Total Replacement of Varus Ankle
Three-Component Prosthesis Design

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INTRODUCTION
In the past few decades, total ankle replacement (TAR) has become an increasingly recommended and accepted treatment in patients with end-stage ankle osteoarthritis (OA). However, controversy still exists about the appropriate indications for TAR, specifically in ankles with coronal plane deformities. These concerns are particularly true for patients with a varus deformity, where the talus has tilted into varus within the ankle mortise due to a medial soft tissue contracture and lateral soft tissue incompetence. While standing, the center of force transmission is medialized. The forces within the joint are amplified by activation of the triceps surae, and the Achilles tendon may become an invertor, thereby acting as an additional deforming force on the hindfoot.

KEYWORDS
- Ankle osteoarthritis
- Total ankle replacement
- Varus deformity
- Varus instability
- 3-component ankle prosthesis

KEY POINTS
- In most cases, a varus, misaligned, unstable ankle needs additional surgeries after a 3-component total ankle replacement to become balanced.
- Balancing the ankle using osteotomies above, at, and below the ankle in combination with soft tissue releases (medial side) and reconstruction (lateral side) is crucial for patient treatment.
- Radiographic assessment includes bilateral, weight-bearing anteroposterior and lateral views of the foot and ankle and hindfoot alignment view. Weight-bearing computed tomography can be helpful in identifying and quantifying degenerative changes, malposition, and deformities of the hindfoot.
- Long-term success highly depends on the extent to which the surgeon was able to balance the ankle.
Theoretically, the malalignment can be addressed intraoperatively with correcting cuts, but there are obvious limitations. Additional measures are necessary to obtain a balanced ankle, namely osteotomies with the specific aims of (1) realigning the hindfoot, (2) transferring the ankle joint under the weight-bearing axis, and (3) normalizing the direction of the force vector of the triceps surae. These measures are particularly crucial when implanting a 3-component total ankle system, where the second interface of the prosthesis allows the polyethylene insert to freely translate and rotate on the flat surface of the tibial component. Although not explicitly proved, the long-term success of TAR seems to largely depend on the extent to which the surgeon is able to balance the ankle joint complex.

**Indications and Contraindications for Total Ankle Replacement**

TAR has become a widely accepted treatment option in patients with end-stage ankle OA. However, in varus malaligned and/or varus unstable ankles, the success of TAR depends on how well the surgeon is able to balance and stabilize the ankle. This is particularly true when using a 3-component total ankle system, which is able to adapt its axis of rotation to the patient’s osteoarthritic ankle; however, it does not provide intrinsic stability to the ankle. The relative contraindications include a significantly reduced ankle dorsiflexion power due to neurologic disorders where active dorsiflexion may be weakened or unable to be improved postoperatively. Extensive scars around the ankle and atrophy of the periarticular soft tissue mantle is another relative contraindication for TAR. The absolute contraindications for TAR include acute or chronic infections with or without osteomyelitis, nonmanageable hindfoot malalignment and/or instability, and neuromuscular disorders with or without neuroarthropathy.

**Preoperative Planning**

**Clinical examination**

Preoperative planning starts with the careful assessment of patient history, including a complete study of all available medical records mentioning any previous surgical treatments. The following aspects should be addressed in detail: actual pain, limitations in daily life, sports and recreational activities, and all previous and current treatments. All patients should be asked if they had any trauma, surgeries, concomitant diseases, or infections in the past. In patients with ankle stiffness and/or equinus contracture, it should be clarified whether the stiffness and/or contracture has progressed over the last few months. Patients with any of the aforementioned contraindications should be excluded.

The routine physical examination includes careful inspection of both lower extremities and observation of the patient while walking and standing. The patient’s neurovascular status should be evaluated; in particular, the integrity of the tibial nerve function should be proved. Alignment, deformities, and foot/ankle/hindfoot position are visually assessed. In cases with a cavovarus deformity, the first ray is assessed to evaluate if a fixed plantar flexion is causing the hindfoot varus. Muscular functional status and atrophy should be assessed, and special attention should be paid to possible tightness of the heel cord and function of plantar flexors, including posterior tibial muscle and flexor hallucis longus muscle. Next, pain or tenderness on palpation is evaluated. Hindfoot and ankle stability is assessed manually with the patient sitting. Finally, tibiotalar range of motion is measured in the sagittal plane (plantar flexion/dorsiflexion) and in the coronal plane (eversion/inversion). Ankle range
of motion is determined with a goniometer, which is placed along the lateral border of the leg and foot. All goniometer measurements are performed in the weight-bearing position as described by Lindsjö and colleagues. To ensure the range of motion measurement is solely from the tibiotalar joint and not also in combination with the midfoot/hindfoot joints, it is recommended to use weight-bearing lateral radiographs in the position of maximal dorsiflexion and plantar flexion.

**Radiographic evaluation**
As non–weight-bearing radiographs do not show the true extent of the deformity (Fig. 2), the routine radiographic evaluation should include bilateral weight-bearing anteroposterior and lateral views of the foot and ankle (Fig. 3A–C). For appropriate assessment of inframalleolar alignment, a hindfoot alignment view (Saltzman view) should be performed (Fig. 3D). Weight-bearing radiographs should be used to identify and quantify degenerative changes, malposition, and deformities of the tibiotalar joint. Furthermore, possible concomitant degenerative changes and/or deformities in the adjacent joints of the hindfoot and midfoot should be identified and assessed. Recently, the routine use of weight-bearing computed tomography was started to assess hindfoot alignment and the complexity of the degenerative changes of the hindfoot (Fig. 4). Magnetic resonance imaging (MRI) is not routinely recommended. However, in some cases, this imaging may be helpful to evaluate possible tendon and muscular pathologies.

**Surgical Strategies**
At the time of TAR, periarticular osteotomies are indicated when the preexisting deformities cannot sufficiently be addressed by correcting resection cuts, soft tissue releases (including ligaments, capsular, tendons), ligament reconstructions, and/or tendon transfers, for example, a stable and well-balanced ankle joint complex would not be achieved with all these measures.

**Periarticular osteotomies**
Periarticular correcting osteotomies have been shown to be the most successful treatment to balance a malaligned ankle with early stage OA while still preserving the ankle...
However, despite the procedure’s success, only a few studies report on its use in the treatment of advanced stage ankle OA where the malaligned ankle joint cannot be preserved and thus TAR is considered. Periarticular osteotomies are divided into supramalleolar, intraarticular, and inframalleolar osteotomies.

A supramalleolar osteotomy is considered in cases where the origin of deformity is located above the ankle joint (Fig. 5). As a principle, it is done before replacement of the ankle. The procedure aims to translate the ankle joint to be in line with the weight-bearing axis and to normalize the direction of the force vector of the triceps surae, thereby realigning the hindfoot. An open or closing wedge osteotomy on the medial or lateral side, or, in severe deformities, an anterior, domelike osteotomy can be considered to achieve a neutral TAS angle and/or to correct a pathologic slope of distal tibia (Fig. 6). The height of osteotomy is selected according to the CORA with the aim to move the longitudinal axis of the tibia to cross the tibiotalar joint at its center.

Performed as a stand-alone procedure or in addition to a tibial correcting osteotomy, a fibular osteotomy (Fig. 7) is considered when addressing a malpositioning that may hinder reduction of the talus, for example, shortening, lengthening, derotation, or abduction. Used implants for internal fixation of osteotomies should not hinder the insertion of the components of the ankle (Fig. 8).

An osteotomy of the medial malleolus serves to release the medial ankle with severe varus deformities, where the tension of the deltoid ligament hinders the talus from being properly positioned within the ankle mortise, for example, when there is a persisting talar tilt at the end of an ankle replacement.

In contrast to a supramalleolar correction, an inframalleolar osteotomy is considered after TAR if there is a persisting malalignment of the hindfoot (Fig. 9).
A calcaneal osteotomy aims to realign the hindfoot and normalize the direction of the force vector of the triceps surae. A lateral sliding osteotomy of the calcaneus (with or without lateral closing wedge)\textsuperscript{55,56} or a Z-shaped calcaneal osteotomy\textsuperscript{57,58} can be considered to achieve a neutral alignment of the hindfoot.

Osteotomies of the medial arch aim to realign the forefoot with the hindfoot. In the case of forefoot pronation, for example, a plantarflexed first metatarsal, a dorsal closing wedge osteotomy of first cuneiform is considered.\textsuperscript{31,59}

Fig. 3. Weight-bearing radiographs of same patient as Fig. 2. (A) AP view of the ankle, (B) lateral view of the foot and ankle, and (C) AP view of the foot. (D) Hindfoot alignment view (Saltzman view). These standard radiographs are taken bilaterally to assess the amount of deviation from the unaffected, contralateral foot and ankle and the overall deformity.
Additional procedures
Although periarticular osteotomies are effective at balancing a malaligned ankles, in some instances they may not be sufficient to achieve a stable and well-balanced ankle. Therefore, additional procedures are often necessary for the long-term success of the replaced ankle.

A subtalar arthrodesis is considered to correct a fixed deformity, stabilize a highly unstable joint, or address pain originating from progressive degenerative changes. In most instances, an interposition technique with the use of a bone graft should be considered to tighten the collapsed ligaments of the ankle joint complex.

A ligament reconstruction is considered to stabilize the talus in the corrected position within the ankle mortise. Anatomic repair of the remaining ligaments can be augmented with the use of free tendon autografts, for example, plantaris tendon or semitendinosus tendon. If available, the use of allografts can also be considered. Although effective for stabilization of the ankle joint complex, tenodesis techniques should not be used, because they change the biomechanics and limit the motion of the ankle joint.

Tendon transfers are considered to restore and balance muscular forces. In cases with a dysfunctional peroneal brevis, a peroneus longus to peroneus brevis tendon transfer should be considered.

Surgical Technique
The surgery can be performed under general or regional anesthesia. The patient is placed in a supine position, with the ipsilateral back of the patient lifted until a strictly upward position of the foot is obtained. A pneumatic tourniquet is applied on the ipsilateral thigh.

Fluoroscopic assessment should be done under anesthesia before surgery. With passive manipulation and application of varus or valgus stress, the extent of correction of the talar position and the amount of lateral ankle instability can be assessed.

Fig. 4. Weight-bearing computed tomography scans are used to assess hindfoot alignment and the complexity of the degenerative changes of the hindfoot (same patient as Fig. 2). (A) AP view. (B) Lateral view shows a well-centralized talus beneath the tibia and significant degenerative changes at ankle joint.
If the varus deformity has its origin above the ankle joint, for example, in cases with a malunited tibial fracture or a tibia vara, a supramalleolar osteotomy is done first (see Figs. 5–7). Usually the osteotomy can be done through the same anterior approach, which later can be used for TAR. Although an opening wedge osteotomy

Fig. 5. A 68-year-old female patient suffering from progressive pain due to secondary OA in a severe varus deformity after a malunited ankle fracture at the age of 14 years. (A) The AP view shows a varus angulation of the distal tibia (TAS-angle) of 12° and a significantly shortened medial malleolus; the talus is tilted into varus by >20°. (B) The hindfoot alignment view confirms the varus malalignment of the hindfoot. (C) The lateral view shows the well-centralized position of the talus beneath the tibia.
is considered for minor corrections, a dome osteotomy is considered for a correction of more than 8°, because graft incorporation and bone healing would take too long for such an extended correction. In cases with a concomitant recurvatum deformity, the osteotomy is opened at its anterior aspect as well to realign the distal tibia in the sagittal plane. When fixing a plate, fixation should be done to avoid interfering with the subsequent TAR. After the supramalleolar correction, the anatomic axis of the tibia should cross the tibiotalar joint in its center in both the coronal and sagittal plane.

If TAR is still necessary after supramalleolar correction, the surgeons use the standard technique: the jig references the tuberosity of tibia for alignment in the coronal plane and the anterior tibial border for alignment in the sagittal plane (Fig. 11). If the talus cannot be reduced after insertion of all components, the medial ankle complex may be too tight or the fibula may be too long. Although an extended deltoid ligament release has been advocated by others,¹⁶,²²,⁶⁰,⁶⁴,⁶⁵ the investigators prefer a flip osteotomy of the medial malleolus (Fig. 12).¹⁵ The advantage of this technique is that the offset position of the medial malleolus is corrected toward normal; subsequently, the medial malleolus may guide the talus to its corrected position. Besides normalizing the external contours of the medial ankle, which may be beneficial when selecting shoe wear, the technique normalizes the pull of the deltoid ligament. This is not the case for Doets’ lengthening osteotomy of the medial malleolus.⁴⁷ In addition, this vertical translational osteotomy weakens the medial shoulder of the ankle with the risk of a subsequent stress fracture.

Thereafter, lateral stability is tested with passive manipulation and varus stress. If the talus tilts into varus while applying varus stress, a ligament reconstruction is

![Fig. 6. A dome osteotomy is used for supramalleolar correction before TAR. (A) The distal tibia and the ankle joint are exposed through an anterior approach, and multiple drill holes are made along the circle. The distal tibia is then rotated into the desired neutral position. (B) Two plates are used for fixation.](image-url)
completed with reattachment of torn ligaments to the fibula. This can be done through the anterior approach (Fig. 13) or by a separate lateral approach (Fig. 14).

As a next step, the heel position is carefully checked through comparison to the lower leg axis. If persistent varus deformity of the heel exists and can easily be corrected manually by applying eversion torque, a peroneus longus to peroneus brevis

Fig. 7. The distal tibia cannot be moved without an osteotomy of the fibula. (A) The fibula is osteotomized with an oblique double cut, and the intermediate bone piece is removed. (B) Thereafter, the fibula is also fixed by a plate. Close attention is paid to the angulation at the osteotomy level.

Fig. 8. The plate fixation of the supramalleolar correction must account for the space needed for the ankle prosthesis. (A) AP view; (B) lateral view.
If the heel cannot be sufficiently corrected, a calcaneal osteotomy is considered. Although a lateral sliding osteotomy has some limitations, the investigators prefer a modified technique of the Italian Z-osteotomy that allows a valgization tilt and a lateral translation of the tuber calcanei.

Fig. 9. (A) After the ankle prosthesis is inserted using the standard technique, the hindfoot alignment is checked clinically. (B) In this case, a valgus deformity has resulted from important supramalleolar correction. (C) After a medial sliding osteotomy of calcaneus, the hindfoot alignment has normalized.
Finally, forefoot alignment is checked by holding the foot in a neutral position. In the case of a plantar-flexed first ray, the first cuneiform or base of the first metatarsal is exposed through a dorsal approach. A closing wedge osteotomy is done to achieve appropriate correction of the forefoot.

Fig. 10. Before starting the surgery, manual testing is used to determine whether the deformity is correctable. (A) Setup. (B) In this case, the talus can be reduced to neutral, indicating that the surgeon is dealing with a correctable deformity (same patient as Fig. 2).

Fig. 11. Resection cuts for TAR. (A and B) The tibial resection bloc is adjusted to longitudinal axis of tibia which will typically result in a larger resection to lateral tibia. (C) Attention is paid to resect minimal bone on medial side. (D) Positioning of the foot in a strictly neutral position will ensure for a symmetrical cut on talar side. (E) After insertion of spacer, a subtle varus position is seen due to medial overstuff.
Fig. 12. Implant insertion and balancing of the ankle. (A) The resection cuts of the talus are finalized. (B) After insertion of the implants, the medial malleolus is in a medial deviation, leaving a substantial gap near the prosthesis and a distinct lateral opening of the ankle. (C) Therefore, an oblique osteotomy with a 45° to the longitudinal tibia axis is performed. (D) Osteotomy before mobilization of the medial malleolus. (E) The medial malleolus is turned to a neutral position and fixed by 2 percutaneous K-wires that serve to insert the cannulated screws. (F) Bone from resection of the tibia is used to fill the gap at the osteotomy site. (G) The AP-view under fluoroscopy shows the final situation with a well-balanced ankle. (H) Lateral view.
Complications

Intraoperative complications include neurovascular injuries. An important consideration, especially with acute corrections, is the posterior tibial nerve. Varus-to-valgus

Fig. 13. Lateral ligament reconstruction through an anterior approach (same patient as Fig. 2). (A) A bony anchor is inserted into a hollow insertion site at the lateral ankle ligaments. (B) Final situation after reattachment of lateral ankle ligaments.

Fig. 14. Lateral ligament reconstruction through a lateral approach. (A) After exposure and debridement, the lateral ankle ligaments are taken by the sutures of a bony anchor. (B) Final situation after lateral ankle ligament reconstruction.
corrections stretch this nerve. Acute tarsal tunnel syndrome can originate from acute varus-to-valgus corrections. A prophylactic tarsal tunnel release may be indicated for such acute corrections, especially in cases with previous scarring.

Perioperative wound-healing problems may result from inappropriate treatment of soft tissue during the surgery, the use of too bulky implants, and previous soft-tissue damage.

Over- or undercorrection may occur following inappropriate preoperative planning, or, if fluoroscopy is not used, for meticulous control of aimed cuts.

Delayed or nonunion of periarticular osteotomies may result from inappropriate fixation techniques or too aggressive loading of the leg in the early postoperative phase. Loss of correction may occur due to implant failure or inappropriately addressed concomitant problems, such as ligamentous incompetence, muscular dysfunction, and forefoot deformities.

**Postoperative Management**

Patients are placed in a below knee splint for 2 weeks followed by a removable walker with instructions to remain partially weight-bearing. In the case of additional interventions such as fusions or soft tissue reconstructions, a lower leg plaster may be used. Once bone healing is achieved (Fig. 15), usually after 8 weeks, full weight-bearing is permitted and a specific rehabilitation program is started. The program includes passive and active mobilization of the ankle, proprioception, coordination, gait improvement, and strength training.

**RESULTS**

In a consecutive cohort of 1244 primary TAR performed between 10/2000 and 12/2015, 140 ankles (18.4%) showed a preoperative varus hindfoot alignment associated with a varus tilt of at least 5° (mean 12° ± 6° [range, 5°-35°] varus tilt) in the mortise preoperatively. There were 98 male and 42 female patients with a mean age of 64 ± 10.7 years (range, 22–85 years). The mean body mass index was 27.5 ± 4.4 kg/m² (range, 17.8–40.5 kg/m²). The cause of OA was posttraumatic in 106 ankles (75.7%), primary in 16 ankles (11.4%), systemic in 12 ankles (8.6%), and secondary/other reason in 6 ankles (4.3%). Two hundred fifty-two additional surgeries (mean 1.8 [range, 0–6] per ankle) were done at the time of TAR (Table 1). The number of additional surgeries was lower in the first 70 ankles treated than in the last 70 ankles treated.

The American Orthopedic Foot & Ankle Society hindfoot score increased from 37.2 (range, 7–70) preoperatively to 76.6 (range, 10–100) at the last follow-up, with a mean of 5.0 ± 3.4 years (range, 2.0–12.8 years). Pain on visual analog scale improved from 6.2 (range, 2–10) preoperatively to 1.8 (range, 0–8) postoperatively. The ankle range of motion improved from 29.6° (range, 2°–60°) preoperatively to 32.7° (range, 10°-60°) postoperatively.

A postoperative dislocation of the polyethylene insert occurred in 3 ankles (2.1%). After revision, all but one were stable, and further evolution was uneventful. In 16 ankles, a revision of a metallic component or conversion into arthrodesis was performed. The Kaplan-Meier Survival estimate was 78.5% at 10 years. A revision of components was done in 10 ankles (7.2%) due to either loosening (3 ankles, 2.1%), subsidence (1 ankle, 0.7%), malpositioning (3 ankles, 2.7%), or deep infection (3 ankles, 2.1%). Although the tibial component was revised in 2 ankles (1.4%) and the talar component in 1 ankle (0.7%), a revision of both components was performed in 7 ankles (5.0%). A conversion into an ankle arthrodesis was done in 6 ankles (4.3%).
Fig. 15. Radiographic control after 8 weeks (same patient as Fig. 5). (A) The AP view shows a well-balanced ankle with advanced healing at the osteotomy site. (B) The alignment view reveals a well-aligned hindfoot after supra- and inframalleolar correction. (C) The lateral view shows a well-balanced ankle with stable implants.
SUMMARY

Careful radiographic assessment of the talar position in all 3 planes is mandatory to successfully replace an end-stage osteoarthritic ankle joint associated with a concomitant major varus deformity. As correcting resection cuts for the prosthesis may not be able to restore proper position of the talus within the ankle mortise and provide overall stability of the ankle, additional osteotomies above or below the ankle or selective fusions may be necessary to obtain a well-balanced ankle and hindfoot joint complex. Besides lateral ligament reconstruction, peroneal tendon reconstruction or peroneus longus to peroneus brevis transfer and meticulous reorientation of the forefoot are mandatory for the long-term success of the replacement of a varus ankle. Overall, the key to success is to use all treatment modalities necessary to restore appropriate alignment of the hindfoot complex. From experience, the authors have learned to become more aggressive and use additional measures to balance the ankle. This strategy has led to an improved outcome.

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