The Varus Ankle and Instability

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KEYWORDS

• Varus • Ankle • Instability • Treatment

Hindfoot varus has been recognized as an anatomic risk factor that promotes chronic lateral ankle instability.[1–3] Hindfoot varus is present in 8% of patients with ankle instability, and with 28% it is the most commonly found condition in patients with persisting pain or recurrent instability after lateral ankle ligament reconstruction.[4] Varus malalignment may occur isolated at a single structural level (eg, supramalleolar) or as part of a complex deformity with multiple structures involved (eg, cavovarus deformity). In order to select the optimal treatment strategy, a thorough understanding of the static and dynamic causes of deformity and their biomechanical effects is mandatory.

BIOMECHANICS IN THE VARUS ANKLE

Abnormalities in the frontal, sagittal, and/or transversal plane of the hindfoot lead to asymmetric force distributions across the joints.[5] As such, it is the nature of a varus hindfoot that medial joint areas become overloaded, bearing the potential for premature degeneration of the cartilage.[6,7] However, compared with a valgus ankle, progression of osteoarthritis in a varus ankle is slow. The reason for this slow progression has been found in a stronger medial bone support, which theoretically could be protective and delay arthritic changes.[8,9] In addition, kinematics at the hindfoot are altered as a result of a misdirected pulling vector of the Achilles tendon. At heel strike, the varus hindfoot provokes an inversion moment exerted by the Achilles tendon. Thus, the strain on the lateral structures of the ankle is increased and the ligaments are exposed to a higher failure risk. Recurrent ankle sprain in patients with varus malalignment of the hindfoot is a frequent finding.[10] Up to 30% of patients who have been operated on for recurrent ankle instability reveal some kind of hindfoot varus that has not been detected at the initial workup.[4] Lateral instability itself is the second most common cause of posttraumatic osteoarthritis of the ankle.[11] The combination of mechanical and functional instability at the hindfoot—as typically present in varus

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Table 1
Causes of simple hindfoot varus malalignment

Source of Hindfoot Varus	Clinical Example
- Knee	Medial osteoarthritis
- Lower leg	Malunited tibial fracture
- Supramalleolar	Malunited pilon fracture
Tibiotalocalcaneal varus	
- Ankle joint	Chronic instability with varus osteoarthritis
- Talocalcaneal	Tarsal coalition
- Calcaneal	Malunited calcaneal fracture

deformities—promotes the development of ankle osteoarthitis.[12–15] Based on these facts, varus malalignment of the hindfoot must be recognized and addressed when treating instability of the ankle and subtalar joint.[16]

ANATOMIC CHARACTERISTICS OF SIMPLE AND COMPLEX VARUS HINDFOOT DEFORMITY

Simple Hindfoot Varus Malalignment

In isolated hindfoot varus deformities, malalignment is the result of an anatomic aberration at a single level either below at or above the ankle joint (**Table 1**).[17–19] The lever arm of the Achilles tendon is increased and its pulling vector medialized. Therefore, the inversion moment at the hindfoot is increased.[20] In case of a fixed varus deformity at the subtalar joint, the situation is worse because compensatory movement in inversion and eversion takes place solely at the ankle.[21] Thus, the susceptibility to an ankle sprain or chronic ankle instability is high. Over time, hindfoot varus may result in additional midfoot and forefoot malalignment, transforming a simple and isolated varus deformity into a complex one.

Complex Varus Deformities

Regarding complex deformities, the hindfoot varus is one element of a multitude of structures contributing to the malalignment of the foot and ankle. The most common type of such a deformity is the cavovarus foot.[22] A synopsis of causes leading to cavovarus deformity is presented in **Table 2**. Severity of each component varies depending on cause, extent of motor imbalance, and patient age.[23] Premature onset of disease distorts the entire hindfoot and forefoot anatomy because of pathologic growth of bones and makes a reconstructive procedure more demanding.[23]

Medial or plantarmedial peritalar subluxation describes the anatomic properties of a cavovarus foot. The posterior tibial tendon is strong and contracted, resulting in varus hindfoot alignment[24] and adduction of the midfoot and forefoot, whereas the peroneus brevis is weak or even absent. Because of varus malalignment at the heel, the pulling vector of the Achilles tendon becomes medialized, increasing the inversion moment and thus varus deformity.[25] In addition, a weak tibialis anterior muscle (eg, in Charcot-Marie-Tooth disease) becomes overpowered by the peroneus longus muscle, thus plantarflexing the first ray. The amount of plantarflexion at the first ray determines the height of the medial arch and thus the cavus component. Besides this mechanism, the plantarflexed first ray adds a rotatory malalignment of the forefoot, in other words, hyperpronation. The plantar fascia is generally contracted, adding to the adduction component and cavus deformity. Because there is a rotatory component in

Table 2
Causes of complex hindfoot varus deformity

Cause of Cavovarus	Pathology
Idiopathic	
Neurogenic	
- Cerebral disease - Spinal cord disease - Peripheral neural disease	Cerebral palsy, stroke polio, tethered cord, amyotrophic lateral sclerosis, Charcot-Marie-Tooth, spasticity of tibialis anterior or posterior, L5 motor radiculopahty
Residual clubfoot	
Traumatic	Lower leg compartment syndrome, talar neck malunion, peroneal nerve palsy, knee dislocations
Systemic inflammatory disease	Rheumatoid arthritis

cavovarus feet at the tarsus, the navicular moves into a more superior than medial position relative to the cuboid. The Chopart joint becomes torqued and fixes hindfoot varus. The evolution from supple to rigid cavovarus foot deformity is continuous. Once it has become rigid during stance phase, there is less shock absorption than, for example, in a valgus hindfoot deformity. The cavus deformity reduces the area of contact with the ground and increases localized pressure at the planta pedis, possibly leading to metatarsalgia and heel pain.[23] As a result of the previously mentioned biomechanical alterations, the lateral foot becomes overloaded,[26] and together with an impaired capacity of shock absorption due to subtalar locking and relative weakness of peroneus brevis, the risk of lateral ankle instability is increased. In addition, a fixed cavovarus deformity forces the talus into a varus tilt with chronic varus overload and possible evolution into medial ankle osteoarthritis.[2,12,16,27]

Normally forefoot-driven cavovarus deformity as explained previously is distinguished from hindfoot-driven variants. In the latter, the varus deformity represents the beginning of a pathologic process that contributes to further development of cavovarus deformity. Examples include lower leg compartment syndrome with deep posterior flexor contracture resulting in equinovarus and a malunited fracture of the talus.[5]

CLINICAL ASSESSMENT

The patient is examined barefoot both during walking and in a standing position. It is important to have the patient take off the trousers in order to estimate all lower limb axes. The alignments of both legs and hindfeet are evaluated. The goal of clinical evaluation is to assess the stability of the ankle joint and to obtain a detailed appreciation of the deformity type. Leg, hindfoot, midfoot, and forefoot deformities should be checked and assessed in order to estimate the rigidity and potential of possible correction. Throughout the clinical evaluation particular attention is paid to signs of concomitant pathologic conditions such as peroneal tendinopathy and lateral as well as medial instability, osteochondral lesions, osteoarthritis including ankle impingement, occult fractures, and neuropathy of the superficial peroneal nerve. However, in the following paragraphs the focus is on assessment of varus malalignment and ankle instability.

Inspection

Hindfoot alignment is observed during stance and includes inspection of soft-tissue conditions, for example, atrophy. Pelvic tilt, leg length discrepancies, and knee axis are

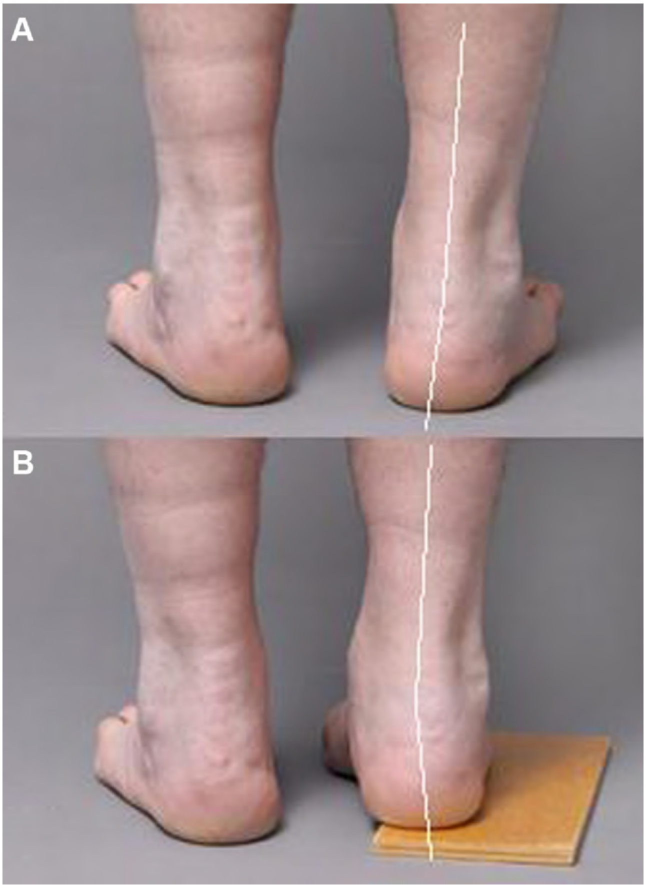

Fig. 1. The heels of a patient with a varus malalignment on the right side but physiologic hindfoot valgus of 0° to 5° on the left side (*A*). The Coleman block test reveals flexible hindfoot deformity (*B*).

assessed. Measurement of hindfoot alignment is performed while looking at the patient from behind (**Fig. 1**). The angle between long axis of the leg and axis of the calcaneus is measured. Normal values range from 0° neutral to 5° valgus. Any varus is pathologic.

The examiner could look for a peek-a-boo heel, as described by Manoli[28]: When examining the patient from the front, the visibility of the medial heel pad indicates the presence of hindfoot varus. The height of the medial longitudinal arch and the amount of first ray plantarflexion are noted, and special attention is paid to the position of the forefoot and midfoot under varus and valgus stress as well as pronation and supination. Analysis of gait and distribution of callosities at the plantar aspect may reveal dynamic components and could indicate regions that are overloaded.

Palpation

During palpation, special attention is paid to tender spots along the course of the medial and lateral ligament complexes around the ankle as well as along the joint lines of the ankle, subtalar, and Chopart joints. Tenderness along the peroneal tendons may indicate tendinopathy or partial rupture and needs specific imaging, for example, magnetic resonance imaging (MRI). Occasionally a prominent osteophyte formation points toward arthritic disorders. If local swelling is observed, palpation allows identification of joint effusion, tenosynovitis, or ganglion formation.

Function and Specific Tests

The flexibility of hindfoot varus—for example, in forefoot-driven hindfoot varus—can be tested by means of the Coleman block test (see **Fig. 1**).[29]

Range of motion (ROM) at the ankle, subtalar, and Chopart joints is assessed. Reduced ROM at any of those joints helps to identify the locus of rigidity and deformity. Reduced ROM at the ankle with concomitant equinus indicates a short gastrocnemius-soleus muscle complex. In order to assess the contribution of a short gastrocnemius-soleus complex, the so-called Silferskjöld test is performed (**Fig. 2**). It is important to rule out shortening of the Achilles tendon and contractures of the triceps surae because they may play an important role in correcting the hindfoot and

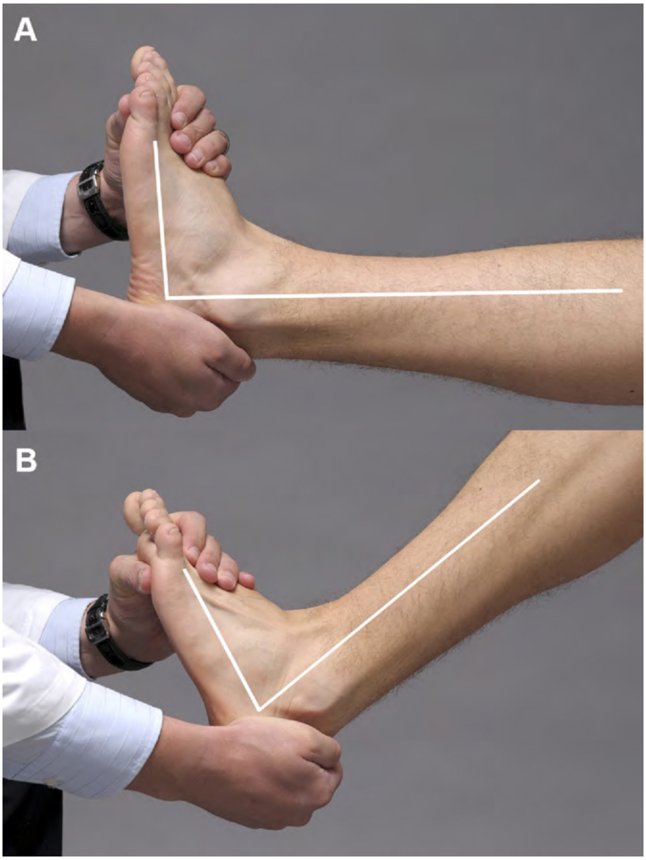

Fig. 2. The so-called Silferskjöld test to evaluate contracture of the gastrocnemius-soleus complex. With the knee held in maximum extension, dorsiflexion is minimal (*A*). When flexing the knee to 90° the dorsiflexion augments, indicating isolated contracture of the gastrocnemius muscle unit (*B*).

Fig. 3. Assessment of hyperpronation of the forefoot due to hyperactivity of the peroneus longus muscle.

in determining whether additional surgery should be performed. Hyperactivity of the peroneus longus, although debated, is tested as follows: The patient is examined in the sitting position and is asked to forcefully dorsiflex at the ankle joint with the knee in full extension. In this position the examiner places one thumb underneath the first metatarsal head and the other thumb underneath the second, third, and fourth metatarsal heads. The patient is then asked to maximally plantarflex the foot against resistance of the examiner. If pronation of the forefoot occurs with a strong plantarization of the first ray, hyperactivity of the peroneus longus muscle is present. Patients who plantarflex their foot without pronation of the forefoot are considered to have a normal activity of the peroneus longus muscle (**Fig. 3**).

Stability of the anterior talofibular and calcaneofibular ligaments is always compared with the contralateral side. The anterior drawer test (**Fig. 4**) is used to examine the anterior talofibular ligament, whereas the talar tilt (**Fig. 5**) assesses the stability of the calcaneofibular ligament. Valgus tilt allows evaluating integrity of the deltoid ligament. Any laxity or sign of generalized hypermobility should be evaluated.

Active muscle force against manual resistance allows documentation of each muscle group. Finally, the examination is completed with neurologic examination for sensation and reflexes. Bilateral absence of Achilles tendon reflexes may indicate the presence of peripheral neuropathy and requires additional neurologic workup.

RADIOGRAPHIC ASSESSMENT

Conventional Radiography

Standard anteroposterior and lateral views of the ankle under weight-bearing conditions are performed. In addition, the authors also recommend hindfoot alignment or long axial views to measure the amount of varus deformity. In order to rule out adjacent joint arthritis, dorsoplantar and lateral views of the foot are obtained. On the lateral view of the foot, the cavus deformity can be measured using various angles. Most commonly the talus–first metatarsal (Meary) and talocalcaneal angles as well as the calcaneal pitch angles are assessed in order to describe the deformity. On the mortise view, the congruency of the ankle joint can be judged and the lateral distal tibial angle (LDTA) measured (normal value 88°).[30] Varus tilt either due to medial tibial plafond erosion and arthritis or lateral ligament incompetence can easily be

Fig. 4. Testing of the anterior talofibular ligament. The ankle is held in 20° plantarflexion and grasped with the dominant hand. With the nondominant hand, the tibia is fixed. Forced anterior translation is exerted with the dominant hand at the heel. Any increased anterior shift of the talus within the mortise when compared with the healthy side indicates ligament incompetence.

distinguished. Small but rounded ossicles found close to the fibular tip may indicate an old ligamentous avulsion injury.

Additionally, possible risk factors for chronic ankle instability, although more of academic interest, include an increased talar radius (normal: 18 mm), a small tibiotalar coverage (normal: 88°), and deeper frontal curvatures (normal: 1.0).[31–34]

Stress View

Stress views are rarely indicated but may be necessary in case of suspected instability but clinically not apparent laxity of the lateral ankle ligaments. Stress

Fig. 5. Testing of the calcaneofibular ligament. The ankle is held in neutral or slight dorsiflexion and grasped with the dominant hand. With the nondominant hand, the tibia is fixed. Forced lateral tilt is exerted with the dominant hand at the heel. Any increased lateral opening of the talus within the mortise when compared with the healthy side indicates ligament incompetence.

Fig. 6. Hindfoot view as described by Saltzman and el-Khoury.[40] The hindfoot is in significant varus deformity.

radiographs can be obtained manually or with the aid of a specific stress device. When performing the anterior drawer test, a subluxation of 9 mm or a difference greater than 5° to the healthy side indicates instability. When performing a talar tilt, a value of at least 10° or greater than 5° difference is suspicious for existing instability.[35–37] However, because of its moderate reliability, use of stress testing may be questionable.[38] The authors do not perform stress testing at their institution.

Hindfoot Assessment

Full-length anteroposterior and lateral views of the lower limb are used to identify the anatomic and mechanical axis of the knee, tibia, heel, and ankle. These views allow the measurement of the LDTA and TAS as well as the ability to find the center of rotation of angulation in case of tibial deformity, and they help in preoperative planning of osteotomies.[39]

Saltzman and el-Khoury[40] introduced the hindfoot view, a modification of the Cobey view (**Fig. 6**).[41,42] The superiority of the hindfoot view for visual judgment of the hindfoot alignment and its correlation to pedobarographic load distributions after total ankle replacement has been confirmed.[43] In addition, the hindfoot view has proven good-to-excellent intraobserver reliability. However, interobserver reliability is very low and is clearly surpassed when using a long axial view only.[44] One of the drawbacks of the hindfoot view is its susceptibility to rotatory malpositioning of the foot. Thus, the measurements obtained with the hindfoot view need to be interpreted with caution.[41] A far more reliable angle measurement can be done using the long axial view or the medial and lateral borders of the calcaneus.[45]

Whereas preoperative assessment of hindfoot alignment under weight-bearing conditions is done in a standardized fashion, there is not yet a technique available to do so under non–weight-bearing conditions, for example, during surgery. More recently, Min and Sanders[46] described varus-valgus referencing relative to the medial process of the posterior calcaneal tuberosity in the unloaded Mortise view. Its usefulness and feasibility will be the subject of future research.

Advanced Imaging

Nowadays, MRI and computed tomography (CT) allow precise three-dimensional depiction of the bones and soft tissues. Therefore, these technologies are mainly indicated for evaluation of the lateral ligamentous complex and concomitant pathologic conditions such as peroneal tendinopathy, osteochondral lesions, and/or osteoarthritis. MRI has been found to be highly specific in detecting lesions of the anterior talofibular (100%) and calcaneofibular (83%) ligaments; however, sensitivity is poor (56% and 50%, respectively).[47] Because of its superiority when compared with a simple arthro-CT, examination the authors perform CT only in selective cases, for example, to estimate the amount of fibular malrotation, to measure the true extent of osteochondral lesions of the talus, or to evaluate presence of a tarsal coalition.

CONSERVATIVE TREATMENT

Conservative treatment plays an important role when addressing chronic ankle instability. In the presence of postural abnormalities or mechanical deformities, for example in cavovarus foot, the value of a nonoperative treatment is questionable because it may not be effective enough in correcting rigid deformities and thus fail over time. However, some individuals will not allow themselves to be operated on, and for some, comorbidities increase health risks and outweigh the benefits of surgery. This group includes elderly patients and those with inadequately regulated diabetes mellitus, advanced peripheral vascular disease or cardiovascular disease, specific neurologic disorders, or respiratory disease.

Although conservative treatment does not address the underlying cause of a mechanically induced varus hindfoot deformity, it might be beneficial in cases of flexible varus deformity and when ligamentous insufficiency has been identified as the primary cause.

Conservative treatment should be followed for up to 6 months. If after a standardized nonoperative protocol there is no improvement, surgery may be considered.

Physical Therapy

Physical therapy has been shown to influence functional instability by improving proprioception, peroneal muscle preactivation, and eversion strength.[48–51] An aggressive stretching protocol is performed in order to lengthen the gastrocnemius-soleus unit and to reduce tension exerted through the Achilles tendon. By so doing, the inversion moment can be reduced and stability improved.

Braces

Braces can decrease severity and frequency of ankle sprains in athletes with chronic instability. Laced braces have been shown to be most effective.[52,53] In addition, improved stability can be achieved with taping. Although the inversion moments at the ankle are reduced by means of taping, the effect of taping is limited. It has been shown that almost 50% of the stabilizing effect is gone after 10 minutes of exercise.[54,55] However, proprioception might still remain improved due to other reflex mechanisms. Braces may also help to stretch the gastrocnemius-soleus unit.

Insoles and Orthoses

The primary goal of insoles and orthoses is to equalize pressure distribution and thus offload painful areas while supporting the medial arch. Lateral wedging may partially correct flexible hindfoot varus and decrease subjective instability.[26] Prefabricated products are available, but custom-made devices have advantages, especially in patients with rigid deformity. Additional support may be achieved with specific shoe modifications, for example increased width of the heel sole. In case of secondary degenerative changes, rocker-bottom soles could alleviate pain by reducing the propulsive work at the ankle joint.

APPROACHING THE PATIENT WITH VARUS ANKLE AND INSTABILITY

It is beyond the scope of this article to discuss in detail each surgical treatment of cavovarus deformity. The authors instead present conceptual thoughts in order to explain the approach to the patient with varus hindfoot deformity associated with chronic instability.

The goal of any reconstructive type of surgery is to achieve a plantigrade, fully functional, and stable foot. In order to choose the adequate treatment (eg, osteotomies, ligament reconstruction, fusions), surgeons should identify the apex and rigidity of deformity, assess associated muscle imbalances, and evaluate involvement and amount of joint degeneration.

Whenever possible, a joint-preserving approach should be considered.[56–61] The apex of deformity is found at the location where the malformation is most pronounced. Thus, for example, in the case of a hindfoot-driven cavovarus, the origin is found at the hindfoot with variable deformities found at the midfoot and forefoot.

The application of osteotomies, fusions, or a combination of both always depends on the severity of deformity. Normally, an oblique or Z-shaped calcaneal osteotomy is powerful enough to realign the heel in relation to the pulling vector of the Achilles tendon. In more severe varus deformity, realignment could be achieved by means of a laterally closing-wedge subtalar arthrodesis, and in extreme varus deformity subtalar fusion should even be combined with a lateral sliding calcaneal osteotomy.[62] In cavovarus feet, the anteromedial part of the ankle is overloaded because of deformity[16,24] and chronic lateral ankle instability.[12,13,63] A lateralizing calcaneal osteotomy unloads the medial ankle compartment[64] and might be considered in early stages of ankle osteoarthritis.[15] In contrast, subtalar arthrodesis exerts additional strain on the ankle joint, which already has or is at risk of degeneration.[56]

In a hindfoot-driven cavovarus deformity with subtle midfoot and forefoot malalignment, additional osteotomies at the forefoot may be preventable. However, in most cases an excessively plantarflexed and rigid first ray with consecutively increased medial arch and forefoot supination can be found. A majority of patients also demonstrate increased inclination of the first through fifth metatarsals with increased pressure underneath the corresponding metatarsal heads. Metatarsalgia is the result.

In such cases a dorsiflexion osteotomy of the first metatarsal, and sometimes first through third metatarsals, is performed.

Conversely, in forefoot-driven cavovarus, a dorsiflexion osteotomy of the metatarsals could be sufficient to correct the hindfoot varus moment as long as the tarsal deformity remains flexible.[65] The metatarsal osteotomy lowers the medial arch. If the longitudinal arch height cannot be lowered to the desired amount, an additional plantar fascia release should be considered.[66]

OSTEOTOMIES

The use of osteotomies in the treatment of ankle instability due to varus malalignment has recently gained new interest. The goal of osteotomies is to realign the hindfoot and to unload overstressed cartilaginous regions while adjusting the tension of the surrounding tendons and ligaments. Any type of osteotomy can be applied together with a combination of simple ligament repair or more sophisticated reconstructions.

As mentioned previously, when attempting to correct malalignment, the apex of deformity must be determined.[59]

In the absence of degenerative changes or in case of asymmetric osteoarthritis of the hindfoot, realignment surgery should be preferred over corrective arthrodesis in order to preserve joint motion at the hindfoot and to reduce abnormal stress transmissions through the midfoot and forefoot.[8,67,68]

Supramalleolar Osteotomy

A supramalleolar osteotomy is indicated in case of asymmetric ankle osteoarthritis or a malaligned distal tibial plafond. Depending on leg length, the osteotomy can be done either in a medial opening-wedge or lateral closing-wedge fashion. This procedure can be with or without a fibular osteotomy (**Fig. 7**).[8,27,68–76] However, in most cases the fibula is osteotomized as well. If the fibula is obviously overlong (eg, as seen after improper fracture fixation), the talar body cannot be brought into neutral position within the mortise. In such a situation the shortening of the fibula is a powerful means to realign the hindfoot. Fibular osteotomies can either be done in a Z-shaped or oblique fashion and should be fixed by means of a plate.

Although supramalleolar osteotomies have been described for the treatment of hemophilic ankles,[75] Takakura and colleagues[66,56] more recently introduced the concept of low tibial osteotomies in the treatment of primary osteoarthritis of the ankle. Eighteen patients with primary varus ankle osteoarthritis and medial joint narrowing but normal radiographic appearance of the lateral ankle compartment were included. Correction was achieved by means of a medial open-wedge osteotomy, which was filled with bone graft harvested either from the iliac crest or tibia. In all patients a fibular osteotomy was added. Just a few patients needed a repair of the lateral ligaments. All osteotomies united. Encouraged by the results obtained in this group, a few years later the same authors extended their indications to posttraumatic ankle arthritis.[67,68] However, in this series (including 9 patients with posttraumatic varus deformity), union was seen in all but 1 patient 2 months postoperatively.

Talar Osteotomies

In patients with clubfoot deformity, the talar head is positioned laterally to the midline axis but the forefoot is adducted and inclined with additional flexion at the talonavicular joint. A midfoot cavus is the result. In such patients, residual cavovarus deformity can be addressed by means of a lateral column shortening or by a talar neck osteotomy as proposed by Klaue.[77,78] The goal is to medialize the talar head and

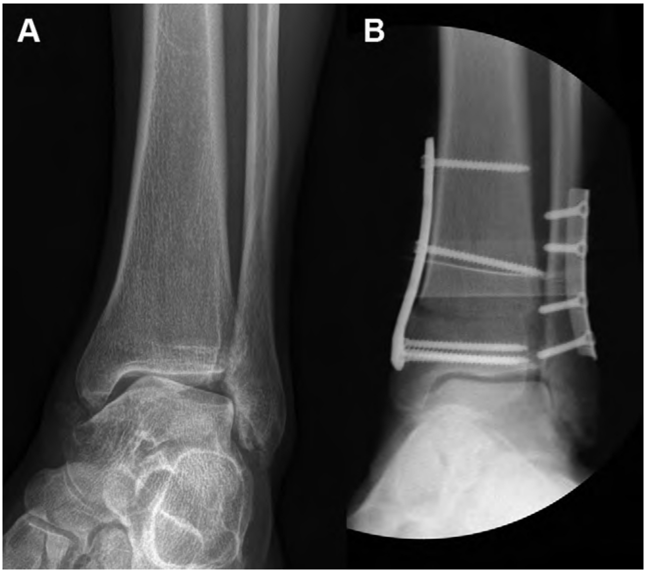

Fig. 7. A 50 year-old man had chronic lateral ankle instability and progressive pain due to medial ankle osteoarthritis. The preoperative anteroposterior view of the ankle (*A*) reveals a varus tilt of 15°. The lateral distal articular tibial angle measures 88° on the long leg views. The lateral half of the talar cartilage was intact and confirmed by arthroscopy. A medial open wedge osteotomy of the distal tibia corrected the lateral distal articular tibial angle to 92° in order to unload the medial compartment. In addition, an anatomic lateral ligament reconstruction with a gracilis tendon autograft, resection of osteophytes at the lateral gutter, and fibular shortening by 3 mm of the talus markedly realigned the ankle within the mortise (*B*).

move it inferior to correct both varus and cavus. The maximum shift achieved averages 10 mm. The osteotomy is done starting proximal lateral at the edge of the cartilage and driven medially. If not enough lengthening is obtained, a bone graft can be interposed. One of the most dangerous risks is avascular necrosis of the talar head. This risk might explain why this osteotomy has not become popular among orthopaedic surgeons. Klaue proposed a lateral Ollier approach to preserve blood supply to the talar head. In severe deformity, a lateralizing calcaneal osteotomy may be necessary. Early results of the talar osteotomy showed satisfactory results.

Despite such congenital pathologic conditions as clubfoot deformity, posttraumatic malunions of the talar neck after fracture are observed in up to 32% of cases. Most of these pertain to unrecognized injuries, secondary dislocation after nonoperative treatment of displaced fractures, and inadequate surgical reduction or fixation.[79] The malunion forces the talar head medially and cranially in relation to the neck, causing anterior ankle impingement, varus deformity of the neck, and hindfoot malalignment, as well as restricted subtalar joint motion. The results after osteotomy in cases of preserved cartilage are acceptable.[80,81]

Calcaneal Osteotomies

Valgus calcaneal osteotomy in lateral instability should be performed for dynamic hindfoot varus to correct abnormal inversion stress through the medialized force of the Achilles tendon, which acts in this configuration as an inverter.[4] One of the goals is to change the tendon pull direction to bring it to more of a pronator function. The other effect is that the foot is corrected during heel strike.[5]

Calcaneal osteotomies are well-known in orthopaedic surgery and have become widely used. This procedure is a powerful tool to correct rigid but not forefoot-driven hindfoot varus. However, by lateralizing the heel, the medial column could become stressed and painful. In such a situation an elevating (dorsiflexing) first metatarsal osteotomy should be considered.[29,82] If hindfoot malalignment is driven by a flexible or fixed forefoot deformity, therapy must always include correction of the pathologic condition in the forefoot.

A calcaneal osteotomy can be done in various ways. Dwyer[83,84] popularized a curved shaped and lateral closing-wedge osteotomy. The problem with this osteotomy is that it allows only small corrections and through calcaneal shortening the lever and moment arm for the Achilles tendon become shorter and weaker, respectively.[24,64]

A more powerful form of correction is the lateral sliding osteotomy (**Fig. 8**). The transverse osteotomy is performed perpendicular to the long axis of the calcaneus from posterosuperior to anteroinferior. The tuberosity can be displaced laterally by 10 mm. Two 6.5-mm displacements are used to fix the osteotomy and provide rotatory stability. In cavovarus deformity, a slight cranial displacement of 10 mm allows reduction of the cavus component. Good to excellent results were reported in cavovarus feet when a lateral sliding osteotomy was combined with a first metatarsal osteotomy.[61]

The most powerful osteotomy by far is the Z-shaped osteotomy of the calcaneus.[82] This procedure allows a correction in three planes. Because of its scarf-like design, it offers intrinsic stability while the tuber is shifted laterally. Lengthening of the calcaneus, shortening, internal or external rotation, and inversion and eversion can be added by means of resecting or adding bone blocks into the osteotomy site. It has been shown that in cavovarus feet, a Z-shaped osteotomy restores force distribution across the varus ankle while reducing peak pressures. Because of lateralization of the ground contact point, the pressure within the tibiotalar joint shifts laterally. In the presence of normal subtalar joint mobility, with calcaneal osteotomies, peak pressures alterations in the tibiotalar joint are improved.

The authors use a simple lateral sliding or Z-shaped lateral sliding osteotomy and may add a lateral ligament reconstruction to correct varus and to restore stability. When considering a lateral ligament repair,[85] the osteotomy is performed first. A lateral curved incision is done. Subcutaneous dissection is performed carefully in order to avoid the sural nerve. Periosteal stripping is kept minimal. The cranial and plantar borders of the tuber calcanei are identified, followed by insertion of blunt Hohmann retractors. Afterward, the cut is performed by means of an oscillating saw. The nondominant hand is placed on the medial aspect of the posterior part of the calcaneus. This maneuver allows immediate control of the penetrating saw blade. At times, periosteal incision on the medial, dorsal, and plantar osteotomy site must be done with a scalpel to allow lateral shifting of the bone. The osteotomy is fixed using two 6.5-mm partially threaded cancellous screws. Usually sufficient lateralization is achieved without the need of wedging. Lateral closing-wedge osteotomy is reserved for additional curved calcaneal deformities.

In case of slight degeneration of the ankle joint associated with chronic lateral ligament instability, Lee and colleagues[15] recommend a release of the deltoid ligament, augmentation of the lateral ligaments[86] combined with a lateralizing osteotomy of the calcaneus. The goal is to even stress loading at the talar cartilage and, of course, to delay progression of osteoarthritis. In the series by Lee and colleagues,[15] good stability was found in 9 of the 11 patients. Treatment failed for 2

Fig. 8. Conventional radiographs (preoperative, *A, B*; postoperative, *C, D*) of a 15-year-old girl with recurrent lateral ankle sprains. A modified Broström procedure together with a lateralizing calcaneal osteotomy was performed. One year postoperatively, the patient was able to completely resume sports activities.

patients. Both showed a pronounced preoperative talar tilt of 11° and 12°, respectively. Overall results were promising at a mean follow-up time of 22 months.

Midfoot and Forefoot Osteotomies

Excessive pronation in the forefoot drives the hindfoot into supination.[8,9,69] A flexible plantarflexed first ray may arise from hyperactivity of the peroneus longus, which can be decreased by means of a peroneus longus to brevis transfer.[8,9]

Otherwise fixed plantarflexion of the metatarsals, for example as seen in idiopathic cavovarus foot, can be addressed by a dorsiflexion osteotomy. Dorsiflexion osteotomies may involve a single metatarsal or more metatarsals. Larger plantarflexion deformities might be better addressed using a fusion of the first tarsometatarsal joint.[5]

In forefoot-driven hindfoot varus, the deformity is caused by a rigid and massively plantarflexed first ray. In such a situation a dorsiflexion osteotomy of the proximal first metatarsal bone is recommended.[29,87,88] Vienne and colleagues[9] published the results of a consecutive series of patients with cavovarus deformity and recurrent ankle instability. All patients revealed a failed prior ligament stabilization surgery. The plantarflexed first ray and hindfoot varus were flexible. Each patient was clinically detected to have a hyperactivity of the peroneus longus muscle. All were successfully treated by means of a lateralizing calcaneal osteotomy and peroneus longus to brevis transfer. In half of the patients, a Broström procedure[85,89–93] was added to address lateral ligament insufficiency. All patients showed good results with subjective and objective lateral stability.

ADVANCED OSTEOARTHRITIS AT THE HINDFOOT AND STRATEGIES

In contrast to deformities that allow preservation of the joints, more severe and rigid deformity or end-stage osteoarthritis may be better addressed by arthrodesis. In the case of an intact and well-aligned ankle joint but arthritic and deformed subtalar and Chopart joint, a corrective triple arthrodesis could be considered. The authors use a modified and calcaneocuboidal joint–sparing triple arthrodesis technique (**Fig. 9**).[94] Besides an increased risk of ankle degeneration,[56] one must be aware of the risk of nonunion, which has been reported to range between 2% and 33%. The highest risk has been found in patients with neuromuscular disease. In contrast, once fusion is complete and solid and the foot plantigrade, outcomes are satisfying.[95–98]

Advanced stages of ankle osteoarthritis lead to less favorable outcomes, even after adequate foot and ankle realignment and lateral ligament reconstruction.[99] In such cases performance of an ankle arthrodesis or implantation of a total joint replacement are to be anticipated.

DYNAMIC BALANCING—TRANSFERS AND LENGTHENING

Peroneal muscle imbalance with impaired inversion strength is likely to be present in cavovarus feet. The peroneus brevis muscle is weak, whereas the peroneus longus may reveal hyperactivity. A pronatory moment is exerted at the forefoot because of increased plantarflexion of the first ray. The compensatory hindfoot varus cannot be halted by the action of peroneus brevis muscle. In this situation the most important lateral and dynamic stabilizer, the peroneus brevis, should be reinforced and the pathologic action of the peroneus longus abolished. The transfer of the peroneus longus to brevis tendon adds dynamic support to the lateral ankle. A lateral transfer of the tibialis anterior tendon to either the lateral cuneiform or cuboid is advocated in severe cases, provided the tibialis anterior muscle has sufficient strength (M4–M5 required).[100]

Equinus deformity may contribute to lateral ankle instability because the congruency of the ankle is minimal in plantarflexion. In this situation, stability of the joint depends on integrity of lateral ligaments, and muscle balance only enhances the susceptibility to varus thrusts. Ankle dorsiflexion may be sufficiently improved after correction of the talo–first metatarsal angle; however, if dorsiflexion does not exceed 5°, subsequent Achilles tendon lengthening or release of the gastrocnemius should be considered.

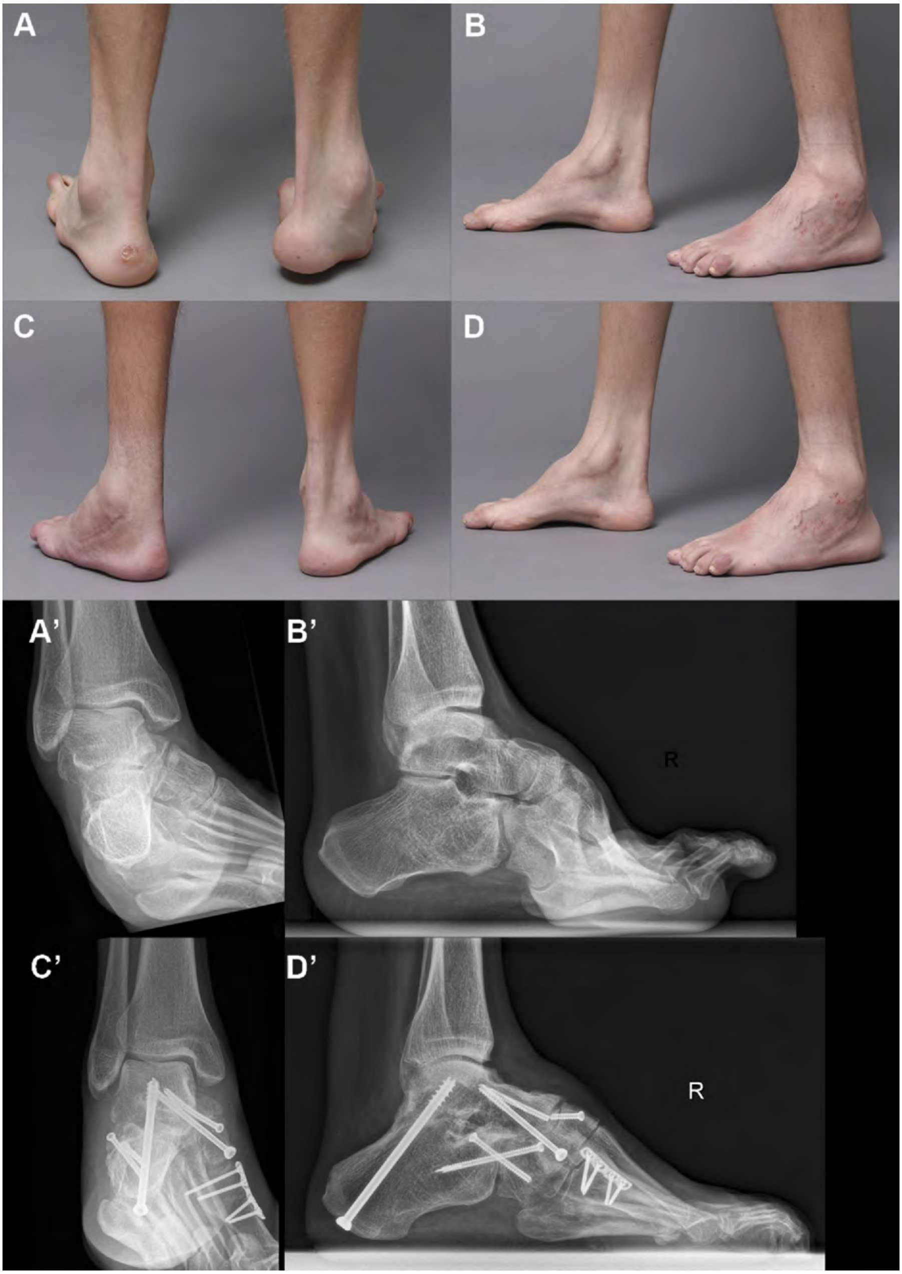

Fig. 9. An 18-year-old man had severe bilateral and rigid cavovarus feet suffered from associated chronic lateral ankle instability. Note the remarkable varus and cavus foot deformity (preoperative clinical photographs (*A, B*) and X-rays (*A′, B′*). Surgical correction was performed by means of a Steindler release, posterior tibial tendon- and Achilles tendon lengthening, a dorsal closing wedge osteotomy of the first metatarsal, and triple arthrodesis. Intraoperatively, no remaining instability was found. Thus, a lateral ligament reconstruction was not necessary. One year postoperatively ([*C, D*] clinical photographs; [*C′, D′*] X-rays), a plantigrade foot is present. The patient continues with sports without concerns about pain and with full stability.

LATERAL LIGAMENT REPAIR OR RECONSTRUCTION

The scientific literature confirms the effectiveness of lateral ankle repair or reconstruction for the treatment of chronic ankle instability. The primary aim of surgical therapy is to restore the integrity of ligaments. However, application of surgical therapy in patients with unstable varus ankle, especially cavovarus foot, remains unclear. Sammarco and Taylor[61] treated patients who had cavovarus foot pathology without adding a lateral ankle ligament reconstruction and reported good to excellent clinical results. Vienne and colleagues[9] reported on patients with cavovarus foot deformity who had had chronic ankle instability after previously failed surgeries. The varus malalignment was corrected by a calcaneal osteotomy, and dynamic balancing was achieved using a peroneus longus to brevis transfer. In half of the patients, an additional lateral ankle ligament reconstruction was performed because of persisting instability. At an average follow-up of 37 months, all patients were satisfied and American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot scores improved from 57 to 87 points.[9] Conversely, Fortin and colleagues[16] reported complete resolution of pain and improved stability in all patients who were treated by lateral ankle ligament reconstruction combined with realignment surgery.

Whereas functional instability in the absence of static hindfoot malalignment can successfully be addressed by means of nonoperative measures,[101,102] obvious deformities need surgical correction. Symptoms are relieved by hindfoot realignment in case of varus deformity without the need of additional ligament repair. In a retrospective series by Sammarco and Taylor[60] of 21 ankles in 15 patients with cavovarus foot, 5 available for follow-up presented with instability as the primary concern. All were treated with combined hindfoot and forefoot osteotomy for the correction of deformity. Outcome assessed by AOFAS score was excellent in all patients except one in which follow-up was complicated by deep venous thrombosis and delayed union of the fourth metatarsal osteotomy.[60] The number of patients, however, does not allow concrete conclusions as to whether ligament repair should be added or not.

Based on these facts and in contrast to simple chronic ankle instability without varus deformity, the answer regarding whether ligament reconstruction in patients with cavovarus is necessary has not yet been found.

Ligament Repair and Augmentation

The ideal patient with regard to an anatomic and direct ligament repair with or without local augmentation has mild to moderate lateral ankle instability without deformity and reveals viable ligament tissue quality, absence of hyperlaxity, and a normal body mass index.

The technique of anatomic ligament repair was first introduced by Broström in 1966[89] and was subsequently modified by others. Karlsson and colleagues[103] described advancement of the ligament into the fibula whereas Gould and colleagues[86] and Kuner and colleagues[104] described a ligamentous augmentation by means of the extensor retinaculum or fibular periosteal sleeve, respectively.

Anatomic repair demonstrates durable, good to excellent results in 80% to 90% of patients after 26 years.[86,105–108] Nonetheless, the results in continuing or recurrent instability are less favorable.[103,106,109] Larger size and body weight, hyperlaxity, and increased physical demands during work and/or in sports impair outcome.[103,106,109,110] Inadequate reconstruction of the anterior talofibular ligament leads to elongation and insufficiency and increases the stress on the cervical and interosseus ligament as well. Because of incompetence of the anterior talofibular ligament, the cervical ligament could tear and lead to subtalar instability. Inadequate reconstruction of the calcaneofibular ligament results in persisting pain and increased varus thrust at the ankle joint.[111]

Ligament Reconstructions Using Grafts

In obese individuals and in patients with hyperlaxity or prior failed lateral stabilization, more limiting and nonanatomic types of reconstructions can be considered. However, these indications are rare. The concept is based on a complete or partial tenodesis of the peroneus brevis tendon after rerouting.[112–115] Although good and excellent outcomes after nonanatomic repairs have been reported, there are some serious drawbacks, for example, restricted subtalar motion, residual ankle instability, and increased risk of secondary osteoarthritis, making the routine use of such reconstruction questionable.[10,116–118] Another drawback of nonanatomic reconstruction is the higher rate of complications due to a more extensile soft-tissue dissection. Delayed wound healing has been found in 4% of patients as opposed to 1.6% in patients who have been treated by an anatomic repair. Nerve injuries have also been found more frequently in patients after nonanatomic reconstruction versus anatomic reconstruction (nonanatomic reconstruction, 10%; anatomic repair, 4%; anatomic reconstruction, 2%).[119] In order to reduce the risks, more recently, percutaneous techniques were introduced.[120,121]

Current anatomic reconstruction of lateral ankle ligaments use either hamstring or plantaris tendon grafts, which are rerouted in order to replace the anterior talofibular and calcaneofibular ligaments.[117,122–127]

The results of open and anatomic ligament reconstructions using grafts are promising. Coughlin and colleagues[127] in a series of 28 patients described subjective satisfaction as excellent in 86% and good in the remaining 14%, with an improvement in mean AOFAS score from 57 points preoperatively to 98 points after a follow-up of 2 years. Subtalar motion was not or minimally reduced as shown earlier in anatomic reconstructions by Paterson and colleagues,[125] Coughlin and colleagues,[127] and Hintermann and Renggli,[124] who used semitendinosus or gracilis grafts. It seems that anatomic reconstructions could lead to better long-term outcomes and reduced rates of subtalar degeneration. Even patients with hyperlaxity do well and reveal good outcomes. This result is interesting because it does away with the former belief that only nonanatomic reconstructions could achieve adequate stability in patients with hyperlaxity.[127] One patient had irritation of the sural nerve, and only 2 showed superficial cellulitis that resolved after oral administration of antibiotics. The series did not include patients who required hindfoot varus correction. Hintermann and Renggli[124] reported similar results in a series of 52 patients who had had an anatomic transfer of the plantaris tendon. Two of these patients required additional calcaneal osteotomy for hindfoot varus. After an average follow-up of 3.5 years, AOFAS score of 98 points was reached with 98% of patients reporting a good to excellent outcome.[124] Direct comparison between anatomic and nonanatomic ligament reconstructions is difficult because of different scoring systems and techniques used. However, Krips and colleagues[128–130] showed an advantage of anatomic repair in the long-term follow-up with higher scores and improved function and stability as well as decreased rates of revision and osteoarthritis. To the authors' knowledge there is no single prospective and randomized study that investigates nonanatomic versus anatomic reconstructions.

The authors prefer an open or percutaneous anatomic technique using a gracilis autograft. The technique has recently been described in detail by Klammer and colleagues.[121]

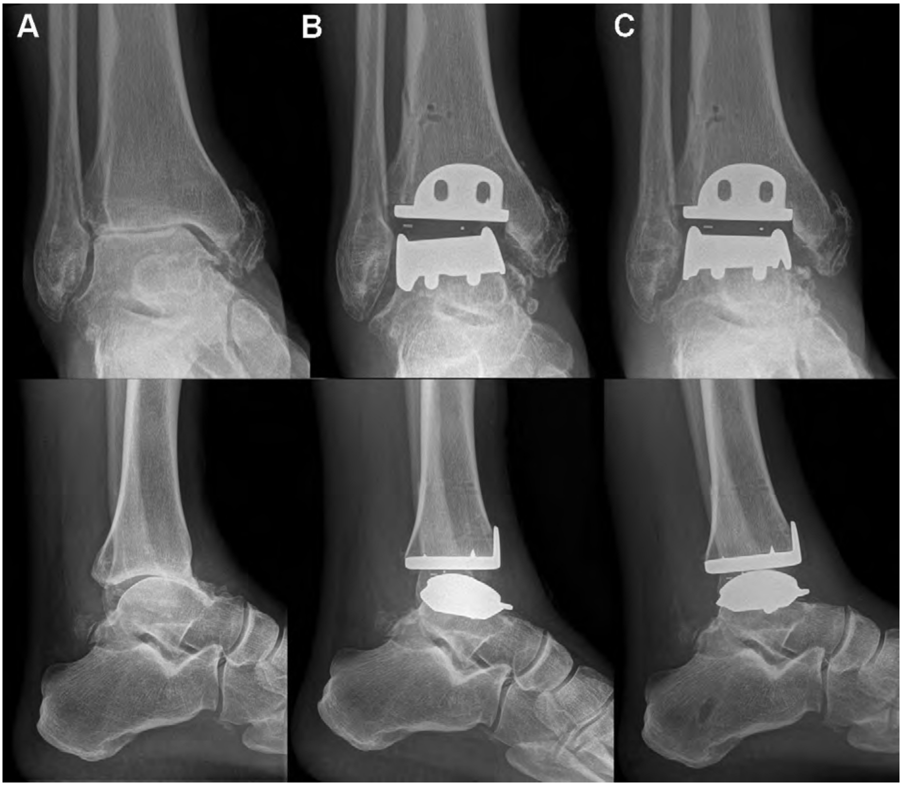

Fig. 10. A 50-year-old patient had had a total ankle replacement because of primary ankle osteoarthritis. Preoperative radiographs show advanced joint degeneration with anterior subluxation of the talus but no varus tilting (*A*). The postoperative radiography after a few days after implantation of the prosthesis shows talar tilting due to acute postoperative lateral ligament insufficiency (*B*). Balancing was restored with anatomic lateral ligament reconstruction using a gracilis autograft and increased inlay thickness (*C*).

TOTAL ANKLE REPLACEMENT IN THE UNSTABLE VARUS ANKLE

The success of total ankle replacement depends not only on design but also on anatomic hindfoot alignment and proper ligament balancing (**Fig. 10**). Edge loading of the polyethylene is a risk factor for early failure.[131–134] Therefore, a physiologic hindfoot position of 0° to 5° valgus should be attempted in all cases. Whereas Wood and Deakin[135] described an increased failure rate in ankles with a preoperative malalignment of more than 15° varus, Hobson and colleagues[134] reported safe and reliable results in patients who had a well-aligned total ankle replacement but who had had a preoperative varus ankle deformity up to 30°. Similar results were obtained by Kim and colleagues[136] in patients with a preoperative varus between 10° and 22°.

In contrast, Coetzee[137] recommended ankle fusion in patients with varus deformities greater than 20° because of the high failure rate of total ankle replacement in this patient category.

In case of a varus deformity located at the tibial plafond but congruent ankle configuration (talar tilt $<10°$), the joint line should be reoriented by performing a tibial bone cut that runs perpendicular to the mechanical axis of the tibia and parallel to the floor. This step might be followed by a medial release of the deltoid or distal translation of the medial malleolus.[136,138] If the height of the tibial cut exceeds the maximum thickness of the inlay, in other words if the varus deformity of the tibial plafond is greater than (5° to) 10°, an additional supramalleolar osteotomy is required.[71,72] This situation corresponds to stage 1 varus ankle according to Frank Alvine's classification. In stage 1, varus is induced by medial tibial erosion but absence of relevant ligament instability.[139]

In case of an anatomically oriented tibial plafond but incongruent talus within the mortise (talus tilts within mortise), the latter must first be restored. According to the Alvine classification, progression into stage 2 is characterized by lateral ligament insufficiency and medial and lateral ectopic bone formation that may inhibit anatomic placement of the talus within the mortise. The medial and lateral gutters are liberated from osteophytes in order to allow realignment of the talus. Medial tightness may inhibit reduction.[139] Thus, ligament balancing is done by releasing the deltoid ligament or by performance of a medial malleolar lengthening osteotomy.[138,139] Persisting lateral ankle joint gaping of more than 5° requires an additional anatomic lateral ligament reconstruction as previously described.[137] Alternatively, when ligament insufficiency is caused by an overlong fibula or in the presence of subfibular impingement, a fibular shortening osteotomy could be considered.[136]

In a well-aligned total ankle replacement with full restoration of joint congruence but persisting hindfoot varus, further extraarticular correction is needed.[136,138] This correction may be achieved with a lateral sliding calcaneal osteotomy or with subtalar or triple arthrodesis, depending on joint degeneration or in case of Alvine stage 3 varus ankle (medial malleolar bone erosion combined with a subluxation of the subtalar joint).[138,139]

SUMMARY

Varus ankle associated with instability can be simple or complex. Multiple underlying diseases may contribute to this complex pathologic entity. These conditions should be recognized when attempting proper decision-making. Treatment options range from conservative measures to surgical reconstruction. Whereas conservative treatment might be a possible approach for patients with simple varus ankle instability, more complex instabilities require extensive surgical reconstructions. However, adequate diagnostic workup and accurate analysis of varus ankle instability provide a base for the successful treatment outcome.

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