

## Special Article

# Total ankle arthroplasty and deformity - is there a limit?

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## Abstract

Total ankle arthroplasty (TAA) has undergone a paradigm shift over the past decades, moving from being regarded as inferior to arthrodesis to becoming a preferred option for many patients with end-stage ankle arthritis. Advances in implant design, better understanding of biomechanics, and refinement of surgical techniques have expanded its indications and outcomes. Compared with arthrodesis, TAA offers preserved ankle motion, improved functional results, and lower risk of adjacent joint degeneration, while providing equivalent pain relief. Historically, coronal plane deformity thresholds, such as limiting TAA to patients with less than 10–15° of malalignment, were considered necessary to ensure implant survival and stability. However, recent studies challenge these rigid criteria, demonstrating successful outcomes even in cases with deformities up to 30°, provided that appropriate osseous realignment and ligamentous stability are achieved intraoperatively. Evidence increasingly supports that residual, rather than preoperative deformity, is the critical prognostic factor influencing long-term implant success. This perspective emphasizes the importance of comprehensive preoperative planning, including assessment of limb alignment, hindfoot and subtalar joint involvement, and ligamentous balance. With adjunctive procedures for correction, modern prosthetic designs, and careful patient selection, TAA can yield stable, plantigrade, and functional ankles across a broader spectrum of deformities than previously accepted. The question “Is there a limit?” may no longer be defined by a strict degree of malalignment, but instead by the surgeon’s ability to restore alignment and stability, ensuring durable and satisfactory outcomes for patients undergoing ankle replacement.

**Level of evidence I; Type of study; Evaluation of results.**

**Keywords:** Arthroplasty, Replacement, Ankle; Ankle Joint / surgery; Joint Deformities, Acquired / surgery.

## Introduction

With increased understanding of pathophysiology and innovation in implant design, there has been a shift in the discussion of ankle arthroplasty viability compared to traditional arthrodesis which draws into question the feasible limits of ankle arthroplasty. The procedure has evolved significantly, from once being viewed as inferior to arthrodesis to now being considered a preferred option for a broader spectrum of patients and pathologies. When compared with arthrodesis, total ankle arthroplasty (TAA) utilization has increased and has emerged as the preferred alternative<sup>(1)</sup>. It has shown improved functional outcomes, comparable pain

relief (2–6), preserved range of motion and reduced incidence of adjacent joint osteoarthritis<sup>(2, 3–12)</sup>.

The use of coronal plane deformity thresholds—such as reserving ankle arthroplasty for patients with 10–2° of malalignment is largely arbitrary<sup>(13–21)</sup>, though no definitive cutoff has been clinically validated. Doets et al.<sup>(22)</sup> reported 8-year survival rates of 48% and 90% for ankles with and without preoperative deformity >10°, respectively, showing a significant difference. Wood et al.<sup>(15)</sup> recommended that TAA should not be performed in patients with a preoperative coronal plane deformity greater than 15°, citing a 7-fold higher risk of developing edge loading in comparison to preoperative

Study performed at the Northwestern University Department of Orthopaedic Surgery, Evanston, Illinois, USA.

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neutrally aligned ankles; this study was limited, however, by small sample size and use of a single implant. In contrast, Trajkovski et al.<sup>(13)</sup> found no differences in complications or outcomes between patients with 10° and 20° of preoperative deformity and argue that the main prognostic factor is not the degree of preoperative deformity, but rather residual deformity which is dependent on surgical technique. Recent literature shows a trend toward expansion of indications for TAA in increasingly severe deformities so long as adequate alignment is achieved at the time of arthroplasty<sup>(23,24)</sup>. The senior author argues that no amount of pre-existing coronal plane malalignment is unacceptable if osseous realignment and ligamentous stability can be achieved.

Improvements in prosthesis design<sup>(25,26)</sup>, surgical technique<sup>(27,28)</sup>, increased adoption of ancillary soft tissue procedures for realignment and balancing, and careful patient selection help address these concerns<sup>(10,11)</sup>, resulting in a stable, well-balanced ankle which is necessary for acceptable outcomes following joint replacement surgery<sup>(29,30)</sup>. Multiple studies have reported successful outcomes in preoperative coronal plane deformities of up to 30°<sup>(17,31)</sup> if correction of alignment and instability is performed adequately, without a meaningful increase in complications and with satisfactory clinical outcomes<sup>(17,18,24,31-36)</sup>.

## Ankle Joint Deformity

Understanding ankle biomechanics is critical when planning for TAA. Surgeons should consider the following: limb and ankle alignment, bony and ligamentous anatomy of the ankle joint, ankle motion (in the sagittal, coronal, and transverse planes, and contributions of the talocrural and subtalar joints to motion. Degenerative changes in other joints, such as the subtalar, midtarsal, knee, and contralateral ankle should be taken into account as well.

Malalignment and instability should be thoroughly evaluated in preoperative planning prior to TAA, as both can lead to edge-loading of the implant, polyethylene wear, progressive deformity, and high early failure rates. Malalignment can be due to: <sup>(1)</sup> previous tibial fractures which result in diaphyseal or metaphyseal tibial malalignment (either in the coronal or sagittal plane);<sup>(2)</sup> multi-articular degeneration of the hindfoot involving the subtalar and midtarsal joints (i.e., rheumatoid patients) which can result in varus or valgus malalignment; and<sup>(3)</sup> ankle joint pathologies that include distal tibial articular surface malalignment, talar tilt due to ligamentous instability, or both<sup>(37)</sup>. Deformities are divided into those arising proximal to the ankle joint, those at the level of the joint (talar tilt), and those associated with deformity below the ankle joint. It is essential to achieve reasonable correction of deformities and a neutral final position of TAA implant with plantigrade foot for the success of the procedure.

## Deformities Proximal to the Ankle Joint

Deformities proximal to the joint can either be remote or supramalleolar deformities. Examples of remote proximal

deformities include genu varum, genu valgum, and tibial diaphyseal malunion. Diaphyseal or metaphyseal tibial malalignment usually needs to be addressed with osteotomy before considering TAA<sup>(38)</sup>. Supramalleolar deformities may be congenital, posttraumatic, or acquired secondary to erosion of the tibial plafond joint surface. Diagnostic evaluation must include bilateral long-leg standing radiographs to assess alignment comprehensively.

## Deformities At the Ankle Joint

When the malalignment is in the ankle joint, it can be due to: (1) tibial joint line deformity or progressive degeneration; (2) an incongruent (unstable) joint; or (3) both. These deformities are usually in the coronal plane. An ankle is defined as congruent when the difference between the talar and tibial alignment is < 10°; otherwise, it is incongruent. This allows four categories of deformity to be defined: varus-congruent, valgus-congruent, varus-incongruent, and valgus-incongruent<sup>(38)</sup>. Intraarticular deformities frequently involve erosive changes of the tibial plafond, malleolar dysplasia, and osteophytes that may make reduction difficult.

## Deformities Distal to the Ankle Joint

Compensatory varus/valgus deformities can occur in the foot. Deformities of the distal tibia usually are compensated in the subtalar joint and the forefoot. The subtalar joint will compensate for a distal tibial varus deformity by moving into an everted position. Because the average eversion in the subtalar joint is 10°, varus deformities >10° may cause symptoms on the lateral border of the foot. Further compensation occurs in the forefoot, with distal tibial varus compensated by forefoot pronation. This is seen as a valgus forefoot or a plantar flexed first ray when the patient's foot is examined in the non-weight bearing position. Distal tibial valgus will be compensated with subtalar inversion and forefoot varus. The need to correct the compensatory deformities depends on their extent and rigidity. The goal of correction is to create a plantigrade foot, and the compensatory deformity may be treated with arthrodesis, osteotomy, or tenotomy to achieve this goal. Muscle imbalance may also be associated with a compensatory deformity and require treatment with tendon transfer.

## History and Physical Examination

Evaluation begins with general medical and surgical history and focused history of the affected ankle with regards to pain, potential causes, prior treatments, level of disability, analgesic use, and concomitant diagnoses (i.e. diabetes mellitus, osteoporosis, polyneuropathy, neuromuscular diseases, etc.).

Physical examination involves assessing lower extremity alignment, particularly ankle and hindfoot varus/valgus deformities. Determining the relative contributions of the tibiotalar joint, hindfoot, midfoot, and forefoot to the

deformity is crucial. Midfoot and forefoot deformities such as planus, cavus, adduction or abduction, or excessive first ray plantarflexion/dorsiflexion should also be carefully documented. Evaluating range of motion is critical, as preoperative motion significantly influences postoperative outcomes<sup>(39)</sup>. The arc of inversion and eversion should also be documented. In severe valgus deformities, if the arc of inversion has been lost, this article's senior author recommends hindfoot arthrodesis given the deformity and rigidity, including deltoid reconstruction with allograft, prior to TAA in staged fashion (12 weeks following hindfoot correction).

Patients with end-stage ankle arthritis often have degenerative changes in adjacent joints. Symptomatic joints should be identified through clinical examination. A thorough neurovascular examination should also be performed. The ideal candidate for TAR is: middle aged or older, reasonably mobile, minimal significant comorbidities, with low impact activity demands, good bone stock and healthy soft tissues.

Absolute contraindications to TAA include: acute or chronic infections, peripheral vascular disease, inadequate soft tissue envelope, severe osteonecrosis of the talus (>1/3 of the talus), neuromuscular diseases which preclude active dorsiflexion, and Charcot neuroarthropathy<sup>(26,40)</sup>. Relative contraindications include young, active patients, history of prior infection, marked osteoporosis, history of prior fusion, and mild osteonecrosis of the talus<sup>(26)</sup>. Importantly, inability to correct proximal tibial or distal hindfoot/midfoot deformity is a contraindication to TAA; placing the ankle in a malaligned position to correct for a proximal deformity is not recommended.

## Imaging

Standard standing anteroposterior and lateral views of the ankle, dorsoplantar and lateral views of the foot, and hindfoot alignment view (HAV; Saltzman view) should be obtained. Bilateral radiographs should be taken for comparison<sup>(41)</sup>. Weight bearing computed tomography (WBCT) scans are ideal, however, standard CT scans, including 3-dimensional reconstructions, allow for a detailed understanding of bone erosions or cysts, osteophytes, degenerative changes, and planes of deformity. Large anteromedial and inferolateral talar osteophytes that can prevent reduction of the talus into the ankle mortise. These osteophytes can form a ring around the talar neck and have previously been termed "horseshoe osteophytes"<sup>(42)</sup>. There are often large anterior fibular osteophytes that also require resection. The CT scan also helps define the presence and degree of malleolar dysplasia, which may need to be addressed surgically. The presence of degenerative changes may influence the decision to proceed with arthrodesis procedures rather than joint sparing procedures to correct deformity.

## Surgical Technique

TAA may be performed under either general or regional anesthesia. While some surgeons may place a pneumatic

tourniquet on the ipsilateral thigh, the senior author prefers to perform all procedures without the use of a tourniquet. Prior to making incision, the ankle should be assessed under fluoroscopic guidance; with passive range of motion and application of varus and valgus stress, the extent of talar correction and the degree of ankle instability may be assessed. Standard technique for TAA is employed. Implantation of the total ankle in the setting of severe deformity is not significantly different than in a patient without deformity as correction of the hindfoot and/or proximal deformity should be performed prior to the total ankle replacement. The techniques of TAA in the setting of severe varus and valgus deformity are described below.

## Varus Deformity

Controversy surrounding the acceptable degree of deformity prior to TAA is particularly relevant in patients with varus malalignment, where the talus is tilted into varus within the ankle mortise due to medial soft tissue contracture and lateral soft tissue insufficiency. During weight bearing, the center of force transmission shifts medially, resulting in increased joint loading. This is further exacerbated by activation of the triceps surae, as the Achilles tendon may function as an inverter in this context, thereby contributing additional deforming forces to the hindfoot and further challenging alignment correction.

While intraoperative correction of malalignment through bone cuts is theoretically possible, this approach has inherent limitations. If the deformity is done through bony cuts and not through addressing deformity of the hindfoot, this will leave persistent deforming forces and decrease the longevity of the implant, increasing stress on the poly or causing increased wear of the tibial implant and should not be the primary choice for correcting deformity.

Proximal deformities generally originate the distal femur, proximal tibia, or tibial shaft, often due to prior trauma. Before considering TAA, correcting this proximal deformity is critical to reestablish proper anatomical alignment. Surgical correction typically involves a proximal or midshaft tibial osteotomy, utilizing either plates or intramedullary nails. Following successful osteotomy and realignment, surgeons may proceed with a standard TAA in a staged fashion. Typically, at least 3 months between the two surgeries is appropriate.

When the deformity is located distally, the clinical approach varies depending on whether the deformity is intra-articular or supramalleolar. Intra-articular deformities, such as those caused by distal tibial or low pilon fractures, usually do not require additional osteotomy as the bone cuts performed during TAA can effectively correct these deformities. Standard TAA techniques can generally resolve intra-articular deformities without complication, provided that careful preoperative planning confirms deformity correction within standard TAA cuts.

In contrast, supramalleolar deformities present a more complex scenario. These deformities occur above the

planned TAA bone cuts and, if left uncorrected, can lead to excessive secondary deformities after arthroplasty. Addressing these deformities typically involves a dome osteotomy or wedge osteotomy, either medial opening or lateral closing, based on the specific nature and severity of the deformity. Dome osteotomy often offers the advantage of aligning with an anterior surgical incision, facilitating subsequent TAA procedures. Concurrent fibular osteotomy is usually performed to maintain correct ankle joint biomechanics by preserving the central rotation axis and can easily be done with a MIS burr or small lateral incision. After the osteotomy heals adequately, a standard TAA can be carried out safely. In the case of a SMO the senior author advises at least 6 months before TAA to ensure appropriate bony healing and in some cases, correction of deformity will decrease the pain within the ankle sufficiently such that the patient does not wish to proceed further.

### **Correction of Cavovarus Hindfoot Deformity Prior to Total Ankle Arthroplasty**

In evaluating cavovarus deformity of the hindfoot prior to TAA, careful examination of hindfoot mobility is crucial to determine whether the deformity is flexible or rigid. This flexibility can be confirmed by passively manipulating the hindfoot into a neutral alignment. If passive correction to neutral alignment cannot be achieved, this indicates rigidity, and the surgeon should strongly consider performing an arthrodesis, as attempting joint-preserving corrections in rigid deformity typically leads to suboptimal outcomes.

However, when the hindfoot demonstrates sufficient flexibility, hindfoot osteotomy and selective arthrodesis of the midfoot can be utilized to achieve optimal alignment. Aggressive correction of both the static and dynamic aspects of cavovarus deformity is imperative, as comprehensive deformity correction greatly improves the long-term success of the subsequent TAA.

The senior author's approach to addressing cavovarus deformities of the hindfoot in preparation for TAA is intentionally aggressive. In his experience, subtle under-correction often leads to persistent deformity, resulting in recurrent issues and potential revision surgery. Thorough correction involving both hindfoot and midfoot procedures is critical to ensuring stable, balanced alignment and optimal outcomes following TAA.

The first procedural step involves performing a plantar fascia release through a small plantar medial incision. This release helps alleviate the plantar component of the cavus deformity and enables superior translation of the calcaneal osteotomy and 1st TMT dorsiflexion arthrodesis.

The second, and very important step, is performing a lateral closing wedge calcaneal osteotomy, utilizing a triplanar technique. Specifically, this involves osteotomy with simultaneous lateral and slight superior translation. This method corrects both cavus and varus deformities effectively, significantly altering and improving the biomechanical

forces transmitted through the ankle joint. This correction is paramount to the long-term function and durability of the ankle replacement.

Next, the senior author universally performs a peroneus longus-to-brevis tendon transfer, irrespective of the severity of the deformity. This transfer reliably removes the plantarflexion pull of the peroneus longus (PL) tendon, reducing the dynamic plantarflexion of the 1st ray during gait. The risk associated with this procedure is minimal. His preference is to perform the transfer approximately 4-5 cm proximal to the distal tip of the fibula. The PL tendon is securely sutured to the brevis tendon under appropriate tension before distal transection.

Following these procedures, a talonavicular capsular release is generally necessary to achieve complete hindfoot realignment. However, caution is essential here, as overly aggressive release, including the middle facet or deep deltoid ligament, can result in severe, problematic valgus instability. The senior author's approach is therefore conservative, limiting the release primarily to the talonavicular capsule and, if necessary, a careful partial release of the spring ligament. This approach reliably achieves correction without compromising medial stability.

In cases where the posterior tibial tendon (PTT) is significantly contracted and contributes dynamically to the varus deformity, a proximal medial incision above the medial malleolus is employed to perform a gentle Z-lengthening. This lengthening, approximately (1-1.5) cm, allows tendon relaxation and facilitates correction.

Most cavovarus deformities feature a component of midfoot cavus, necessitating correction. The senior author's preferred procedure is a 1st TMT dorsiflexion arthrodesis, either via a traditional open dorsal approach, which can potentially coincide with the future TAA anterior incision, or a minimally invasive dorsal-medial approach. Minimally invasive techniques allow for reliable correction while minimizing soft-tissue disruption. First TMT fixation is typically accomplished using screws or staples, based on surgeon preference. Although a dorsiflexion osteotomy of the first metatarsal is occasionally proposed as an alternative, we have found it often insufficient to produce the robust correction required in these cases.

Finally, addressing lateral collateral ligament instability is crucial to achieving a lasting correction. The timing of lateral ligament reconstruction (either concurrently with hindfoot correction or subsequently during TAA) involves nuanced decision-making. Simultaneous reconstruction has the advantage of simplifying the subsequent TAA but carries the drawback of uncertainty regarding the ideal tensioning relative to ankle alignment, potentially leading to recurrence.

In the setting of these cases it is important to understand that the goal is stability, not mobility. Using a posterolateral approach ensures adequate spacing between skin incisions. Manual reduction of the ankle into neutral alignment is critical and if cannot be achieved it may be more appropriate to perform this at the time of the TAA. If the ankle is mobile and

reducible to neutral, lateral ligament reconstruction at this stage is appropriate. Temporarily stabilizing the corrected ankle position with a robust transarticular K-wire allows confident tensioning of the lateral collateral reconstruction. Excision of lateral talar and fibular osteophytes are required prior to stabilization. In cases with pronounced cavovarus deformity and instability or with incongruent varus deformity, the senior author prefers an additional Evans procedure with use of the InternalBrace™ (Arthrex; Naples, FL) to stabilize the ankle.

A temporary cement spacer can be placed, maintaining a neutral tibiotalar relationship that prevents elongation of the lateral ligament reconstruction and allows flexibility before performing TAA. Because of the medial tibial wear that is typically present, unless an implant is placed within the joint, the lateral ligaments are not strong enough to maintain position and therefore necessitates something to fill that void. Ultimately, the sequencing of procedures—whether to stage or combine hindfoot and lateral ligament reconstructions with TAA—is a decision dependent on individual patient anatomy, deformity severity, surgeon comfort, and clinical judgment.

When the hindfoot cavovarus deformity is rigid or only partially correctable, hindfoot arthrodesis is recommended to achieve lasting correction. The senior author's preferred technique involves a single lateral incision along the course of the peroneal tendons, extending proximally and distally, facilitating access to effectively address the deformity through multiple simultaneous corrections.

Through this approach, a lateral closing-wedge subtalar arthrodesis is performed along with calcaneocuboid (CC) and talonavicular (TN) joint fusions. The lateral approach not only allows direct correction of the rigid hindfoot deformity but also accommodates concurrent lateral ligament stabilization using an Evans procedure augmented with an internal brace. As previously described, a peroneus longus-to-brevi tendon transfer is routinely performed to neutralize dynamic plantarflexion and varus-producing forces. Additionally, correcting the forefoot-driven component of cavus typically requires a 1st TMT dorsiflexion arthrodesis providing comprehensive midfoot and hindfoot realignment.

In these rigid deformities, due to the effectiveness of the lateral closing-wedge arthrodesis, a separate talonavicular capsular release usually becomes unnecessary. However, addressing persistent imbalance from medial soft tissue tension may still be required. Specifically, if the PTT demonstrates significant tension relative to the peroneus brevis tendon, this persistent force could predispose the foot to recurrent varus over time, despite successful arthrodesis. Therefore, PTT lengthening or even tenotomy can be beneficial. The senior author's preference in these rigid deformities is typically a small-incision PTT tenotomy, which reliably prevents residual dynamic varus pull and maintains long-term correction.

Once hindfoot arthrodesis has been performed, the ankle typically remains in slight residual varus alignment; however, this minimal residual deformity is typically corrected during

the TAA as the bone cuts and polyethylene restore neutral alignment of the ankle. However, any residual varus deformity of the hindfoot or midfoot may require a revision lateral calcaneal closing wedge osteotomy or revision 1st TMT arthrodesis if there is residual deformity at the time of TAA despite preoperative correction. After allowing approximately three months for adequate fusion and healing, confirmed by computed tomography (CT), proceed with TAA, addressing any residual ankle deformity or revision work concurrently, if necessary.

While some surgeons advocate combining hindfoot arthrodesis procedures (such as triple arthrodesis) with TAA in a single operation, the complexity and extent of surgical intervention in severe cavovarus deformities may significantly increase intraoperative complications and potentially compromise implant longevity. Existing clinical data suggest staging these procedures: first achieving a stable and corrected hindfoot alignment, then following with TAA. Ultimately, the choice of a staged or simultaneous approach hinges upon the surgeon's expertise, experience, comfort level, and individual patient factors. For surgeons less experienced or comfortable with extensive simultaneous corrections, a staged surgical protocol remains the recommended approach for managing severe or rigid cavovarus deformities prior to TAA.

When performing TAA in the setting of significant residual varus deformity, the standard anterior surgical approach is utilized. However, due to the deformity, gaining adequate exposure can be challenging. To address this, a slightly more extensile incision, extending distally toward the talonavicular joint and occasionally exposing the naviculocuneiform joint, can greatly improve visualization. This extended approach allows effective release of additional medial soft-tissue structures to achieve proper joint alignment.

Once adequate exposure is obtained, anatomical axes reference for the tibial cut or from patient-specific cutting guides are used. Provided that any proximal deformity has already been fully corrected, standard tibial and talar cuts are performed without significant deviation from typical TAA techniques. In cases where residual soft-tissue tension and deformity remain a concern, an accessory posteromedial incision can be advantageous. This secondary incision allows for posterior capsule release, facilitating improved ankle dorsiflexion and enhancing joint mobility. After performing the tibial and talar resections, joint preparation and total ankle component implantation proceed in the standard manner, initially selecting the smallest polyethylene component available.

Following prosthesis placement, assessment of medial soft-tissue tightness is necessary. A medial (deltoid) ligament release is frequently indicated, although not universally required. When the ankle remains in varus despite lateral ligament stabilization, a stepwise medial release is recommended. Initially, release the deep deltoid ligament from the tibial insertion, extending posteriorly with a blunt elevator as needed to complete the release to the level of the PTT. If further correction is required, elevate the superficial deltoid ligament from its insertion along the

medial malleolus, preserving proximal periosteal attachments to minimize instability risks. This staged medial soft-tissue release typically provides approximately 4–5° of additional correction, effectively addressing persistent varus alignment.

Following medial releases, assess ankle stability. An appropriately stable ankle prosthesis should exhibit stability in neutral dorsiflexion during varus and valgus stress testing. Residual instability in plantarflexion is common and typically acceptable. However, continued instability in neutral dorsiflexion mandates further intervention, either by primary or revision lateral ligament reconstruction. When lateral instability persists, utilize the smallest polyethylene insert initially to properly tension the reconstruction, and subsequently upsize the polyethylene component slightly to reinforce joint stability further.

Several adjunctive techniques have been described in severe residual varus deformity situations, such as vertical medial malleolar osteotomy. This procedure involves making a vertical osteotomy anteriorly through the medial malleolus down to the level of the tibial component and translating it inferiorly to correct residual deformity, subsequently stabilizing it with plates/screw fixation. The senior author does not prefer this method due to risks of nonunion, malunion, and associated complications. Instead, meticulous soft-tissue release and careful correction at the deformity's source remain the favored strategies.

Adequate debridement of both the medial and lateral gutters is crucial for achieving optimal ankle positioning. Medially, aggressive gutter debridement using a reciprocating saw or power rasp effectively removes remaining soft-tissue impediments. Laterally, careful removal of anterior fibular and talar osteophytes is necessary to eliminate anterolateral impingement; however, caution must be exercised to avoid overly posterior or central dissections, which risk destabilizing critical ligament structures, such as the CFL and PTFL, potentially leading to recurrent instability.

Finally, correcting equinus deformity through Achilles lengthening frequently becomes necessary. To optimize joint alignment and ligamentous balancing, Achilles lengthening is generally performed early in the procedure, immediately following the bone cuts and prosthesis trial placement but before completing any lateral ligament stabilization or final soft-tissue tension adjustments. This sequence ensures precise correction of equinus deformity and facilitates stable, durable ankle reconstruction outcomes.

Despite all described techniques above, some patients will still have residual varus postoperatively. If dynamic varus, an anterior tibial tendon transfer to the lateral cuneiform 4–5 months postoperatively can be performed to reposition the tibialis anterior tendon to account for dynamic varus. While this can be performed at the same time as the TAA, there is more tension placed on the anterior wound and therefore increased risk of wound complications. The senior author prefers to save this as a salvage operation for recurrent varus after performing the above procedures.

## Within the Ankle Joint

Within the ankle joint itself, varus deformities are classified as either congruent or incongruent, each necessitating a distinct surgical approach. Congruent deformities, characterized by distal tibial wear with bone loss implies intact ligamentous structures such as the anterior talofibular ligament (ATFL) and calcaneofibular ligament (CFL), generally permit straightforward correction with standard TAA. Surgeons must verify adequate tibial bone stock preoperatively. In cases of significant bone loss, revision implants with larger stems might be necessary to ensure proper fixation and alignment. This does not imply that concomitant hindfoot and midfoot correction is not required; this is just to say that ligamentous reconstruction may not be necessary in these cases, particularly in the setting of mild deformity.

Incongruent deformities, however, present a greater challenge due to associated ligamentous instability, typically identified by widening or tilting of the lateral talar surface relative to the fibula. Typically, the severity of deformity is greater with incongruent deformities than congruent deformities. This instability signifies compromised CFL and ATFL ligaments, requiring concurrent ligament reconstruction to achieve lasting correction. The standard anterior approach for TAA can be complemented by an additional posterolateral approach dedicated to ligament reconstruction. In milder instability cases, surgeons may opt for an augmented Broström procedure reinforced with an InternalBrace, carefully avoiding interference with implant placement by strategic anchor positioning. Severe instability frequently necessitates an Evans procedure to adequately restore lateral ankle stability. Technical considerations in ligament reconstruction procedures involve careful selection and placement of fixation anchors. Smaller anchors, such as a 3.5 mm SwiveLock® (Arthrex; Naples, FL), are recommended and should be strategically placed in areas such as the talar neck to minimize implant interference. Severe cases consistently benefit from the additional stability provided by an Evans procedure, with the understanding that stability is more critical than mobility in this population and return to running and cutting sports should not be an expectation (Figures 1–3).

## Valgus Deformity

Valgus deformity of the ankle can originate as a result of: developmental pathophysiology (e.g., fibular hemimelia), cartilage injuries (e.g., posttraumatic osteoarthritis, osteochondral defects), and ligamentous imbalance (e.g., PTT insufficiency, deltoid ligament injury) leading to progressive collapsing foot deformity (PCFD). TAA in valgus deformity, while less common than varus, is challenging and often fails as a result of an insufficient deltoid ligament complex<sup>(18)</sup>. Furthermore, longstanding valgus deformity of the ankle leads to residual deformity of the hind- and midfoot, which result in significant valgus stress on TAA implants. Durable reconstruction of the deltoid ligament complex is essential in successful joint replacement for patients with valgus



**Figure 1.** Preoperative Valgus Deformity.

AP: mortise, lateral ankle; AP: oblique foot XR demonstrating progressive valgus deformity of the foot and ankle with prior 1<sup>st</sup> TMT/MTP fusion. Key findings include lateral talar tilt, widening of the medial ankle joint space, lateral subluxation of the talus relative to the tibial plafond, and collapse of the medial longitudinal arch. Additional features include hindfoot valgus alignment, forefoot abduction, and evidence of degenerative changes in the subtalar and tibiotalar joints.



**Figure 2.** Preoperative Valgus Deformity Status Post Flatfoot Reconstruction.

AP: mortise, lateral ankle XR status post flatfoot reconstruction. Procedures included: medial slide calcaneal osteotomy, gastroc recession, loose body and exostosis excision, medial collateral ligament (spring/deltoid) reconstruction, flexor digitorum longus-to-posterior tibial tendon transfer, lateral collateral ligament reconstruction (Broström).



**Figure 3.** Preoperative Valgus Deformity Status Post Total Ankle Arthroplasty.

AP: mortise, lateral ankle XR status post TAA. Adjunct procedures included: syndesmosis open reduction internal fixation with Internal-Brace™ fixation, Achilles tendon lengthening.

deformity. Therefore, a critical step in preoperative planning involves determining deltoid ligament competency (e.g., congruent deformity), or incompetency (e.g., incongruent deformity). While various associated procedures may be indicated to achieve neutral alignment depending on severity of deformity, Demetracopoulos et al.<sup>(24)</sup> demonstrated similar outcomes of patients with moderate and severe valgus deformity treated with TAR.

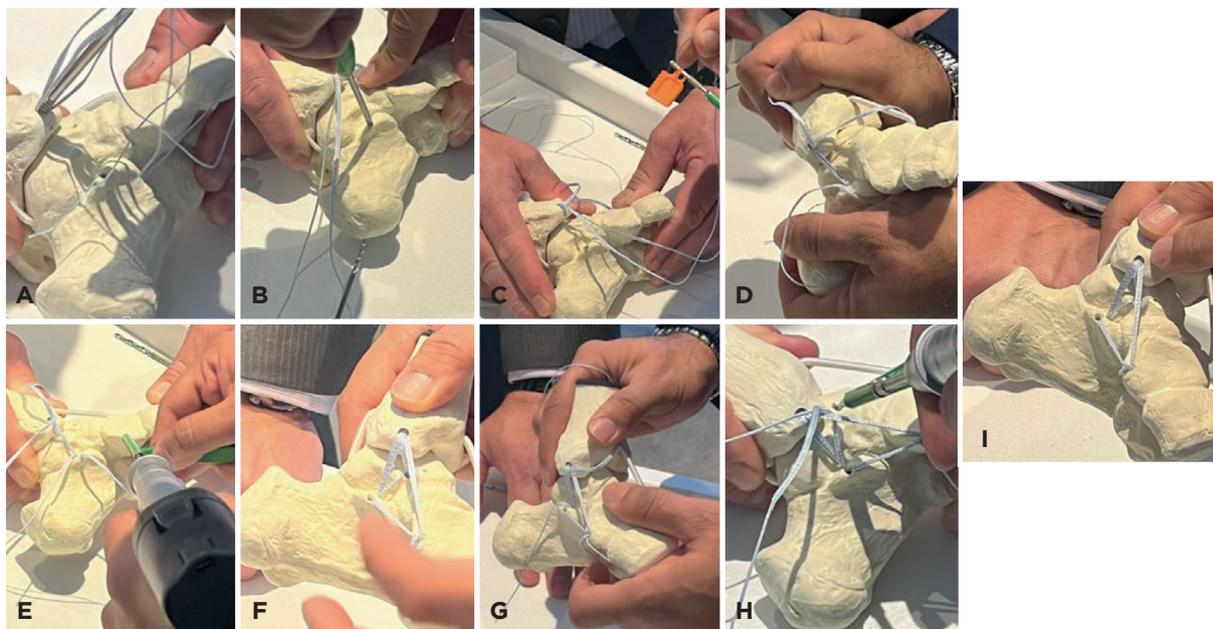
Valgus deformity can generally be categorized into two distinct types, with the key differentiating feature being the presence or absence of medial talar escape which occurs when the inferior aspect of the medial talus displaces inferiorly relative to the medial malleolus. This phenomenon indicates significant disruption of both the deep and superficial deltoid ligaments, facilitating not only a valgus angulation but also external rotation of the talus; this is most commonly seen in patients with incongruent valgus deformity.

When medial talar escape is identified, a comprehensive approach to medial soft tissue reconstruction becomes essential. Merely “stuffing” the ankle joint with the polyethylene implant is inadequate due to the combined rotational and angular instability. Instead, a strategic, staged reconstruction is advocated, particularly if the hindfoot remains flexible.

The recommended staged surgical procedure includes multiple components aimed at achieving stability and

correcting the deformity. Initially, the procedure may involve a gastrocnemius recession to address any contractures contributing to the deformity. A peroneus brevis-to-longus transfer can be beneficial in reducing lateral deforming forces. Additionally, a medial displacement calcaneal osteotomy (MDCO) is typically preferred to re-align the heel under the mechanical axis of the leg. While some surgeons opt for a lateral column lengthening osteotomy, it is less favored by the senior author.

Furthermore, addressing medial soft tissue reconstruction through a posteromedial approach involving the flexor digitorum longus (FDL) tendon transfer is recommended. This approach also integrates a deltoid and spring ligament reconstruction, ideally utilizing an internal brace for reinforcement. A modification of Caio Nery’s technique described by the senior author involves placing a double-loaded 4.75 mm SwiveLock anchor into the tibia<sup>(43)</sup>. Subsequently, two limbs of the internal brace are inserted into the sustentaculum tali. One limb from the tibia is then secured to the navicular, with an additional limb from the sustentaculum also routed to the navicular. Further stabilization involves connecting limbs from both the tibia and sustentaculum directly into the talus. This configuration effectively reconstructs the deep deltoid ligament complex, maintaining the foot in a neutral position during tensioning. In all cases, native tissues should be imbricated in addition to the internal brace (Figure 4).



**Figure 4.** Medial Collateral Ligament Reconstruction Technique.

A modification of Caio Nery’s technique described by the senior author: A) place a double-loaded 4.75mm SwiveLock® anchor into the tibia; B) drill and tap sustentaculum tali for two 3.75 mm anchors; C) insert 2 limbs of the InternalBrace into the sustentaculum tali; D) place the ankle in neutral position; E) drill and tap medial/plantar navicular; F) secure 1 limb from the tibia and 1 limb from the sustentaculum to the navicular; G) evaluation after navicular and sustentaculum anchors are placed; H) reconstruction of deep deltoid, drilling immediately anterior to the medial malleolus and inferior to the talar cartilage securing 1 limb from the tibia, 1 limb from the sustentaculum; I) final appearance is demonstrated.

If there is evidence of significant midfoot instability or deformity, performing a first TMT plantarflexion arthrodesis will further stabilize the midfoot and complement hindfoot correction. If there is no instability, a Cotton osteotomy is recommended. The senior author prefers plantarflexion of the medial column in a valgus total ankle either through either 1st TMT plantarflexion arthrodesis or Cotton osteotomy to decrease risk of recurrence.

In cases presenting with severe lateral defects, temporary use of a cement spacer may be required. This spacer functions to maintain neutral foot alignment during the healing phase of the medial soft tissue reconstruction. Typically, after allowing approximately three months for soft tissue healing and stabilization, definitive TAA can then be successfully performed. This staged protocol provides the optimal environment for implant longevity and improved functional outcomes in patients undergoing valgus TAA.

In cases of rigid hindfoot deformity with medial talar escape, the approach becomes significantly more challenging. A medial-based triple arthrodesis through a slightly posterior medial approach, avoiding proximity to the anterior TAA incision, is recommended. Following triple arthrodesis, deltoid ligament reconstruction can be effectively achieved through the same surgical approach. Performing a subtalar fusion alone is insufficient in rigid deformities. Concurrently, a MDCO may be considered to further realign the hindfoot into slight varus, either performed simultaneously or reserved for the subsequent TAA. An anterior cement spacer may be utilized to maintain ankle neutrality during healing as discussed above.

Finally, consideration must be given to lateral ligament integrity. In rigid (and some flexible) deformities, lateral ligamentous erosion from the calcaneus abutting the fibula may lead to residual instability. Correction of lateral instability is typically reserved for the TAA itself, preventing inadvertent recurrence of valgus deformity due to premature lateral stabilization.

During TAA, whether following a staged reconstruction for medial talar escape or in the context of mild valgus with lateral talar erosion and preserved medial containment, key principles guide successful outcomes. In these scenarios, deltoid integrity has either been restored surgically or remains intact.

Due to ligamentous laxity, resection cuts may be slightly less aggressive. Surgeons may consider a shallower tibial and talar cut; however, implant sizing becomes critical, particularly for the talus. In patients with residual ligamentous laxity despite the above soft tissue stabilization procedures, a slightly shallower cut decreases the risk of insufficient polyethylene thickness to stabilize the ankle. Slight variations in cut height—usually within 1 mm – are generally acceptable. Following resection, tibial and talar components are implanted and trial polyethylenes are used to tension the soft tissues.

Soft tissue tensioning is paramount to eliminate any residual valgus. This often requires a larger polyethylene insert than average. Once medial stability is confirmed, varus instability

must be assessed. Paradoxically, some patients may present with residual varus instability despite initial valgus deformity; this is addressed with a Broström procedure, possibly augmented with an InternalBrace or suture anchors. For more substantial lateral instability—especially post-triple arthrodesis—an Evans procedure is added to augment the Broström.

Following lateral stabilization, the polyethylene insert is upsized to restore balance and stability. Final confirmation involves ensuring neutral positioning of the ankle with good varus-valgus stability in mid-stance. Mild clicking in plantarflexion is not uncommon but should not be present in the neutral stance.

Careful attention must be given to the hindfoot, even if a prior MDCO was performed; in some cases, primary or revision MDCO should be considered. There is a significant shift of the weight bearing axis to the medial side of the tibia that should be performed if there is any hindfoot valgus to prevent recurrent valgus.

Final attention should be given to the medial column. If a medial column has been performed and there is persistent varus now that the ankle has been corrected, revision of the medial column fusion with a plantarflexion osteotomy through the fusion should be done. If no medial column fusion has been performed, this should be reassessed and performed if required, with the senior author preferring a 1st TMT fusion.

While medial malleolar osteotomies have been proposed to tension the deltoid, this is not the senior author's preference and use of this technique has become less utilized by many surgeons. The major downside of this technique is that it introduces the chance of nonunion which can lead to tibial implant migration. Advancement of medial soft tissue reconstruction techniques has supplanted use of the medial malleolar osteotomy for soft tissue stability (Figures 5-7).

## Peritalar Instability

Some deformities are more complex than may be appreciated on initial assessment. All ankles with valgus deformity are not a result of a pes planovalgus deformity; indeed, some may have an underlying cavovarus foot. Chronic lateral ligament instability is common with cavovarus deformity and may lead to peritalar instability<sup>(44)</sup>. If noted, even in the setting of a flexible hindfoot, the most appropriate intervention is subtalar fusion to stabilize the hindfoot prior to TAA. Soft tissue procedures and midfoot correction using algorithms described above may be addressed once the subtalar fusion is performed.

## Role of Staging

The decision to stage TAA is subjective and no specific guidelines exist given the complex nature of these cases. Surgeons should consider the following: patient factors (e.g., medical comorbidities, smoking), incision placement, operative time under tourniquet, and the blood supply to the



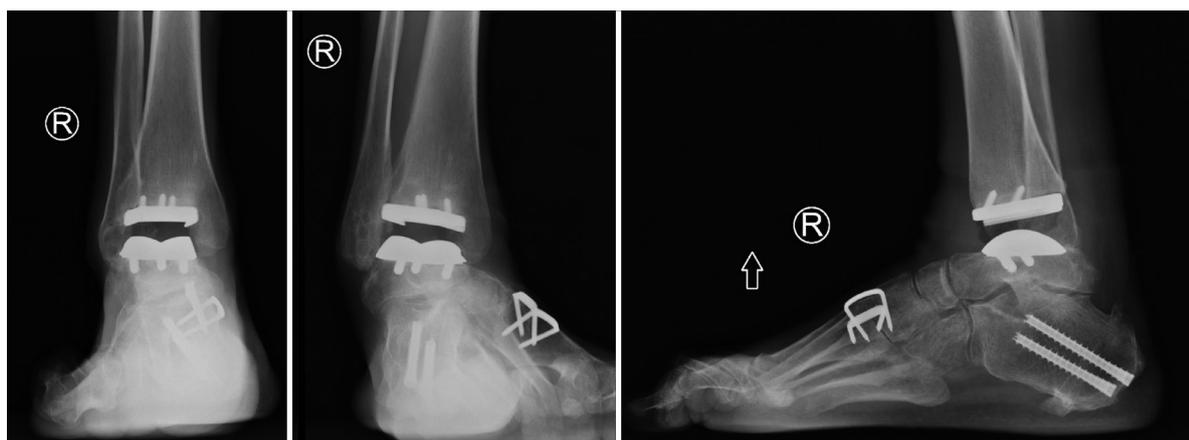
**Figure 5.** Preoperative Varus Deformity.

AP: mortise, lateral ankle XR demonstrating demonstrating varus deformity of the foot and ankle with prior 1<sup>st</sup> TMT arthrodesis malunion, Broström, lateral calcaneal osteotomy. Key imaging findings include medial talar tilt, narrowing of the medial ankle joint space, lateral gutter widening, and medial subluxation of the talus beneath the tibial plafond. Additional findings include hindfoot varus alignment, adduction of the forefoot, and degenerative changes of the tibiotalar and subtalar joints.



**Figure 6.** Preoperative Varus Deformity Status Post Cavus Reconstruction.

AP: mortise, lateral ankle; AP: oblique foot XR demonstrating demonstrating varus deformity of the foot and ankle status post talonavicular capsulotomy, posterior tibial tendon lengthening, deltoid ligament release, exostosis and loose body excision, revision lateral column reconstruction (non-anatomic Evans), revision 1<sup>st</sup> TMT arthrodesis, revision lateral slide calcaneal osteotomy.



**Figure 7.** Preoperative Varus Deformity Status Post Total Ankle Arthroplasty.

AP: mortise, lateral ankle XR status post TAA. Adjunct procedures included: Achilles tendon lengthening, deltoid ligament release, talonavicular capsulotomy, posterior tibial/flexor digitorum longus tendon lengthening, posteromedial capsular release.

talus. Area available for skin incisions becomes limited when multiple procedures need to be performed. This article's senior author relies on minimally invasive (MIS) techniques which aid in reducing operative time and potential complications while simultaneously allowing for multiple procedures to be performed at the time of surgery. Avascular necrosis of the talus is also a risk and circumferential dissection of the soft tissues around the talus in a single stage is hazardous. This is the case when a double or triple arthrodesis is performed with a TAA in a single stage.

Staging complex cases is not an indicator of lack of skill, rather, it is a necessity. When a holistic approach is taken, the decision whether to stage or not becomes easy. Staging also allows surgeons to evaluate the outcome of adjuvant procedures over time and provides the benefit of reconsidering operative plans, if needed.

## Discussion

Achieving neutral alignment with TAA results in similar functional outcomes regardless of the severity of preoperative deformity<sup>(13)</sup>. However, patients with severe varus deformity require ancillary procedures an estimated 70% more frequently than those with mild varus<sup>4</sup>. Trajkovski et al.<sup>(13)</sup> found 81% of varus ankles required ancillary procedures (as described above) versus 47% with neutral alignment. Furthermore, patients with preoperative varus deformity were twice as likely to undergo repeat surgery compared to neutrally aligned ankles, often due to issues like lateral gutter impingement or persistent pain.

Despite higher rates of ancillary procedures and subsequent surgeries in varus deformity patients, prior literature reports no significant differences in clinical outcomes, postoperative pain, or implant survivorship at mid-term follow-up (average 34.2 months, 4 years)<sup>(13,14)</sup>. Hobson et al.<sup>(31)</sup>, studying STAR prosthesis patients grouped by  $<10^\circ$  vs  $11^\circ$ – $30^\circ$  deformity, also found similar postoperative range of motion, incidence of complications, patient-reported outcomes, and implant survivorship (overall 4-year failure rate 14.6%). However, the primary reason for failure differed: gross instability was more common in the large deformity group, while fracture was more common in the minimal deformity group.

Early clinical reports recognized preoperative varus or valgus deformity as a potential cause of TAA failure<sup>(45-48)</sup>. Deformity thresholds associated with higher risks were often cited as  $>10^\circ$ ,<sup>40</sup> or  $>15^\circ$ <sup>(15,16,49,50)</sup>. Some suggested valgus positioning might be better tolerated than varus<sup>(51)</sup>, though one study found higher revisions with preoperative varus<sup>(52)</sup>.

Coetzee<sup>20</sup> described strategies for managing deformities, particularly valgus secondary to PTT dysfunction, suggesting procedures ranging from soft tissue releases and tendon repairs/augmentations to triple arthrodesis for severe cases, proposing  $10^\circ$ – $15^\circ$  of instability as potential cut-offs for TAA. Bluman and Chiodo<sup>(50)</sup> emphasized addressing all concomitant deformities in valgus ankles. For rheumatoid

arthritis patients often presenting with valgus, Wood et al.<sup>(53)</sup>, recommended hindfoot fusion (staged or concurrent) for alignment, though cautioned about potential lateral gaps if correction occurs without ligamentous release<sup>(54)</sup>.

Regarding correction techniques, Ellis and DeOrto<sup>(55)</sup> described intraoperative correction of slight deformity using a laminar spreader with the INBONE prosthesis, noting valgus was harder to correct this way<sup>(56)</sup>. Bonasia et al.<sup>(37)</sup> suggested tibial cut modification for distal tibial deformities  $<10^\circ$  and pre-TAA osteotomy for more severe cases. Bonnin et al.<sup>(57)</sup> using the Salto prosthesis, did not consider substantial deformity a contraindication provided it was corrected first, often with procedures including triple arthrodesis and use of cemented components<sup>(58)</sup>. In line with addressing associated deformities, Kim et al.<sup>(59)</sup> found that significant preoperative deformity ( $>15^\circ$ ) was not associated with worse TAA outcomes when performed in conjunction with hindfoot fusion<sup>(60)</sup>.

New studies reporting revision rates in neutrally versus deformed ankles have been published. In 2022, van Es et al.<sup>(61)</sup> reported long term results of 254 cases of TAA with ceramic coated implant (CCI) mobile-bearing prosthesis at a mean 6.9 years of follow-up and found lower survival in the deformed ( $>5^\circ$ ) group. Conversely, Allport et al.<sup>(62)</sup>, reporting on the Mobility mobile-bearing prosthesis, found identical survivorship after 56 months between the neutral and deformed ( $>10^\circ$ ) group. However, more additional procedures were performed in the deformed group.

Failure is more likely due inability to achieve neutral alignment following TAA; Pyevich et al.<sup>(63)</sup> observed that patients with tibial components placed in  $>4^\circ$  of valgus had significantly more postoperative pain than patients with neutrally aligned components. Further, unaddressed or residual deformity has been linked to accelerated polyethylene wear,<sup>(64,65)</sup> increased failure risk,<sup>(29,66)</sup> edge loading,<sup>(16,67-69)</sup> component fracture,<sup>(65)</sup> lower survivorship,<sup>(22)</sup> higher revision rates<sup>(15,49,52,69)</sup>, and instability.<sup>(70)</sup> We agree with the findings of prior studies which argue deformity isn't a contraindication if correctable before or during TAA<sup>(30,71,72)</sup>, though this often requires additional procedures and experienced surgeons<sup>(52,71,72)</sup>.

## Conclusion

With newer implants and further understanding of ligamentous balancing, there should be no absolute value of preoperative deformity that precludes ability to perform TAA. The only limitation is the inability to correct the deformity, in which case, arthrodesis may reduce complications. When compared to cavovarus deformity, patients with planovalgus deformity fare better with ankle arthrodesis as the residual hindfoot motion provides adequate compensation to achieve an acceptable gait. Such compensatory motion of the hindfoot is not present in a cavovarus deformity. In severe pes planus and ankle valgus, if limiting number procedures is important and patient activity demand is low, arthrodesis is an effective procedure with minimal risk. Keeping In mind the greater likelihood of complications, a staged reconstruction

may be considered in younger patients with higher demands. However, these are complex cases requiring experience, and

staged surgery is recommended until the surgeon becomes proficient and facile.

**Authors' contributions:** Each author contributed individually and significantly to the development of this article: RB\*(<https://orcid.org/0000-0002-6702-8871>), and VU \*(<https://orcid.org/0009-0001-5367-491X>) Conceived and planned the activities that led to the study, Clinical examination, Performed the surgeries, Data collection, Survey of the medical records, Interpreted the results of the study, Participated in the review process, Statistical analysis, Bibliographic review, Formatting of the article; ARZ \*(<https://orcid.org/0000-0003-1023-6407>) Participated in the review process, Statistical analysis, Interpreted the results of the study, Bibliographic review, Formatting of the article. All authors read and approved the final manuscript. \*ORCID (Open Researcher and Contributor ID) .

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