltoid ligaments, and are not immunosuppressed.[40–42] When planning TAA, the body weight of a patient is also considered. Obese patients have increased forces transmitted to the implant, making it prone to failure. Other relative contraindications are poor bone stock, immunosuppression, smoking, ankle malalignment, history of septic arthritis, and diabetes. TAA is absolutely contraindicated in patients with high physical demands, poor vascular status, significant neuropathy, infection, neuromuscular deficits, avascular necrosis of the talar body, chronic pain syndrome, and noncompliance.[40–42,46] Ankle malalignment should be avoided to achieve successful ankle joint replacement. Deformities may arise below the ankle joint, at the ankle joint, or above the ankle joint.[46] Flatfoot is the most common deformity located below the ankle joint that contributes to malalignment. The surgeon should address the underlying condition to achieve a tripod effect with the first and fifth metatarsals and a heel in neutral.[40] Deformity arising at the ankle joint may be caused by posttraumatic arthritis or a history of ankle sprains causing a varus ankle joint.[2,46] Patients should also be evaluated for ankle equinus. A Silfverskiold examination is used to assess ankle dorsiflexion with knee bent and extended, with hindfoot in neutral. When decreased ankle dorsiflexion is noted, Achilles tendon lengthening or gastrocnemius recession is then performed according to the results of the Silfverskiold test.

Complications following TAA can be attributed to inappropriate patient selection, surgeon experience, and surgeon error.[42] Proper patient selection decreases the risk of complications. Thorough preoperative patient evaluation as well as following clinical guidelines can help achieve a successful surgical outcome.[42,46,47] In addition, outcomes of ankle implants are directly related to the surgeon's experience. Studies show an increase in 5-year survival of ankle implants when a surgeon has performed more than 30 procedures.[42–44] According to a study by Myerson and colleagues,[48] the rates of wound complications decreased from 24% to 8% with increased surgeon experience. A decrease in intraoperative complications including tendon lacerations, nerve laceration, and malleolar fractures has also been seen as a result of accommodation for the steep learning curve.[47,48] According to Mann,[49] complications for this procedure can be divided into 3 groups: low, medium, and high grade, using the Glazebrook classification system. Nine of the 78 ankles (12%) had high-grade complications that included aseptic loosening, deep infection, and implant failure in 4 ankles. Subsidence and postoperative malleolar fracture accounted for 6 patients (7%) with medium-grade complications. Low-grade complications included 6 patients (7%) with superficial skin infection and intraoperative malleolar fractures. Aseptic loosening is associated with pain and, radiographically, a dark halo around the loose component. It is caused by disruption or insufficient bony ingrowth.[42] Deep infection occurred in 3 patients and they were treated with open debridement and 6 weeks of intravenous antibiotics, with no recurrence of infection seen at 9-year follow-up. Osteolysis is lucency seen on radiographs that is typically caused by microscopic debris causing a mediated response or mechanical lysis.[42] Failure of the implants occurred as a result of osteolysis in 2 of the 4 ankles. One ankle implant failed secondary to fracture of the polyethylene piece from forceful axial loading. All 4 ankles were revised and functioning well at 6-year follow-up.[49] Subsidence of the implant may be seen and can be caused by soft bone, overly aggressive bone resection, improper prosthesis placement, sepsis, and an implant that is too small. If this occurs, revision of ankle implant or ankle arthrodesis should be considered.[42] Mann and colleagues[49] noted subsidence in 3 of the patients who had an ankle fusion as a result. Malleolar fractures are associated with surgeon error during the intraoperative period by inappropriate use of a saw blade, which thereby weakens the bone.[10,42]

Failing to address ankle malalignment can cause malleolar fractures during the postoperative period.[42] With superficial skin infection, wound dehiscence ranges vary from 2% to 40% following TAA.[48] Early, conservative local wound care and oral antibiotics can help prevent further complications. According to Saltzman,[50] nerve injury was seen in 20.3% of patients who underwent TAA, compared with 7.6% of patients who had ankle fusion. During surgery, care must be taken to avoid nerve damage to the superficial or deep peroneal nerve. Injury to either nerve is usually a result of laceration or traction.[42] Studies show that medial and lateral gutters of the ankle can be painful after ankle arthroplasty. Spirt and colleagues[51] noted 58 gutter debridements in reoperation of 127 ankles. Eight of the 3-4 ankles had pain in the medial gutter, as reported by Kurup.[52]

Higher revision rates are associated with TAA compared with ankle arthrodesis. Spirt and colleagues[51] noted a 28% revision rate in 306 ankle arthroplasties. A large study performed by SooHoo and colleagues[53] reviewed a total of 4705 ankle fusions and 480 ankle implants. Higher rates of revision surgery were needed: 9% at 1 year and 23% at 5 years in patients who underwent TAA, versus 5% and 11% for ankle fusion. In contrast, Haddad and colleagues,[54] in their review of 1262 patients, found that the rate of revision surgery was lower in patients with ankle implants, at 7% compared with 9% with ankle arthrodesis. When TAA has failed and revision of an implant is impossible, ankle arthrodesis may be the only option before below-the-knee amputation is considered.[13] In a study of 306 ankle arthroplasties, below-knee amputation was performed in 8 patients. Below-knee amputation and deep vein thrombosis are some of the other complications that can occur. In a study by Spirt,[51] amputations were performed because of severe pain in 4 patients and infection in 3 other patients. One of the patients considered below-knee amputation as a surgical option even before undergoing TAA. All patients who underwent below-knee amputation had preoperative hindfoot malalignment.[51]

The authors' experience with ankle replacement surgery has been successful and suggests that it is an acceptable alternative in the treatment of end-stage ankle arthritis when done with protocol-driven indications and appropriate associated conjunctive procedures. The authors think that the key is selecting the right patient, performing a complete evaluation of the extremity, and evaluating a good bone to body size. The patient whose underlying disorder is not corrected before or at the time of implantation is highly susceptible to failure. Patient whose activity levels are altered to meet a lower physical demand and who are conscious of their limitations seem to do the best. The use of an ankle replacement continues to become more predictable when these guidelines are followed.

Because primary osteoarthritis is not common in the ankle joint, the patient population with the highest need of a total ankle is a younger population, usually stemming from posttraumatic arthritis. The ankle replacement surgery is best suited for older patients with degenerative joint disease of the ankle and not involving the subtalar joint, without surrounding soft tissue disorder. However, this patient population is the minority who suffer from end-stage ankle arthritis because pure osteoarthritis in the ankle joint is almost nonexistent. Options for the younger population consist of ongoing physical limitations with pain, amputation, or possible attempt at total ankle replacement. In the younger population who will undergo ankle replacement surgery, it is inevitable that revision and additional surgery will be needed (**Figs. 10–15**).

## TOTAL ANKLE ALLOGRAFT TRANSPLANT REPLACEMENT

Fresh bipolar osteochondral allograft of the ankle joint has been sporadically reported in the literature as another alternative to ankle fusion. Allograft transplant replacement uses a fresh graft of the ankle harvested from a cadaver. Similar to total ankle replacement, ankle allograft replacement permits a more normal function. The main advantage of the allograft ankle replacement is the return of some movement in the ankle


**Fig. 10.** A preoperative lateral radiograph with secondary ankle joint arthritis and a subtalar joint arthrodesis. A tibial-talar joint arthrodesis coupled with an already subtalar joint fusion most likely leads to further periarticular breakdown. In this case, the foot and ankle surgeon may consider a TAA to prevent further arthrodesis.

with a biologic implant. The potential complications are similar to other operations: the specific concern of the allograft replacement is that the bone and cartilage that is transplanted may not heal, and further arthritis may develop. If this complication occurs with large bony defects, it can be converted to a more traditional total ankle replacement, or even an ankle fusion.

The main advantage of this type of procedure is the potential for replacement of the ankle joint with viable living cartilage cells. The most important aspect of the transplant is the correct sizing to match the ankle. Kadakia and colleagues[55] reported a high failure rate and high revision rate in patients who underwent osteoarticular ankle allograft replacement, which they attributed to high body mass index and a more active

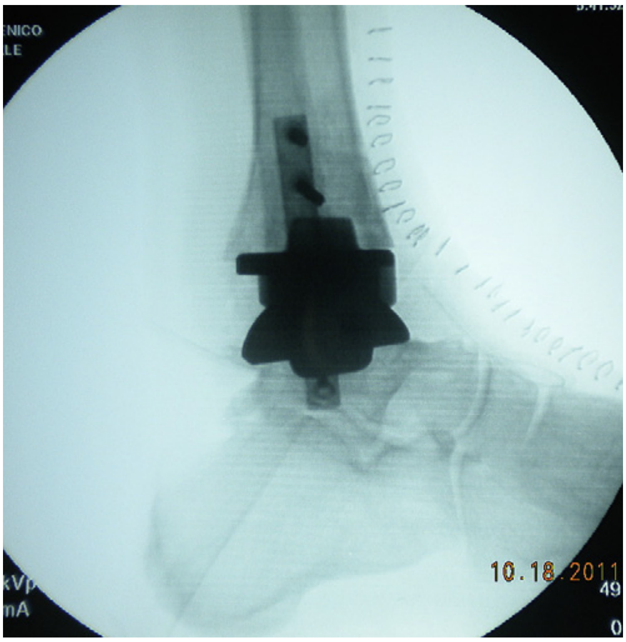


**Fig. 11.** An intraoperative image of a total ankle replacement using an Agility ankle replacement.


**Fig. 12.** An intraoperative image of an INBONE total ankle replacement.

patient population. To avoid failure, they suggested that surgeons carefully select patients, that they handle the implants with care, use cutting guides for accuracy, and place the graft early because cartilage is nonviable after 18 days.

### *Supramalleolar Osteotomy*

Supramalleolar osteotomy is a surgical procedure to correct a congenital or acquired deformity of the distal tibia to improve the function of the foot and ankle. This osteotomy is a joint-sparing procedure performed in the juxta-articular region of the tibia. A supramalleolar osteotomy can correct deformities in all planes. Rarely are deformities of the distal tibia managed only by a corrective osteotomy. The frequent existence of accompanying end-stage ankle arthritis is accountable for the clinical symptoms. Indications for a low tibial osteotomy consist of malunited ankle/plafond and distal tibial fractures, congenital deformities, ankle arthritis stemming from the tibial side of the joint, and

**Fig. 13.** A postoperative lateral image of a Salto Talaris ankle replacement.


**Fig. 14.** A postoperative lateral image showing a STAR ankle replacement.

growth plate injuries.[56] Other indications include juxta-articular tibial deformities, maligned arthrodesis, paralytic disorders, and tibial torsion.[57,58] Contraindications consist of impaired neurovascular status, active skin infection, active bone infection, and other comorbidities. Standard anterior-posterior and lateral radiographs of the foot and ankle along with long leg calcaneal axial, rearfoot alignment views of the tibia and fibula, and possibly the knee, can assist in identifying the level of the deformity. The radiographs are used to describe the following characteristics: limb alignment, joint orientation, anatomic axes, mechanical axes, and center of rotation of angulation (CORA).

Normative values for the relations among these various parameters are used to assess deformities. The CORA is the apex of the deformity, consisting of the distal and proximal diaphyseal lines. The distal tibial deformities present with osteoarthritic changes of the ankle joint, or are associated with an ankle fusion malunion. Clinical deformities may or may not be evident, but chronic pain and an increase in pain


**Fig. 15.** The amount of (*A*) flexion and (*B*) extension following the implantation of a STAR ankle replacement.

Fig. 16. An anterior view of a patient who has an ankle varus with end-stage ankle arthritis secondary to a physeal arrest. This patient would benefit from a prophylactic tarsal tunnel decompression and a supramalleolar osteotomy.

with usage is common. Because of the natural motion of the subtalar joint, a mild-moderate distal tibial deformity is well tolerated with a rearfoot and midfoot that is supple. In cases with inadequate compensatory motion, the deformity is poorly tolerated. The ability of the foot to compensate for the deformity above the ankle depends on the flexibility of the foot. In scenarios in which a frontal plane deformity such as distal tibia varus or valgus, the forefoot must be able to compensate to remain plantigrade. In scenarios of a stiff hindfoot, there is less capacity for the foot to compensate. Because the naturally occurring subtalar joint motion provides more inversion and less eversion, in scenarios with an unaffected subtalar joint, the hindfoot can compensate for a valgus supramalleolar deformity better than it can compensate for a varus tibial malunion. The soft tissue envelope must be examined well and taken into consideration. An acute correction of the deformity may cause stress on the


Fig. 17. A patient with an ankle valgus with end-stage ankle joint arthritis secondary to trauma. A supramalleolar osteotomy and a fibular lengthening is needed for realignment.

soft tissues and, in particular, the posterior tibial nerve. A tarsal tunnel syndrome can be caused with an acute varus or procurvatum correction. In patients who present with these conditions, the surgeon should consider a prophylactic tarsal tunnel release.

When performing the osteotomy, the goal is to create the osteotomy as close as possible to the level of the deformity to restore abnormal angles to as close to normal as possible and realign the center of the ankle joint for proper biomechanical function. Performing an osteotomy away from the apex of the deformity corrects the deformity and causes translation. The osteotomy can be a wedge cut, straight cut, or a focal dome osteotomy. Advantages of a focal dome osteotomy consist of a lack of thermal necrosis, minimal periosteal dissection, it can be performed percutaneously, and that it has inherent stability with excellent bone-to-bone contact. The osteotomy accounts for the angular and translational components of a typical opening or closing wedge osteotomy. Focal dome osteotomies minimize the lengthening and shortening of the tibia.[58] Numerous fixation methods have been used to achieve stability at the osteotomy site. Fixation techniques consist of a multitude of internal and external fixation constructs. Contraindications consist of impaired neurovascular status, active skin infections, and active bone infections (**Figs. 16** and **17**).

## SUMMARY

End-stage ankle arthritis is a debilitating condition that leads to pain and swelling in the ankle joint, with symptoms aggravated by standing and ambulation. Ankle arthritis commonly results from a history of trauma, or a series of recurrent injuries to the ankle. However, it may develop from other causes such as uneven loading of the ankle joint caused by an alignment deformity or from inflammatory arthritis such as rheumatoid arthritis, gout, or secondary to a serious joint infection. Patients with severe ankle arthritis often have limited ankle motion with an antalgic gait.

Nonoperative treatment is designed to improve function and decrease pain and is based on limiting the amount of loading through the ankle joint, masking the symptoms with antiinflammatory medication and pain medications. Nonoperative care can consist of ankle bracing and rocker-bottom shoe wear.

Operative treatment may be helpful if nonoperative treatment is unsuccessful. These options consist of joint-sparing and joint-destructive procedures. Ankle arthrodesis currently remains the gold standard for advanced ankle arthritis. Although predictable, this procedure has long-term consequences that the surgeon must consider. Available joint-sparing procedures consist of arthrodiastasis, total ankle allograft replacement, supramalleolar osteotomies, and total ankle replacements. Despite promising reports, it has been the authors experience that ankle arthrodiastasis has limitations and realistic expectations are needed regarding long-term results. The authors therefore use this procedure in younger patients who are too young to have an ankle arthroplasty and do not want a fusion. With mixed and limited reports on total ankle allograft replacement, this is a procedure that needs to be assessed more in the years to come. Supramalleolar osteotomies are performed to realign the distal tibia and improve foot and ankle function in those patients who suffer from end-stage ankle joint arthritis and juxta-articular tibial deformity. In the right scenario, this procedure can be powerful and possibly delay additional surgery to the ankle joint.

Newer ankle implants provide patients with decreased pain and improved function. However, these patients must be educated on future physical limitations. Current clinical outcomes of ankle replacement are satisfactory and are more predictable. In terms of function, the ankle replacement is better than an ankle fusion. Ankle replacement preserves motion at the ankle and allows improved function. The motion of the ankle implant also provides a protective function for the remaining joints in the foot, which can develop arthritis because of increased stress of a fused ankle. As more ankle replacements are inserted and more surgeons are performing the procedures, the medical industry will continue to expand, refine, and improve the already successful ankle implants. With increasing supportive medical literature and predictable outcomes, the authors think that implants will continue to be the procedure of choice for selected patients who suffer from end-stage ankle arthritis.

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