Joint Preservation Strategies for Managing Varus Ankle Deformities

Beat Hintermann, MD*, Roxa Ruiz, MD

KEYWORDS

• Varus ankle • Deformity • Ankle osteoarthritis • Joint preserving strategies

KEY POINTS

- A meticulous analysis of the varus deformity and thorough understanding of underlying causes is mandatory for success in joint preserving surgery
- A supramalleolar osteotomy (SMOT) cannot restore parallel joint lines between the tibial plafond and talar dome in ankles in most asymmetric varus osteoarthritic (OA) ankles
- Additional measures such as calcaneal osteotomies and dorsiflexion osteotomies of first ray and soft tissue procedures are necessary in most cases
- A better understanding of the 3-dimensional structural changes in the ankle mortise and the talus may be essential for further improvement of joint-preserving surgery

INTRODUCTION

Because of its posttraumatic origin, ankle osteoarthritis (OA) generally affects younger patients.[1,2] Ankle arthrodesis may relieve pain and thus be beneficial in the short-term; however, the outcome at midterm to long-term is often dissatisfying.[3,4] Though ankle replacement has become a viable alternative in the last years, the long-term outcome is still uncertain.[5–7] Therefore, reconstructive surgery including osteotomies and soft tissue balancing procedures have gained interest for the treatment of asymmetric ankle OA.[8–22] This is particularly true for varus ankle OA in younger patients, where long-standing untreated lateral ligament instability may result in unbalanced loading of the medial joint space, painful asymmetric ankle OA, and varus deformity of the foot and ankle.[12,23]

The focal static and a dynamic overload within the ankle joint leads to a medialization of the center of force.[18,24,25] Furthermore, the force within the joint is amplified by the activation of the triceps surae, which becomes an invertor and applies an

Center of Excellence for Foot and Ankle Surgery, Clinic of Orthopaedics and Traumatology, Kantonsspital Baselland, Rheinstrasse 26, Liestal CH-4410, Switzerland
* Corresponding author.
E-mail address: beat.hintermann@ksbl.ch

Foot Ankle Clin N Am 27 (2022) 37–56
https://doi.org/10.1016/j.fcl.2021.11.002
foot.theclinics.com

additional deforming force on the hindfoot.[11] A further additional deforming force may be created by the posterior tibial (PT) muscle when it exceeds the eversion force of the peroneus brevis (PB) muscle.[26] The goal of surgical measures is to balance the ankle to normalize the joint load, thus preserving the ankle joint from further deterioration.[11,21]

The goal of this article is to provide basic information on varus ankle deformities, to understand their pathology, and elaborate a rationale for joint preserving strategies to successfully treat this deformity and to postpone OA of the ankle joint.

BACKGROUND

Ankles with pathologic varus deformities suffer from medial joint overload with associated subsequent medial tibiotalar joint degeneration. This in turn causes further medial load shift resulting in a vicious cycle of ever-increasing mechanical malalignment.[25] The ability of the foot and ankle to tolerate created varus malalignment depends, to a significant extent, on the flexibility of the foot to secondarily accommodate and compensate for this deformity. With a proximal varus deformity, the subtalar joint must evert to maintain a plantigrade foot.[27] Most recently, in a cadaveric study on 8 ankles, Zhu and colleagues[28] found a lateral shift of the center of force and lateral stress concentration for mild tibial varus. However, as the tibial varus continued to progress, the center of force shifted medially, and the lateral stress concentration decreased. This phenomenon might be explained by the valgus inclination of the subtalar joint in compensation for the varus tibial malalignment. However, regardless of the ability of the subtalar joint to compensate for the deformity, the mechanics of the ankle joint remain abnormal and, ultimately, irreversible articular damage occurs.

MORPHOLOGY AND CLASSIFICATION OF VARUS DEFORMITY OF THE ANKLE

To assess the varus deformity of the ankle, the angle of distal tibial articular surface[29] (TAS; α, normal value 91°–93°) and the tibiotalar angle 22 (TT; β, normal value $91.5^\circ \pm 1.2^\circ$) are used (**Fig. 1**). The degree of the talar tilt (TT) in the ankle mortise can then be calculated as the difference between TAS and TT. When, according to earlier findings, the cut-off for clinically relevant ankle tilting is set at 4°,[30] 2 types of ankle joints can be differentiated: the congruent joint (tilt $\leq$4°) and the incongruent joint (tilt >4°) (**Fig. 2**).

According to Takakura and colleagues 1995,[21] varus-type OA of the ankle is classified into the following 4 stages: (1) no narrowing of the joint space, but early sclerosis and formation of osteophytes; (2) narrowing of the medial joint space; (3) obliteration of this space with subchondral bone contact; and (4) obliteration of the whole joint space with complete bone contact. An additional type of varus ankle where the obliteration of the joint space is localized only in the medial gutter, whereas the tibiotalar joint space is preserved and classified by the authors as stage 3a.[21]

PRINCIPLES OF JOINT PRESERVING SURGERY

The specific aim of joint preserving surgery is to redistribute the mechanical axis to change the intraarticular load distribution, for example, in the varus malaligned ankle to move the center of load from medial to lateral.[9,11,13–15,17–20,31–37] In general, the joint preserving surgeries address the hindfoot deformity above the level of the ankle joint using supramalleolar osteotomies (SMOT) and soft tissue procedures[11,13,14,16,17,19,20,31–33,36–38] or below

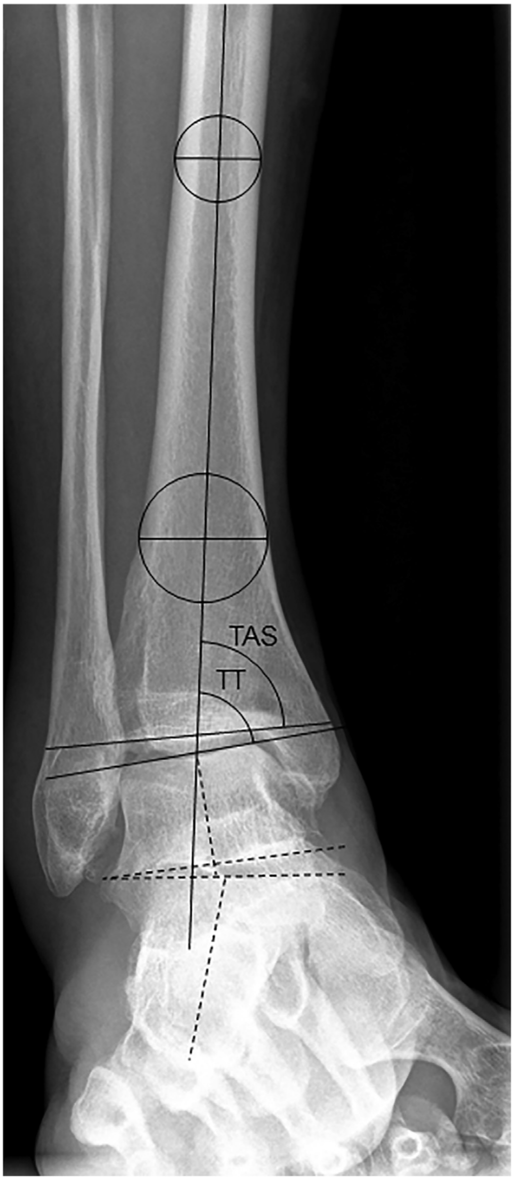

Fig. 1. Anteroposterior (AP) radiograph showing the TAS angle, formed between the longitudinal axis of the tibia and the distal articular surface of the tibia, and the talar tilt (TT) angle also measured with reference to the longitudinal axis of the tibia. The degree of the TT in the ankle mortise is calculated as the difference between TAS and TT. The compensatory valgus tilt of the subtalar joint can also be calculated with the help of measuring the calcaneal axis.

the ankle joint using calcaneal osteotomies and osteotomies of the first metatarsal or medial cuneiform.[26,39–42]

As a rule, the surgical procedure starts with supramalleolar correction, followed by soft tissue procedures. Once the ankle joint complex is balanced, a calcaneal

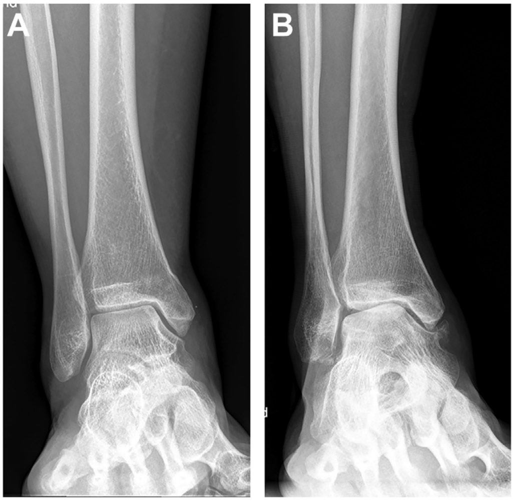

Fig. 2. Weight-bearing AP radiographs showing (*A*) a congruent varus deformity (Takakura. stage 0) and (*B*) an incongruent varus deformity (Takakura stage 2).

osteotomy may be considered in the case of a remaining heel malposition. Thereafter, remaining forefoot deformities are addressed, in particular correction of a plantar-flexed first ray.

SUPRAMALLEOLAR CORRECTING OSTEOTOMIES

Realignment surgeries include correcting osteotomies above the ankle (eg, SMOT), below the ankle (eg, inframalleolar osteotomies), and at the ankle (eg, intraarticular osteotomies).

As a principle, the correcting osteotomy is planned at the center of rotation of angulation (CORA). The closer the CORA is to the ankle joint, the greater is the effect on the ankle joint (greater lateral distal tibial angle).[20,43] Whereas, the closer the CORA is to the knee, the greater is the effect on the knee joint (greater medial proximal tibial angle). Congenital deformities usually have a CORA at the level of the plafond, developmental deformities a CORA just proximal to the distal tibial physis, and postfracture deformities a CORA at various levels, depending on the level of the original fracture and the magnitude and direction of associated translational deformities.

For the correction of a varus deformity, either a medial opening wedge osteotomy (**Fig. 3**A) or a lateral closing wedge osteotomy (**Fig. 3**B) can be used. Most authors prefer an open wedge osteotomy, as it allows the surgeon not only to perform gradual correction using distraction, until the desired degree of correction is obtained,[11,15,17,20,22,32,36–38,44–46] but also simultaneous correction in the sagittal plane, if necessary, by applying the distraction force anteromedially to move the anatomic axis of the tibia closer to the center of rotation of the talus. This correction may be necessary for patients in whom the talus is translated anteriorly.[47] Others prefer a lateral closing wedge osteotomy especially in patients with compromised medial soft tissues and in patients who have a congruent deformity (ie, Takakura stage 0 and 1) with substantial supramalleolar deformity, such as a malunion of a distal tibial fracture.[10,11] It has been suggested that lateral closing wedge osteotomies are technically easier.[36] Advantages of a lateral closing wedge osteotomy include stability, the lack of

Fig. 3. Wedge-type osteotomies of the distal tibia. The extent of wedge resection or the quantity of bone graft needed to achieve the desired degree of correction can be calculated with equation H = tan α1*W, where H equals the height of the wedge to be resected or grafted, α1 is the magnitude of deformity plus the degrees of overcorrection, and W equals the width of the tibia at the level of the osteotomy.[8] (*A*) Open-wedge osteotomy of the distal tibia. A 51-year-old male patient with stage 3a OA. AP radiographs showing (a) preoperative obliteration of the joint space only at the tip of the medial malleolus; (b) 8 weeks after surgery, a substantial improvement; and (c) 10 years after operation, an excellent clinical result with no pain. (*B*) Lateral closing wedge osteotomy. A 46-year-old male patient with stage 3b osteoarthritis. AP radiographs showing (a) preoperative obliteration of the

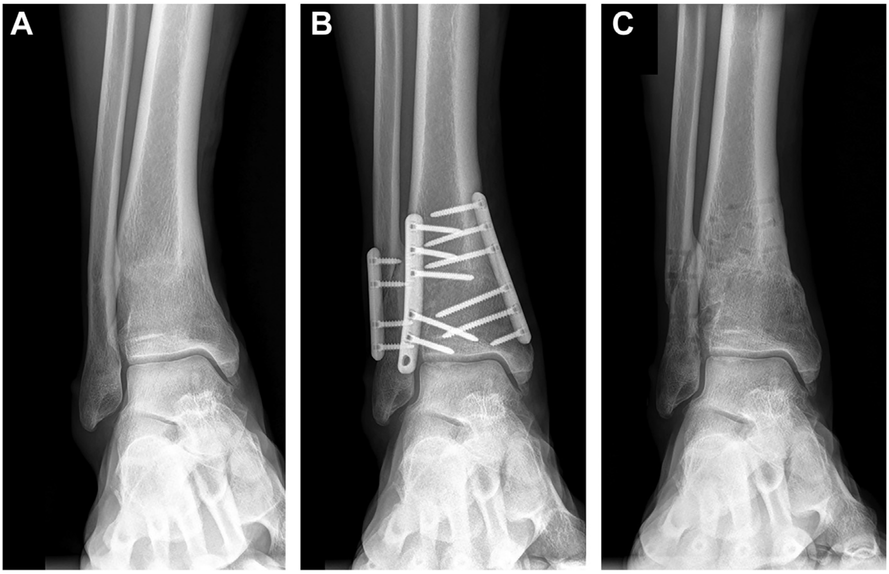

Fig. 4. Dome osteotomy of the distal tibia. A 63-year-old male patient with stage 2 OA. AP radiographs showing (*A*) preoperative narrowing of the joint space only in the medial gutter; (*B*) 8 weeks after surgery, a congruent joint; and (*C*) 5 years after surgery, an excellent clinical result with the patient sensing no pain.

a need for allograft, and the ability to perform a simultaneous fibular osteotomy through the same incision. Disadvantages include the inability to gradually determine the degree of correction and the need for a biplanar cut in patients with a coexisting sagittal plane deformity. Because the medial cortex of the distal tibia is weak and substantial soft-tissue contractures may be present, supplemental medial plate fixation may be necessary to avoid loss of correction. In addition, it has been suggested that a closing wedge osteotomy results in leg shortening and lateral compartment muscle weakening.[21] However, no differences regarding clinical outcome, radiographic outcome, or healing time of the osteotomy were reported in idiopathic ankle OA.[20,48]

In a patient with a varus deformity with a TAS angle of more than 6° to 8°, an opening wedge osteotomy would need a wide bone graft, which would significantly stretch the medial soft tissues, including the PT tendon. Thus, the authors prefer a dome osteotomy through an anterior exposure of the distal tibia (**Fig. 4**).[11,49,50] In most instances, a fibular osteotomy is needed through a separate lateral approach to achieve the wanted correction.[11,49–51] Similarly to the wedge osteotomy, the height of the dome osteotomy is determined such as to get the center of the tibiotalar joint slightly lateral to the anatomic axis of the tibia.

joint space at the medial corner in the roof of the dome of the talus of medial joint space and (b) 3.5 years and (c) after 5 years after correcting osteotomy of fibula an improved joint space. Even though there remained a talar tilt angle on weight-bearing of 12°, the patient was extremely satisfied.

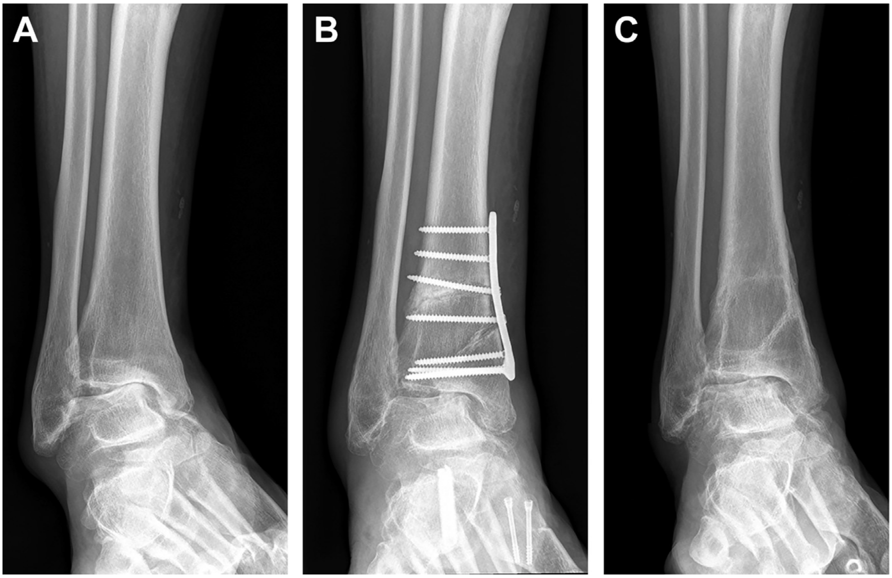

Fig. 5. Double osteotomy of the distal tibia. An intraarticular open-wedge osteotomy is performed to restore the distal articular surface, in addition to an open-wedge osteotomy to medialize the loading axis of the tibia. A 52-year-old male sports teacher with stage 3a OA. AP radiographs showing (*A*) preoperative obliteration of the joint space at the medial corner in the roof of the dome of the talus with impaction into the plafond and an angle of talar tilt on weight-bearing of 11°. (*B*) Four months after surgery, an improvement of talar tilt to 7° is seen, with remaining medial joint obliteration, and (*C*) 5 years postoperatively, no change can be seen. Despite this disappointing radiographical result, the patient was satisfied with the obtained result and was still able to perform his profession as a sports teacher.

If the TAS is impacted significantly, resulting in more than 5° of varus of the medial joint, an intraarticular osteotomy can be considered to restore congruency at the tibiotalar joint (**Fig. 5**).[31,52,53]

In the presence of a recurvatum deformity at the distal tibia and/or anterior extrusion of the talus, an additional antecurvatum correction is done following the same principles.[11,14,47,54]

After the osteotomy is performed, the distal tibial bloc is tilted posterior so that the elongation of the anatomic axis of the tibia, on the sagittal plane, meets the center of rotation of talus.[47]

In the incongruent varus OA ankle, where the talus has tilted into varus (Takakura stage 2–4), talar reduction can be hindered by medial soft tissue contracture (eg, deltoid ligament or PT contracture) and through bone formation in the lateral compartment of the ankle.[55]

To compensate for cartilage loss at the medial tibiotalar joint, a medial opening wedge osteotomy is aimed to obtain a TAS angle of 2° to 4° valgus. Once the amount of angular correction is determined, the height of the CORA for the osteotomy is determined so that the anatomic tibial axis at the tibiotalar joint is in its center or slightly lateral.[31]

ADDITIONAL PROCEDURES

Once supramalleolar correction is done, the achieved alignment is carefully assessed by visually inspecting the position of the heel to the axis of the calf. Fluoroscopy is used to check the achieved tibiotalar alignment (TAS angle) in the frontal plane and the achieved talocalcaneal alignment (talocalcaneal angle) in the horizontal plane. Also, lateral stability of the tibiotalar joint is checked by applying an inversion force.

- In the case of subtalar contracture, subtalar fusion is done for talocalcaneal realignment.[41,49,56]
- In the case of medial soft tissue contracture, a release of the PT tendon is done to restore talocalcaneal alignment.[57,58] In most instances, a release of the superficial deltoid ligament is also necessary.[16,57]
- Obtained correction is checked by fluoroscopy. If there is still a varus tilt of the talus that increases when applying inversion stress force, a lateral ligament reconstruction is considered usually as a Broström type repair.[16] If the remaining ligament structures are incompetent, reconstruction with the use of a free tendon graft or internal brace may be considered.[59]
- In the case of an incompetent PB tendon, a peroneus longus (PL) to PB tendon transfer is considered.[60,61] The base of the fifth metatarsal and the PL tendon are exposed. After dissection, the PL tendon is attached by a transosseous suture to the fifth metatarsal while the foot is held in dorsiflexion and eversion to get maximal tension to the transferred tendon.
- In the case of incompetent peroneal tendons (both) or nerve palsy, a transfer of the anterior tibial tendon[57,62] or PT tendon can be considered.[58,63]
- If thereafter, the heel is still in a varus position, a Z-osteotomy of the calcaneus is performed to tilt the heel into valgus and to slide it laterally (**Fig. 6**).[64] Alternatively, a lateral sliding osteotomy with or without a closing wedge[65] can be performed; however, the potential correcting effect is lower.
- If the forefoot evidences a pronation deformity due to a plantarflexed first ray, a dorsiflexion osteotomy is performed at the level of the first cuneiform or base of the first metatarsal (see **Fig. 6**).[57]

POTENTIAL COMPLICATIONS

All these techniques are often not sufficient to correct the talar position to normal or to fully restore joint congruency.[13,14,31] The underlying cause may be that the medial articular surface of the ankle joint is worn out, resulting in progressive joint incongruity with loss of intrinsic stability. This allows the talus to remain in a varus position. Furthermore, the medial malleolus can erode and become inclined medially instead of vertically, which further adds to the likelihood of a recurrent deformity. However, though the talus remains in varus, functional outcome and pain relief often significantly improve.[8–11,13–15,17,19–21,25,35]

DISCUSSION

Surgical realignment procedures can successfully restore normal joint function or halt further disease progression in ankles with asymmetric varus ankle OA.[13–15,19–22,32] Though progress has been made on indications and possibilities of joint preserving surgical treatment of the ankle with varus deformity and ongoing OA, the mechanism and the effect of the various measures are still not fully understood, and there are still some controversies.

SMOT in the varus ankle is designed to shift the weight-bearing axis to the lateral side of the ankle joint and unload the medial side, and, with this, it is expected to correct the often-existing TT.[11,31,49] Though joint space could not be restored to normal, SMOT was found to be successful in most cases.[8–11,13–17,19–21,25,35] Lee and

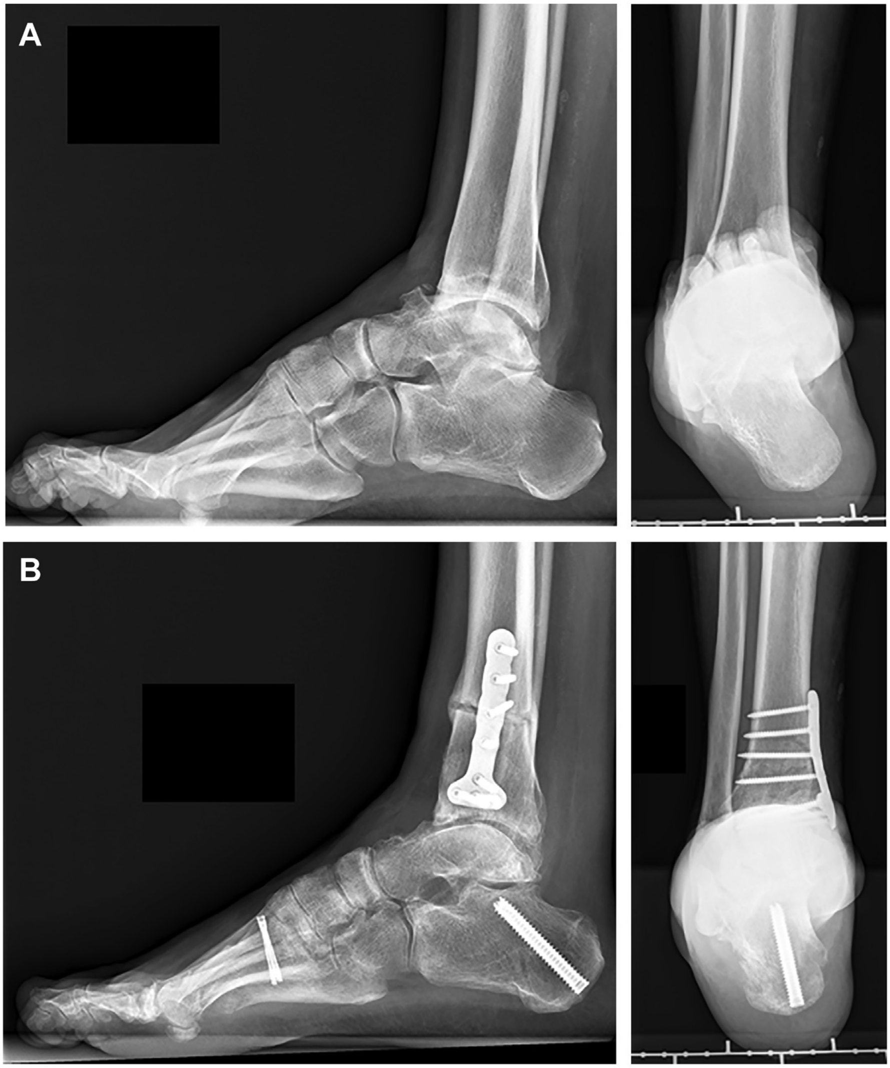

Fig. 6. Additional bony procedures Same patient as in Fig. 5. (*A*) Preoperatively, a severe. cavovarus deformity is seen with a heel varus and plantarflexed first ray. (a) lateral. view, (b) hindfoot alignment view. (*B*) Four months after surgery, the inframalleolar deformity has significantly been corrected after performing a z-osteotomy of the calcaneus with varus tilt and lateral slide, and a dorsiflexion osteotomy at the base of first metatarsal. (a) Lateral view, (b) hindfoot alignment view.

colleagues[35] reported that of 13 ankles with a preoperative Takakura stage 2 or 3A OA, only 4 improved to Takakura stage 1 after surgery. All 3 ankles with Takakura stage 3B, OA improved to stage 2 after surgery. In a series of 44 patients, Krähenbühl and colleagues[13] reported that ankles with a preoperative Takakura stage 2 or 3A showed a significantly higher survival rate at 5 years (88% [95% confidence interval (CI), 67–100] and 93% [95% CI, 80–100]) compared with ankles with a preoperative Takakura stage of 3B (47% [95% CI, 26–86], *P* = .044). In the same patient cohort, no higher failure rate was found in patients with Takakura stage 4.[66] Similar results were reported by Hongmou and colleagues[46] in a consecutive series of 41 patients of which a total of 22 cases (57%) achieved a lower Takakura stage, 13 (33%) had no change and 4 (10%) had an increased stage. The mean Takakura stage was significantly decreased (P = .008) postoperatively. These results were supported by others[8,9,11–15,17,19,35] who also reported that the preoperative OA stage did not correlate with the postoperative clinical findings. If an improvement to stage 1 is a requirement for a satisfactory result, as Tanaka and colleagues[22] had concluded, then SMOT should not have been considered effective. Therefore, the indication for SMOT cannot be dependent on the OA stage only, there must be other factors determining the outcome (**Fig. 7**).

One factor may be the TT angle. An excessive TT angle is often cited as one of the relative contraindications to SMOT. Some authors reported a significant decrease of the TT[9,31,32,54,66,67]; however, some did not.[19–21,35] Lee and colleagues[35] considered a TT angle exceeding 7.3° to be a negative factor, whereas Tanaka and colleagues[22] considered a TT angle exceeding 10° to be a negative factor for SMOT. A large TT angle implies disability of the lateral ligament complex or an erosion of the medial malleolar subchondral bone. However, no significant difference could be detected between the 5-year survival rate for patients with a preoperative tilt of the talus in the ankle mortise of 4° to 10° (85% [95% CI, 68–100]) and that for patients with a preoperative tilt of greater than 10° (65% [95% CI, 46–93], P = .117).[13] Obviously, preoperative TT angle should not be an over-estimated factor when SMOT is considered for the treatment of ankle OA.[38]

Overcorrection has been reported to lead to better results than undercorrection, particularly in advanced stages of OA.[55] The ideal amount of overcorrection is still a matter of debate. Tanaka and colleagues[22] aimed to achieve a TAS angle of 96° to 98° because overcorrection yielded better results in their patients. However, Lee and colleagues,[35] after having seen subsequent problems after performing major correction of up to 108°, such as subfibular pain, revised their strategy to an overcorrection of 3° to 5°, while adding a deltoid release and a calcaneal osteotomy instead. In general, there is agreement that the optimal correction with SMOT is a 2° to 4° slight overcorrection of the TAS angle or a correction in reference to the normal contralateral limb.[11,13,15,17,35,38,49] However, Harstall and colleagues[10] proposed a correction to neutral alignment of the tibial plafond only, to not decompensate the hindfoot into hypervalgus and to prevent creating a deformity that could compromise the results of a total ankle replacement, which might be necessary at a later time point.

With SMOT, the varus deformity can be effectively corrected proximal to the ankle joint, leading to restoration of the talar center on the axis of the tibia and dispersion of the stress on the ankle joint surface.[12,28,31,55,68] Traditional tibial correction based on the TAS angle leads to high variation in the locations of the postoperative mechanical ankle joint axis point.

Haragucchi and colleagues[55] found that if the crossing point of the tibial axis with articular surface of the tibial plafond was insufficiently moved to the lateral side, the clinical outcome was less satisfactory. They advocated that modification of the procedure to shift the mechanical axis more laterally is required for these ankles. This is supported by the findings of Hintermann and colleagues,[31] who reported better outcome after intraarticular plafond plasty combined with an additional medial open wedge osteotomy of the distal tibia to move the mechanical axis more lateral, than Mann and colleagues[53] had done with a singular intraarticular correction.

The necessity for adding a fibular osteotomy is still controversial. Some authors proposed to combine SMOT with a fibular osteotomy in all the cases,[10,20–22,35,55] some suggested the fibula should always be preserved,[32,44,53,67] and some decide to

Fig. 7. Posttraumatic varus deformity with Takakura stage 4 OA and a nonunited medial malleolus. A 43-year-old trail runner who sustained a complex ankle fracture was advised by several doctors to go for an ankle fusion. (*A*) Two years and 3 months after internal fixation of the fracture, standard radiographs show a varus malunited ankle (TAS 12°) with

perform it depending on each case (**Fig. 8**).[9,11,12,19,46] As a rule, if the angle between the tibial axis and the line given by the tip of medial and lateral malleolus is more than 5° higher than the nonaffected site when compared (which indicates a longer fibula or varus shift, or the fibula has a rotational deformity, or interferes in the reduction of tibial plafond and talus), a fibular osteotomy is indicated through a lateral approach at the same level or higher than the tibial osteotomy.[46,50] When, after SMOT, a residual talar varus tilt is observed, a shortening and valgus osteotomy may be considered.[48] Stufkens and colleagues,[69] in a cadaveric study, found that creating a supramalleolar valgus deformity did not cause a shift in contact stress toward the lateral side of the tibiotalar joint, and the restricting role of the fibula was revealed by carrying out an osteotomy. Therefore, solely correcting the angle of the distal tibia on its own may not redistribute the intraarticular forces enough, an additional correction of the position and length of the fibula should be considered in every single case. In medial opening-wedge SMOT, a fibular osteotomy may be considered to minimize the increase of pressure in the talofibular joint, especially when the osteotomy gap is large.[70]

A high heel moment arm (HMA)[71] in varus ankle OA indicates a varus deformity of the distal tibia, a decrease in the height of the medial half of the talus, or abnormal alignment of the talus and calcaneus.[38] In rare cases, a high HMA is also associated with varus deformity of the calcaneus body, which sometimes requires a lateral sliding calcaneus osteotomy with[65] or without[15,64] a closing wedge. Although the HMA is usually seen to be significantly improved, it often does not reach the normal range (1.6–3.2 mm),[71] which may be related to the coexistence of hidden subtalar joint varus or the uncorrected varus deformity of the calcaneus body.[38] Several studies showed little change to the stress in the ankle joint stress alignment,[72,73] whereas in feet with a cavovarus deformity, a significant lateralization of the center of force, as well as a significant peak pressure reduction at the ankle joint, was found.[74,75] In analogous biomechanical studies, an SMOT provided equally good redistribution of elevated ankle joint contact forces[70,75]; the effect was higher in SMOT combined with a fibular osteotomy, however.[70]

When the talus is tilted into varus, the calcaneus may compensate in the opposite direction, resulting in a z-shaped deformity.[56,76] Such contradictory movement of the calcaneus may often result in a clinical appearance of a well-aligned hindfoot. As its height has decreased, the surrounding soft tissue structures do typically demonstrate additional loss of tension with clinical appearance of a “floppy hindfoot.” A lateral sliding osteotomy will increase the varus tilt of the talus and the medial overload of the tibiotalar joint; therefore, a medial sliding osteotomy in association to soft tissue reconstruction or a subtalar fusion might be considered to reorientate the talus within the ankle mortise (**Fig. 9**).

The stability of the talus depends on the finely matched bone structure and the healthy soft tissue around the talus, including the lateral collateral ligaments, the ligaments between the talus and calcaneus, and the extrinsic tendons (ie, the created

complete obliteration of the tibiotalar joint space. (*B*) Postoperative situation after performing a dome osteotomy, fibular osteotomy, and medial sliding osteotomy of the calcaneus. (*C*) Nine years after correcting the osteotomy, the patient is still pain-free and very satisfied to be able to run. The radiographs show some incongruency and narrowing of the joint space, according to a Takakura OA stage 2. The recovery of the articular surfaces can be better seen in the weight-bearing CT scans: (*D*) coronal plane view; (*E*) sagittal plane view.

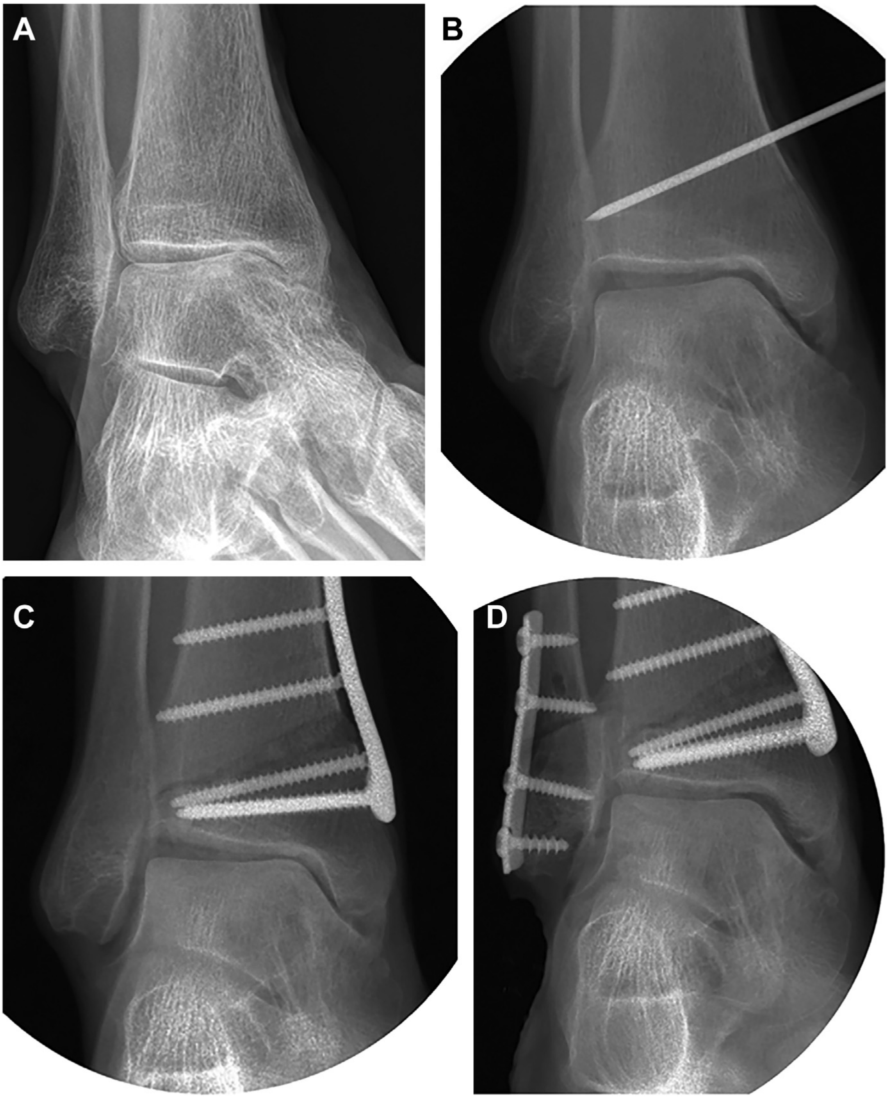

Fig. 8. The effect of a fibular osteotomy. A 62-year-old very ambitious marathon runner who is suffering from progressive medial ankle pain after having sustained several ankle sprains in the adolescence. (*A*) The AP radiograph shows a narrowing of the joint space at the medial corner in the roof of the dome of the talus and an obliteration only at the tip of medial malleolus preoperatively with an angle of talar tilt on weight-bearing of 6°. (*B*) Intraoperative fluoroscopy of the nonloaded ankle with a Kirschner wire placed where the medial open wedge osteotomy is planned. (*C*) After having performed the correcting osteotomy of the distal tibia, the talar tilt angle increased to 11° despite of a Broström type reconstruction of the lateral ankle ligaments. (*D*) A shortening osteotomy of the fibula with some valgus angulation was needed to achieve a congruent ankle joint.

Fig. 9. Varus-valgus deformity in a 46-year-old female suffering from severe medial ankle pain. (*A*) The preoperative AP radiograph shows a narrowing of the joint space at the medial corner in the roof of the dome of the talus and an obliteration only at the tip of the medial malleolus with a talar tilt on weight-bearing of 7°. The hindfoot alignment view shows a valgus malalignment of the heel with a HMA of 6 mm. The obliteration of the medial gutter with subchondral sclerosis and beginning erosion can be best seen in the weight-bearing CT scan. (*B*) One year after performing a medial open wedge osteotomy of the distal tibia, correcting osteotomy of the fibula and a medial sliding osteotomy of the calcaneus, the joint incongruency persists with a talar tilt angle of 3°; the medial gutter is again open and subchondral sclerosis has significantly disappeared, which can be seen in the weight-bearing CT scan. Notice the big amount of medial translation of calcaneal tuberosity that was necessary to balance the ankle. Postoperatively, the medial ankle pain completely disappeared.

forces by their muscles) of the foot. Instability of the talus can be caused by abnormal bone structure, or dysfunction of related ligaments and tendons. In different stages, these abnormalities can exist alone or simultaneously and affect each other. Although lateral ligament reconstruction is considered in general as an important step of treatment for medial ankle OA,[2,16,45,53] some authors suggest that treatment of chronic lateral ankle instability is not important for the result of realignment surgery and believe that chronic instability disappears after shifting the weight-bearing load to the lateral aspect of the ankle.[21,22]

It has been suggested that besides insufficient lateral ankle ligaments, the altered morphologic characteristics of the bony, articular and periarticular anatomy, as well as muscular dynamics play an important role in the etiology of varus ankle deformity, especially of cavovarus deformity where the talus is typically seen to dislocate anterolaterally out of the ankle mortise.[26,41,61,77,78] Hyperactivation of PL and PT muscles may explain why cavovarus deformity often is accompanied by a plantarflexed first ray.[26,61,78] During the push-off phase of the gait cycle, the hindfoot is forced into supination creating varus malalignment. Plantarflexion of the first ray by the PL occurs in patients with spastic cerebral palsy.[79] Under such conditions, plantarflexion of the first ray in the sagittal plane is increased, provoking a supination force at the hindfoot in the push-off phase. As a result, the transmission of axial forces through the ankle joint is altered, and the Achilles tendon serves as an inverter of the hindfoot, enhancing the varus stress. Therefore, deforming forces should be transferred to obtain normal movement and function.[26,57,58,60–64,80] In addition, a correcting osteotomy to dorsiflex the first ray should be considered.[57,80] However, to date, little is known about the effect of all these measures in joint preserving surgery of the OA varus ankle. Most reports have focused on how to balance the ankle in total ankle replacement surgery.[80–84]

SUMMARY

Careful clinical and radiographic assessment of the talar position in all 3 planes is mandatory for success in the treatment of asymmetric OA varus ankles. Because articular surfaces may be worn out, isolated ligament reconstruction on the lateral side of the ankle joint may not restore proper position of the talus within the ankle mortise. Osseous balancing with osteotomies above or below the ankle, or subtalar fusion, may thus be the main step for successful restoration of talar position within the ankle mortise. Overall, the key for the success of joint preserving surgery is to understand the underlying causes that have contributed to the varus OA in each case, and to use all treatment modalities necessary to restore the appropriate alignment of the hindfoot complex. Although SMOT is suggested to have the main effect on restoring ankle joint function, additional procedures might be necessary for proper correction of varus deformity and thus to achieve long-term success. Overall, joint preserving surgery has evolved to a successful option in early and midstage medial ankle OA caused and slowing of the degenerative process.

CLINICS CARE POINTS

- A varus ankle deformity can be successfully addressed by osteotomies and soft tissues procedures.
- Osteotomies must aim to correct the deformity at its origin (supramalleolar, intramallelar and/or intraarticular).
- Additional soft tissue procedures might be necessary to stabilize the ankle and to eliminate the deforming forces.
- Though joint congruity cannot be fully restored in most cases, joint preserving prcedures were shown to significantly reduce pain and to delay the ongoing degenerative process.

- While the radiographic result may not meet the surgeon's expectation, the clinical result and patient's satisfaction is often higher.

DISCLOSURE

The authors have nothing to declare.

REFERENCES

1. Saltzman CL, Salamon ML, Blanchard GM, et al. Epidemiology of ankle arthritis: report of a consecutive series of 639 patients from a tertiary orthopaedic center. Iowa Orthop J 2005;25:44–6.
2. Valderrabano V, Hintermann B, Horisberger M, Fung TS. Ligamentous posttraumatic ankle osteoarthritis. Am J Sports Med 2006;34(4):612–20.
3. Fuentes-Sanz A, Moya-Angeler J, Lopez-Oliva F, Forriol F. Clinical outcome and gait analysis of ankle arthrodesis. Foot Ankle Int 2012;33(10):819–27.
4. Hendrickx RP, Stufkens SA, de Bruijn EE, Sierevelt IN, van Dijk CN, Kerkhoffs GM. Medium- to long-term outcome of ankle arthrodesis. Foot Ankle Int 2011;32(10):940–7.
5. Jastifer JR, Coughlin MJ. Long-term follow-up of mobile bearing total ankle arthroplasty in the United States. Foot Ankle Int 2015;36(2):143–50.
6. Krishnapillai S, Joling B, Sierevelt IN, Kerkhoffs G, Haverkamp D, Hoornenborg D. Long-term Follow-up Results of Buechel-Pappas Ankle Arthroplasty. Foot Ankle Int 2019;40(5):553–61.
7. Mann JA, Mann RA, Horton E. STAR ankle: long-term results. Foot Ankle Int 2011;32(5):S473–84.
8. Barg A, Pagenstert GI, Horisberger M, et al. Supramalleolar osteotomies for degenerative joint disease of the ankle joint: indication, technique and results. Int Orthop 2013;37(9):1683–95.
9. Colin F, Bolliger L, Horn Lang T, Knupp M, Hintermann B. Effect of supramalleolar osteotomy and total ankle replacement on talar position in the varus osteoarthritic ankle: a comparative study. Foot Ankle Int 2014;35(5):445–52.
10. Harstall R, Lehmann O, Krause F, Weber M. Supramalleolar lateral closing wedge osteotomy for the treatment of varus ankle arthrosis. Foot Ankle Int 2007;28(5):542–8.
11. Hintermann B, Knupp M, Barg A. Supramalleolar Osteotomies for the Treatment of Ankle Arthritis. J Am Acad Orthop Surg 2016;24(7):424–32.
12. Knupp M, Stufkens SA, Bolliger L, Barg A, Hintermann B. Classification and treatment of supramalleolar deformities. Foot Ankle Int 2011;32(11):1023–31.
13. Krahenbuhl N, Akkaya M, Deforth M, Zwicky L, Barg A, Hintermann B. Extraarticular Supramalleolar Osteotomy in Asymmetric Varus Ankle Osteoarthritis. Foot Ankle Int 2019;40(8):936–47.
14. Knupp M, Hintermann B. Treatment of asymmetric arthritis of the ankle joint with supramalleolar osteotomies. Foot Ankle Int 2012;33(3):250–2.
15. Lee KB, Cho YJ. Oblique supramalleolar opening wedge osteotomy without fibular osteotomy for varus deformity of the ankle. Foot Ankle Int 2009;30(6):565–7.
16. Lee HS, Wapner KL, Park SS, Kim JS, Lee DH, Sohn DW. Ligament reconstruction and calcaneal osteotomy for osteoarthritis of the ankle. Foot Ankle Int 2009;30(6):475–80.

17. Lee WC. Extraarticular Supramalleolar Osteotomy for Managing Varus Ankle Osteoarthritis, Alternatives for Osteotomy: How and Why? Foot Ankle Clin 2016; 21(1):27–35.
18. Nuesch C, Huber C, Paul J, et al. Mid- to Long-term Clinical Outcome and Gait Biomechanics After Realignment Surgery in Asymmetric Ankle Osteoarthritis. Foot Ankle Int 2015;36(8):908–18.
19. Pagenstert GI, Hintermann B, Barg A, Leumann A, Valderrabano V. Realignment surgery as alternative treatment of varus and valgus ankle osteoarthritis. Clin Orthop Relat Res 2007;462:156–68.
20. Stamatis ED, Cooper PS, Myerson MS. Supramalleolar osteotomy for the treatment of distal tibial angular deformities and arthritis of the ankle joint. Foot Ankle Int 2003;24(10):754–64.
21. Takakura Y, Tanaka Y, Kumai T, Tamai S. Low tibial osteotomy for osteoarthritis of the ankle. Results of a new operation in 18 patients. J Bone Joint Surg Br 1995; 77(1):50–4.
22. Tanaka Y, Takakura Y, Hayashi K, Taniguchi A, Kumai T, Sugimoto K. Low tibial osteotomy for varus-type osteoarthritis of the ankle. J Bone Joint Surg Br 2006; 88(7):909–13.
23. Barg A, Pagenstert GI, Hugle T, et al. Ankle osteoarthritis: etiology, diagnostics, and classification. Foot Ankle Clin 2013;18(3):411–26.
24. Davitt JS, Beals TC, Bachus KN. The effects of medial and lateral displacement calcaneal osteotomies on ankle and subtalar joint pressure distribution. Foot Ankle Int 2001;22(11):885–9.
25. Knupp M, Stufkens SA, van Bergen CJ, et al. Effect of supramalleolar varus and valgus deformities on the tibiotalar joint: a cadaveric study. Foot Ankle Int 2011; 32(6):609–15.
26. Ortiz C, Wagner E. Tendon transfers in cavovarus foot. Foot Ankle Clin 2014; 19(1):49–58.
27. Wang BSCL, Chalayon O, Barg A. Does the Subtalar Joint Compensate for Ankle Malalignment in End-stage Ankle Arthritis? Clin Orthop Relat Res 2015;473(1): 318–25.
28. Zhu Y, Li X, Xu X. Ankle joint pressure change in varus malalignment of the tibia. BMC Musculoskelet Disord 2020;21(1):148.
29. Stiehl JB. Inman's joints of the ankle. Baltimore, Maryland: Williams & Wilkins; 1991.
30. Cox JS, Hewes TF. Normal" talar tilt angle. Clin Orthop Relat Res 1979;140:37–41.
31. Hintermann B, Ruiz R, Barg A. Novel Double Osteotomy Technique of Distal Tibia for Correction of Asymmetric Varus Osteoarthritic Ankle. Foot Ankle Int 2017; 38(9):970–81.
32. Kim YS, Park EH, Koh YG, Lee JW. Supramalleolar Osteotomy With Bone Marrow Stimulation for Varus Ankle Osteoarthritis: Clinical Results and Second-Look Arthroscopic Evaluation. Am J Sports Med 2014;42(7):1558–66.
33. Knupp MSSA, Pagenstert GI, Hintermann B, Valderrabano V. Supramalleolar Osteotomy for Tibiotalar Varus Malalignment. Tech Foot Ankle Surg 2009;8(1):17–23.
34. Kroon M, Faber FW, van der Linden M. Joint preservation surgery for correction of flexible pes cavovarus in adults. Foot Ankle Int 2010;31(1):24–9.
35. Lee WC, Moon JS, Lee K, Byun WJ, Lee SH. Indications for supramalleolar osteotomy in patients with ankle osteoarthritis and varus deformity. J Bone Joint Surg Am 2011;93(13):1243–8.
36. Myerson MS, Zide JR. Management of varus ankle osteoarthritis with joint- preserving osteotomy. Foot Ankle Clin 2013;18(3):471–80.

37. Takakura Y, Takaoka T, Tanaka Y, Yajima H, Tamai S. Results of opening-wedge osteotomy for the treatment of a post-traumatic varus deformity of the ankle. J Bone Joint Surg Am 1998;80(2):213–8.
38. Qu W, Xin D, Dong S, Li W, Zheng Y. Supramalleolar osteotomy combined with lateral ligament reconstruction and talofibular immobilization for varus ankle osteoarthritis with excessive talar tilt angle. J Orthop Surg Res 2019;14(1):402.
39. Kraus JC, Fischer MT, McCormick JJ, Klein SE, Johnson JE. Geometry of the lateral sliding, closing wedge calcaneal osteotomy: review of the two methods and technical tip to minimize shortening. Foot Ankle Int 2014;35(3):238–42.
40. Maskill MP, Maskill JD, Pomeroy GC. Surgical management and treatment algorithm for the subtle cavovarus foot. Foot Ankle Int 2010;31(12):1057–63.
41. Ortiz C, Wagner E, Keller A. Cavovarus foot reconstruction. Foot Ankle Clin 2009;14(3):471–87.
42. Tennant JN, Carmont M, Phisitkul P. Calcaneus osteotomy. Curr Rev Musculoskelet Med 2014;7(4):271–6.
43. Horn DM, Fragomen AT, Rozbruch SR. Supramalleolar osteotomy using circular external fixation with six-axis deformity correction of the distal tibia. Foot Ankle Int 2011;32(10):986–93.
44. Ahn TK, Yi Y, Cho JH, Lee WC. A cohort study of patients undergoing distal tibial osteotomy without fibular osteotomy for medial ankle arthritis with mortise widening. J Bone Joint Surg Am 2015;97(5):381–8.
45. DeCarbo WT, Granata AM, Berlet GC, Hyer CF, Philbin TM. Salvage of severe ankle varus deformity with soft tissue and bone rebalancing. Foot Ankle Spec 2011;4(2):82–5.
46. Hongmou Z, Xiaojun L, Yi L, Hongliang L, Junhu W, Cheng L. Supramalleolar Osteotomy With or Without Fibular Osteotomy for Varus Ankle Arthritis. Foot Ankle Int 2016;37(9):1001–7.
47. Scheidegger P, Horn Lang T, Schweizer C, Zwicky L, Hintermann B. A flexion osteotomy for correction of a distal tibial recurvatum deformity: a retrospective case series. Bone Joint J 2019;101-B(6):682–90.
48. Krause F, Veljkovic A, Schmid T. Supramalleolar Osteotomies for Posttraumatic Malalignment of the Distal Tibia. Foot Ankle Clin 2016;21(1):1–14.
49. Knupp M. The Use of Osteotomies in the Treatment of Asymmetric Ankle Joint Arthritis. Foot Ankle Int 2017;38(2):220–9.
50. Wagner PCF, Hintermann B. Distal Tibia Dome Osteotomy. Tech Foot Ankle Surg 2014;13(2):103–7.
51. Siddiqui NA, Herzenberg JE, Lamm BM. Supramalleolar osteotomy for realignment of the ankle joint. Clin Podiatr Med Surg 2012;29(4):465–82.
52. Al-Nammari SS, Myerson MS. The Use of Tibial Osteotomy (Ankle Plafondplasty) for Joint Preservation of Ankle Deformity and Early Arthritis. Foot Ankle Clin 2016;21(1):15–26.
53. Mann HA, Filippi J, Myerson MS. Intra-articular opening medial tibial wedge osteotomy (plafond-plasty) for the treatment of intra-articular varus ankle arthritis and instability. Foot Ankle Int 2012;33(4):255–61.
54. Cheng YM, Huang PJ, Hong SH, et al. Low tibial osteotomy for moderate ankle arthritis. Arch Orthop Trauma Surg 2001;121(6):355–8.
55. Haraguchi N, Ota K, Tsunoda N, Seike K, Kanetake Y, Tsutaya A. Weight-bearing-line analysis in supramalleolar osteotomy for varus-type osteoarthritis of the ankle. J Bone Joint Surg Am 2015;97(4):333–9.
56. Hintermann B, Knupp M, Barg A. Joint-preserving surgery of asymmetric ankle osteoarthritis with peritalar instability. Foot Ankle Clin 2013;18(3):503–16.

57. Chen ZY, Wu ZY, An YH, Dong LF, He J, Chen R. Soft tissue release combined with joint-sparing osteotomy for treatment of cavovarus foot deformity in older children: Analysis of 21 cases. World J Clin Cases 2019;7(20):3208–16.
58. Dreher T, Beckmann NA, Wenz W. Surgical Treatment of Severe Cavovarus Foot Deformity in Charcot-Marie-Tooth Disease. JBJS Essent Surg Tech 2015;5(2):e11.
59. Hintermann B, Ruiz R. Foot and ankle instability. Springer International Publishing; 2021.
60. Kilger RKM, Hintermann B. Peroneus Longus to Peroneus Brevis Tendon Transfer. Tech Foot Ankle Surg 2009;8(3):146–9.
61. Krause FG, Henning J, Pfander G, Weber M. Cavovarus foot realignment to treat anteromedial ankle arthrosis. Foot Ankle Int 2013;34(1):54–64.
62. Krause FG, Pohl MJ, Penner MJ, Younger AS. Tibial nerve palsy associated with lateralizing calcaneal osteotomy: case reviews and technical tip. Foot Ankle Int 2009;30(3):258–61.
63. Kagaya H, Yamada S, Nagasawa T, Ishihara Y, Kodama H, Endoh H. Split posterior tibial tendon transfer for varus deformity of hindfoot. Clin Orthop Relat Res 1996;(323):254–60.
64. Knupp MHM, Hintermann B. A New Z-Shaped Calcaneal Osteotomy for 3-Plane Correction of Severe Varus Deformity of the Hindfoot. Tech Foot Ankle Surg 2008;7(2):90–5.
65. Dwyer FC. Osteotomy of the calcaneum for pes cavus. J Bone Joint Surg Br 1959;41-B(1):80–6.
66. Krahenbuhl N, Zwicky L, Bolliger L, Schadelin S, Hintermann B, Knupp M. Mid- to Long-term Results of Supramalleolar Osteotomy. Foot Ankle Int 2017;38(2):124–32.
67. Kobayashi H, Kageyama Y, Shido Y. Treatment of Varus Ankle Osteoarthritis and Instability With a Novel Mortise-Plasty Osteotomy Procedure. J Foot Ankle Surg 2016;55(1):60–7.
68. Tanaka Y. The concept of ankle joint preserving surgery: why does supramalleolar osteotomy work and how to decide when to do an osteotomy or joint replacement. Foot Ankle Clin 2012;17(4):545–53.
69. Stufkens SA, van Bergen CJ, Blankevoort L, van Dijk CN, Hintermann B, Knupp M. The role of the fibula in varus and valgus deformity of the tibia: a biomechanical study. J Bone Joint Surg Br 2011;93(9):1232–9.
70. Choi GW, Lee SH, Nha KW, Lee SJ, Kim WH, Uhm CS. Effect of Combined Fibular Osteotomy on the Pressure of the Tibiotalar and Talofibular Joints in Supramalleolar Osteotomy of the Ankle: A Cadaveric Study. J Foot Ankle Surg 2017;56(1):59–64.
71. Saltzman CL, el-Khoury GY. The hindfoot alignment view. Foot Ankle Int 1995;16(9):572–6.
72. Michelson JD, Mizel M, Jay P, Schmidt G. Effect of medial displacement calcaneal osteotomy on ankle kinematics in a cadaver model. Foot Ankle Int 1998;19(3):132–6.
73. Steffensmeier SJ, Saltzman CL, Berbaum KS, Brown TD. Effects of medial and lateral displacement calcaneal osteotomies on tibiotalar joint contact stresses. J Orthop Res 1996;14(6):980–5.
74. Krause FG, Sutter D, Waehnert D, Windolf M, Schwieger K, Weber M. Ankle joint pressure changes in a pes cavovarus model after lateralizing calcaneal osteotomies. Foot Ankle Int 2010;31(9):741–6.

75. Schmid T, Zurbriggen S, Zderic I, Gueorguiev B, Weber M, Krause FG. Ankle joint pressure changes in a pes cavovarus model: supramalleolar valgus osteotomy versus lateralizing calcaneal osteotomy. Foot Ankle Int 2013;34(9):1190–7.
76. Hintermann B, Knupp M, Barg A. Peritalar instability. Foot Ankle Int 2012;33(5): 450–4.
77. Vienne P, Schoniger R, Helmy N, Espinosa N. Hindfoot instability in cavovarus deformity: static and dynamic balancing. Foot Ankle Int 2007;28(1):96–102.
78. Younger AS, Hansen ST Jr. Adult cavovarus foot. J Am Acad Orthop Surg 2005; 13(5):302–15.
79. Aleksic M, Bascarevic Z, Stevanovic V, Rakocevic J, Baljozovic A, Cobeljic G. Modified split tendon transfer of posterior tibialis muscle in the treatment of spastic equinovarus foot deformity: long-term results and comparison with the standard procedure. Int Orthop 2020;44(1):155–60.
80. Hintermann B, Ruiz R. Total replacement of varus ankle: three-component prosthesis design. Foot Ankle Clin 2019;24(2):305–24.
81. Choi WJ, Kim BS, Lee JW. Preoperative planning and surgical technique: how do I balance my ankle? Foot Ankle Int 2012;33(3):244–9.
82. Daniels TR. Surgical technique for total ankle arthroplasty in ankles with preoperative coronal plane varus deformity of 10 degrees or greater. JBJS Essent Surg Tech 2014;3(4):e22.
83. Roukis TS. Tibialis posterior recession for balancing varus ankle contracture during total ankle replacement. J Foot Ankle Surg 2013;52(5):686–9.
84. Roukis TS, Elliott AD. Use of soft-tissue procedures for managing varus and valgus malalignment with total ankle replacement. Clin Podiatr Med Surg 2015; 32(4):517–28.