Kaj Klaue

The Foot

From Evaluation to Surgical Correction

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With 861 Figures

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Fig. I.

Preface

This book is the logical result of my own curriculum. As a researcher I learned how to build up experimental protocols based on a rational way to analyze biological and mechanical pathways. Every step of the protocol is based on secured knowledge. As a clinical worker, I learned to find out the basics of efficient surgical treatment based on understanding pathology. I grew up in a mechanical automobile engineering environment and during high school I got interested in biology which led to the natural interest to apply mechanics in biological processes. The kick to mechanics in biology occurred in 1974 when I acquired "Medical Engineering", a Year Book Medical Publishers publication edited by Charles Dean Ray. No doubt that the after moon landing's atmosphere boosted my curiosity in this field. Meeting Professor Stephan M. Perren at his time was decisive in having the chance to develop new techniques in experimental orthopaedic surgery within a special fertile atmosphere.

The treatment of Foot and ankle disorders belong to the earliest means of medical care. Historical rather than rational reasons brought up medical foot and ankle care. Interesting enough, surgical care in this field today demonstrates probably the widest variation in whole medicine. Textbooks reflect this variation and often set the reader in front of multiple different possible treatments to single pathological entities. As a reader I often remain puzzled for two reasons: – I miss the rational link between symptomatic dysfunction and pathology; – I am disappointed not to find the logical treatment to pathology based on biological and mechanical rules. This book strives at being proof against obscure and irrelevant treatments. It has not the pretention to claim originality or exclusivity but proposes treatments which are logically linked to pathology.

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Service Part

Introduction

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This book should provide the reader with Ariadne's thread through the maze of foot conditions from symptoms to surgical solution. The approach begins with an inquiring and focused case history. This dialogue raises suspicion in the search for diagnosis and is therefore followed by a focused clinical examination. The clinical exam is divided into different sections, with the study of the statics of the lower limb being, in most cases, fundamental. This usually leads the physician, in more than 90% of cases, to a reliable diagnosis.

The reader is then referred to the eventual paraclinical evaluation (conventional radiographs) or more sophisticated exams such as computed tomography (CT), magnetic resonance imaging (MRI), scintigraphy, and combined exams such as positron emission tomography (PET)–CT. From here the book moves on to surgical treatment, which is a rational and generally complex, multifactorial correction. Descriptions of operative techniques explaining the individual steps involved in the surgical "menu" complete the manual.

This manual follows the principle that says, "Question everything," asking "Why?" regarding every step on the path to diagnosis, particularly anything relating to treatment. In an inquiring way, this book avoids the ambiguous suggestions introduced by the words "you can also do this; you might do that," which are of no help to the surgeon looking for a fully rational path to improve the treatment of pathological conditions. It appears that rational surgery on the foot and ankle results in a list of procedures that can correct the orientation, the stable load-bearing ability, and the propulsive function of the complex osteoarticular framework of the foot and ankle.

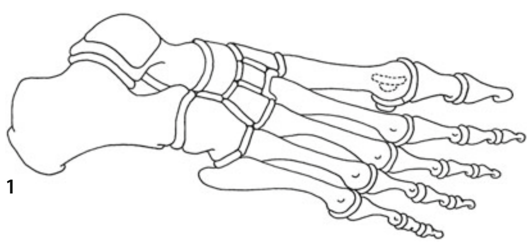
References to further reading within the book are noted by ***(A)*** medical history (anamnesis), ***(E)*** clinical examination, ***(R)*** radiologic screening, ***(O)*** surgical orthopedic treatment, ***(F)*** surgical fracture treatment, and ***(T)*** operative techniques. Figures and illustrations are noted by Arabic numbers. The references are thus specified by the chapter (letter ***A, E, R, O, F,*** or ***T***) and the figure number.

1 General considerations

Bipedalism first appeared in the phylogeny of humankind about 3–4 million years ago (1). Recent research suggests that the rigidity of the longitudinal arch of the foot, which is specific to our species, has been part of the very early time of phylogeny (2, 3). This evolution, although obviously helpful for the further development of the species, was a real mechanical challenge to the foot and ankle. The support polygon was drastically reduced from the quadruped, and balance was preserved progressively while narrowing the gait pattern. The foot and ankle became the location of the most frequent trauma: the sprained ankle. Our species also demonstrates a slow (and sometimes insufficient) adaptation of the anatomic structure to its new function: the unstable first ray (4). More precisely, instability is considered to be a symptomatic clinical pathological entity demonstrating insufficient joint alignment during function. We would therefore distinguish instability from hyperlaxity, which may occur and remain asymptomatic throughout life. Instability can also occur without hyperlaxity. Instability usually causes pain and/or apprehension, and if not treated may lead to articular lesions and destruction.

The foot and ankle have a structure inherited from that of the hand. As the weight-bearing and walking organ, it is therefore very young with a short adaptation period. From a prehensile organ, the hand, with its high articular mobility and a low duty in carrying weight, it has become a structure designed to act with a low articular mobility and with a high duty in force transmission.

From the ankle joint to the tip of the toes, there are ***28 bones joined by more than 35 joints***.



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The very quantity suggests that not all of these joints are essential for normal function. In fact, in this manual we will often refer to "essential" and "adaptive" joints. The essential joints may be defined by their indispensable role for a specific task in walking or running, while adaptive joints may be defined by a low arc of motion, linking bones by a tremendously strong ligamentous system assisted by intrinsic and extrinsic muscles. Those many essential and adaptive joints might explain why we can move slowly or softly or at a brisk pace.

If we want to introduce some priorities in the surgical treatment of foot and ankle disorders, we should put the stability of the body during stance and gait first. In such a way we aim to achieve a judicious balance between a multiarticular frame and a number of extrinsic muscles. Instability due to foot and ankle pathology might be corrected by reorienting osteotomies and/or by fusing adaptive joints together with muscle tendon transfers to achieve an equilibrated muscular system (motor propulsion and active suspension).

2 Anamnesis

Ideally, the podiatric patient who suffers from foot pain should be seen first by a general practitioner or family physician. The general practitioner would exclude the major "extrinsic pathologies" such as compressive radiculopathies of the lumbar spine or dermatologic diseases. Rheumatoid polyarthritis is believed to start with the signs of destructive arthropathies at the feet in the majority of cases (5).

The medical history must be inquiring, with the examiner taking the role of a detective. The chronology of the symptoms and the speed of progression are relevant. During the interview, the medical professional should ask questions indirectly, avoiding suggestions.

Subjective disorders

Pain

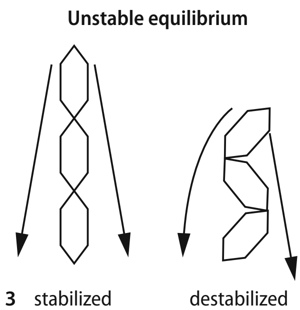
The great majority of reported disturbance is pain. Pain can have many aspects that guide the examiner to a related pathology. Pain can be elicited by simple weight bearing in conditions linked to static disorder or while walking or running in pathological conditions involving muscles, tendons, and joints. It can be significant when moving after rest, can occur during weather changes, or can move under different barometric conditions (mountains, air traffic), guiding the diagnosis toward a degenerative disease. Pain can, conversely, increase during activity that would lead the diagnosis toward an osteoarticular malorientation or a musculotendinous problem. Pain can also arise without weight bearing and at night, which may be linked to a neurologic problem.

Pain can have different characteristics. It can be reported as sharp or precisely located in a joint problem, dull in a degenerative disease, or wandering, diffuse, inconstant, or burning, and may include "electric discharges" in neurologic diseases. Precisely located plantar pain very often indicates a local overload and thus an osteoarticular imbalance of the foot. It may also indicate malalignment of the whole lower limb.

Pain might be linked to footwear. For the foot and ankle surgeon, it is essential to know whether the pain occurs barefoot, either standing or walking. There are typical locations of pain due to irritating footwear, such as the medial aspect of the first metatarsal head, the lateral aspect of the fifth metatarsal head, the lateral basis of the fifth metatarsus, or at the level of the insertion of the Achilles tendon. When considering pain linked to footwear, the adaptation of the footwear to the particular anatomy of the foot must first be discussed. Orthopedic surgery should be limited to (re)establish painless and free function without footwear. Surgical treatment aimed at adapting the foot to footwear should be classified under the practice of plastic and aesthetic surgery.

Instability

Instability is a subjective feeling experienced by the patient, whereas hyperlaxity is an objective sign that can be assessed by the examiner. Instability might be linked to hyperlaxity, but this is not always the case. As mentioned above, stable alignment might be the main aim in restoring undisturbed foot and ankle function. Instability is perceived as pain, apprehension, or both. It is often linked to traumatic lesions of the ligamentous entity of a local osteoarticular unit. It may also be linked to a failure of the muscular balance around the foot and ankle. In the forefoot, failure of the intrinsic musculature may be involved. The alignment of the osteoarticular structures in the forefoot follows the rules of an unstable equilibrium that is stabilized by a specific musculature (6). As such, ***a minute imbalance of muscular antagonists***



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causes a slight deformity that, in fact, tends to increase any imbalance.

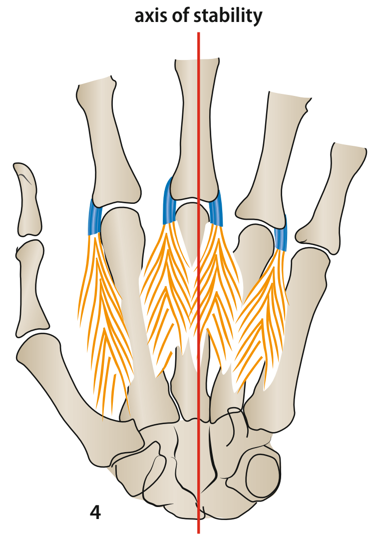
As mentioned above, stable alignment might be the main aim in restoring undisturbed foot and ankle function. Instability is perceived as pain, apprehension, or both. The patient often reports trauma in the past.

In the hindfoot, instability causes pain either laterally, at the anterolateral corner of the upper ankle joint ***(E80)***, or medially, at the level of the posterior tibial tendon and/or anterior to the medial malleolus. Apprehension is most critical when dealing with hindfoot instability.

In the midfoot, pain due to instability might be centered within the sinus tarsi and/or the medial aspect of the navicular bone.

In the forefoot, instability might cause pain at the level of the tarsometatarsal joints and/or at the plantar level of the metatarsal heads. Static buttressing and dynamic push-off are basically influenced by the mobility of the tarsometatarsal joints and the relative length of the metatarsi.

During evolution, the ***central axis of the foot shifted from the third ray (hand)***



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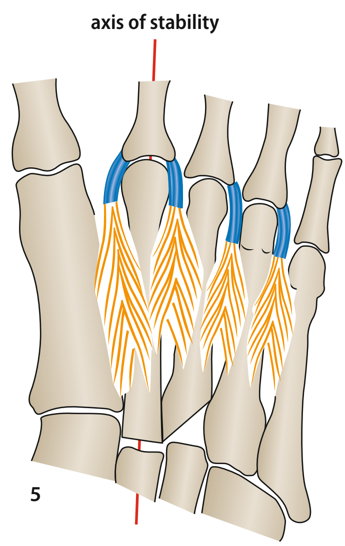
to the second ray (foot).



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This evolution is seen in the anatomic position of the interosseus musculature.

Since the fairly recent existence of *Homo erectus* (about 3–4 million years), there has not been enough time to adapt the holding structures (ligaments) to the mechanical duty of the first plantar ray. In the hand, the first metacarpus is not bound by ligaments to the second metacarpus, which allows the prehensile function of the hand. In the foot, too, the first metatarsus does not have a ligamentous hold to the lateral metatarsi. This characteristic jeopardizes the stability of the foot in weight bearing, walking, running, and jumping. Instability of the first tarsometatarsal joint reduces the anteromedial buttress of the foot and overloads the adjacent rays. The patient suffering from an unstable first ray complains about a plantar ***"hazelnut" at the level of the central (second and/or third) metatarsi***

6

while walking barefoot (4).

Despite the presence of the intermetatarsal ligaments in between the lateral sesamoid bone and the fifth metatarsus, intermetatarsal instability may occur and play a role in the pathogeny of perineural fibrosis of the peripheral plantar nerves. It is probable that "Morton's neuroma" (7) may be caused by the alternating pressure of the metatarsi against the nerve. This might be especially relevant between the third and fourth metatarsi due to the ***separation between the "navicular" and the "cuboid" forefoot***.

7

This causes the nerve and surrounding tissue to thicken, undergo fibrosis, and be destroyed.

Impaired function

The function of the feet is to give the body stability while standing, walking, and running. But due to the bipedalism of the human species, functional stability is, in fact, a real challenge. The most frequent trauma encountered in clinical practice is the sprained ankle. Impaired function might be due to recurrent sprains or other posttraumatic conditions. A considerable number of people, however, suffer from a morphologic disposition causing a state of dynamic imbalance of the foot, thus impairing function. Such unfavorable morphology originates from either a congenital disposition or, more rarely, progressive degeneration. In addition, inflammatory (polyarthritis) and metabolic (diabetes mellitus) diseases rank among the primary causes of foot imbalance by destructive means. A limited gait perimeter is the most important functional factor that should be assessed and treated by the foot and ankle surgeon.

Relevant parameters

It is essential to assess the **time** and consequently the chronological progression of any pain, instability, or impaired function. Long-term progression of pain or impaired function might correspond to joint degeneration and progressive misalignment. Short-term progression or that beginning with an acute event might be related to a cartilaginous, bony, ligamentous, or capsular lesion. Previous surgery of the lower limb or trauma that changes the length or angulation of the osteoarticular structures changes the weight-bearing pattern of the foot, which might be unable to compensate.

The patient might be able to indicate precisely the **localization** of the pathology, easing the pathway to diagnosis. On the other hand, he or she might indicate diffuse pain or pain at a distance from the primary disorder. The levers of the foot are complex and include the heel and the metatarsus. The longitudinal levers include a number of joints, all of which must be oriented and stabilized by the combined effect of connective tissue and muscles. These levers, besides being multiarticular, are oriented in a helicoid fashion, starting at the (posterior) heel in a ***slight***

oblique plane (valgus; talus–calcaneus) and ending in a perfectly ***horizontal plane***

at the metatarsal heads that we call the **anterior heel**.

The whole construction is dynamically held by 10 extrinsic muscles and tendons optimizing the path to gait. Any defect of a lever, which may be due to joint hyperlaxity, misalignment, or defective muscle, can cause pain, instability, and impaired function at a certain distance from the pathology.

Symptoms depend on **physical activity**. The relationship between musculoskeletal activity and pain, instability, or impaired function will inform the clinician about the origin of the disorder. Physical activity clarifies such information. If running or jumping cause trouble, walking and standing alone might not cause any discomfort. Change of the gait perimeter is a reliable factor assessing foot function. Pain at rest is difficult to interpret and may be related to neurologic, inflammatory, or metabolic disorders. Micromotion of an arthrotic joint (which includes an inflammatory component) causes pain at rest. The first path after rest (e.g., morning) often corresponds to the first painful stress to an arthritic joint. **Barometric influence** on pain is typical for degenerative joint diseases but may also be linked to the mechanical interference between occasional osteosynthetic material (plates and screws) and bone.

Footwear may influence foot pathologies. The most striking impact is that of high-heeled shoes (8). Chronic use of such shoes causes all kinds of pathologies, logically following the overload of the anterior heel, instability of the hindfoot, and shortening of the calf musculature.

Previous surgery of the foot and ankle changes the natural path of pathology and is therefore a challenging parameter for the surgeon seeking to alleviate pain, instability, and impaired function. The contralateral foot might help in finding the cause of the disorder. Previous reorienting procedures (osteotomies and arthroplasties) located proximal to the ankle may influence foot function.

Clinical Examination

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1 Observation

Statics

Statics is the mainstay of the clinical examination of the foot and ankle. If the bony and articular alignment of the lower leg and foot doesn't follow a few simple rules of statics, function is probably jeopardized, and painful degeneration follows. Generally speaking, comparing the foot to the vertebral column, human bipedalism is stabilized by the musculature, and the ligaments are secondary.

The first static examination is performed while looking at the patient from behind while he or she is standing on an elevated ***platform of about 1 square meter*** (examination cube; 9).


9

For a comprehensive examination, the platform should be made of a thick glass plate that must support all usual body weights, and the space below should be occupied by an inclined mirror.

Pelvis and lower leg

The examiner stands behind the patient, with his or her eyes at about the level of the pelvic crests in such a way as to best evaluate any eventual ***pelvic inclination within the frontal plane***.


10

The level of the knees gives information about eventual length discrepancies of the lower legs.

The frontal angulation of the knees shows the mechanical axis between hip and heel. Quantitative assessments are made by ***measuring the intercondylar and intermalleolar spaces*** and considering their mutual relationship.


11


12

Genu valgum is often compensated for by a varus of the hindfoot but worsens the stability in cases of hindfoot valgus. The converse is true for genu varum in the presence of a neutral axis of the hindfoot or in varus. If the problem is one of instability, surgical angular correction may be indicated at the proximal aspect of the leg ***(O189)***.

The ***perimeter of each calf***

is measured because it is a very sensitive parameter for evaluating atrophy of the extrinsic foot musculature that is due to an occasional limp caused by unilateral pain.

The extrinsic musculature is essential to stabilize the foot and ankle during stance and gait. There are 10 extrinsic muscles that coordinate and motorize the foot. The triceps surae is the most powerful. In the normal foot, the torque measured around the upper ankle joint is four times greater for the flexors than for the extensors. Around the lower ankle joint ***(E85)***, the supinators have twice as much power in torque compared to the pronators (10). The relationship between the powers of the muscles is essential and very sensitive. The natural difference between the agonists and antagonistsin flexion/extension and pronation/supination allows for a constant bone and joint recoil to the ground and thus counteracts gravity and weight bearing. This natural and functional difference can be termed “functional muscle tonus.” Balance between muscle power and gravity is critical. A slight imbalance of the muscles may cause structural deformities by bending bones and joints. In critical cases, especially myopathies and central neuropathies, selective electroneurography is indicated.

Hindfoot

Sitting down, still behind the standing patient, ***the examiner faces the lower leg and the hindfoot***.

The axis between the upper ankle joint and the heel (tuber calcanei) is carefully evaluated (hindfoot axis). A stable lower limb includes a ***discrete valgus of the hindfoot*** axis (about 5–7 degrees).

Symmetry of both heel cords is evaluated. ***Eventual irregularities***, which may be painful at palpation, may hide chronic tendinitis ***(R159)***.

16

Symmetry of the hindfeet is evaluated. The hindfoot may be in valgus that is more or less pronounced or clearly placed ***"ad latus"*** to the lower leg ***(E42)***

17

in the case of a chronic rupture of the posterior tibial tendon.

The hindfoot may, alternatively, ***show a varus***,

18

which should always be considered together with the angulation of the lower leg.

The hindfoot axis determines the weight-bearing pattern of the heel and the ***wear of the shoes***.

19

Exaggerated, symptomatic valgus and varus of the hindfoot may be linked to a deformity observed within both the horizontal and sagittal planes: eversion and inversion. The valgus and everted foot is called ***"flat foot,"***


20


21

while the varus and inverted foot is termed ***"cavus foot."***


22


23

The symptoms of an exaggerated eversion or inversion of the foot are the indications for treatment. Symptomatic eversion is mostly due to a painful abutment of the lateral process of the talus onto the anterior process of the calcaneus ***(O316)*** and eventual tendinopathy of the posterior tibial tendon ***(T812)***. Symptomatic inversion is mostly linked to functional instability during stance and walking and painful overload of the lateral column of the foot.

Considering the horizontal plane alone, the angulation between the lateral edge of the calcaneus and the lateral aspect of the fifth metatarsus is evaluated. In normal feet, the lateral wall of the calcaneus is aligned with the fifth metatarsus. Pes abductus presents a relevant lateral angle of the forefoot. This may partially compensate a varus of the hindfoot and improve functional stability. Pes adductus, on the other hand, in which the foot is angled medially at the tarsometatarsal joints ***(O330)***, tends to worsen the functional instability of a hindfoot varus.

Footprint

The weight-bearing pattern of the foot is then assessed by the reflected image of the loaded foot. The alignment of the calcaneus to the fifth metatarsus is verified. The "footprint" is divided between, roughly speaking, the heel (calcaneus) and the anterior heel (metatarsal heads). As both heel and anterior heel have contact with the floor, the ***most usual footprint***


24

includes a weight-bearing lateral edge of the foot, leaving part of the plantar aspect of the medial foot without contact with the solid, horizontal ground (medial longitudinal arch).

The anterior heel should have a homogeneous weight-bearing print across the whole width of the forefoot (4). If the ***anteromedial aspect of the foot-print***

25

indicates reduced weight bearing, this might be a sign of an unstable first ray and an overloaded second metatarsus.

Occasional instability of the first ray ***(E115)*** disturbs the homogeneous load distribution of the anterior heel. By ***"escaping" in extension***

26

and eventually in ***adduction***,

27

the first metatarsus leaves the stiffest rays on the tarsometatarsal level, taking the resulting overload (12). This overload results in striking callosities beneath the corresponding central metatarsal heads. Plantar pain under the central metatarsals is the main sign of instability of the first ray (11).

Such imbalance ends in a degenerative lesion of the "plantar plate" situated beneath the central metatarsal heads and constituted by the confluent distal fibers of the plantar fascia and the intermetatarsal ligament, thus reinforcing the corresponding articular capsule. If such a plantar "tear" is big enough so that the toe is no longer able to be held to the ground, the toe undergoes ***dorsal subluxation***,

28

and the tip of the toe no longer touches the ground ***(O383)***.

Observing the ***dorsal aspect***


29

of the metatarsophalangeal joints allows assessment of an eventual subluxation or a true dislocation due to a “torn plantar plate”***(E117, R145)***.

The ***missing buttress of the second toe***


30

on the footprint is testimony to the imbalance of the anterior heel, and the radiograph shows the ***overlap of the second metatarsus***

31

with the basis of the first phalanx.

The midfoot demonstrates a more narrow contact surface to the floor, located at the lateral edge of the foot. The variability of the width of this contact “strip” located between the anterior and the posterior heel depends logically on both the height of the midfoot and the global orientation of the foot within the frontal plane (valgus).

The ***collapsed midfoot demonstrates a wide footprint***,


32

2

and the cavus foot shows a ***smaller footprint***.

33

However, the change of orientation within the frontal plane modifies considerably the weight-bearing pattern: An increased varus position ***enhances the buttress of the lateral column of the foot (E37, E38)***.

A stable morphological example of the pes cavus is the ***cavus valgus type***.

34

The lateral column does ***not demonstrate any plantar buttress***.

35

Tiptoe

The patient is then asked to ***rise onto the tips of the toes.***

36

A **normal foot demonstrates a varus** of the hindfoot, showing good functioning of the talocalcaneonavicular joint and the functional motors by means of the tibialis posterior muscle and the fibularis longus muscle. If the patient indicates apprehension while standing on tiptoe, the stability of the hindfoot must be investigated more closely by assessing the axis of the hindfoot, the ligaments, and the extrinsic musculature.

The cavus foot ***(E33)*** changes its weight-bearing pattern considerably with ***a different orientation within the frontal plane***.

37

With the patient standing on tiptoe, this weight-bearing pattern is noted by observing the ***plantar skin of the lateral column (right foot) (E33)***.

38

The mobile, flexible flat foot with a ***collapsed midfoot (E32)***

39

is not linked to a missing varus of the heel while on tiptoe but ***demonstrates strong inversion of the foot.***

40

This foot has a wide range of movement within the talocalcaneonavicular joint, demonstrating sufficient power of the posterior tibialis musculature.

Frequent pathology includes chronic rupture of the posterior tibial tendon ***(T812)***. The static examination demonstrates a ***pes "ad latus"***

41

and a ***missing varus of the heel in the digitigrade position (E36)***.

42

If the patient indicates pain in the anterior heel, the sagittal alignment of all metatarsal heads must be assessed (metatarsalgia) ***(E116)***.

Asking the patient to lift one foot demonstrates the ability to stabilize the body using a single lower limb.

The body weight is then concentrated on the anterior heel, and, again, the anterior weight-bearing print should be homogeneous to maximize the weight-bearing surface and reduce local pressure. As a rule of thumb, pressure on the plantar skin never exceeds 10 kg/cm^2 (10). ***Standing on tiptoe and on one leg may provoke a slight valgus of the heel***,

43

which is a sign of stabilization due to the missing contralateral foot. Occasionally, metatarsalgia increases when standing on one foot. ***Discrepancy of the metatarsal length***

44

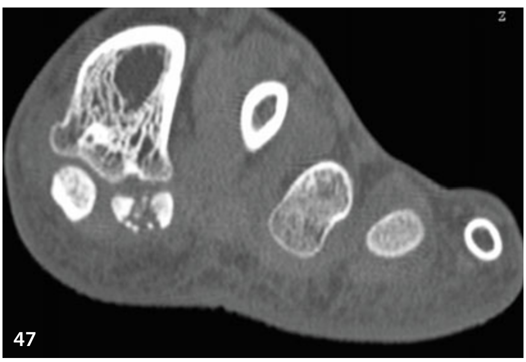
can explain any ***pain experienced during push-off***.

45

46

The metatarsus turns vertical, and if the second (and third) metatarsus is longer than the first one, the patient may feel a painful corresponding overload beneath the second (and third) metatarsal head ***(O418)***.

On the other hand, pain beneath the first ray may be evidence of a ***pathological overload of the sesamoid bones (R157)*** and reveal eventual fractures ***(T763)***.



47

The patient is then evaluated standing and from the side. All toe pulps should touch the floor, and the inclination of the tips of the toes to the bearing surface is critical because of the toes' push-off function. Despite the three articulated bones in the lesser toes, mutual retractile flexion (accordion) is avoided by the following:

- The "windlass mechanism" of the plantar fascia (12), which passively flexes the first phalanx
- The tensioning of the flexor digitorum brevis, which stabilizes the middle phalanx
- The tensioning of the long flexor of the toes, which presses the pulp of the toes onto the ground

Toe alignment

Asking the patient to ***stand at the edge of the examination cube*** with all toes free should demonstrate in the healthy foot the windlass mechanism of the plantar fascia: The plantar fascia is a strong mechanical link joining the heel and the basis of all phalanges. Steady weight bearing compresses the bony beams of the foot, tending to reduce the longitudinal arch and thus tighten the plantar fascia. ***Spontaneous flexion of all metatarsophalangeal joints*** ensues (8, 12).

48

49

The patient then turns 90 degrees to face the examiner. Rotation of the lower leg and hindfoot is considered by focusing the attention on the knee axis. ***With both patellae positioned within the frontal plane***,

50

the normal foot demonstrates an external rotation of about 15 degrees.

Excessive external rotation of the bimalleolar angle (ankle) is generally well supported and is often associated with a genu (crus) varus. ***External rotation of the feet***

51

may be augmented by excessive pronation of the lower ankle joint.

As the horizontal alignment of the toes has wide, individualized, symptomless variety, in a barefoot, walking subject, painful and generally disturbing misalignment may occur after surgical operations. ***Painful adductus of the big toe***

52

is one such misalignment.

This deformity is generally not tolerated due to pain and discomfort ***(O411, T841)***.

Rotational alignment is also critical. The big toe and the second and third toes are generally in a "neutral" position, as evidenced by the orientation of the toenail (horizontal). The ***fourth and the fifth toes may be turned slightly in supination***.

53

However, if the axial rotation of the toe ***exceeds 45 degrees***

54

of supination, there is a likelihood of a painful buttress of the outer edge of the nail, which may need correction ***(T849)***.

Heels standing

The integrity of the anterior tibial muscle is tested in a neutral position in the lower ankle joint by asking the patient to extend his or her foot dorsally. The lower ankle joint is inverted by the muscle action.

Rupture of the anterior tibial muscle tendon

55

causes eversion of the lower ankle joint due to the activity of the fibularis tertius muscle. Rupture rarely occurs, however, and mainly results from cortisone injections ***(E93)***.

Attention is given to the simultaneous activity of the tibialis anterior and the extensors of the toes. During active extension of the foot, all tendons around the dorsum of the foot are observed. Any slight weakness of the tibialis anterior muscle leads to recruitment of the long extensors of the toes. This is also evident in the case of shortening of the calf muscles ***(E74)***. It causes a strong pull on the toes, resulting in ***dorsal extension at the metatarsophalangeal*** and plantar flexion at the proximal interphalangeal joints ***(O389)***.

56

This position of the toes may become chronic and irreducible ***(E123)***; this condition is termed ***"hammer toes."*** It should occasionally be investigated on the neurological level. Often, a pes cavus is associated.

Nonstatic observation

The patient is then asked to ***sit on the edge of the examination cube*** and face the seated examiner.

57

Unloaded alignment

This position corresponds to both the hip and knee being flexed. Any length discrepancy of the thighs is best seen in this position. The patient is asked to hold his or her feet horizontally, and the anatomic horizontal rotation angle between knee and foot axis is assessed (about 15 degrees). ***Rotation of the lower leg within the horizontal plane*** is assessed by considering the bicondylar knee and bimalleolar ankle axes

58

This assessment can also be performed in a standing position considering the plane of the patella (frontal plane) and the angle between the foot axis and the sagittal plane ***(E50)***.

The action of the anterior tibial muscle is seen in a neutral position of the lower ankle joint by asking the patient to extend his or her foot dorsally.

Extension power of the foot is augmented by the ***long extensors of the hallux and the toes (recruitment)***.

59

Sole of the foot

With the patient still seated as above and in front of the examiner, the plantar skin is visualized. The plantar skin reacts to chronic and repetitive pressure by thickening the epidermis of the skin and forming ***calluses***.

60

A reduced total weight-bearing surface (load concentration) and reduced subcutaneous plantar fat cause calluses. Pathological morphotypes such as pes cavus adductus may present painful calluses and eventual ***skin breakdown*** (ulcers).

61

The anterior heel corresponds to the horizontal alignment of all metatarsal heads. This is especially true in weight-bearing conditions ***(E24)***. In non-weight-bearing conditions, the horizontal view may demonstrate a ***convex contour of the plantar skin and hammering of the lesser toes.***

62

In those cases, there is often an unstable first ray and the corresponding absent anteromedial buttress of the foot. Calluses beneath the central (second and third) metatarsal heads demonstrate the secondary local overload. Those calluses are painful on palpation ***(E116, O340)***.

Diabetes mellitus causes a peripheral neuropathy in which deep sensibility is lost, probably along with the activity of the intrinsic musculature. Concentration of bearing load and callus formation in diabetic patients are considered the precursors to skin breakdown and the appearance of ***malum perforans***.

63

When the pulps of the toes do not make contact with the ground for a variety of reasons, calluses form beneath the metatarsal heads. This demonstrates the importance of the toes in load sharing during walking and running. Toes may present painful plantar calluses proximal to the distal phalanx, ***beneath the distal condyles of the proximal phalanx.***

64

This typically happens when the short flexors are insufficient (intrinsics) and the ***intermediate phalanx is dorsally extended*** (so-called swan-neck deformity).


65

It may also occur after the long flexor of the toe is transferred to the first phalanx for treatment of symptomatic hammer toes ***(O387)***. If the interphalangeal joints are hypermobile (hyperlaxity), the first and second interphalangeal joints hardly resist passive extension of the toe.

Interdigital calluses may form at the level of the interphalangeal joints. Rigid flexion of the distal interphalangeal joints may cause ***subungual calluses***.


66

This is due to shortening of the long flexor tendons and may have neurologic or traumatic (calcaneus fractures, including compartment syndrome of the foot) causes. Calluses around the toes are usually due to a mechanical dysfunction and are very painful ***(F454)***.

2 Palpation

Heel cord

The patient lies relaxed on his or her chest, placing the shins on a soft roll to passively flex the knees. This relaxes the gastrocnemius muscles. The examiner palpates the lateral and medial edges of the distal heel cord and examines the eventual peritendinous edema and/or irregularities of the tendon. Peritendinous edema might give the feeling of a crisp, dry sponge on palpation (tendinitis). Pain on palpation is the driving point ***(E16)***. The fulcrum of pain can be located at the insertion of the heel cord at the back of the tuber calcanei (enthesopathy).

If the knees are straight with the feet over the edge of the examination surface, both gastrocnemius muscles are in tension. Both feet should ***show a slight plantar flexion.***


67

If, however, one foot demonstrates a ***neutral position without flexion,***


68

a ruptured heel cord should be strongly suspected. By squeezing the calf muscles, the consequent muscle shortening provokes ***passive flexion of the foot*** in normal conditions.


69

If this maneuver doesn't occur, the ***heel cord is certainly ruptured*** (Thompson test) ***(T794)***.


70

Ruptures of the tendon at this location may be secondary to ***corticoid injections.***


71

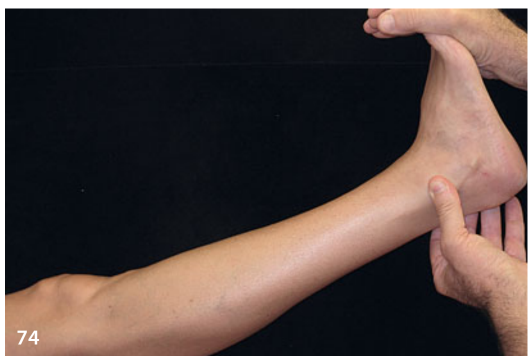

72

Turning onto his or her back, the patient keeps the knees relaxed, and the examiner holds the lower leg from behind (calf) with one hand and the foot with the other hand. The foot is held avoiding inversion/eversion (locking the talocalcaneonavicular joint). First positioning the lower leg to ***relax the knee in flexion***,


73

the foot is pushed in passive dorsal extension of the upper ankle joint.

Normal conditions allow the ankle to be moved 20–30 degrees in extension. Still holding the lower leg but with the ***knees straight***,


74

the same passive dorsal extension is performed. If the extension angle of the foot does not exceed or is less than the right angle, we talk about a "functional pes equinus" by expression of a shortened gastrocnemius musculature (13) ***(T858, T793)***.

Functional pes equinus results naturally in chronic overload of the anterior heel and may induce metatarsalgia ***(E116)***.

In the standing patient, palpatory pain located at the anterior aspect of the last centimeter of the Achilles tendon may be related to an anterior bursitis, which in turn may have been triggered by an "aggressive" ***posterocaudal osteophyte of the calcaneus***

75

(Haglund) ***(O176)***.

To continue, the patient sits on the examination cube, relaxing the knees and ankles, and the ***examiner sits in front of the patient***.

76

Heel

The examiner holds the foot and deeply palpates the ***plantar, central aspect of the tuber***

77

calcanei. This pressure elicits pain in cases of calcaneodynia. Additionally, the proximal medial aspect of the plantar fascia will also be tender on palpation ***(T860)***.

Plantar fascia

Palpating from the plantar aspect of the tuber calcanei distally, the medial edge of the plantar fascia may be identified. The medial edge of the plantar fascia is demonstrated by pushing all toes in passive dorsal extension together with the whole foot: The fascia undergoes tension, and the ***medial edge is easily seen beneath the skin***.

78

If this palpation is painful, we are talking about a plantar fasciitis. If the medial edge of the plantar fascia presents irregularities such as painful firm nodules, there is a likelihood of facing plantar fibromatosis or morbus Ledderhose.

Upper ankle joint

The tibiofibulotalar joint is usually called the ankle joint. Mechanically this joint moves in flexion-extension following a slight conical path, with the center of the cone being medial. To emphasize the important and complex articular mobility of the hindfoot, we call this joint the "upper ankle joint." The laxity of the upper ankle joint is determined by the ligamentous structures with a fixed medial pillar, the medial malleolus, and a slightly mobile lateral pillar or "guide," the lateral malleolus.

Lateral ankle

Both tibia and fibula are connected by a strong three-part ligament, the tibiofibular syndesmosis. Traumatized, nonfractured ankles may result in painful insufficiencies of the syndesmosis. ***Forced external rotation of the foot in a neutral position*** may rupture the anterior syndesmosis, and the passive stress test in this direction is painful. This stress pushes the talus in external rotation and the fibula follows, while the tibia lags behind. Pain is thus located at the anterior aspect of the syndesmosis ***(O221)***.

Beneath the tibia, the fibula is connected to the talus by two rather lax lateral fibulotalar and calcaneal ligaments. Their function is to avoid joint subluxation before weight bearing.

The medial pillar is made up of the strong deltoid ligament, which links the tibia to the talus, calcaneus, and navicular bone.

Distal to the hip joint, the medial aspects of the joints are tight and less prone to giving way than the lateral aspect of the limb. The lateral condyle of the femur glides on the tibia, while the medial condyle rotates on the tibia. The upper ankle joint is also more lax on the lateral side than on the medial, and the subtalar joint is tightly fixed on the level of the sustentaculum tali with more mobility on its lateral aspect.

During weight bearing, the synergy between the ligaments that avoid joint subluxation and the musculature constitutes the essential stabilizing factor.

Following a sprain of the hindfoot, the lateral ligaments, especially the ***anterior fibulotalar ligament,*** is usually first to sustain a tear ***(T771)***.


79


80

2

Palpating the origin of the ligament


81

and its insertion on the ***lateral aspect of the talar neck***


82

may remain painful for a longer period if the ligament is insufficient.

Forced supination of the foot stresses the anterior fibulotalar ligament, which may rupture and leave the talus while held firmly on its medial aspect, in an ***exaggerated anteroposterior drawer***.


83


84

Due to the wide range of normal and asymptomatic joint laxity, the asymmetry between the symptomatic and the asymptomatic foot is relevant in this test.

Acute ruptures and insufficient healing of those ligaments may cause functional incongruities of the upper ankle joint surfaces that are painful, leading to apprehension, "giving way," and posttraumatic joint degeneration ***(O210)***. The talus is no longer held by the lateral ligament and shifts anteriorly ***(R140)***. A chronic static shift of the talus anteriorly is due to the conical shape of the talar dome, which is wide anteriorly and narrow posteriorly.

Conversely, an overly strong ligamentous repair or a repair that does not allow for physiologic mobility of the upper ankle joint may lead to a (rare) posterior shift and joint destruction.

Medial ankle

If palpating the anterior aspect of the medial malleolus is painful, there is a high likelihood of a severe sprain that jeopardizes the stabilizing effect of the medial pillar of the joint.

The anterior fibers of the ligamentum deltoideum might be painful at palpation in the case of a severe sprain of the ankle in which the talus is rotated (internal rotation) excessively within the malleolar fork. Unlike a simple internal rotation around the medial malleolus (medial pillar) and a rupture of the lateral ligaments, a lesion at the ligamentum deltoideum signifies a severe sprain in which only the posterior fibulotalar ligament might have resisted. This lesion is, however, common in certain malleolar fractures. Together with the posterior dislocation of the distal fibula, the medial malleolar dislocation/dissociation brings the rotating talus to shear off the posterior tibiaI articular rim. Without fracture and in relation to a sagittal hyperlaxity of the upper ankle joint in internal rotation, a lesion of the anterior part of the deltoid ligament may be the result of a significant joint instability.

Lower ankle joint

Motion

The inversion of the subtalar joint stresses the fibulocalcaneal ligament, which yields under load. Subtalar hyperlaxity is tested specifically ***between the talar neck and the heel***

85

2

when evaluating the arc of the talocalcaneonavicular joint, which shares its exceptional mobility with the hip joint. To be precise, the path of motion of the calcaneus beneath the talus follows a helix situated on an inclined, flattened part of a cone, the center of which is located at the level of the sustentaculum tali. The axis of the cone is oblique from posterolateral to anteromedial. The cone is flattened on its superolateral aspect: Its curve has a smaller radius medially than superiorly and laterally. The underlying calcaneus (male part of the joint) thus rolls and slides beneath the talus. ***The calcaneus moves posteriorly during heel strike,***


86

which includes pronation, and ***moves toward the anterior during push-off,***


87

which includes supination of the coxa pedis.

In maximal pronation, the talus abuts the calcaneus laterally (angle of Gissane),

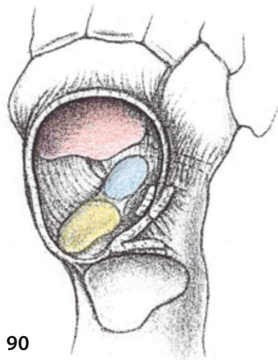

88

while ***in maximal supination the talus abuts the calcaneus medially*** (sustentaculum tali).


89

The path of motion of the navicular beneath the talus follows the calcaneus: During weight bearing (pronation), the navicular is pulled laterally, following the calcaneus, which moves posteriorly. During push-off, motored by the strong pull of the tibialis posterior muscle, the navicular moves medially, preceding the anterior move of the calcaneus (supination).

The articular play of the navicular and the sustentaculum tali (calcaneus) around the talar head very much resemble the abduction–adduction of the hip joint. The shape and configuration of the proximal navicular joint facet and the anterior/medial calcaneal joint facets are ***very similar to the coxal acetabulum***.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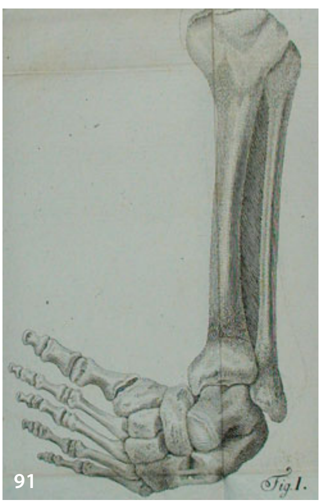
Antonio Scarpa (14) noted this morphologic and functional resemblance, especially in relation to pathology such as clubfoot, which demonstrates ***subluxation of the talocalcaneonavicular joint.***



91

He named the talocalcaneonavicular joint the **"coxa pedis."** The mainstay of the acetabular arch is made up of the calcaneocuboid joint, which allows some motion between both the anterior (navicular) and posterior (sustentaculum tali) acetabular walls (8).

Again, to emphasize the important and complex articular mobility of the hindfoot, we call this joint, together with the posterior subtalar joint, the "lower ankle joint."

The anterior part of the lower ankle joint is made up of the navicular bone. The navicular bone is basically a transversal bone that directs the three medial rays of the foot. Shifting around the talar head, the whole foot is either inverted or everted. The main extensor of the foot is the anterior tibial muscle, which inserts distal to the coxa pedis and thus either inverts or everts the foot while pulling it strongly in dorsal extension.

The ***strength of the anterior tibial muscle and toe extensors***


92

is evaluated during active extension of the foot. The examiner opposes resistance to foot motion and evaluates the produced force.

Insertion of the tibialis anterior tendon occurs on both the first cuneiform and the first metatarsus. Painful enthesopathy of this tendon is quite frequent, and direct palpation of the insertion and restrained active extension of the foot cause the pain. ***Rupture of the tibialis anterior tendon***

93

is common after local cortisone injections, which can cause necrosis. The consequent functional disability is obvious ***(E55, T818)***.

Different locations on the lower ankle joint may demonstrate specific pathological conditions:

Lateral process of the talus

The lateral process of the talus forms the posterior aspect of the sinus tarsi, which includes a high concentration of mechanoreceptors, giving us information about the statics and stability of the lower limb. In the case of a hindfoot sprain that includes the lower ankle joint, the sinus tarsi may continue to cause pain ***(R155)***.

While Scarpa observed a "dislocation" of the talocalcaneonavicular joint or coxa pedis in the congenital clubfoot, we can talk about a "protrusio" of the same coxa pedis in the pronated foot ***(O255)***. In pronated feet ***(O246)***, pain may be the result of talocalcaneal impingement ***(E88)***. Along its spiral and pronating motion beneath the talus, the calcaneus stops its movement abutting the lateral process of the talus. Fortunately, normal feet have different soft tissue structures that slow down pronation. Contact of the processus lateralis tali with Gissane's angle of the calcaneus may be painful and is also a frequent cause of fracture: The strong pronation and internal rotation of the foot beneath the talus may ***fracture the lateral process of the talus***

94

by impingement ("snowboarder's fracture").

Subtotal subtalar coalition (bar) ***(R158)*** may cause pain when the sinus tarsi is palpated due to micromotion.

Sustentaculum tali

The sustentaculum tali is a small and very strong bone that is part of the calcaneus and the ***mainstay of the medial longitudinal arch*** (4, with permission)

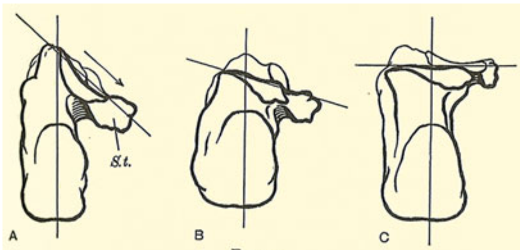


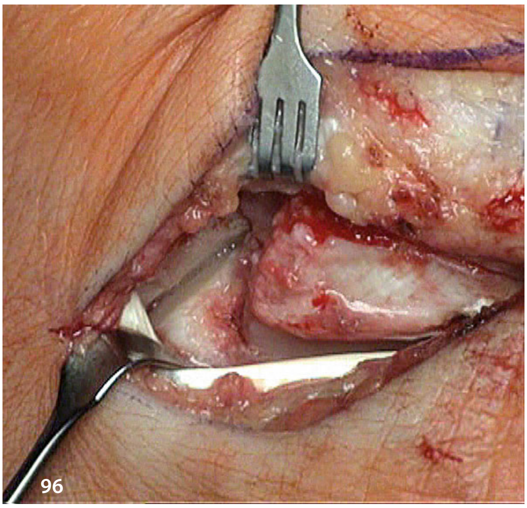
FIG. 35

95 Calcanea of the Gorilla, Neanderthal and Modern Man

of the foot. This arch is actually specific to *Homo sapiens*, beginning with *Homo erectus* (15).

The sustentaculum tali lifts the talus phylogenetically, and with this move it is assisted functionally by the tibialis posterior muscle and tendon.

The sustentaculum tali is tightly fixed to the above-lying talus by a strong capsule and by ligaments. The flexor digitorum longus tendon runs above, while the flexor hallucis longus tendon runs below. The sustentaculum tali constitutes the posterior wall of the acetabulum pedis. Right behind the sustentaculum is the canalis tarsi, with an important neurovascular bundle passing close to the talus (roof). In supinated feet, the sustentaculum tali abuts the posteromedial tubercle of the talus, thus closing the canalis tarsi. Posttraumatic osteophytes (after subtalar subluxation or dislocation) at this location may induce invalidating pain by ***medial subtalar impingement***.


96

Talonavicular joint

Pain on palpation can be due to arthritis and joint degeneration. Diagnostic articular anesthetic infiltration may confirm such a suspicion.

Posterior subtalar joint facet

The posterolateral border of the subtalar joint may be palpated behind the fibular tendons. It is at the base of the aforementioned cone that guides the helicoidal articular path of the calcaneus beneath the talus. This spot is especially painful in subtalar arthritis due to arthrosis that might be degenerative due to chronic overload (malorientation with hindfoot varus or valgus), chronic instability, or trauma (calcaneus or talus fracture). Pain more posteriorly and deep, painful palpation might be the expression of a posterior impingement with the upper ankle joint (tibia). Passive hyperflexion of the foot may be irritating and painful. Three bones are in close proximity to each other here, and the intermediately placed talus may suffer through a ***large posterolateral or posteromedial tubercle,***


97

which may fracture or present an impinging os trigonum. ***Diagnostic anesthetic infiltration*** indicates surgical treatment ***(O186, T581)***.

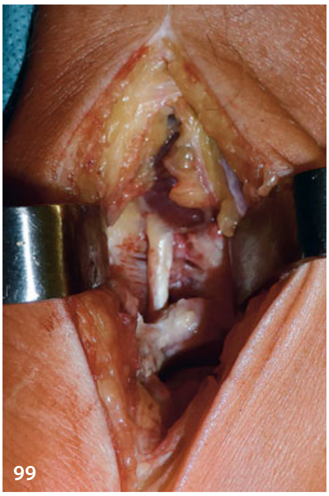

98

It may also be due to a soft tissue impingement involving the upper or lower ankle joint.

Exceptional cases involve congenital malformations such as additional muscle bellies (fibularis quartus or accessory soleus muscles). Some of those abnormal muscles and tendons may insert into the posterior aspect of the talus.

This condition might cause neurologic symptoms while compressing the tibial nerve.

On the medial side and on the same level, the impingement may involve the flexor hallucis longus tendon between both posterior talus tubercles, which present a ***restricted passage to the tendon.***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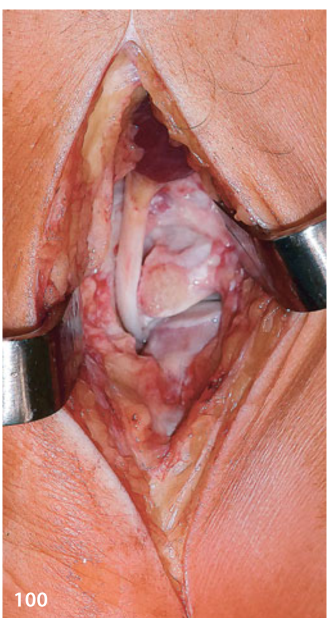
Operative revision and ***liberation of the passage*** may be helpful in rare cases.


100

Navicular bone

Passively mobilizing the lower ankle joint, the ***medial aspect of the navicular bone***


101

is palpated without difficulty.

The importance of its prominence is critical. Abnormal pain at this point may be a sign of a morphologic particularity such as an ***accessory navicular bone (O295).***


102

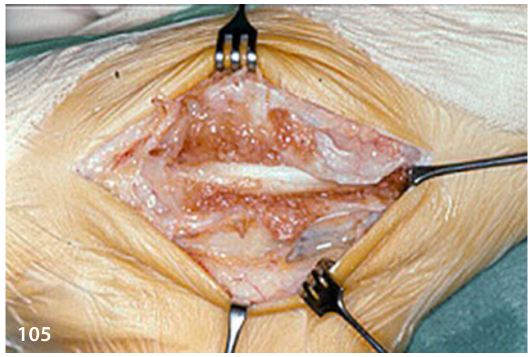

103

The *posterior tibial* muscle is tested while the examiner holds the lower leg with one hand and asks the patient to ***flex and adduct the foot***


104

During this maneuver, the examiner opposes resistance to the motion of the foot and with one finger palpates the retromalleolar and inframalleolar space in which the tendon glides. This tendon is poorly vascularized and frequently undergoes chronic degeneration or rupture in elderly patients and in pathological inflammatory conditions such as rheumatoid arthritis. The degenerating tendon generally increases in volume, which may correspond to scarring tissue, including local irregularities due to partial ruptures and spontaneous repair in the past. In those cases, the tendon rupture is located in the retromalleolar region. Palpation may demonstrate no supination power and submalleolar and retromalleolar pain ***(E42)***.

Starting at the navicular, where pain may be linked to an enthesopathy, and running proximally, palpation of the ***posterior tibial tendon may reveal effusion and/or tendon and synovial irregularities***.


105

These pathologies are very painful on palpation and may be accompanied by the aforementioned crisp, dry sponge feeling.

Scarring of the tendon increases its diameter, which may ***rupture preferentially about the posterior aspect of the medial malleolus (R161, T812).***


106

2

Anterior calcaneal process

At the top of the anterior calcaneus, the strong retinaculum or bifurcate ligament is inserted laterally, as is the main part of the musculus extensor brevis. This might be the location of ***traumatic avulsion***,

107

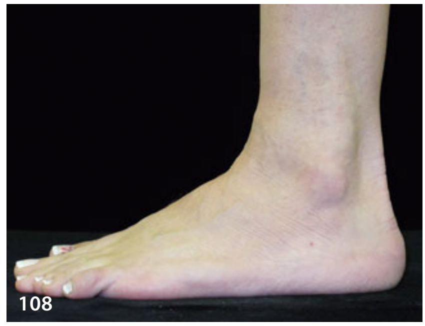
which may or may not involve bone, after sustaining a forced supination trauma.

Calcaneocuboid joint

The calcaneocuboid joint is the mainstay of the lower ankle joint or acetabulum pedis. As a saddle-shaped joint, it opens and closes the acetabulum pedis more or less horizontally. It also cushions the sudden pronation of the calcaneus at heel strike. The lateral aspect of the calcaneocuboid joint may be palpated easily. Palpation is best performed in slight passive flexion and abduction of the foot to avoid interference with the fibularis brevis tendon. Pain at palpation may be due to a past trauma such as an articular fracture.

Fibular muscles and tendons

Both fibular tendons are guided around the lateral malleolus in a smooth gutter, which might allow the ***fibular tendons***



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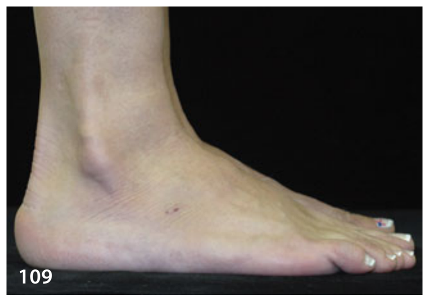
to pop out occasionally,



109

although this is most often a benign particularity that causes no pain or discomfort.

Both tendons have essentially different functions: The musculus fibularis brevis is a pure pronator of the foot at the midtarsal joints and acts as an antagonist of the musculus tibialis posterior. The musculus fibularis longus is essential for holding the medial longitudinal arch of the foot by inserting into the plantar aspect of the first cuneiform and first metatarsus. It acts as an antagonist of the musculus tibialis anterior.

The *musculus fibularis brevis* is tested similarly to the musculus tibialis posterior by ***asking the patient to abduct the foot***

110

while the examiner, opposing resistance with his or her hypothenar, palpates the course of the tendons about the lateral inframalleolar and retromalleolar space.

The *musculus fibularis longus* is tested similarly to the musculus tibialis anterior by ***asking the patient to strongly flex the first metatarsus*** toward the plantar plane

111

without moving his or her foot at the talocalcaneonavicular joint.

The action of the fibularis longus tendon is palpated at the retromalleolar space.

The critical locations on the tendons that may be linked to pathology (longitudinal splits) ***(T809)*** are beneath the lateral malleolus and at the curve around the cuboid bone.

The fibular tendons may be tender on palpation on their path along the lateral wall of the calcaneus. A crisp feeling akin to the squeezing of a synthetic dry sponge may also be felt.

In some cases, the peroneal tubercle might have an abnormally large dimension and be very painful to palpation. Degenerative lesions of the tendons are due to overuse or overload. An overload such as this occurs in chronic malposition of the hindfoot such as hindfoot varus or cavus and should be evaluated in the static position ***(E18, O203)***.

This situation corresponds to a chronic inflammation of the tendons, which have the tendency ***to split along their axes***

112

without increasing diameter.

Pain on palpation at the proximal tip (basis) of the fifth metatarsus may be linked to an enthesopathy of the fibularis brevis tendon. This is common with a varus adductus foot morphotype. A fracture of the tip of the fifth metatarsus may result from a loaded supination trauma, though it does not include the whole insertion of the fibularis brevis tendon and generally heals without medical intervention.

Naviculocuneiform joint

Pain on palpation can be due to arthritis and joint degeneration. Instability due to hyperlaxity may be assessed radiologically ***(R151)*** (plantar articular gap) or during surgery ***(T645)***.

Second and third tarsometatarsal joints

The central tarsometatarsal (TMT) joints are adaptive joints. Their medial part plays a role in smoothing the push-off during gait. The central TMT joints are the least mobile. The second ray became the central axis of the foot during evolution from its ancestor, the hand, and the symmetry of the interosseus musculature is testimony to this evolution ***(A5)*** (4). Painful palpation of the central Lisfranc joints may be linked to degeneration of those joints. In this case, it is common to palpate a preeminent osteophyte at this location. A majority of rheumatoid arthritis cases are linked to this kind of symptom. Posttraumatic conditions, including lesion of the cuneiform 1–metatarsus 2 ligament (Lisfranc's ligament), may cause clinically relevant subluxation that is difficult to assess radiologically ***(R143)***.

Fourth and fifth TMT joints

The lateral TMT joints are essential joints and are more mobile than the first TMT joint. As a prolongation of the calcaneus foot, only two joints link the metatarsal heads to the heel. Painful palpation and mobilization of the lateral TMT joints may occur after trauma. Such symptoms are frequently seen after reorientation of the axis of the foot (e.g., correction of pes planus). Changing the weight-bearing axis of those joints may provoke such irritation. Articular desensitization or interposition arthroplasty may considerably improve this condition ***(T680)***.

Metaphyseal fractures of the fifth metatarsus may be the result of supination trauma, but this also includes the fibularis brevis and fibularis tertius tendons. This results in a mechanically unstable situation that requires very stable fixation for successful healing (Jones fracture).

First TMT joint

Mobility of this joint was reduced considerably during evolution from the prehensile organ (hand) to a weight-bearing organ (foot). However, the missing ligamentous structure linking the first metatarsus to the central axis makes it a delicate structure, and instability of the first ray is a very common problem that causes imbalance of the forefoot and secondary disability. Due to the medial position of the first ray, the imbalance causes, in general, an angulation toward medial (adduction) and dorsal (extension). The triggering effect of proximal particularities and deformities (kinematic chain) such as general hyperlaxity, tight heel cord, genu valgum, and hindfoot valgus must be assessed during the clinical examination. Stability may also be jeopardized by intrinsic muscular imbalance that has undergone a local compartment syndrome (16) or simple trauma. As a physically unstable construction that is stabilized by balanced agonists and antagonists, the forefoot may then develop a rapid deformity at the first TMT joint ***(O345)*** due to the absence of strong ligamentous structures, missing because of phylogenetic reasons.

Painful ***palpation of the medial articular space of the first TMT joint***


113

may accompany instability of the first TMT joint.

Passive mobility of this joint must be assessed precisely. The foot is held in a neutral position (right angle at the upper ankle joint and without pronation or supination) by the examiner ***with one hand at the metatarsals 2–5.***


114

The other hand ***takes hold of the first metatarsus and moves it up and down***

115

starting at the plantar (horizontal) position within the sagittal plane.

The mobility path in dorsal extension is particularly interesting because it reflects the resistance to functional anteromedial buttressing of the foot during gait and push-off (17). Similarly to the sagittal "Lachmann" of the knee, it demonstrates the stability of this part of the foot. The fulcrum of rotation (or deflection) is most proximal to the TMT joint due to the type of joint (plane gliding joint or arthrodia) (11). Testing the activity of the fibularis longus muscle is part of the stability test of the first TMT joint ***(E111)***.

Second and third metatarsal heads

The second and third metatarsal heads, together with both sesamoid bones of the first ray, can be considered the bony, static, weight-bearing centrum of the forefoot ***(O350)***. In fact physiologic distribution of static load is shared between the tuber calcanei and the metatarsal row that we call the anterior heel ***(E24)***. Within the anterior heel, load is equally distributed on the six aforementioned bony prominences.

Painful ***plantar palpation of the second metatarsal head***

116

(together with the third head) is very often linked to an unstable first ray. It may express a lesion of the corresponding plantar plate, which acts as a mechanical continuity of the plantar fascia. In progressed cases, the metatarsophalangeal joint becomes unstable due to the rupture of the plantar plate ***(O383)***. The ***dorsal aspect of the joint also becomes painful***

117

on palpation, and the sagittal drawer test positive. The horizontal alignment of the first three metatarsal heads is relevant for a functional push-off. During push-off, the metatarsus becomes vertical; therefore, their relative length, especially in relation to the first metatarsus, is critical. Radiologic assessment in weight-bearing conditions is indispensable.

The joint and the dorsal aspect of the second (eventually third) metatarsal head may also become painful without subluxation. ***Swelling (left foot) and pain on palpation and with motion***

118

may be the clinical expression of a ***metatarsal head necrosis (morbus Freiberg) (T725)***.

119

Fourth metatarsal head

The fourth metatarsus may become painful during walking and running and on precise palpation. This condition is not linked to the instability of the first ray and often requires exclusively localized surgery.

Lesser intermetatarsal space

At the level of the anterior heel, distal ramifications of the nervus plantaris lateralis are not protected by the digitations of the plantar fascia and are located within the plantar fat. They are located at the lower half of the metatarsal heads and so are submitted to high strain because of the intermetatarsal mobility at the spot where the nerve divides into the two plantar digital nerve ends. Continuous repetitive strain on nerves may cause fibrosis, which in turn destroys the axons. This process leads to the formation of pseudoneuroma (7), which may cause burning pain ***(T855)***. Squeezing all metatarsi within the sagittal plane may elicit the same pain. This pain is increased with additional ***intercapital digital pressure.***

120

Tactile sensation between the toes may be reduced due to the autodestruction of the nerve ***(R164)***. It must be noted, however, that the presence of the pseudoneuroma on magnetic resonance imaging does not necessarily imply corresponding symptoms.

Metatarsophalangeal joints

First ray

Palpatory pain and dorsal pain during passive flexion of the first metatarsophalangeal joint together with an ***evident dorsal osteophyte (left foot)*** of the first metatarsal head (***O371)*** are often the clinical manifestations of hallux rigidus. Mechanical prerequisites that combine to bring about an increase in functional overpressure within the first metatarsophalangeal joint are as follows: The first metatarsus is aligned with the first phalanx within the horizontal plane; the gastrocnemius muscles are tight; and the morphotype is often Egyptian with a positive index metatarsus ***(O367)***. Surgical correction in all stages is usually helpful ***(O370, O372, O375)***. The *long flexor of the hallux* is tested while opposing resistance to the flexion of the end phalanx.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122

Lesser rays

Stability within the sagittal plane is tested to verify the integrity of the plantar plate. In the case of a significant lesion of the plantar plate, palpation of the dorsal rim of the first phalanx is very painful ***(E117).***

The *long flexors of the toes* are tested easily as the patient is asked to flex his or her toes toward plantar. Attention should be given to the flexion of the distal interphalangeal joint. As a matter of synergy, this is generally easier when all flexors of the foot are innervated simultaneously. Dysfunctional intrinsic muscles, including the short flexor of the toes, may then appear due to a break in the flexion arc of the toes. Ankylosis of any origin can be detected with this exam. A lesion of the plantar plate due to chronic overload of the metatarsal head may cause progressive ***dorsal subluxation of the metatarsophalangeal joint***.

Dysfunction of the stabilizing intrinsic muscles may appear as insufficient local metatarsophalangeal flexion.

Sesamoids of the first ray

Painful plantar palpation of the sesamoids may be due to an articular pathology of the metatarsosesamoid joint. Multifragmentary sesamoids are reputed to be more frequent in those who play football (18). Trauma may cause acute fractures of the sesamoid bones ***(T760)***. The patient often refers late to his or her doctor at the painful, nonunion stage.

Toes

Calluses can cause a lot of pain in the toes. The interphalangeal joints are not essential but should allow the pulp of the distal phalanx to make slightly oblique contact with the ground. An ankylosed flexion of the proximal interphalangeal joint might be compensated for by hyperextension of the distal interphalangeal joint, but this can cause some discomfort in footwear. Flexion contracture of both interphalangeal joints may be the expression of a past compartment syndrome of the foot or a neurologic disease. *Intrinsic muscles of the foot* are very sensitive to plantar hematoma or any cause of augmented pressure within the plantar muscular compartments. These compartments are separated by very tight fascia and have very little room to expand. Very frequently following foot trauma, including a simple, slightly displaced calcaneus or a metatarsal fracture that was not treated by immediate open reduction and internal fixation, hammer toe is likely to occur. The metatarsophalangeal joint rests in an exaggerated dorsally extended position, together with a progressively ***ankylosing flexion of the first interphalangeal joint,***


123


124

while the distal interphalangeal joint may remain more or less normal.

In severe cases and/or compartment syndromes of the lower leg, however, the distal interphalangeal joint gets ***tethered in flexion***


125

by a strongly retracted flexor digitorum longus (claw toe).

Sensibility

The anatomic distribution of skin sensibility is divided across the dermatomes of the nervus fibularis superficialis, the fibularis profundus, the saphenous, the suralis, and both plantaris medialis and lateralis, together with the sensitive part of the nervus abductor digiti minimi. Symptoms due to nerve compression are rare and may be linked to tumors such as ***ganglia***


126

or anatomic malformations such as ***abnormal, additional muscles (left medial ankle)***.

127

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3 Active joint mobility and functional exam

Active joint mobility

Upper ankle joint

The patient, still sitting on the edge of the examination cube, faces the seated examiner. After the motors of the foot are checked, the effectiveness of the musculature on the joints, especially the essential joints, must be verified. The patient flexes the knee at about 60 degrees and rests his or her heel on the knee of the examiner, thus relaxing all the extrinsic muscles.

Observing the foot from lateral, the patient pulls the foot in extension, avoiding pronation of the lower ankle joint. The true extension angle of the upper ankle joint is ***measured in between the tibial axis and the posterior lateral edge of the foot***,

129

which corresponds to the level of the calcaneus.

Then flexing the foot, the same landmarks are considered to ***quantify flexion***.

130

Lower ankle joint

Quantifying active motion of the lower ankle joint is difficult. A good alternative for verifying relevant mobility of the lower ankle joint is to ask the patient to describe the largest circles he or she can draw in space with the big toe. To do this, the patient will mobilize both the upper and lower ankle joints at their maximum. A valuable alternative to this coordinating motion is to ask the ***patient to lie prone on the examination table***

131

132

with both feet extended over the edge of the table by levering out the extended lower legs. This allows for contemporaneous dynamic visualization of both feet in pronation and supination.

With the patient sitting once again, the active mobility of the metatarsophalangeal and both interphalangeal joints are verified in flexion and extension.

Functional exam

Walking barefoot should always be observed with knees and lower legs visible. All compensation mechanisms appear when both knee joints and feet are observed together. A strong genu varum may be compensated for by a strong hindfoot valgus and/or pronounced external rotation of the feet ***(E51)***. This rotational component may be located within the lower leg, and the amount of rotation may be quantified statically ***(E50)***. Four exercises of progressive difficulty verify global foot and ankle balance:

Walking tiptoe

Performing the exercise standing, the patient is asked to walk on tiptoe. The tuber calcanei will be pulled medially by the synergic activity of the triceps surae and the musculus tibialis posterior. A prerequisite to this function is stable coordination of the extrinsic musculature. The agonist–antagonist coordination between the musculus tibialis posterior and fibularis brevis as well as that between the fibularis longus and tibialis anterior are verified. Absence of the varus of the heel while rising on the tips of the toes may be linked to several pathologies, such as a coalition ***(R158)*** between two or more of the four bones of the hindfoot or insufficient function of the musculus tibialis posterior ***(E42)***.

Walking on the heels

Normal anatomic conditions should allow anyone to raise the forefoot and walk, bearing all weight on the tuber calcanei. Inability to do this can be related to insufficiency of the extensor musculature ***(E55)*** due to either local traumatic pathology or neurologic problems such as a lumbar radicular compression of the motor fibers of L5. The metatarsophalangeal joints may be excessively extended due to ***"recruitment" of the long extensors of the toes.***

133

This condition is common in some deformities such as cavus feet due to a proximal neurologic disorder. Generally, those feet progress to a generalized fixed hammer toe deformity.

Hopping on one leg

Hopping on one leg gives a good picture of the function of the gastrocnemius (jumper's muscle) because it works over two main joint groups, the knee joint and the upper and lower ankle joints. With this anatomy, extending the knee joint powered by the quadriceps puts tension on the gastrocnemius muscles, thus multiplying the action of the gastrocnemius alone in flexing the ankle joints.

Additionally, this exercise shows the ability to coordinate the extrinsic musculature and the potential to amortize the landing. Again, stiffness of the joints as well as a lack of coordination of the musculature of the hindfoot can be seen in the inability to use the elastic potential of normal foot anatomy. Lack of mobility at an essential joint such as a subtalar coalition is markedly demonstrated during this test.

Static tiptoe

The single-leg tiptoe stance test gives a good clinical image of the power of the soleus muscle (ballerina's muscle). Rising on the tips of the toes and balancing on one leg is the most difficult physical exam because it involves the proprioception and coordination of all 10 extrinsic muscles of the foot.

Radiologic Screening

K. Klaue, *The Foot*,
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3

1 Conventional radiographs

Whenever possible, all conventional radiographs should be performed with the patient standing, under weight-bearing conditions. This is one of a number of factors that allow for comparative studies, and, as it is the condition that most closely approaches the foot's normal function, it is the true counterpart of the clinical picture obtained during clinical examination.

Hindfoot

Anteroposterior view (frontal plane)

This view is critical to assess the ***axis of the hindfoot within the frontal plane***.

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If the forefoot is normal, the projection of the second metatarsus should be vertical. Some essential aims are visualization of the following:
1) The angulation of the talus beneath the tibia
2) The shape of the distal fibula
3) The plantar aspect of the tuber calcanei in relation to the upper ankle joint

More specifically:
1) The angle of the talus dome to the vertical in a standing patient (talar tilt) should be very close to 90 degrees. This angle bears testimony to stability, although the axis of the tibia is not relevant itself due to evident mechanical reasons.
2) The shape of the fibula is critical in reduced malleolar fractures. Anatomic congruence of the tibiotalar joint through the distal fibula is essential for functional stability.
3) The plantar edge of the tuber calcanei shows the exact weight-bearing spot of the heel. In a stable hindfoot, the center of the tuber must be located lateral to the center of the talar dome ***(A8)***.

Hindfoot varus

The image of the tuber calcanei is situated medial to or on the vertical line passing through the middle of the talar dome.

The varus component is ***located at the subtalar joint level***.

135

The angulation may be ***located within the upper ankle joint***,


136

thus demonstrating a talar tilt.

Hindfoot valgus

It is essential to determine the fulcrum of the angulation. It is either ***in the upper ankle joint***


137

or ***in the lower ankle joint*** (subtalar).


138

Lateral view (sagittal plane)

In this view, the radiologic beam is centered on the upper ankle joint. The upper ankle joint must therefore be fully visible. This view should ***always be taken from medial to lateral,***

139

with the aim of achieving a true lateral image of the upper ankle joint. The mutual alignment of the talus, the calcaneus, the navicular, and the cuboid is seen.

The calcaneal pitch is the angle between the lower tangential straight line to the calcaneus and the weight-bearing plane. The distal convergence of both talus and calcaneus axes is noted.

3

Arthrosis of the upper ankle joint

Due to the conical shape of the talar dome within the horizontal plane, the ***talus tends to shift anteriorly***

140

if improperly retained by the ligaments, thus creating a progressive incongruence with the tibial joint surface.

Foot

Anteroposterior (dorsoplantar) view (horizontal plane)

This view must always be taken for each foot individually to obtain a true vertical "shadow" of the foot. The beam is centered on the second cuneiform with an inclination of 15 degrees from distal to proximal in order to be vertical to the dorsum of the foot. In this way the joints can be observed, and the talus and calcaneus axes can be seen. In the normal foot, the straight alignment of the talus on the first metatarsus is essential.

The four bones – ***talus, navicular, medial cuneiform, first metatarsus – are aligned on one axis.***

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The lateral wall of the calcaneus is more or less aligned on the fifth metatarsus. Eventual misalignment must be localized specifically for optimal surgical correction. The morphotype of the foot is determined. "Index metatarsus" refers to the relative length of the first and second metatarsi. The alignment of the metatarsal heads should run on a parabolic line (19).

Pes abductus

The axis of the talus does not fit with the axis of the first metatarsus.

If the abductus is ***located at the talonavicular joint***,

142

the coverage of the talar head by the navicular bone is reduced.

The abductus may be ***centered on the tarso-metatarsal joints***,

143

and the navicular bone and the first cuneiform are well aligned on the axis of the talus.

3

Unstable first ray

An unstable first ray demonstrates a sagittal hypermobility that reduces the anteromedial weight-bearing ability. Consequently, ***the second metatarsus***, which is strongly fixed at its base, takes the functional load and ***undergoes hyperplasia.***

144

In general, these feet present a hypermobile first ray within the sagittal and the horizontal planes, and the space between the first cuneiform and the second metatarsus is increased.

The second metatarsophalangeal joint is subluxed due to the insufficient first ray and the consecutive local overload on the second metatarsus.

The relevant congenital pathomorphologic parameters of the unstable first ray are probably the ***oblique orientation of the cuneometatarsal joint*** within the horizontal plane and the presence of a ***small articular facet between the basis of the first and the second metatarsus***.

Splay foot

The ***divergence between the axis of the first and the fifth metatarsi is increased***.

145

146

The hold of the first metatarsus to the lesser metatarsi is insufficient due to the missing ligamentous structures. The head of the first metatarsus thus slips off the sesamoid bones, which are firmly tightened to the second metatarsus.

Index metatarsus minus

The normal alignment of all metatarsal heads follows a parabola. Here, the ***first metatarsus is proximal to the parabola***

147

because it is shorter. This foot may thus present an overloaded second (and third) metatarsus, which is larger (4).

Index metatarsus plus

The ***first metatarsus is longer than the second***.

148

Here, the big toe is also longer than the second toe. This constellation jeopardizes the first metatarsophalangeal joint, which may be overloaded and undergo premature degeneration ***(O367)***.

Lateral view (sagittal plane)

This view should always be taken from medial to lateral, and the plane should include the lateral edge of the hindfoot (calcaneus). The straight alignment of the talus to the first metatarsus is essential. Here too, the four elements ***talus, navicular, medial cuneiform, and first metatarsus are aligned*** on one axis.

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3

Within the sagittal plane, a flat foot may demonstrate a ***sag at the talonavicular joint.***

150

The talus protrudes into the acetabulum pedis. A curved dorsolateral osteophyte of the talar head shows the pathological motion within the cup. The whole hindfoot undergoes an equinus position because the midfoot is collapsed. The foot lever is not effective.

The misalignment of the flat foot may be localized anywhere on the first ray. The sag must be localized specifically for optimal surgical correction. On this image, ***plantar gapping of the naviculocuneiform and cuneometatarsal joints***

151

should be noted.

The longitudinal arch might have increased, which is the case in many muscular imbalances and is thus linked to neuromuscular abnormalities. The localization of the apex of the arch gives an idea of the cause. The ***posterior pes cavus***

152

is present in weak calf muscles such as in poliomyelitis. Note that the talus is aligned with the first metatarsus.

The ***anterior pes cavus***

153

may be associated with an imbalance between the tibialis posterior and fibularis musculature.

Here, the talus is not aligned with the first metatarsus.

Special incidences

Oblique

This view is not done under weight-bearing conditions. The foot is inclined toward the medial, and the ***beam is orthogonal to the lateral metatarsus***.

154

The calcaneonavicular space (coalitions) and the lateral tarsometatarsal joints are more easily seen.

Brodén's view

This view is not done under weight-bearing conditions. The foot is held in an orthogonal position, and the beam is inclined proximally by about 20–40 degrees. The whole leg is internally rotated about 45 degrees, and the beam is ***centered on the sinus tarsi***,

155

with the aim of visualizing the posterior subtalar joint facet. This image is relevant in checking joint morphology after trauma and is the most appropriate radiograph for diagnosing an articular fracture.

Forefoot axial (Güntz–Müller)

The patient stands on a double-wedged, radiolucent, solid structure with the aim of ***raising the toes and the heel from the horizontal surface.***

156

The radiologic beam is conducted horizontally from the back toward the toes, and the film is placed vertically in the frontal plane in front of the foot. The objective is to demonstrate the ***vertical alignment of the metatarsal heads***

157

and, in particular, the sesamoid bones of the first ray.

Stress views of tarsometatarsal joints

In rare cases in which the posttraumatic stability of the tarsometatarsal joints is questioned, the forefoot can be stressed in adduction or abduction under a dorsoplantar radiologic incidence. This test can be performed under fluoroscopy to adjust the view axis.

2 Computed tomography

Because computed tomography (CT) is not usually performed under weight-bearing conditions, the foot is placed and held in an orthogonal position within both sagittal and frontal planes. This simulates the weight-bearing position of the osteoarticular structures. The bony structures are better seen, including bone necrosis.

The three-dimensional reconstruction shows the spatial aspect of deformities such as ***subtalar coalition***

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or impingements.

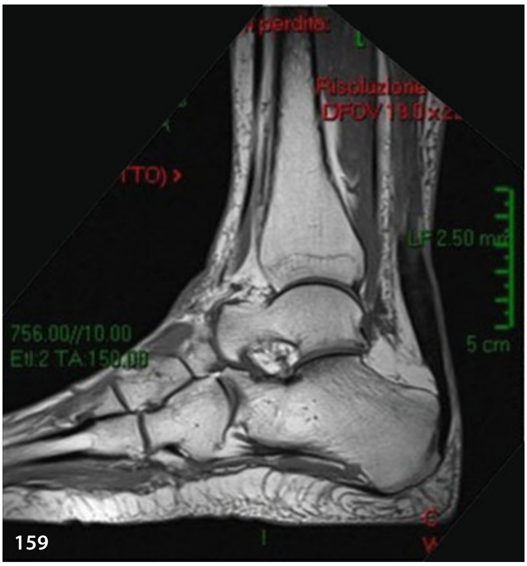
CT arthography

Intraarticular disorders may be best visualized by intraarticular contrast with CT. Intraarticular bodies and osteochondritis tali are good indications for this technique.

3 Magnetic resonance imaging

Magnetic resonance imaging (MRI) should be done in the same position as for CT. This exam qualitatively shows soft tissue lesions and abnormalities within the joint (cartilage) or outside it (tendons, tumors, nerves, joint capsules), but it lacks precision in demonstrating bone necrosis.

Chronic Achilles degeneration can be visualized in detail ***(E16)***,



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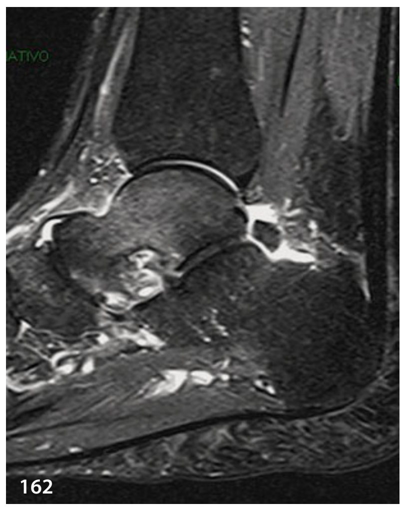
as can ***chronic fibularis tendon lesions (T809)*** and

160

posterior tibial tendon degeneration and scarring ***(T811)***.

161

Fractured posterolateral process of the talus



162

may be evaluated in the context of tibiotalar and talocalcaneal impingement ***(T582)***. Soft tissue abnormalities such as an occasional ***musculus soleus accessorius***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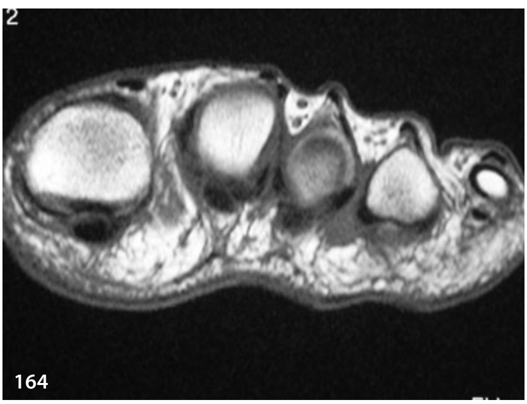
located anterior to the normal soleus and inserting into the medial aspect of the tuber calcanei ***(E128)***, and ***pseudoneuroma***


164

between the third and fourth metatarsal heads are best seen with this technique ***(T854)***.

Surgical Orthopedic Treatment

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The foot is a modernized hand, and while it has the same structure as the hand, it has lost its prehensile function and has acquired both weight-bearing and locomotor functions.

The structural orientation of the foot is essential for stable and pain-free weight bearing. Functional pain at the medial structures of the upper and lower ankles might be due to an exaggerated valgus or "ad latus" of the foot. The converse is true for the varus foot. It must be noted that every operative reorientation of the foot and ankle is amplified distal to the surgical site and may, without other means, create secondary imbalance.

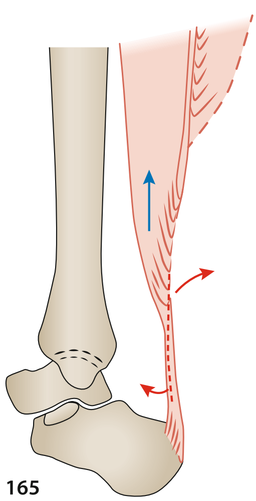
The muscular balance of the foot is essential for secure acceleration and deceleration, and in many cases the muscular imbalance causes the structural disorder.

Surgical treatment of foot and ankle disorders most often incorporates a whole "menu" of different measures combining structural and motor means that converge to a comprehensive aim. Those aims and the treatment rationale are described below.

1 Functional correction of the hindfoot in the sagittal plane

Muscle balance

Hindfoot equinus is a major sign of many foot diseases ***(E73)***. It concentrates on the adaptive shortening of the calf musculature. True equinus, including shortening of the musculus suralis is best treated by ***elongation tenotomy of the heel cord*** because all three muscles are involved ***(T788)***.



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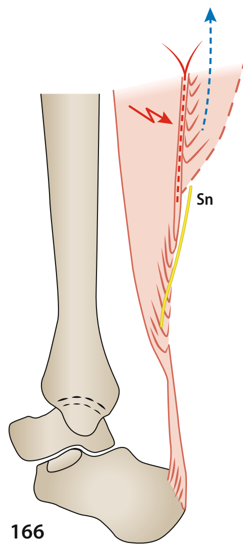
Functional equinus that appears clearly only with the knee joint extended ***(E74)*** is best treated by selective elongation of both gastrocnemii muscles because those muscles insert on the femur. The suralis muscle, which inserts on the lower leg, then preserves its integrity and function. Mild adaptation of this problem is best resolved in young, elastic musculature by anterior ***fasciotomy of the ventral muscle fascia of both gastrocnemii (T791)***.



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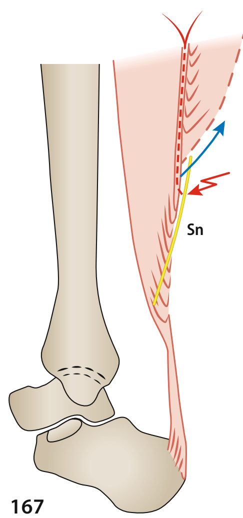
In older, stiff, and/or severe cases, ***tenotomy of both distal gastrocnemii (T793)***



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is more suitable to resolve the functional hyperflexion of the foot.

4

Paralytic pes equinus of the hindfoot must logically be treated by muscular substitution to reanimate extension of the foot. Following the clinical and eventual electroneurologic status, different tendons are better suited for being transferred to act as extensors. The most suitable muscle to be transferred is the ***musculus tibialis posterior onto the dorsum of the foot (T819).***


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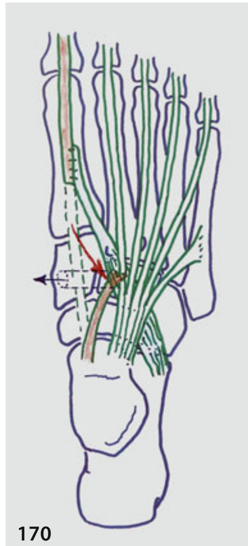
Attention must then be paid to the loss of hold of the longitudinal arch of the foot. It is generally wise to replace the removed posterior tibialis muscle with the flexor digitorum longus to avoid the risk of secondary collapse of the foot in pronation ***(T816)***.

If the posterior tibialis muscle is insufficient or inadequate for other reasons, ***the extensor digitorum longus and hallucis longus are transferred*** onto the dorsum of the foot ***(T821)***.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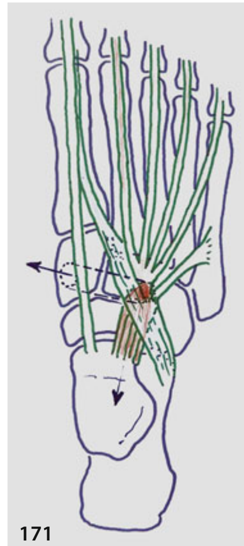
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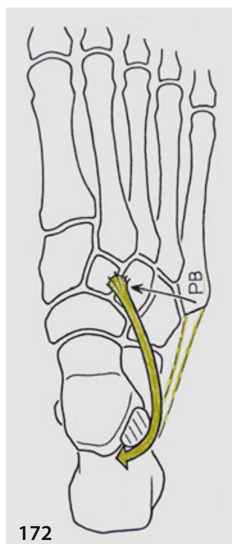
If functional, ***the musculus fibularis brevis is also transferred***.



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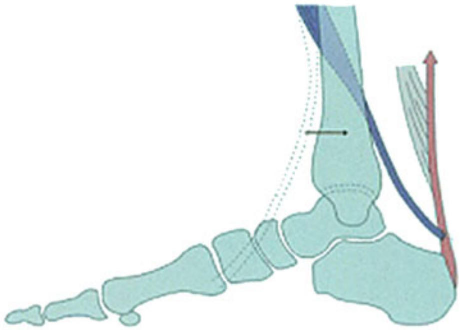
Hindfoot talus is linked to neurologic diseases, which include pathological weakness of the flexors. After evaluation of the relevant power of the foot extensors, those are ***transferred to the heel through the interosseus membrane.***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Such a transfer is usually enough to position a foot plantigrade but is insufficient to substitute for the great power of the normal triceps surae.

Repetitive hammering of the posterosuperior apophysis of the calcaneus on the distal Achilles tendon triggers a chronic pre-Achillean bursitis (20). A tendinitis component may also occur. The aim of treatment is to ***remove the causal osteophyte (T614)***


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to avoid recurrence of the bursitis.

Upper ankle repair

Provided that the static bony alignment of the hindfoot, including the physiologic valgus, is stable, the collateral damage to the cartilage, bone, and ligaments must be addressed.

Cartilage repair

Long-lasting instability may cause ***osteochondral _ lesions***


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that behave like ***articular sequesters***.


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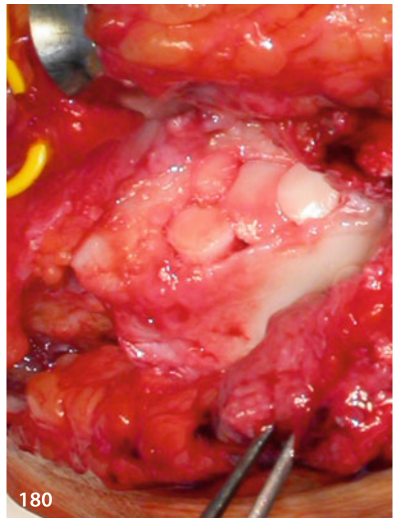
Surgical correction includes alignment, stabilization, and articular repair. *Cartilage repair* includes removal of the necrotic osteochondral tissue and substitution by means of ***autologous osteochondral transplants*** (21) ***(T573)***.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The instability referred to above must be corrected by eventual static (reorientation osteotomy ***(T553, T612)*** and/or ligamentous (***ligament reconstruction***) ***(T773)*** means.


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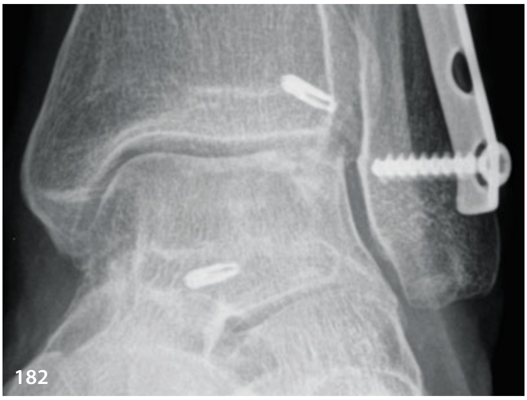
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Anterior cheilectomy of the upper ankle joint

Osteophytes of the anterior upper ankle joint

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represent an impingement that accelerates joint degeneration by impeding function and should be removed. Their origin is mostly due to abnormal motion between the tibia and talus, caused by insufficient ligamentous structures. The containment of the joint must be respected for anteroposterior stability, and thus ***osteophytes located on the talus are addressed first (T575).***


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Posterior cheilectomy of the upper ankle joint

Posterior impingement of the upper ankle joint involves the tibia, the talus, and the calcaneus. The flexion of the hindfoot is impeded by pain and morphologic anomalies, while the impingement is often triggered by trauma in plantar flexion. The posterior debridement concerns ***the posterior process of the talus***,


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which might be fragmented ***(R162)***, or the flexor hallucis longus tendon and its passage between both posterior talar tubercles ***(T581)***. Anatomic abnormalities such as additional muscles ***(E127)*** may also be involved, although this is rare. This surgical approach is exclusively ablative ***to remove the impinging structures***.

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2 Alignment of the hindfoot in the frontal plane

Frontal alignment of the hindfoot and the upper ankle joint is an essential element of varus/valgus stability ***(E15, R134)***. In the upper ankle joint, the talar tilt (frontal plane) is critical because it is a conical hinge joint. Vertical forces should act on mainly horizontal bearing surfaces to avoid shifting along the hinge axis. The mechanical guide is the medial malleolus on one side and the more or less recoiling lateral malleolus, which closes the "mortise," on the other side. It becomes clear that any relevant tilt of the talus within the mortise ***(R136)*** is mechanically unfavorable because of medial or lateral overload. The tibial plafond is less resistant than the talar dome. As a result, in misaligned hindfeet the tibial plafond gives way to overload, and the talus remains grossly intact. In stable upper ankle joints, the talar dome (not the tibial plafond) has a horizontal alignment (±2 degrees) within the frontal plane ***(R134)***. Excepting the rare posttraumatic malunions of intraarticular fractures of the distal tibia or fibula (malleolar fractures), reorienting the upper ankle joint naturally addresses both tibia and fibula.

If the axis of the lower leg presents a relevant angulation within the frontal plane (genu or crus varum) ***(E14)***, the knee joint must be considered and examined closely. A logical reconstruction of the lower limb must be comprehensive. A varus instability of the hindfoot that includes a genu varum with a medial overload of the knee joint would indicate the need for a ***valgus correction at the proximal end of the lower leg***,

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whereas in cases in which the lower leg is vertical, the valgus correction is best performed ***a few centimeters above the ankle joint (T557)***.

The converse is true for, for example, valgus malunion of the upper ankle joint in which the correction is logically performed ***at the level of the deformity*** and naturally addresses both tibia and fibula, such as in ***malunited malleolar fractures (T553)***.


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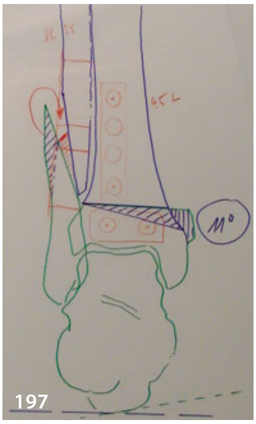
Attention is given to the vitality and perfusion of the soft tissues: A ***closing osteotomy without lengthening of the convex side*** of the correction is always safer.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Isolated malunions after fractures of the distal fibula must be identified radiologically ***(T559)***,


199


200

and a ***correction osteotomy at the fracture site (T561)***


201


202

allows for stabilization through corrected joint congruency and functional restoration.

3 Alignment of the heel in the frontal plane

Referring to the conventional anteroposterior radiograph of the hindfoot under weight-bearing conditions ***(R134)*** and provided that the talar dome is horizontal, the tuber calcanei is, for natural stability, better situated lateral to the center of the talus by about 2 cm.

Hindfoot varus is most often the cause of chronic varus instability ***(R135)***, including recurring sprains and torn ligaments that lead to joint degeneration. Cartilage wear, osteochondritis dissecans, and loose cartilage fragments are the result. The axis of the heel within the frontal plane is modified if the ***tuber calcanei is translated within the frontal plane***


203


204

and/or the tuber calcanei is rotated around a horizontal anteroposterior axis. These modifications can be performed through an osteotomy that divides the bone behind the posterior facet of the subtalar joint ***(T611)***. A lateral shift of the tuber calcanei lateralizes the heel cord at heel strike during gait and thus ***stabilizes the lower ankle joint in valgus***.


205


206

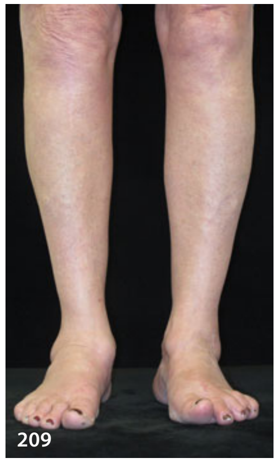
If the effect of lateralizing the tuber calcanei is insufficient, ***dorsally extending the first ray (T685)***


207

enhances the global correction by ***pronation of the foot***.

208

There are conditions that involve deformity in two places, ***both above and below the ankle joints***.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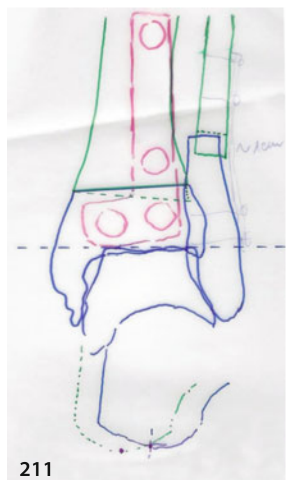
The statics are then considered using a radiograph taken under weight-bearing conditions. The supramalleolar correction, i.e., ***bringing the talus perfectly horizontal***, is planned first ***(T557)***, while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the position of the heel is considered afterward. If the heel is still malaligned, surgical correction is then also ***performed on the heel level (T612).***

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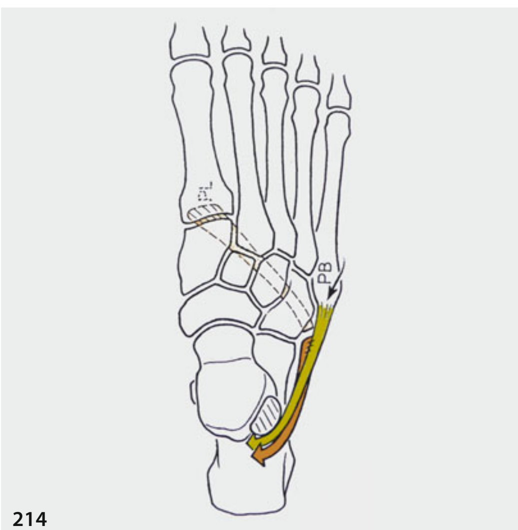
The motor counterpart of such correction is done by ***transferring the fibularis longus tendon*** to the insertion of the fibularis brevis ***(T827)***.



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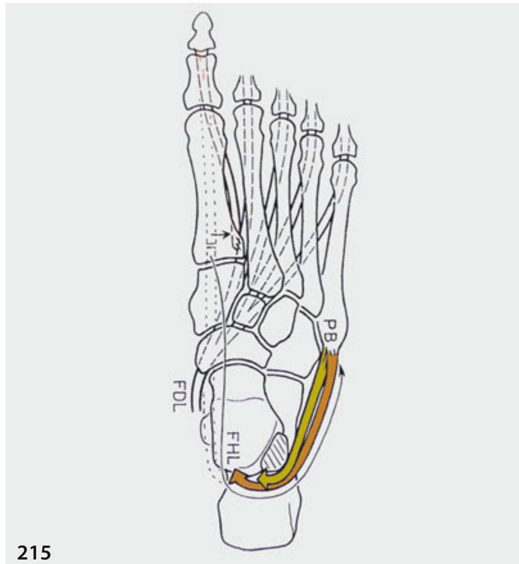
The plantar flexion of the first ray is weakened, and the pronation torque around the lower ankle joint is increased because the fibularis longus inserts on the plantar aspect of the first metatarsus and cuneiform. If a shift of the pronators is not yet sufficient, ***transferring the flexor hallucis longus to the basis of the fifth metatarsus (T833)*** logically increases this action.



215

If the patient demonstrates a *tight heel cord*, which is frequently the case ***(E73)***, releasing the tightness corrects the muscular imbalance. Clinical examination informs the physician about the adequate level of the lengthening procedure ***(O165, O166, O167)***.

Hindfoot valgus may cause progressive overload of the lateral aspect of the upper and lower ankle joints. Correlated lesions include local ***osteonecrosis*** or osteochondritis of the talus.

216

It results in an imbalance of the load and ***overloading of the lateral aspect of the upper ankle joint***.

217

The prerequisite for success is a perfectly vertical lower leg without relevant talar tilt. ***Moving the heel toward medial (T613)***

218

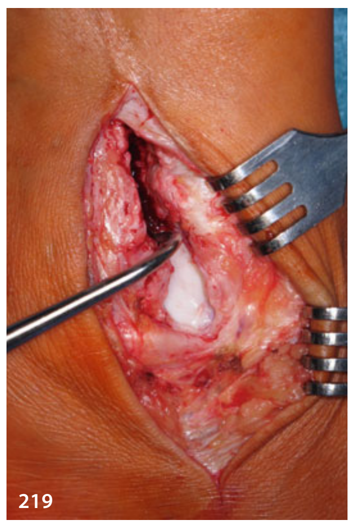
within the frontal plane logically corrects the load within the upper ankle joint.

4 Static articular stabilization of the hindfoot

The *ligamentous repair* is mostly centered on the lateral aspect and must be based on the anatomic position and shape of the ligament to be repaired or replaced.

Syndesmosis reconstruction of the upper ankle joint

Forced external rotation of the foot beneath the lower leg stresses the anterolateral ligamentous structures between the tibia and the fibula. The deltoid ligament is a very strong structure that tightens the medial aspect of the talus and the calcaneus beneath the medial malleolus. The lateral structures are generally less solid and yield at different levels: the fibula with the anterior syndesmosis and the interosseous membrane (malleolar fracture classified "Weber C") or without the syndesmosis (malleolar fracture classified "Weber B"). The ***insufficient (or absent) anterior tibiofibular syndesmosis (E79)*** after, e.g., fibular fracture



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jeopardizes the upper ankle joint by ***instability*** and secondary arthrosis.

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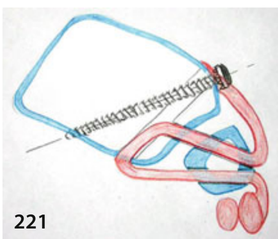
The best stabilization of the syndesmosis is ***surgical reconstruction of all three of its ligamentous parts*** with the anatomic congruency of the fibulotalar joint (22) ***(T770)***.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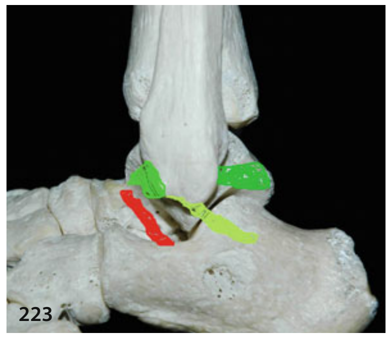
Ligament reconstruction of the ankle joints

In anterolateral instability of the upper ankle ***(E83)***, the talus shifts anteriorly and turns around the medial malleolus within the horizontal plane. Securing back the talus within the mortise is best performed naturally by a competent, anatomically placed, anterior fibulotalar ligament. In the presence of a substantial ligamentous structure, its refixation on the anterior fibula is sufficient (23) ***(T773)***. If this substantial structure is missing, the ligament is replaced by autologous tissue, if possible local and pedicled, to achieve the most "biological" repair. It appears clear that the ***anatomic trajectory of the ligaments***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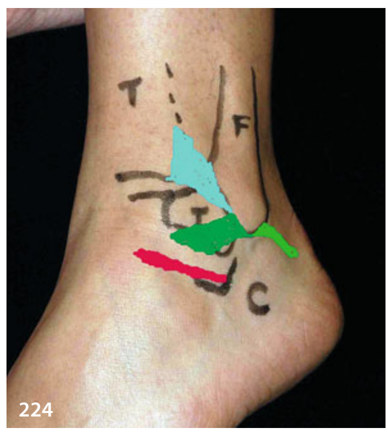

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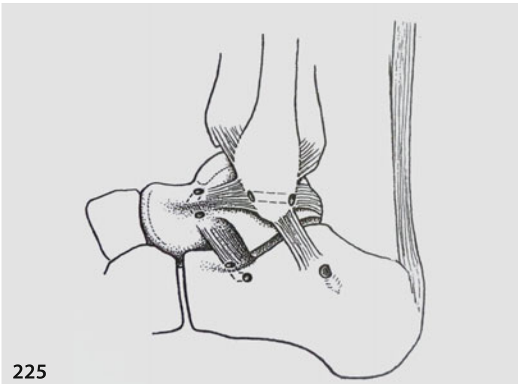
must be respected to achieve physiologic conditions. Under this aspect, then, three ligaments may be addressed for eventual substitution: the ***anterior fibulotalar (T779)***, the ***fibulocalcaneal (T777)***, and the ***cervical (T785)*** (anterolateral talocalcaneal) ligaments.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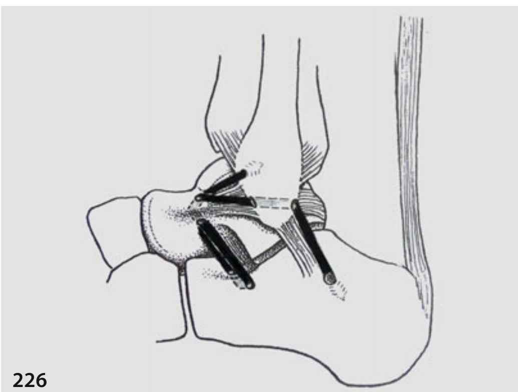
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The posterior ***fibulotalar*** ligament is thus intact and ruptures only in complete dislocation of the upper ankle joint.

A relevant lesion on the medial side is more serious and more arthrogenic due to the secondary laxity: The talus then does not turn around the medial malleolus within the horizontal plane but is free to slide in any direction.

A complete rupture of the deltoid ligament is rare without complete dislocation of the joint. Optimal treatment is performed immediately after the trauma ***(F431)***.

5 Arthrodeses of the hindfoot

Alignment of the hindfoot is obtained through arthrodeses if realigning osteotomies are excluded. Arthrodeses must allow for realignment in all three planes considering angular and translational means.

Upper ankle fusion

If the upper ankle undergoes painful articular destruction limiting its mobility, fusion in the anatomic axis is the logical treatment. The cause of joint deterioration is often linked to ***malorientation***


227

and/or instability, which ***destroys the cartilage layers***.


228

Subtalar mobility should be painless, but an additional subtalar arthrolysis with eventual osteophytectomy can help limit the damage to the lower ankle joint and improve function. Fusion should be done with a very precise anatomic angulation between

4

tibia and talus ***(T565)***, including a slight external rotation because after the fusion the foot is designated to scroll about the coxa pedis. Positioning the talus within the sagittal plane is also critical because, most often, destruction of the upper ankle joint goes along with ***anterior translation of the talus***

229

due to its conical shape within the horizontal plane.

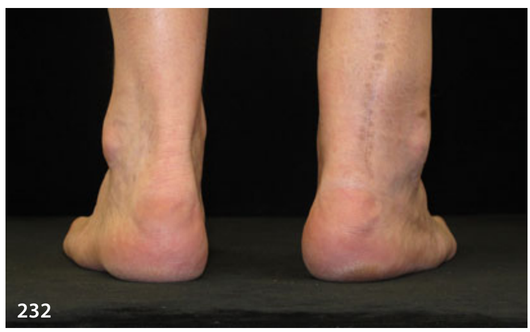
Shifting the whole foot posteriorly (T566)

230

within the ankle mortise centralizes the lower ankle joint beneath the tibia and reduces the foot lever, easing the gait. Attention should be addressed to the length of the fibula. Fusion between tibia and talus includes osteochondral tissue removal, which shortens the limb by a relevant length. The ***fibula should be shortened***


231

by at least the same amount to ***avoid secondary fibulocalcaneal impingement***.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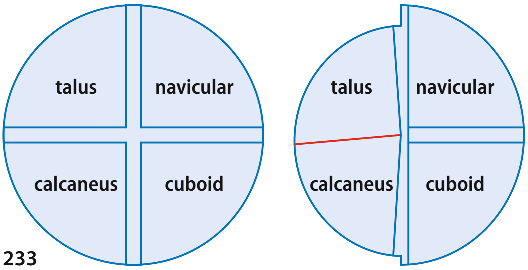
Subtalar fusion

If the subtalar joint undergoes painful articular destruction limiting its mobility, fusion in the anatomic axis is the logical treatment. All four bones of the hindfoot – talus, navicular, calcaneus, and cuboid – are "cross-linked," forming in part the lower ankle joint. If only one of the joints is fused, the ***orientation of the whole hindfoot will be modified*** but not necessarily in the desired fashion.



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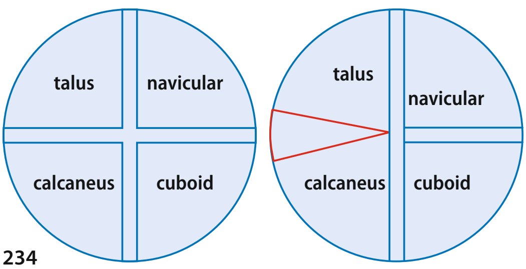
In such cases an interposition spacer (e.g., autologous bone block) must be included to ***restore orientation of the hindfoot*** (***T591***).



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Fusing the subtalar joint alone significantly reduces and modifies motion at the talonavicular joint.

The clearest example of this kind of reconstruction is subtalar fusion after calcaneal malunion.

If the sagittal angle between the axis of the talus and axis of the calcaneus is significantly reduced, or, in particular, ***the calcaneus is flattened after trauma***,


235

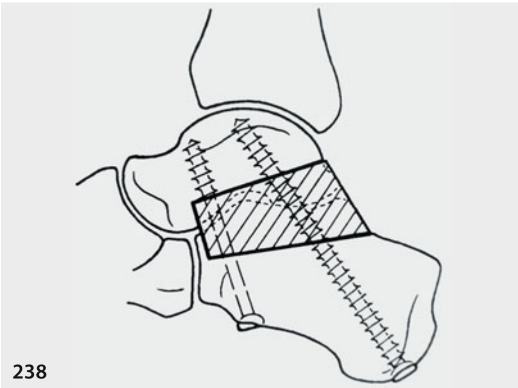
the whole ***ankle joint is maloriented***.


236

The clinical problem is that of pain due to residual mobility within a destroyed joint: to a lateral fibulocalcaneal and to an anterior tibiotalar impingement. ***Push-off is weakened***


237

due to the reduced height of the ankle and the resulting relative lengthening of the heel cord. Reconstruction must involve a ***solid biological (autologous bone) spacer***



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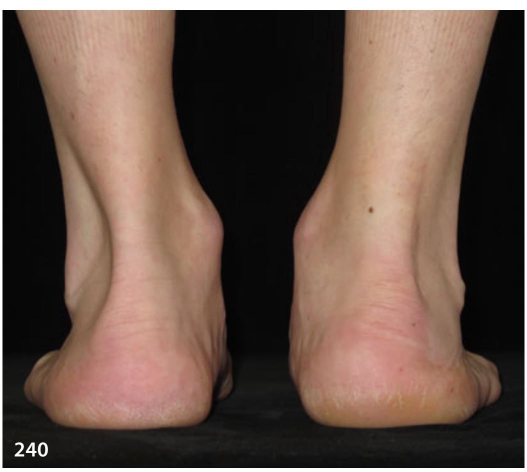
joining both talus and calcaneus to allow for a functional and impingement-free upper ankle joint. The ***height of the ankle joint is corrected,***



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and the ***push-off is restored.***

241

In congenital and degenerative disorders, the correct length of the calf muscles and tendons must be checked precisely and adapted to the structural correction to avoid true equinus of the foot. While in most "flat feet" the heel is in equinus and must be reset by, for example, a gastrocnemius recession, in posttraumatic situations the length of the heel cord is normal and should not be changed when correcting the equinus calcaneus.

Tibiotalocalcaneal fusion

If the painful articular destruction involves both the upper ankle and the subtalar joints (posttraumatic, diabetic arthropathy, chronic deformity with joint degeneration), the hindfoot must be placed in a very precise position beneath the tibia, allowing for uneventful function of the midtarsal and forefoot joints. This includes a perfect plantar foot in relation to the axis of the lower leg and a slight external rotation allowing for rolling over the medial edge of the foot. Stable fixation is demanding because there is no constant, clear tension band side of the hindfoot. The normal alignment of the hindfoot from the distal tibia to the heel is angulated in valgus, varying between 5 degrees and 11 degrees (24). In fact, considering the three-dimensional environment, the ***anatomic transarticular bony alignment of the***

weight-bearing heel to the distal tibia follows a circular arc.


242

This circular arc lies within a vertical plane that cuts the tuber calcanei, the posterior facet of the subtalar joint, and the upper ankle joint in about the center of their articular surface. The posterior facet of the subtalar joint is located slightly posterolateral to the center of the tibiotalar joint. Consequently, the ***vertical plane is angulated inward*** to about 15–20 degrees in relation to the sagittal plane.


243

The most logical fixation device supporting the lower leg on the top of the foot thus follows this arc from the tuber calcanei to the metaphysis of the tibia and consists of a nail ***(T606)***. This nail must be understood as a ***"bone" nail***


244

in contrast to commonly used "medullary" nails. Thanks to the solid bony internal structure of the calcaneus, the talus, and the distal tibia, the nail allows ***bone contact on its whole length***


245

provided that a cavity with the same shape as the nail is drilled along its whole length ***(T602)***. Functional after-treatment allows for more rapid consolidation and rehabilitation.

Talonavicular fusion

Fusing the talonavicular joint alone, both subtalar and calcaneocuboid joint motions are reduced to an irrelevant magnitude; therefore, such a procedure is seldom indicated.

6 Horizontal and sagittal correction of the heel and midfoot

Correction of eversion

Central calcaneus osteotomy

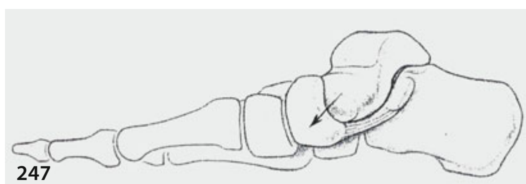
Medial support of the hindfoot is provided by the sustentaculum tali ***(E90)*** and the long medial muscle tendons. If the sustentaculum tali does not hold the talus in the correct position, the resulting deformity must be assessed within the sagittal ***(R150)*** and the horizontal ***(R142)*** planes, both planes that indicate eversion. Within the sagittal plane one observes a flexed talus, while within the horizontal plane there is adduction of the talus corresponding to an increased divergence between the axes of the talus and the calcaneus. As a result, it should be possible to influence and correct the morphology of a symptomatic and mobile flat foot by reorienting the socket of the joint by means of a reorientation of the acetabulum pedis ***(T631)***. A very similar problem has been studied in treating hip dysplasia (coxa pelvis; 25) which, in common with the problem connected with coxa pedis, has seen a preference for an extraarticular procedure, thus respecting the essential mobility of the joint (26). Central calcaneal osteotomy (27) responds to this trend and repositions the talus on the calcaneus within the horizontal and sagittal plane and thus corrects eversion. It secures medial stability without reducing the arc of motion of the coxa pedis ***(E85)***. Additional means include shortening of the posterior tibial tendon and transferring the long flexor of the toes to the plantar cuneiform ***(T813)***. All these measures are effective to restore the longitudinal arch of the foot.

246

Congenital flat feet may be symptomatic medially at the insufficient posterior tibial muscle and tendon and laterally at the crucial angle of Gissane, thus causing an impingement ***(E88)***.

A lack of function of the posterior tibial muscle may also be due to an abnormal insertion pattern about the medial aspect of the foot. Presence of an accessory navicular bone ***(E103, O295)*** and its attachment to the posterior tibial tendon impedes the correct inversion power of the corresponding muscle.

Feet such as these lack articular stability at the midfoot, and the retracted calf muscles cause an ***equinus of the hindfoot.***



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Congenital or acquired flat feet include an insufficient hold of the anterior talus on top of the calcaneus. More specifically, the ***sustentaculum tali is inefficient***.

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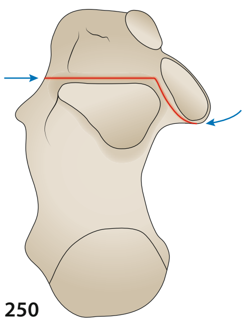
249

The aim is to restore the anatomic alignment of the hindfoot together with normal motion of the coxa pedis. The hold of the talus in its place above the calcaneus is performed by pushing the anterior part of the calcaneus beneath the talus ***(O256, T631)***. The calcaneus is thus divided ***between the posterior facet and the sustentaculum tali (T627),***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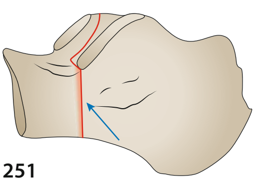
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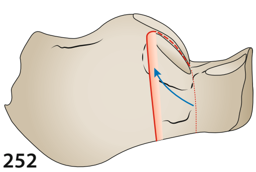
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and a bone block is interposed ***(T629)***. The ***calcaneus increases in length***.


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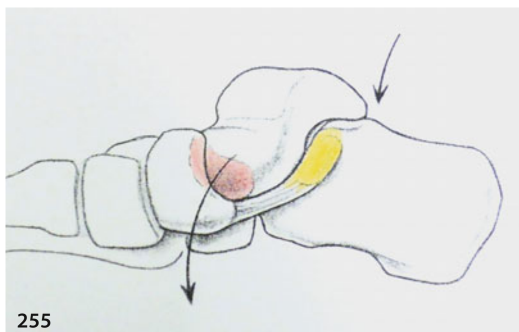
The talus is lifted and turned toward the lateral direction: It moves following a complex helicoidal motion ***(E87)***. ***The talus is raised in supination***.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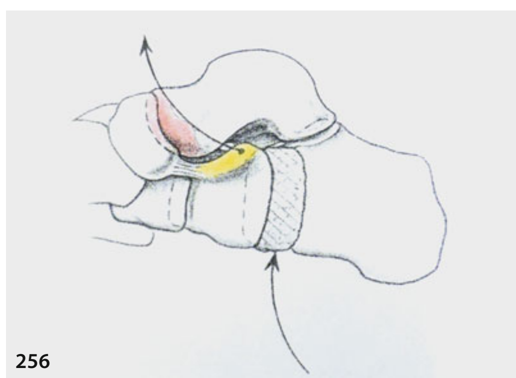
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The acetabulum pedis closes, and the normal valgus of the heel can be restored.

The ***sustentaculum tali is pushed forward*** beneath the anterior aspect of the talus,

257

thus restoring the ***straight alignment of the talus to the first metatarsus*** within the horizontal and sagittal planes ***(R141, R149)***.

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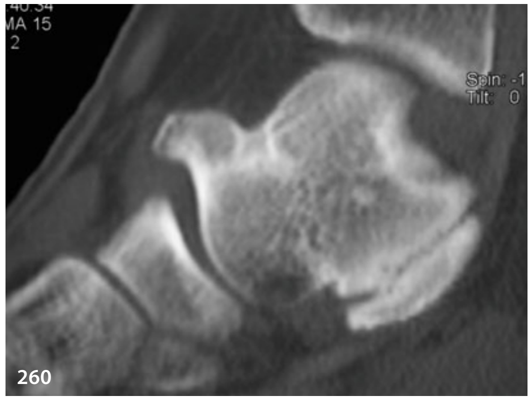
Another cause of misalignment is the **subtalar coalition** ***(R158)*** that may block normal motion of the coxa pedis, resulting in a ***"dorsal beak" onto the talar head.***



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Radiographs under weight-bearing conditions demonstrate the ***sag of the medial column*** at the talonavicular joint ***(R150)***.

261

Prior to elongation osteotomy, the calcaneus must be liberated from the talus to allow for ***reorientation within both transverse and sagittal planes***.

262

The raising of the talus supinates the midfoot and ***realigns the talus to the first metatarsus*** within the horizontal plane.


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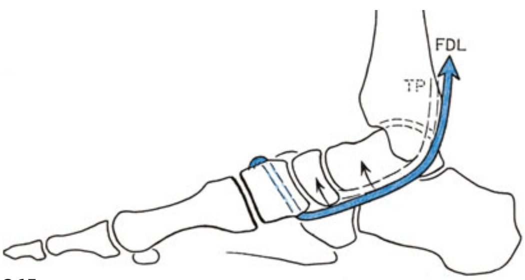
The resulting realignment must be held by a strengthened supinator muscle. Powering the supinators means assisting the medial suspension provided by the posterior tibial muscle and tendon. The flexor digitorum longus tendon follows the path of the posterior tibial tendon and receives about the midfoot a relevant tendon sheath from the flexor hallucis longus tendon. Sectioning the tendon of the flexor digitorum longus proximal to this sheath and transferring it to the plantar aspect of, e.g., the first cuneiform ***(T816) empowers supination***



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and does not result in sacrificing any relevant function to the toes.

Following these procedures, the forefoot is aligned to the hindfoot, and the equinus usually becomes very evident. Testing the effective shortening of the calf muscles ***(E73)***, the corresponding ***lengthening of the tendons*** is then achieved (***T788, T791, T793)***.


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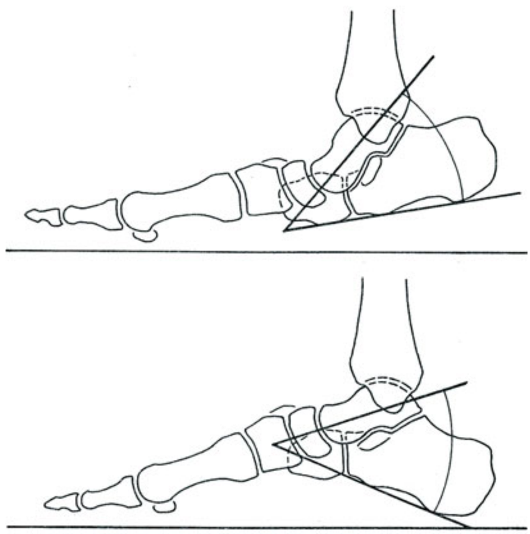
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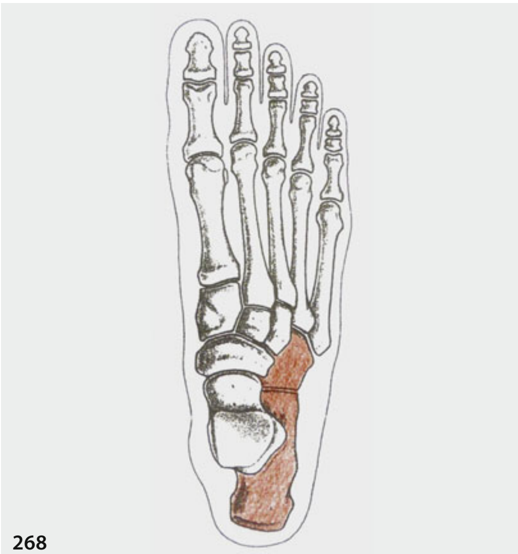
Calcaneocuboid distraction fusion

The "calcaneopedal unit" (28) is a concept elaborated on the basis of the coxa pedis. The entire acetabulum pedis construct includes the calcaneus, the cuboid, and the navicular bones ***(E90)***. ***Fusing the calcaneus to the cuboid*** thus affects only some of the talocalcaneonavicular joint mobility –



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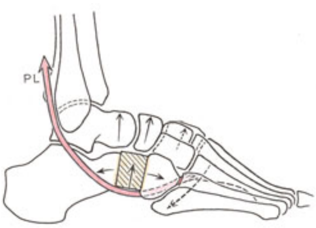
so little, in fact, that its clinical relevance is close to zero. However, the alignment between the calcaneus and the cuboid is essential for the whole hindfoot and forefoot alignment. In particular, moving alignment upward increases pronation of the forefoot, while using it with an interposed bone block corrects eversion and puts the ***peroneus longus tendon under tension***. This effect pulls down the first metatarsus, thus increasing the "cavus effect" on the medial arch.



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Differentiating the localization of the cuboid on the anterior process of the calcaneus allows for rotation of the forefoot within a frontal plane. The center of such rotation is the talonavicular joint (10). Due to its simple lateral approach, this correction is justified in specific calcaneocuboid misalignment, in local arthropathy (arthrosis), and in ***global correction of symptomatic eversion*** (pronation).

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Correction of inversion

Central talus osteotomy

Pes adductus is a relevant component of clubfoot deformity. In young patients suffering a pes cavus-varus-adductus ***(E60)*** without joint degeneration and good mobility, lengthening (and eventually rotating) the talar neck is a very powerful means to ***correct the adductus***.


275


276

In fact, this correction aims at restoring the normal divergence of the talus and the calcaneus. To do so, lengthening the medial column of the foot, together with the release of the adjacent soft tissues by means of joint capsules ***(T616)*** (talonavicular joint) and tendons (posterior tibial tendon) ***pushes the forefoot in abduction (T621)***


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and ***increases the anteromedial weight bearing*** of the foot (left foot).


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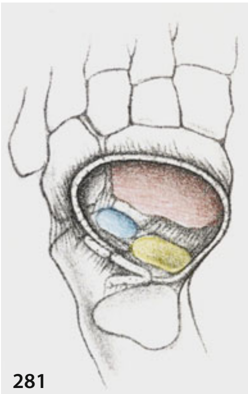
A prerequisite is very safe vascularity of the soft tissues and good mobility of the joints. The intervention includes a complete ***medial opening of the acetabulum pedis (T616)***.



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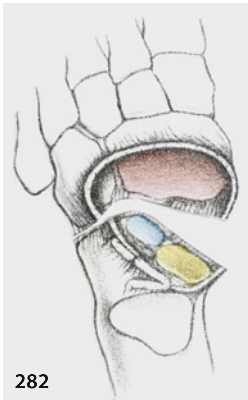

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The effect of the necessary release of the posterior tibial tendon may be increased by transferring it onto the opposite side of the foot (dorsolateral) ***(T819)***. The foot rotates horizontally around the calcaneocuboid joint. Therefore, a frequent complement to the medial opening and eventual lengthening of the talar neck is the ***shortening of the lateral column***

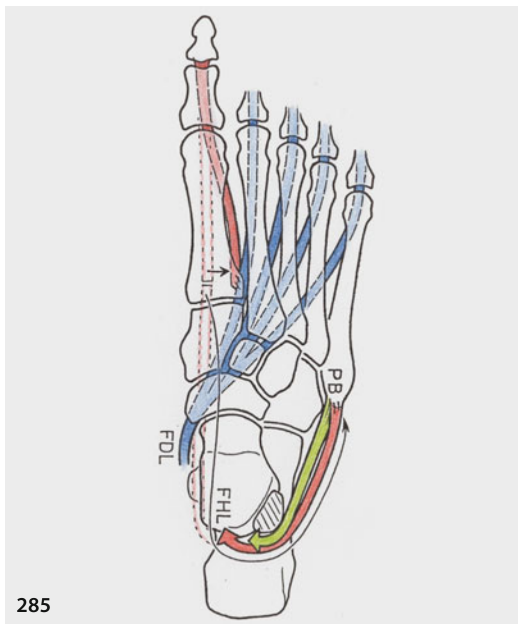
283

284

by fusing the calcaneocuboid joint ***(O323)*** and extending the first metatarsus ***(T685)***. The calcaneocuboid joint minimally affects the mobility of the lower ankle joint and is very well supported. This procedure limits the soft tissue strain on the medial side of the foot.

According to the tridimensional character of the deformity, the exaggerated varus component is also corrected by a lateralizing tuber calcanei osteotomy ***(T612)***. The extension osteotomy of the first metatarsus reduces the anteromedial buttress of the foot.

The motor component of this correction is very important for avoiding relapses because the etiology is essentially neurologic through a muscular imbalance that most often must be cleared by electroneurography. The foot pronators must be powered. This includes, besides the mentioned posterior tibial tendon transfer along the fibularis tertius tendon ***(T819)***, a lateralizing transfer of the anterior tibial tendon, a transfer of the fibularis longus to the fibularis brevis tendon ***(T827)***, and transfer of the ***flexor hallucis longus tendon to the basis of the fifth metatarsus (T833).***



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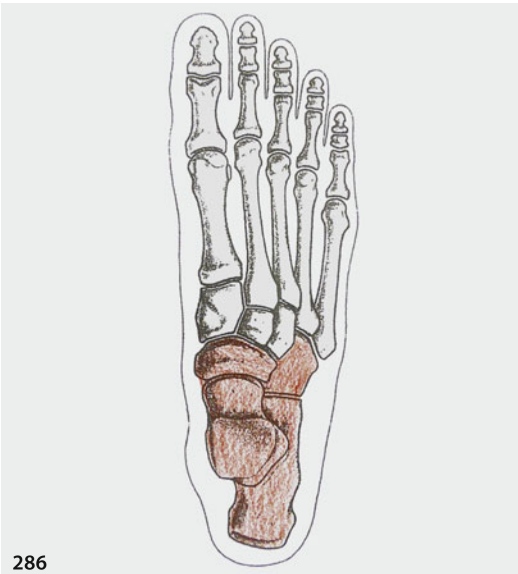
Correction by global fusion: triple arthrodesis

Triple arthrodesis fuses the talonavicular, the talocalcaneal, and the calcaneocuboid joints. Fusing the ***four mentioned bones***



286

is a very efficient intervention that addresses painful degenerative and posttraumatic conditions or ***malorientation of the lower ankle joint***

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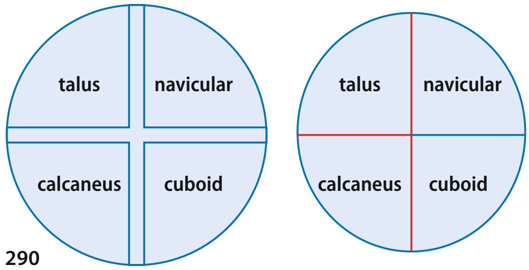
and allows for a free reorientation of the whole hindfoot and midfoot within the sagittal and the horizontal planes ***(T642)***. All four bones are mobilized completely and reassembled with the desired horizontal and sagittal orientation in a ***slightly reduced dimension.***



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The ***talometatarsal axis is realigned*** within both sagittal and horizontal planes.

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If the indication includes a deformity due to neuromuscular imbalance or degenerative insufficiency of the posterior tibial tendon, the corresponding imbalance must be corrected by the adequate tendon transfer ***(O265)***. In some cases, the deformity recurs within the fusion if the imbalance persists. Such recurrences are particularly frequent in Charcot–Marie–Tooth disease, in which the muscular imbalance progresses stepwise. Other expansions of this reconstruction occur in selected cases of diabetic arthropathy in which the medial column of the foot, the talometatarsal axis, is malaligned. Here, the triple arthrodesis is associated with a talometatarsal arthrodesis ***(O321)***.

7 Horizontal and sagittal correction of the midfoot

Correction of eversion

Eversion of the midfoot and/or forefoot corresponds mechanically to a collapse of the longitudinal medial arch of the foot ***(O255)***. An occasional accessory navicular bone is testimony to a certain posterior tibial muscle/tendon insufficiency. In essence, those deformities have to be observed in the three planes of space and only then can be quantitatively evaluated. There are deformities that are more clearly expressed within the horizontal plane (abduction) and others that are more visible within the sagittal plane, which corresponds roughly to a dorsal extension of the medial forefoot and an equinus or plantar flexion of the hindfoot.

Talonavicular fusion

The talonavicular fusion is part of the triple arthrodesis. As previously stated, this single fusion modifies the orientation of the midfoot. The indication is probably exceptional because it blocks a major part of the lower ankle joint's mobility. This is due to this joint being essential for functional hindfoot motion.

Naviculocuneiform fusion

Pes pronatus or planus may present its main deformity distal to the talonavicular joint. The ***abnormal abduction and extension (eversion) of the forefoot*** may concentrate on the naviculocuneiform joint.

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On the horizontal radiologic view of the weight-bearing foot, the talus is well covered by the navicular bone, and ***the pathological angle in abduction is more distal***.

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Orientation within the sagittal plane is less affected.

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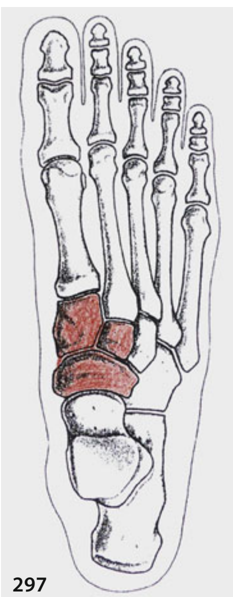
The “talar foot” by means of the first three rays is corrected surgically in either plantar flexion – thus correcting the deformity within the sagittal plane – or/and adduction within the horizontal plane. Both sagittal and horizontal components are more or less pronounced anyway. The naviculocuneiform joints are not essential for foot function and are thus ***destined for correcting these deformities (T648)***.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In cases in which the sagittal sag of the medial column is located at the talonavicular joint *and* the naviculocuneiform joint, the naviculocuneiform fusion is associated with the central calcaneal osteotomy ***(O256)***. One thus simultaneously achieves ***sagittal correction of the talometatarsal axis***

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and ***correction of the abduction***


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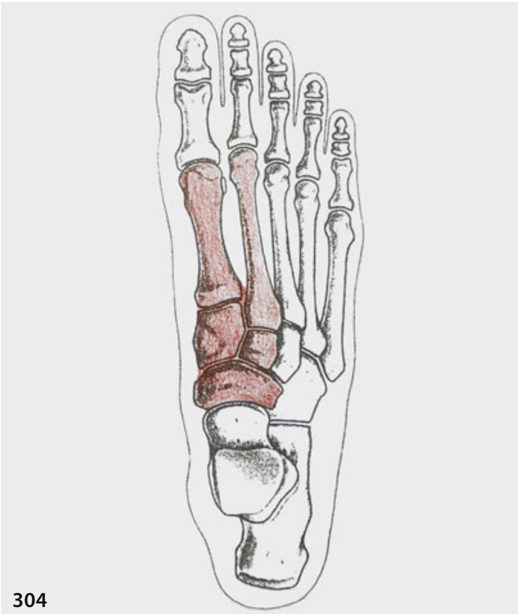
within the horizontal plane while preserving all essential articular mobility of the foot.

The process lateralis tali no longer impinges on the calcaneus at the crucial angle of Gissane.

Naviculometatarsal fusion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In cases of degenerative deformities, the instability is frequently located at the naviculocuneiform level as well as more distally at the cuneometatarsal level. The medial forefoot suffers from a missing functional buttress, and the entire foot pronates. Diagnostics is essential to exclude an eventual insufficient tibialis posterior function. Radiologic verification demonstrates the ***sagittal sag of both naviculo-cuneiform and cuneometatarsal joints***.

305

The horizontal plane demonstrates discrete abduction within the naviculocuneiform joint and a ***metatarsus primus adductus.***

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As nonessential joints, the medial tarsometatarsal joints are fused and arranged in both ***horizontal (adduction) (T665)***


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and ***sagittal (flexion) planes*** to reestablish the anteriomedial buttress of the foot ***(T666)***.

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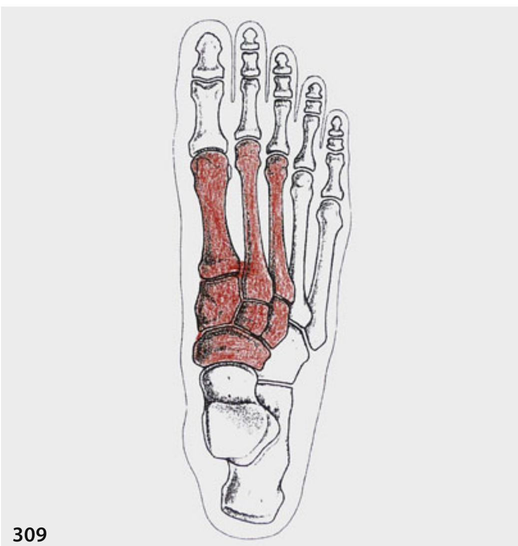
The motor counterpart of the correction of imbalanced pes pronatus is logically corrected by either powering the supinators ***(O265)*** or powering the flexors of the first ray ***(T835)***.

In particular cases in which ***all three medial rays are involved,***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the ***abnormal abduction and extension (eversion) about the midfoot*** or the naviculocuneiform joints is associated with an ***adduction situated at the tarsometatarsal*** joints


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without including any articular sag in the sagittal plane.

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Sometimes called "serpentine feet" or "Z-feet," the correction is also located on both aspects and is thus performed in ***adduction inversion at the naviculocuneiform*** level and in ***abduction eversion at all three medial tarsometatarsal joints.***

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The radiographic appearance demonstrates a ***"true lateral"*** of the hindfoot as well as of the forefoot.

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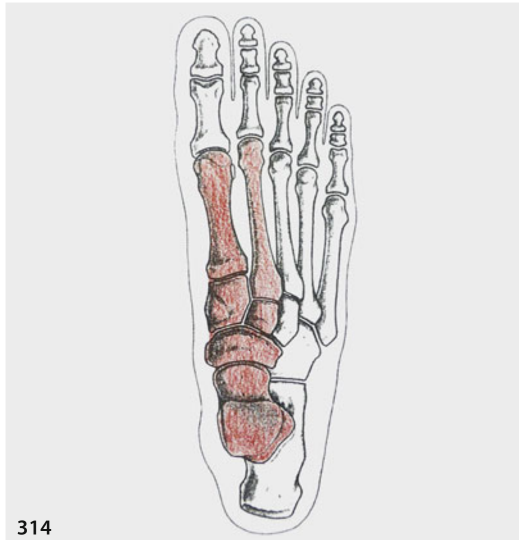
Talometatarsal fusion

If the articular degeneration includes the whole first ray, reorientation is done by ***fusing the talus in straight alignment with the first metatarsus***.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This fusion is justified if the misalignment is symptomatic because it can occur after trauma or diabetic arthropathy. ***Involvement of the talonavicular joint*** must be verified

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because it is the essential joint of the midfoot. As the means of fixation run along the long axis of the foot, axial rotation about this axis must be locked. The simplest locking is achieved through ***axial internal splinting through the third or the second ray***.


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This reasonably invasive fixation is sufficient for lower body weights and addresses the essential stability of the first ray, allowing full ***function of the upper ankle joint***.


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A more invasive kind of reconstruction consists in stabilizing the axial rotation within the subtalar joint, indicated if there is a clinical hyperlaxity ***(E17)*** in heavy patients. The end result then corresponds to an association of a ***first ray stabilization with a triple arthrodesis (O293)***.


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Correction of inversion

Calcaneocuboid fusion

Triple arthrodesis is a very good tool to correct any deformity of the hindfoot situated beneath the upper ankle joint. Fusing the calcaneocuboid joint alone allows for localized shortening of the lateral column of the foot ***(O284)*** and thus a specific ***abduction of the midfoot*** that can be scaled by the quantity of bone removed.

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323

Gliding dorsally, the cuboid within the fusion adds a relevant pronating component within the correction.

First metatarsal extension osteotomy

Structural supination of the foot should also be investigated on the metatarsal level. A plantar-flexed first metatarsal is then easily corrected by an extension osteotomy of the first metatarsus ***(T685)***.

Dorsolateral tarsectomy

Pes supinatus presents a convexity dorsolateral to the foot. This deformity also leads to hindfoot instability with recurrent sprains. By rotating the foot around an oblique axis that includes the plantar aspect of the medial cuneiform and the cuboid, the deformity can be resolved in many cases. Essential joints may be involved depending on the severity of the deformity. A dorsolateral bone wedge is taken from the navicular and cuneiform bones ***(T649)***. The calcaneocuboid joint may also be fused in some cases. Instead of purely shortening the lateral column within the calcaneocuboid joint, the cuboid can be translated upward during the fusion. This concept is very efficient in ***turning the hindfoot in eversion and in extension.***

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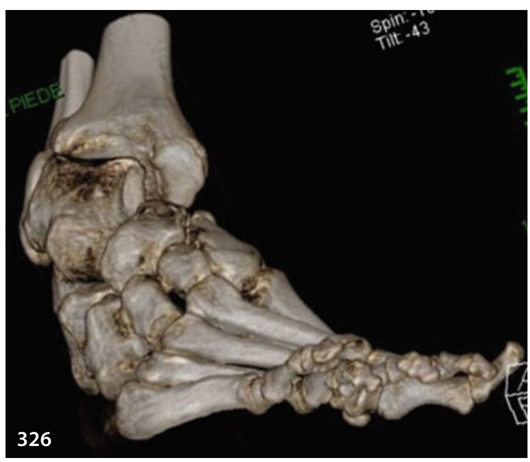
The procedure is especially indicated in severe deformities and in rigid feet suffering a posttraumatic ankylosis that impedes functional adaptation to the ground. The foot is corrected at the location of the deformity ***in extension and pronation.***



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The lateral tarsometatarsal joints ***adapt in flexion*** after the dorsolateral extension.

The motor counterpart consists of powering the pronators of the foot. Correction of imbalanced pes supinatus is performed in a quantitative, rational way by transferring one or more muscle tendons of the supinators to the lateral dorsal aspect of the midfoot. It is wise to quantify the power of those muscles in the preoperative planning. The simplest transfer is the anterior tibial tendon shift to the lateral side of the foot. Transferring the posterior tibialis tendon on the lateral dorsum of the foot has the advantage of weakening the causal supination ***(T819)***. In more severe cases, additional transfer of the long extensor tendons of the toes on the lateral aspect of the dorsum of the foot empowers the dorsal extension of the foot ***(T825)***. This has the advantage of helping correct the claw or hammer toes that often occur in this kind of pathology. However, the power of the long flexor tendons must be evaluated during preoperative planning. While removing the power of the long extensor of the toes, the metatarsophalangeal joints relax in flexion as desired. On the other hand, the long flexors of the toes may provoke increased flexion of the whole toe by curling them. In order to stabilize the toes, the distal limb of the long extensor tendons is fixed onto the corresponding short extensor tendon. On the lateral side of the foot, the simplest transfer is that of the long fibular tendon to the short fibular tendon ***(T827)***. This move has the advantage of weakening the plantar flexion of the bases of the first metatarsus for a passive eversion. Preoperative examination should focus on the stability of the first tarsometatarsal joint. In the case of instability, removing the fibularis longus tendon from its location causes an insufficient anteromedial buttress together with a metatarsus primus adductus. Still on the lateral aspect of the foot, the fibularis brevis muscle and tendon are considerably empowered in severe cases by transferring the flexor hallucis longus onto the base of the fifth metatarsus ***(T833)***.

8 Horizontal and sagittal correction of the metatarsus

Medial and central tarsometatarsal fusion

Pes adductus may be located specifically at the ***tarsometatarsal joints***.

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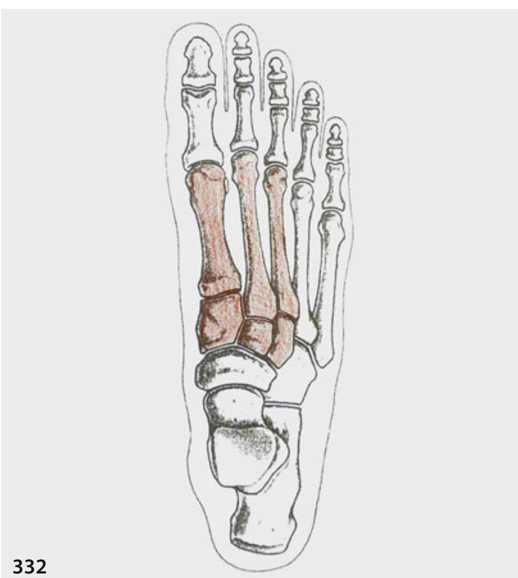
The whole gait may be altered, though without relevant metatarsalgia. The logical treatment is abduction arthrodesis of the ***first three tarsometatarsal joints***.



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The fourth and fifth tarsometatarsal joints may spontaneously follow the correction. In severe cases, an arthrolysis will suffice for reorientation of the lateral column.

The dorsal extension component of the correction is important to consider in order to ***reduce the eventual exaggerated medial arch***

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and thus the overloaded lateral edge of the foot. A slight ***component of pronation*** results.

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The aim is horizontal ***alignment of the talus and the first metatarsus***.


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Due to the length of the metatarsi, the angulation at the fusion site remains modest in consideration of the morphologic result ***(T675)***.

Pes abductus occurs frequently in polyarthritis and in degenerative ***destruction of the medial tarso-metatarsal joints***.


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In this case, the foot ***collapses anteromedially***.


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This condition is treated logically by ***adduction of the central metatarsi and, in particular, flexion of the first metatarsus***.

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This allows for ***restoration of the medial arch*** of the foot.

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Arthrodesis at the corresponding tarsometatarsal joints is the optimal spot to restore functional stability and preserve the essential joints of the foot.

In the sagittal plane, malalignment of the metatarsus may be linked to the corresponding tarsometatarsal arthrosis and causes invalidating metatarsalgia. Fusing the arthritic joints is a highly effective way to realign ***the axes of the two central medial metatarsi in extension***

340

and the medial metatarsus in slight flexion ***(E62)***. This treatment is very efficient because the correction is performed at the base of the bones.

Lateral tarsometatarsal arthroplasty

The pathological abductus or adductus also concerns the morphology of the fourth and fifth tarsometatarsal joints. However, the fourth and fifth rays belong to the "calcaneal foot": These joints should be considered essential, and they require a wide range of functional adaptation during gait and are provided with one joint less than the medial three rays. Simple, complete arthrolysis of the two joints allows the fourth and fifth metatarsi to follow the corrected axis of the third tarsometatarsal joint. If the deformity is very severe or if the ***fourth and fifth tarsometatarsal joints are arthritic,***

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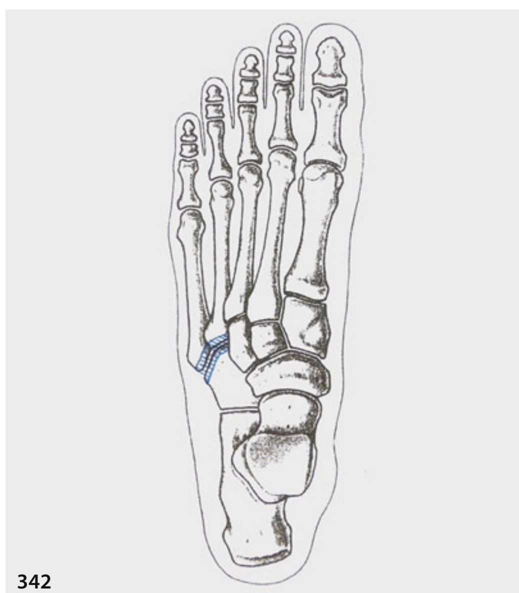
arthroplasty of the two joints by ***resection of the subchondral bone*** and interposing chondrogenic soft tissue (autologous tendons) ***(T680)***



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provides for a ***functional and stable reconstruction***.


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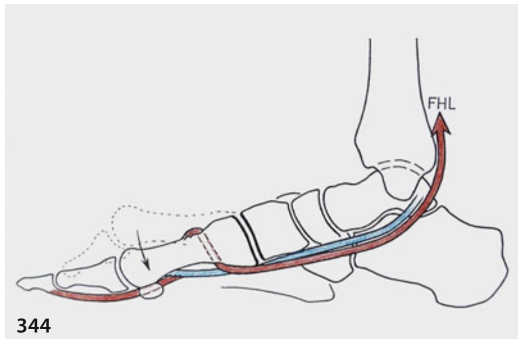
The plantar articular and ligamentous layers remain intact, acting as plantar tension bands ***(T677)***. In cases of tarsometatarsal destructive arthropathy, such as that occurring in rheumatoid arthritis, fusing the central (second and third) tarsometatarsal joints or all three medial tarsometatarsal joints ***(T675)*** may solve the articular and weight-bearing problems of the medial aspect of the anterior heel in one step. In opposition to the individual correction performed at the diaphyseal level, realignment at the first three tarsometatarsal joints allows for the most extensive correction of misalignment of the anterior heel.

9 Correction of the anterior heel

Weight-bearing problems of the anterior heel are due to a functional mismatch of load distribution on the sesamoids and the lesser metatarsal heads (4;17) ***(O350)***.

Muscle balance

Powering the flexors of the first metatarsus should help to achieve a better anteromedial buttress of the foot and correct hyperpronation. In certain cases, powering flexion of the first metatarsus by ***transferring the flexor hallucis longus tendon to the base of the first metatarsus (T835)*** is sufficient to reestablish the medial arch of the foot.



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The distal limb of the tendon is secured onto the distal aspect of the flexor digitorum longus. Unfortunately, the power of this reconstruction is insufficient in many cases; therefore, a bony stabilization is most often required.

First tarsometatarsal and first intermetatarsal space fusion

Alignment of the metatarsal heads and sesamoids is critical for smooth push-off and gait ***(E46, R146, O350)***. Alignment of the metatarsus refers to the sagittal as well as the horizontal alignment of the metatarsal heads (Lelièvre parabola) (19). As a rule of thumb, the radiologic axis of the first metatarsus should be aligned with the axis of the talus in both sagittal and horizontal planes.

Restoring a functional anteromedial buttress of the forefoot is indicated in frequent instability of the first ray ***(E115)***, which is characterized by a hypermobile first tarsometatarsal joint in the sagittal and also in the horizontal plane (4, 11). The radiographic image under weight-bearing conditions often reveals a widened space between the first and second metatarsus and between the first cuneiform and the second metatarsus ***(R144)***. The cuneometatarsal and the metatarsophalangeal joint are often of the ***condylar type***. ***Second metatarsal hyperplasia*** is the rule for clinical relevancy.

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The lateral incidence often demonstrates a slight **plantar opening of the innominate joints.**

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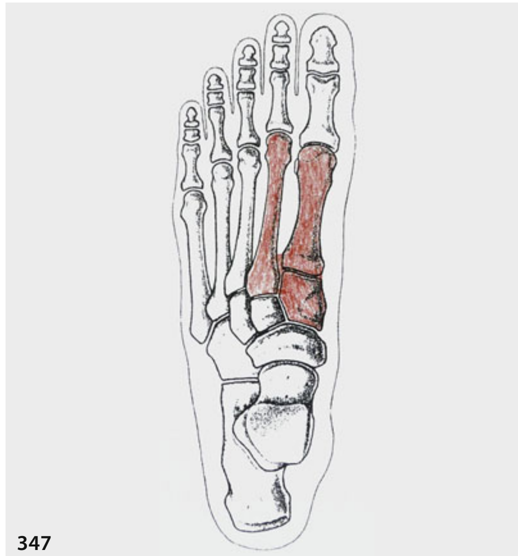
Reorienting the first metatarsus and fusing it to the second metatarsus and the first cuneiform (29) creates a ***new functional and less mobile entity***:



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the three bones ***articulate around the second cuneiform*** and thus limit, but not block, the functional sagittal mobility of the first ray.

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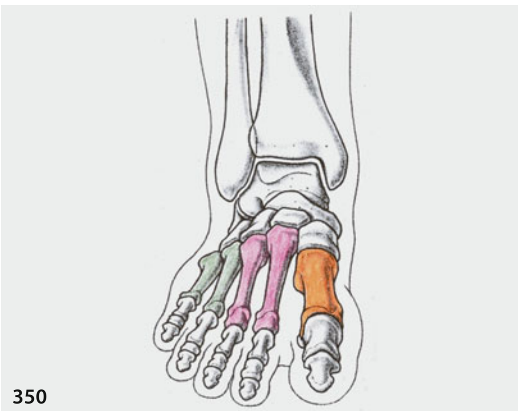
The first tarsometatarsal and intermetatarsal 1–2 arthrodesis provides, by its congruency, the lowest probability of recurrence of metatarsus adductus ***(T665)***.

Extension and shortening osteotomy of the central metatarsals

Symptoms of the missing anteromedial buttress are logically linked to the compensatory overload of the neighboring metatarsals. The ***second and third metatarsals are considered to be the central axis of the foot (A5)***,



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with minimal mobility at the tarsometatarsal level. The position of the metatarsal heads in relation to one another is crucial because during push-off they are loaded together, starting in a roughly horizontal plane and ending in a vertical plane. They are thus loaded on a full arc of 90 degrees ***(E46)***. The importance of the aforementioned Lelièvre parabola becomes clear at this point. If the alignment does not follow the parabola ***(E44)***, for instance when the second and third metatarsals are "too long" in relation to the first metatarsus (so-called Morton's foot; 4), at push-off (i.e., in a vertical position) those central metatarsi remain quite alone in the duty of taking load, which may provoke pain and premature degeneration of the corresponding metatarsophalangeal joints ***(O384)***. In fact, the plantar plate beneath the metatarsal heads suffers and is at high risk of getting torn off, thus jeopardizing the stability of the joint. In the long run, the toe dislocates dorsally, increasing disability and pain.

There are two principles to follow for correcting alignment of the lesser metatarsal heads: either a central diaphyseal or a basal metaphyseal osteotomy.

Diaphyseal osteotomy

Diaphyseal osteotomy allows for an immediate, highly precise correction but is somewhat invasive and includes implants ***(T694)***. The metatarsus can be extended, flexed, shortened, or lengthened without anatomic limitations and without disturbing the adjacent joints. As mentioned above, this correction is most often a ***corollary to the correction of the anteromedial buttress***.

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Logically, this correction is mainly needed on the central metatarsi because they suffer from an occasionally insufficient first ray, which has more mechanical freedom. It happens, however, on rare occasions that the fourth metatarsus (or, very rarely, the third alone) presents an isolated overload that is accompanied by a corresponding plantar callus. In these cases, a precise osteotomy fixed definitively by a plate can produce the desired harmonious functional weight-bearing pattern of the anterior heel.

Metatarsus quintus abductus is sometimes associated with imbalanced medial metatarsi (splay foot) ***(R145)***,

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and the problem is relieved by orienting the metatarsus ***on the diaphyseal level (T711).***

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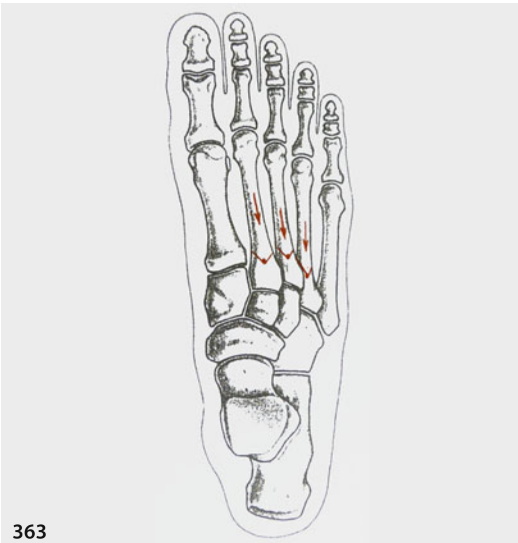
Basal osteotomy

Basal osteotomy, although less invasive, allows for physiologic approximative adjustment of the metatarsal head by weight bearing ("self-adjustment"). The sagittally guided slide of the bone is assured by the ***inclined chevron-like shape of the osteotomy (T706).***

Additionally, the said musculature avoids any rotational malunion that logically would have deleterious consequences on the rotational orientation of the toes and their joints.

In summary, the displacement path of the distal limb of the metatarsus (long limb) is oblique upward, allowing for ***adequate shortening***.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Essential components of the treatment are the postoperative plantar orthosis (***retrocapital cushion or "pelote"***), while the interosseous musculature (dorsal and plantar musculi interossei), which remains intact, ***cushions and limits the sagittal bony correction***.

This procedure ***(T706)*** is less predictive than diaphyseal osteotomy because it is self-adjusting and thus is well indicated in the elderly, osteoporotic, noncompliant, or smoking patient with local vitality problems, including peripheral arteriosclerosis.


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10 Correction of the metatarsophalangeal joints

First ray

The first metatarsophalangeal joint may experience local overload over time. Certain morphology, including a relatively long first metatarsus (index metatarsus plus) and an Egyptian morphotype, favors joint degeneration ***(R148)***.

Following a degree of joint degeneration and reduction in mobility, either the joint can be decompressed or reoriented, the head remodeled, or the joint fused.

Joint decompression

If the joint surface is acceptable in a young person, and the combination of an Egyptian morphotype and an index metatarsus plus is present, the pressure within the joint is reduced by ***shortening the first metatarsus (T684) and/or the first phalanx (T744).***


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Metatarsophalangeal joint reorientation

If the cartilage is still there and the length of the ***metatarsi is balanced***,


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the sagittal diameter is reduced by a ***dorsal closing intraarticular wedge-shaped osteotomy (T715).***


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Cheilectomy

If the joint is less mobile and the ***cartilage is worn out***,

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the ***dorsal third of the metatarsal head is removed***.

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Neither aforementioned principle affects the metatarsosesamoid joint.

Metatarso-phalangeo-sesamoid fusion

In the case of highly ***advanced degeneration***


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and ***involvement of the metatarsosesamoid joint***,

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fusion is indicated.

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The first phalanx should be ***oriented horizontally (T732)***.

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This is well tolerated in the first ray, allowing for most sporting activities even when the correction is performed bilaterally. Functional ***buttressing of the tip of the toe***

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is essential for a ***good clinical result***.

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Lesser rays

Lesser metatarsophalangeal joints (2–5) are essential joints that respond badly to fusion because the soft tissues beneath the phalanges are too weak to allow for the forces of push-off. There are no sesamoid bones protecting the long flexor tendon. Motion between the metatarsus and the first phalanx is essential for a smooth gait. Repeated intraarticular surgery may lead to limited mobility, ankylosis, and painful degeneration with osteophytes.

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Subcapital extension osteotomy

Metatarsus 2 or 3 ***cephalic osteonecrosis*** (morbus Freiberg)

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is best approached by an extending reorienting osteotomy. In fact, the local anatomic conditions demonstrate a long extension of the cartilaginous layer on the plantar side of the metatarsal head. The necrotic part of the head is eliminated by a conical, dorsal wedged intracapital excision and corresponding ***extension osteotomy (T727)***.


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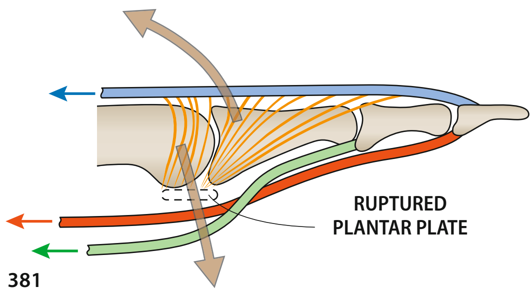
Such a procedure brings the basis of the first phalanx to face an intact cartilaginous layer on the metatarsal side (30).

11 Functional reorientation of the toes

Sagittal plane

The toes are essential to resume a smooth gait and push-off. While the first ray is the last part of the body to leave the ground at push-off, the lesser toes are linked to the windlass mechanism ***(E49)***. This mechanism allows for an elastic recoil through the plantar fascia, starting at the plantar aspect of the heel and ending at the plantar aspect of the first phalanx of the toes ***(E49)*** (12). Weight bearing leaving the toes free causes a passive plantar flexion at the metatarsophalangeal joints**.** When the plantar plate of the metatarsophalangeal joint is torn by chronic overload or iatrogenically after plantar fasciotomy, this ***mechanism is disturbed.***



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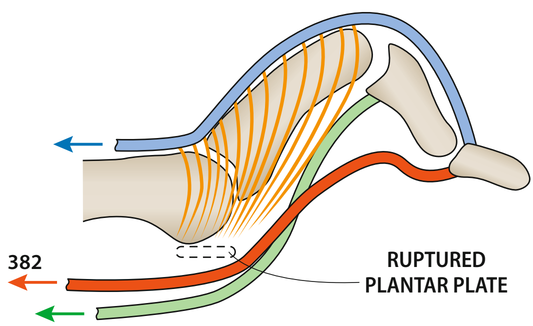
The ***first phalanx is extended, and the second phalanx is flexed***.



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The result is a "hammer toe." At the end of the process, due to the torn plantar plate of the metatarsophalangeal joint, ***the toe dislocates dorsally***.


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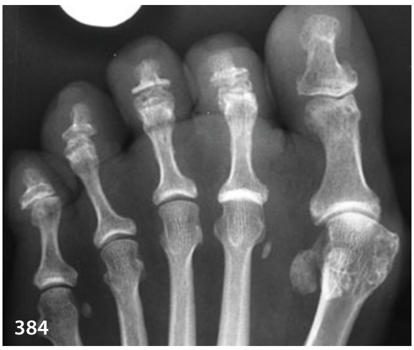
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The aim is thus to restore active metatarsophalangeal flexion ***to relocate the toe, facing the metatarsal head.***


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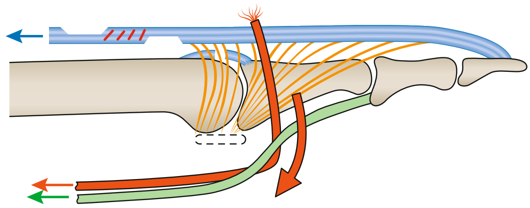
Reducing the metatarsophalangeal dislocation and restoring the axis of the first phalanx by plantar flexion requires an active force pulling the first phalanx plantarward, such as that provided by a tendon transfer.

Tendon transfer

Transferring the long flexor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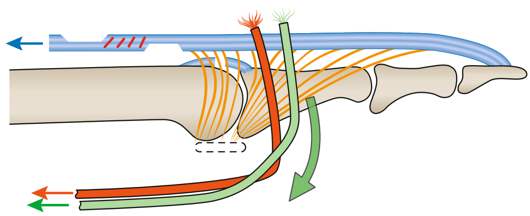
and, in severe cases, ***also the short flexor***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of the toe onto the first phalanx corrects the hammer toe deformity by flexing the first phalanx of the toe.

The ***hammer toe deformity in the relaxed foot***


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does not correct with passive extension of the hindfoot, which tenses the long flexors of the toes.

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Transferring the flexors onto the first phalanx ***corrects the position of the toes*** in the relaxed foot

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and additionally ***pulls down the first phalanx of the toes*** if the hindfoot is extended passively.

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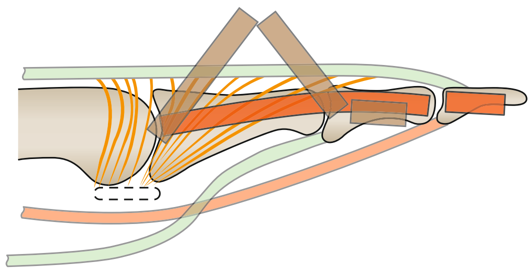
This correction must then be performed on all toes ***(T847)*** because of the strong mutual functional interference of the flexors between the toes. In cases in which passive extension of the distal interphalangeal joint is hyperlax and allows for passive extension of more than 20 degrees, removing the long flexor tendon results in painful hypercorrection of the hammer toe and an absent buttress of the tip of the toe. This complication produces a swan-neck deformity of the toe ***(E65)***.

Proximal interphalangeal fusion

In cases of hyperlax toes, ***fusion of the proximal interphalangeal joint (T755)***



393

allows the essential flexion power to be left to the hypermobile distal interphalangeal joint while ***stabilizing the toe in the correct axis (T759)***

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395

and avoiding the swan-neck deformity ***(E65)***. This procedure alone, however, does not allow the reduction of a dislocated metatarsophalangeal joint.

If the ***metatarsophalangeal joint is dislocated and the proximal interphalangeal joint is ankylosed in flexion,***


396

both ***proximal interphalangeal joint reorienting fusion*** ***and*** ***long flexor tendon transfer to the first phalanx*** restore good function with corrected morphology.


397


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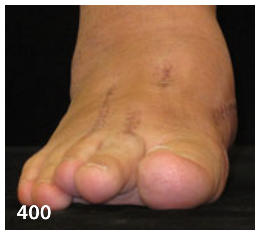
399

Skin plasty

To achieve a functional push-off, the toes must touch the ground at their pulps, and the angle of the toe in function is relevant ***(E125)***. In the case of metatarsalgia treated by elevating the metatarsus by osteotomy or tarsometatarsal fusion, the entire toe also tends to elevate and leave the ground. It appears that the skin and underlying soft tissue above the metatarsophalangeal joint undergo relative shortening, pulling the toes in extension. If systematic stretching of the joints in plantar flexion is not sufficient, lengthening plasty (e.g., ***Z-plasty or V–Y plasty***) of the dorsal skin corrects the position of the toes ***(T511)***.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Distal interphalangeal reorientation

The pulps of the toes are essential for the last contact with the ground during push-off. The sagittal pitch of the distal phalanx is critical in the lesser toes. Localized toe hyperflexion that appears in children is mostly linked to a ***shortening of the corresponding long flexor of the toe***.


402

Treatment logically addresses the flexor close to the insertion at the end phalanx. An ***arthrolysis of the retracted distal interphalangeal joint***


403

is also indicated ***(T551)***.

In cases of painful degeneration of the joint and, especially, hyperlax distal interphalangeal joints, the buttress is transferred proximally, causing pain and discomfort. In the case of (often unrecognized) compartment syndrome of the foot, retraction of the long flexor of the toes causes a flexion contracture of the distal interphalangeal joints that may become rigid. Ectopic calluses are testimony to such a condition. Reorientation of the pulp of the toe is best performed through a ***fusion*** in correct position ***of the distal interphalangeal joint***.


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Horizontal plane

Osteotomy of the first phalanx

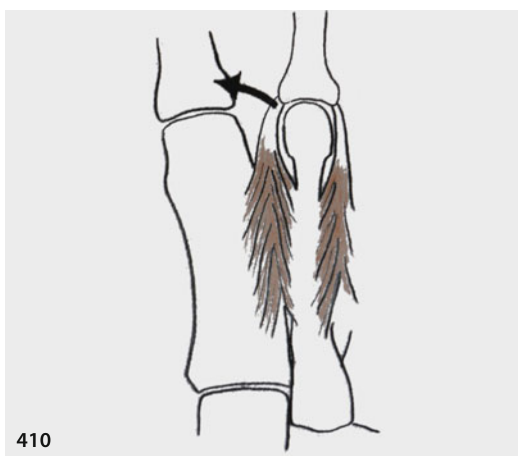
In so-called hallux valgus interphalangeus, neither proximal nor distal joint lines about the first phalanx within the horizontal plane are parallel. This rare deformity may provoke chronic conflict with the second toe and impede function of the long flexor tendon. Alignment through a ***diaphyseal adduction osteotomy*** corrects impingement and function ***(T742).***


408


409

Tendon transfer

Surgical release of the metatarso-sesamoid-phalangeal joint, including tenotomy of the adductor hallucis muscle, may cause a secondary imbalance of the toe in varus ***(E52)***. This deformity is not compatible with a smooth gait. If the joint is functional and not painful, the functional reconstruction is best performed by correcting muscle balance. The ***first interosseous muscle***, if remaining intact after the previous surgical procedures, may be used to ***pull the first phalanx of the hallux in valgus (T841)***.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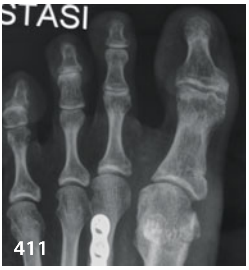
A complete ***medial arthrolysis*** of the joint must accompany this procedure.



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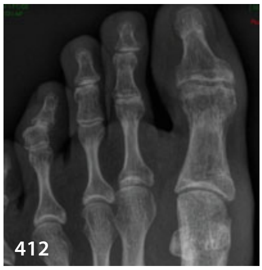
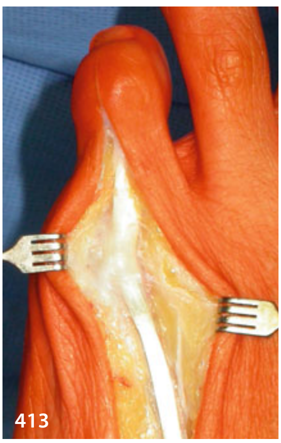

412

Supination of the last toe may result in very painful conditions while bearing weight ***(E54)***. Active pronation can be found using the power of the corresponding extensor muscle. Even though the short extensor does not exist, harvesting the distal limb of the ***extensor digitorum longus tendon***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and connecting it to the abductor digiti minimi does not result in functional insufficiency ***(T851)***.

Axial correction

Discrepancy of the lengths of the toes and metatarsi may occur together and cause an ***imbalance of the forefoot during push-off*** (***E46***) when the metatarsus is vertical.


414

The aim is to restore ***morphologic harmony of the levers*** of the toe pulps.


415

The morphology of the toes indicates that the ***best bone to act on for such an adaptation*** is the first phalanx.


416


417

Precise shortening ***osteotomies of both the metatarsi (T691) and the basic phalanges (T749)*** may resolve this problem.

418

419

Surgical Fracture Treatment

K. Klaue, *The Foot*,
DOI 10.1007/978-3-662-47697-0_5,

A fracture is a solution of continuity of the bone. As such, the anatomic restoration of the bone is clearly the optimal treatment. As a biological structure, the fractured bone causes immediate discharge of blood, which accumulates as hematomas within generally confined spaces. Within the foot are a number of relatively small compartments separated by strong fibrous tissues. These compartments contain muscles (intrinsic) and nervous structures that are very sensitive to hydraulic pressure, and a fresh hematoma due to, e.g., a displaced fracture is likely to produce a local compartment syndrome with deleterious consequences (32). It is probable, though, that severe fracture-dislocations rupture most of the relevant intercompartmental walls and produce swellings that might jeopardize the vitality of the skin. In both cases, the hemodynamic, "mechanical" period lasts up to 6 h, and surgical removal of the hematoma should be considered, if possible, together with the definitive bone and joint repair. Not to operate on a malleolar fracture because of the swelling is unjustified if it is possible to start surgery within the first 6 h after the trauma. After this period, the metabolic action of tissue edema may put the soft tissues at risk when open surgical approaches are involved because the swelling is intracellular and cannot be removed by open surgery.

Fractures of the foot most often involve joint surfaces. When evaluating those fractures and elaborating a plan of treatment, it is mandatory to know whether those joints are essential for function. Essential joints should be reconstructed anatomically, whereas nonessential joints may be used to reestablish functional orientation of the foot by fusion. Due to the importance of bone and joint alignment in the foot, it is essential to restore the shape and dimensions of the bone after trauma.

Fracture treatment by means of reduction and fixation in the foot and ankle is thus mainly a matter of surgical approaches and rational tips and tricks.

1 Ankle fractures

Malleolar and pilon fractures may safely be fixed by using one to three simultaneous open surgical approaches.

The fibula is poorly covered by soft tissue, and the strict lateral incision and, especially, lateral application of a plate may disturb healing and function. A longitudinal incision is best placed ***postero-lateral to the fibula***.

420

The *tibiotalar joint* is best visualized either from the front or the back or both. The anterior approach to the medial malleolus, taken along the axis of the vena saphena magna, is vascularized on both edges by vessels originating from the anterior and posterior tibial arteries and thus allows visualization and correct reduction of the crucial ***anterior arch of the medial malleolus***.

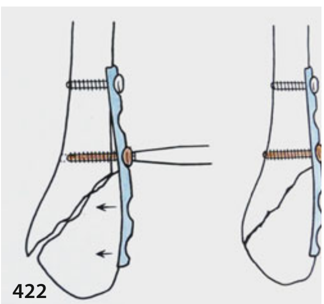
421

The posteromedial approach of the distal tibia, between the neurovascular bundle and the flexor hallucis longus, allows visualization and reduction of fractures of the posterior rim of the tibia ***(T524)***.

Malleolar fractures

A malleolar fracture is a lesion of the stabilizing part of the ankle joint.

Most of the dislocations of the distal fibula go posteriorly, together with the usual shortening of the bone. Plates may act as fixing devices acting like springs: Their wide application surface reduces the pressure on fragile bone, which has to be reduced. The posterolateral aspect of the distal fibula allows for fixing a plate on solid cortical bone and thus offers a relatively large surface on its distal aspect for safely pressing the more fragile distal malleolus ***in the desired anteromedial direction.***



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If the medial pillar, the medial malleolus, is also ruptured, the ***talus is not held to the lower leg by any structure*** and thus dislocates.

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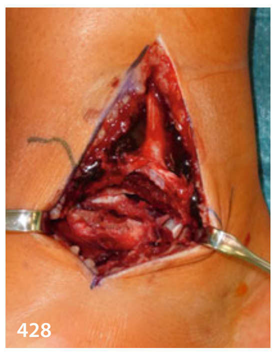
The first aim is thus to reduce and fix the medial malleolus anatomically. The approach is ***anteromedial***, parallel to the saphenous vein.

After ***anatomic reconstruction of the medial malleolus***,



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the fibula is reduced and fixed through a ***posterolateral approach***.

430

Dislocations of the upper ankle joint may include a full rupture of the deltoid ligament without fracture of the medial malleolus. This ligament covers a wide surface beneath the medial malleolus. After reduction of the dislocated joint, it is essential to verify that all layers of the ligament are located at their anatomic sites. Healing occurs through scarring in an uninterrupted orthogonal position of the hindfoot. Useful ***suturing of the deltoid ligament is illusory***.


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432

Pilon fractures

A fracture of the pilon tibial is a lesion of the weight-bearing part of the ankle joint.


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This fracture is most sensitive in the restoration of the lateral pillar. This is the anterolateral corner of the joint, which carries Chaput's tubercle. A ***longitudinal incision centered on this spot***


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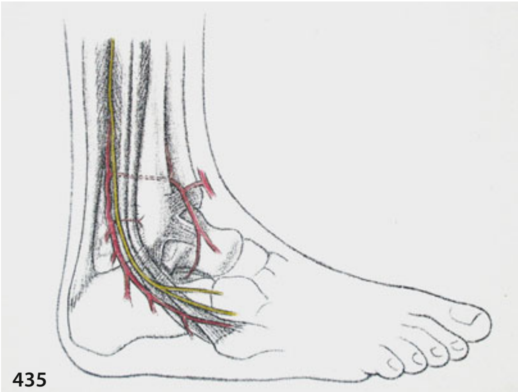
saves the blood supply from the anterior tibial artery on one side and the ***anterior fibular artery*** on the other side. This artery perforates the interosseus membrane about 2 cm above the anterior syndesmosis and ***runs anterolaterally to join the sinus tarsi vessels***.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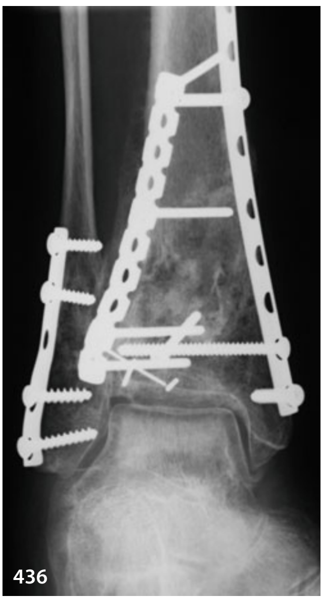
Buttressing the anterolateral pillar of the tibia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by a more proximally anchored plate avoids the frequent secondary impaction that causes secondary arthrogenic joint incongruence.

A second rational vision of the pilon tibial is achieved through a ***posteromedial approach (T525)***.


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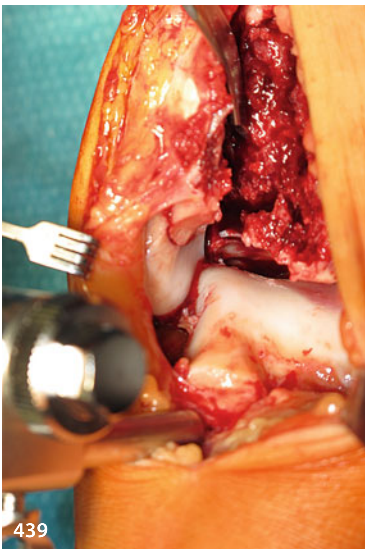
The incision is located halfway between the heel cord and the medial malleolus, leaving the posterior tibial artery and the tibial nerve medial. The flexor hallucis longus muscle remains lateral to the approach to the bone. In complex intraarticular fractures that completely separate the joint surface from the proximal tibia, posterior direct visualization and anatomic reduction of the posterior articular edge of the tibia allow, in a second stage, alignment of the anterior part of the articular fragments from the anterior aspect of the joint.

The fractured fibula is approached through a ***posterolateral approach (T528)***.


438

In pilon fractures, of which there are several particularly centrally dislocated fragments, steady intraoperative joint distraction by a ***"distractor"*** locked ***in the tibia and the talus*** allows for instrumental space to reduce the fragments of the joint surface ***(T568)***. This is particularly useful laterally, for anterolateral impaction of Chaput's tubercle, or medially ***at the anterior aspect of the medial malleolus.***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2 Talus fractures

Talus fractures may be divided into two different types of lesions.

Peripheral fractures

In peripheral fractures, there is a joint problem due to an external force such as a dislocation or quasidislocation in one of the three joints that link the talus to the upper ankle joint, the calcaneus, and the navicular bone. The center of the talus remains intact, while the fracture causes a joint incongruence that impedes smooth articular function. Untreated, these fractures lead to joint stiffness and arthrosis.


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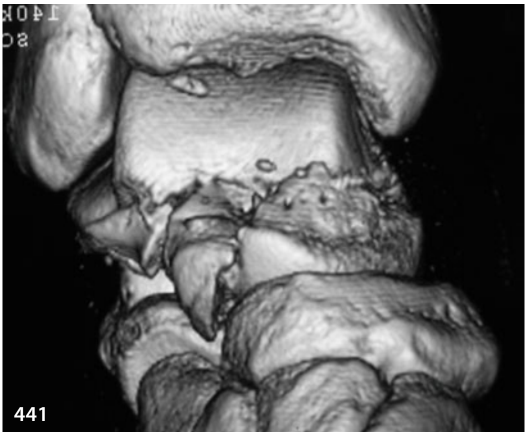
Central fractures

In ***central fractures,***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the general shape and external dimension of the foot are jeopardized. The fracture separates the upper ankle joint from one or both of the other joints. Under this aspect, the fracture type can be compared to the so-called two-column fractures of the acetabulum or to the more complex distal articular fractures of the tibia (AO 43-C fractures).

Untreated, these fractures lead to misalignment of the whole foot with consequent dysfunction and disability.

Approaches

The two lesions can, of course, run together.

Peripheral fractures may be approached directly wherever they occur, and the complexity of the talar joints is such that the fracture fragments in select cases may be better removed rather than reduced and fixed. The function of the local joint must be judged to achieve a rationally sound treatment. Some fractures involve essential aspects of the bone, and due to their small dimensions, the means of fixation may include fibrin glue and/or ***rotational stable (bone guiding) resorbable pins***.


442

Central fractures of the talus


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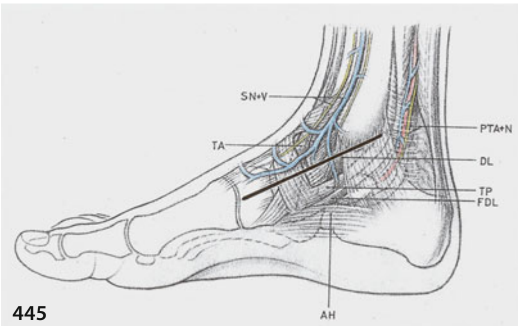
444

should be reduced and fixed from at least two (sometimes three) approaches.

Involving the shape of the whole bone that guides three major joints of the hindfoot, a minute misalignment of the "shell" of the bone may lead to an unacceptable shape on the other side of the bone. The most rational approaches (best efficiency/morbidity coefficient) may be found in the **longitudinal medial approach** from the tibialis posterior tendon insertion passing above the sustentaculum tali, **the anterolateral oblique approach** (modified Ducroquet approach (31)), and the **posterolateral vertical approach**, parallel to the heel cord.

Medial approach

The ***medial approach***

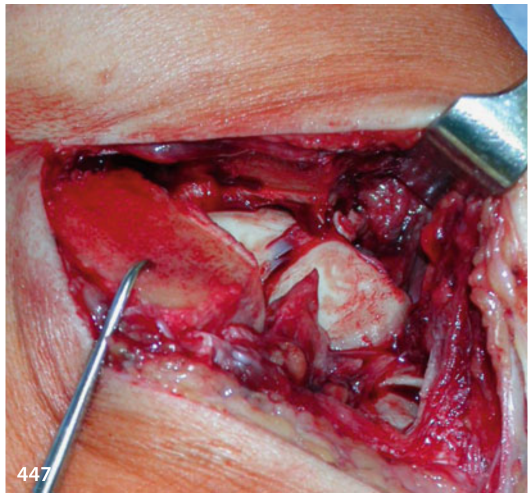


445

is meant to visualize the subtalar joint congruence between the talar head, the navicular, and the sustentaculum tali, as well as the continuity of the medial wall of the talus. In select cases in which the fracture is located in the middle third of the bone, an osteotomy of the medial malleolus and the tilting of it downward and posteriorly allows improved visualization of the fracture while protecting the posteromedial blood supply, which comes from the posterior tibial artery. A ***distracting device fixed between the tibia and the calcaneus***


446

allows for simultaneous ***visual control of the tibiotalar and subtalar joint surfaces***.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Anterolateral approach

The ***anterolateral approach (T537)***


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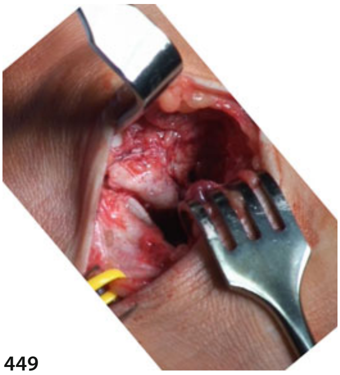
is used to visualize the lateral subtalar joint and the bony wall between the neck and processus lateralis tali.

5

This approach is optimal for visualizing the ***processus lateralis tali and its refixation***



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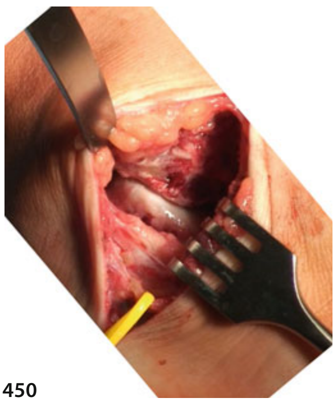
or removal.



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All of this region is visualized without relevant damage to the soft tissue, having both edges of the skin vascularized by the branches of the tibialis anterior artery and the lateral calcaneal artery. The musculus extensor brevis of the toes is reclined from proximal to distal and covers the bony situs well. It allows visualization of the lateral aspect of all four bones of the hindfoot: the talus, the anterior part of the calcaneus, the navicular bone, and the cuboid.

Posterolateral approach

The posterolateral approach ***(T537, T515)*** is performed in one precise, single plane running parallel to the heel cord and medial to the sural nerve. This approach naturally gives the ***optimal axis for screws fixing talus neck fractures***.

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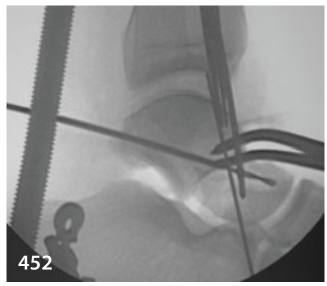


452

The distal belly of the musculus flexor hallucis longus is kept medially, protecting the neurovascular bundle. The entire posterior articular aspect of the subtalar joint is visualized, together with the posterior aspect of the upper ankle joint.

5

3 Calcaneus fractures

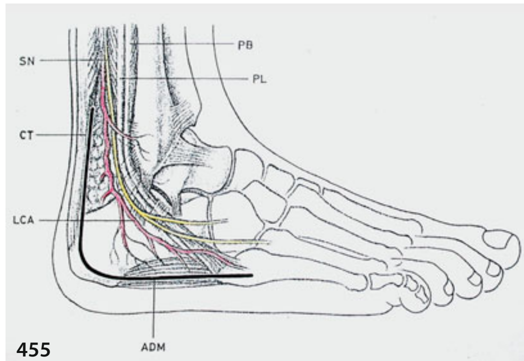
Calcaneus fractures follow a fate similar to that of central talus fractures. A particular aspect of calcaneus fractures is the high risk of bleeding within the deep compartment of the foot, increasing the intracompartmental hydraulic pressure and ***compartment syndrome*** (32). This occurs more often in simple but dislocated fractures in which the intercompartmental walls are intact. Thus, the diagnosis must be made at once to avoid irreversible consequences, which include shortening of the quadratus plantae muscle and shortening of the long flexors of the toes. In the long run, the forefoot presents ***multiple distal hammer toes***.


453


454

Avoiding compartment syndrome of the foot necessitates, after recognition of pathological intracompartmental pressure, the urgent release of the intercompartmental walls (septae or aponeuroses; 32).

Reduction and internal fixation is indicated for all fractures that include intraarticular courses. Even nondisplaced intraarticular fractures of the calcaneus are known to show a high likelihood of secondary displacement, which might produce an articular step. Another particular aspect of calcaneus fractures is that the shape and outer dimension of the bone are mandatory for uneventful function. The aim is thus to restore the shape and orientation of the whole bone. A vascular-safe approach (33) is taken that ***respects the vascularity of the lateral submalleolar aspect of the foot***.



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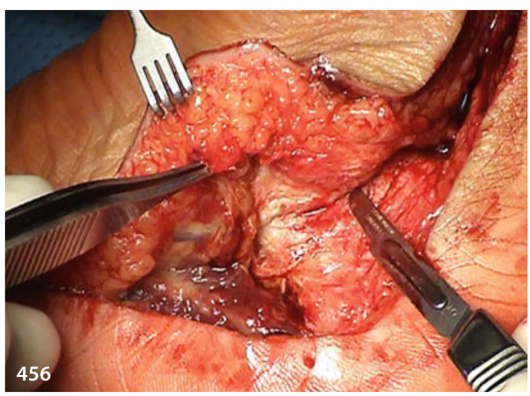
The vascularity of the soft tissue of the hindfoot is "centrifugal." By centrifugal vascularity, we mean a main source of blood supply from the deep layers at the center of a joint and vascularity that spreads out centrifugally from this center. The main weight-bearing function of the calcaneus occurs at the posterior facet, which is located beneath the lateral malleolus. It is therefore logical to approach, visualize, and repair the posterior facet from a lateral approach using the soft tissue of the posterolateral aspect of the foot like a soft tissue flap. The ***posterolateral skin–subcutaneous–periosteal flap*** (34)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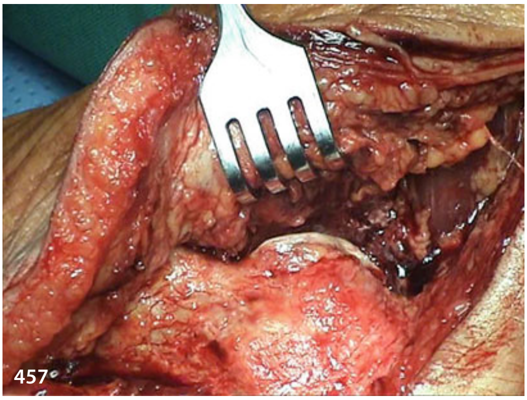
is reclined upward, allowing for visualization of ***the subtalar***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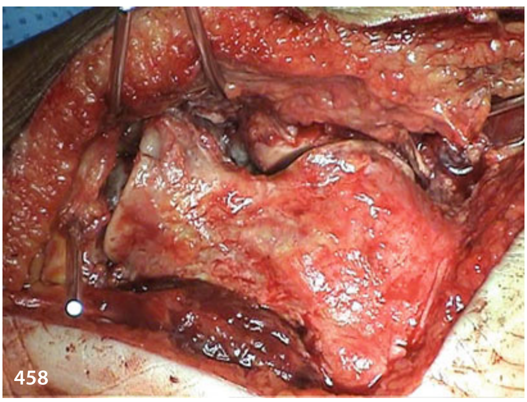
and **calcaneocuboid joints**.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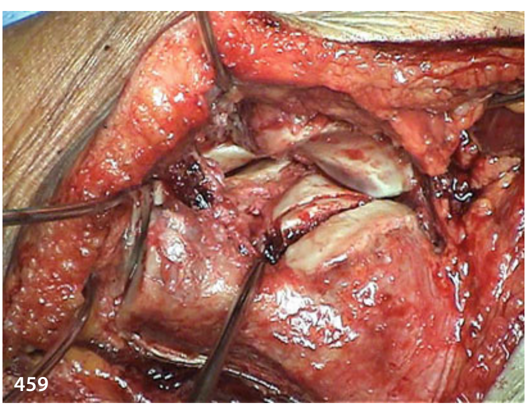
The medial aspect of the subtalar joint (***sustentaculum tali***) may also be visualized and checked with this approach.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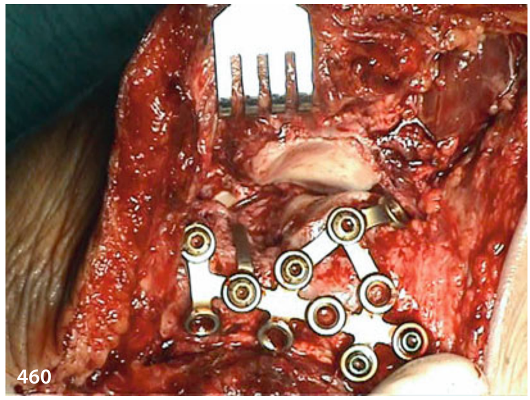
Congruence of the articular surfaces after fixation of the fragments is perfectly visualized,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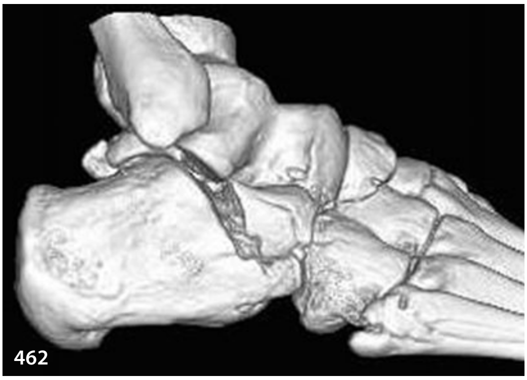
and the approach is safe for ***rapid consolidation of the soft tissues.***


461

In rare cases of anterior calcaneus fractures, meaning fractures of the ***processus anterior calcanei***, the safe approach respecting the vascularity of the soft tissues is the oblique anterolateral approach of the hindfoot ***(T536)***. Those fractures occur through the influence of the talus, which protrudes the acetabulum tali. So-called ***Chopart fracture–dislocations***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also produce these kinds of lesions. For this reason, these fractures are often linked to a fracture of the talus, which is addressed through the same approach.

Medial calcaneus fractures involve the ***sustentaculum tali.***


463

These fractures are severe lesions because the sustentaculum tali is the posterior wall of the coxa pedis and thus holds the talus at its physiologic height. This fracture also corresponds to a protrusion of the talus within the acetabulum pedis by breaking the posterior wall. A minimal dislocation of this fracture should be reduced and fixed anatomically for proper articular function. The best approach is performed directly on the sustentaculum tali between the tendons of the flexor digitorum longus and the flexor hallucis longus (***E96)***. The local bone offers a good hold ***for screws that cross the whole calcaneus***.


464

4 Tarsometatarsal fractures

Surgeons should be highly attentive to tarsometatarsal fractures in foot trauma because they are often difficult to diagnose, and treatment should follow the relevancy of the articular function.

Acute fractures

The freshly traumatized foot should first be evaluated clinically, although the severity of fracture-dislocations of the tarsometatarsal is ***not always suggestive clinically***.


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A **comparison with the other foot** should be made.

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Immediate radiologic assessment prior to any reduction maneuvers allows the setting of a treatment strategy and ***avoids any additional harm***.

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Assessing the comprehensive lesion is essential for ***setting the strategy*** by means of the chronology of treatment.

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These fractures occur through a strong sprain in plantar flexion and rotation of the foot and are common in motorcycle accidents or pedestrians who have been knocked down. The likelihood of compartment syndrome should be evaluated in all these cases.

In **nonevident dislocations**, diagnosis is much more difficult and is often missed. As an example, a short run on uneven ground with scarce visibility and while wearing high heels puts the individual at high risk of such trauma.

Localization of pain and ***painful examination of the single joints*** raises the suspicion of the lesion.

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5

The complexity of ***juxta-articular tarsometatarsal fractures***

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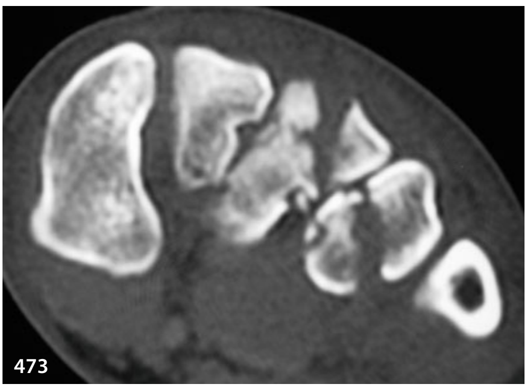
requires ***CT examination*** for a rational treatment plan.



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The key lesion, the torn or insufficient ***Lisfranc's ligament between the first cuneiform and the second metatarsal***, must be recognized.

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The question that arises most is in which cases should the joint be fused or in which cases should it be reconstructed? The central axis (second tarso-metatarsal joint) is the joint that ***best supports an occasional fusion.***

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For **evident fracture-dislocations** ***(F467)***, immediate open reduction allows for recognition of soft tissue entrapments of muscles and/or tendons. It eases reduction and avoids any risk of compartment bleeding. The single central approach, ***lateral to the anterior neurovascular bundle,*** allows for good visualization and handling.

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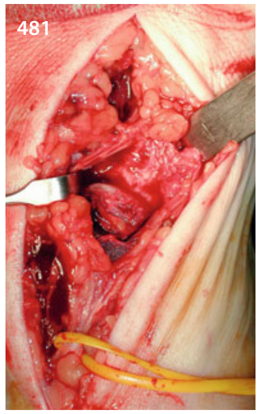
480

It is essential to recognize ***soft tissue entrapments***



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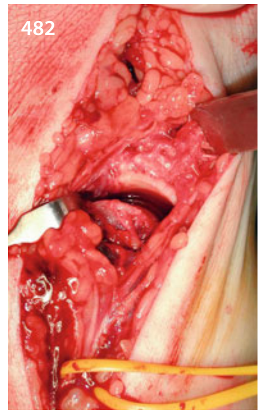

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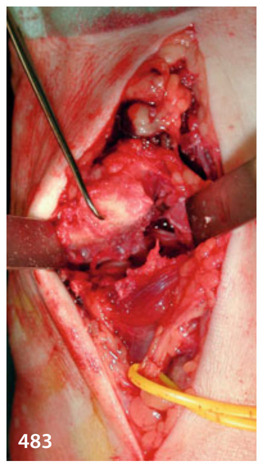
and the reduction of ***locked dislocated fragments.***



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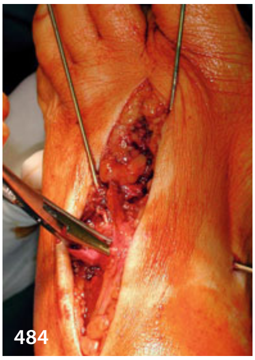
Treatment relies on recognizing the stability of the foot through the central (second and third) rays, which can be fused with no relevant loss of function. Temporary alignment with percutaneous wires is followed by ***percutaneous interfragmentary and transarticular fixation by screws***.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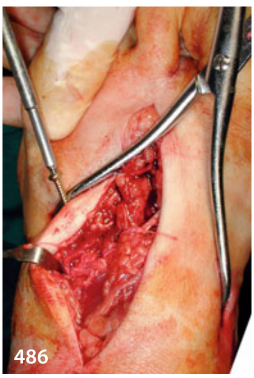
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The first ray holds a kind of intermediate position in the need for anatomic joint reconstruction or fusion.

One also should recall the ***need for mobility at the lateral (fourth and fifth) rays,*** which should not be fused in order to achieve good function. ***Symmetry with the other foot***, if asymptomatic, should be respected


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Malunions and nonunions

Revisions of posttraumatic conditions and revisions after open reduction internal fixation (ORIF) are frequent. In cases of ***complex fracture–dislocations***,


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first surgical repair

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may leave secondary causes of disability. Besides painful articular destructions, the causes are often metatarsalgia ***linked to bone length***

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and overall ***misalignment of the anterior heel***.

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These conditions demonstrate the interdependence between posttraumatic deformities or limitations and the original anatomic particularities ***(E44)***. Here, the destruction of the central and medial (second and first) tarsometatarsal joints required ***fusion (T675)***; the fourth and fifth tarsometatarsal joints required an interposition arthroplasty ***(T680)***; the anterior heel needed a horizontal as well as a sagittal alignment; the mobility of the first metatarsophalangeal joint had to be improved by an adaptive osteotomy ***(T715)***, and the toes needed specific corrections

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to achieve asymptomatic and ***unlimited function***.

5 Healing of traumatized biological tissues

In foot and ankle surgery, soft tissue is relatively thin and requires particular attention. Attention addresses the direct approach to the underlying structures to be treated, such as bones, joints, and tendons. Undermining soft tissue and using steady retractors harm perfusion and jeopardize healing. Multiple incisions to the skin are not a problem per se, and respecting the rule of thumb relating to centrifugal distribution of the vascular supply around joints may help in choosing approaches, especially in trauma.

Strain limits healing of all living tissues (35). **Direct bone healing** occurs only if interfragmentary strain (or relative motion) is less than 2%. In mechanical conditions that include higher strain values, **indirect bone healing** occurs: Bone resorbs at the extremities of the bone fragments (e.g., fracture site; (36)). The increase in distance among the fragments while interfragmentary mobility remains constant results in strain reduction. Periosteal callus is produced in the area of reduced strain and immobilizes the fragments. If the strain cannot be reduced by these natural means, nonunion and pseudarthrosis ensue. If the environment of the bone extremities is nonvital or necrotic, natural stabilization cannot occur, and the nonunion remains atrophic. **Cartilage** does not heal if the tissue layers are submitted to a strain greater than 10%. **Granulation tissue** and, probably, subcutaneous tissue and skin cannot heal if relative motion exceeds 100%. In conclusion, **reduction of strain of divided tissue enhances consolidation**.

On the other hand, joints undergo deterioration if they are immobilized for a relevant period of time ("fracture disease"; 37). Mobilization of joints soon after fractures is at the basis of internal fixation of fractures, and continuous passive motion considerably reduces this invalidating condition. In the special case of the upper ankle joint, up to 6 weeks of immobilization is clinically irrelevant to the end result.

There is thus a comfortable safe period of a few weeks after open surgical treatment of foot and ankle diseases and trauma that can be used to **reduce strain of the soft tissues by immobilization**. Such optimal immobilization seems to be obtained by the ***Jones dressing cast*** (38).

The multiple incisions in the foot and ankle are covered by, e.g., moist fat sterile layers and sterile gauzes. The foot and lower leg are then padded with a significant layer of cotton, and a cover of plaster of Paris immobilizes the dressing. The first look at the operative wounds in programmed cases thus occurs after 2 weeks.

Further functional care after this time depends on the procedure and includes the ankle-foot orthosis (***cam walker***),

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which allows for partial or full weight bearing by ***reducing the mechanical lever*** on the foot by a convex sole. The need to walk around in bad weather conditions under full weight bearing while still applying the cam effect can be eased by an ***air-permeable snow-boot-like cover***.

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Airproof coverage such as polyethylene should be avoided all times because of the immediate creation of wet chambers.

Operative Techniques

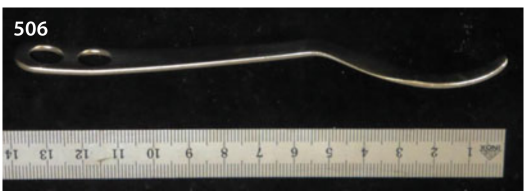
K. Klaue, *The Foot*,
DOI 10.1007/978-3-662-47697-0_6,

1 Skin and subcutaneous handling

The osteoarticular structures of the foot and ankle are very close to the skin. This allows a direct approach to the structures that must be addressed for surgical correction. On the other hand, there seems to be a critical distance in between the skin and subcutaneous incisions to avoid necrosis. In fact, the perfusion of the soft tissue hull about the foot and ankle follows a centrifugal pattern, centered about the main articular joints. If a wide surface of the foot has to be visualized, knowing this pattern of vascularization is essential. In fixing bones such as in arthrodesis or transverse fractures, means of central fixation are safe for preserving the soft tissues. Screws and nails can easily be introduced through small skin incisions and might be optimal in many cases to fulfil the required mechanical stability.

Instruments

To avoid deleterious local compression lesions at the surgical wound edges, ***adequate levers***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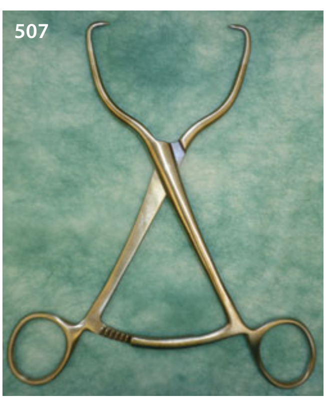
are used to optimize vision and reduce the risk of skin necrosis ***(T610)***. Also, for reducing fractures, adapting subluxing joints, and aligning metatarsals and the ankle, a percutaneous ***compression clamp***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helps secure the stability of the reduction. At the "closed" position of the clamp, the compressing points should be aligned.

Skin plasty

Lesser toes tend to be recruited by the long extensor muscles of the toes to assist the natural foot extensors such as the tibial anterior muscle and tendon. Shortening of the dorsal skin ensues, but it may also occur after previous surgery. The skin must be redirected. Taking the skin from lateral and medial allows for an increase in its length along the long dorsal axis of the foot. If the vascularity allows for undermining the skin, transposition of the skin edges allows for optimal efficacy (***Z-plasty***).


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If the local blood supply is jeopardized, pulling together the edges of a ***V-incision***

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also allows ***some lengthening*** (V–Y plasty).

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2 Surgical approaches

Upper ankle joint

Visualization of this joint is required in malleolar and pilon fractures and in osteotomies and fusions.

Posterolateral

The vertical line ***lateral to the heel cord and medial to the sural nerve (O232)***

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can be used to expose the deep structures in ***between the flexor hallucis longus and the fibular muscles***.

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The flexor hallucis longus muscle is ***pulled medially***

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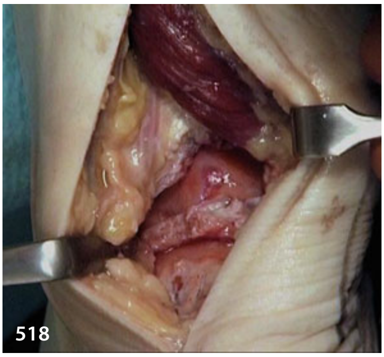
to provide an ***optimal view of the whole posterior aspect of the upper and lower ankle joints***.



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Anterior

The anterior pathway to the upper ankle can be taken through different portals.

The medial aspect of the anterior upper ankle joint is best seen through the space between the anterior tibial tendon and the extensor hallucis longus tendon ***(O212)***. The anterior tibial artery and the fibularis profundus nerve are thus protected laterally together with the extensor hallucis longus muscle ***(T568)***.

Anterolateral

The lateral aspect of the upper ankle joint is of special interest in the ***anterolateral tubercle of Chaput*** such as pilon tibial fractures.

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The pathway goes in between the long extensor tendons of the toes and the anterior fibular artery. Above the retinaculum, though, the ***superficial fibular nerve must be protected and held medially.***

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The easiest way below the retinaculum is to stick to the lateral edge of the most lateral tendon and handle with care toward the lateral direction all the soft tissue located above the anterior tibiofibular ligament (syndesmosis). This approach, which can be extended proximally, allows perfect handling of ***anterolateral lesions of the tibia.***

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Posteromedial

The ***posteromedial approach of the ankle*** is more critical than the others ***(F437)***. The skin incision is slightly curved ***between the medial malleolus and the heel cord.***


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The pathway goes behind ***the tibial nerve***, allowing visualization of and protecting its ***ramus calcaneus.***


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The lateral border of the approach is constituted by the ***flexor hallucis longus muscle belly***.


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This aspect is often interesting in specific fractures of the tibial pilon and control of the posteromedial reduction. It can be very useful to visualize complex pilon fractures using a joint distraction device. The two other approaches to be used simultaneously with the posteromedial approach are the anterolateral approach to the tibia and the posterolateral approach to the fibula.

Fibula

The distal fibula is covered by a few millimeters of skin and subcutaneous tissue. For this reason, the bone should be exposed either anteriorly or ***posteriorly (F438)***.


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The posterolateral aspect of the fibula is optimal for ***internal fixation by plate*** of eventual fractures ***(F422)***.

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Medial utility

The medial aspect of the foot is easily exposed in distal continuation of the posteromedial approach. In fact, it follows the medial lower edge of the bony structures ***from the aforementioned approach to the end phalanx of the big toe (T626, T645, T664)***.

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It considers the upper edge of the abductor hallucis muscle and allows presentation of ***the posterior tibial tendon***,

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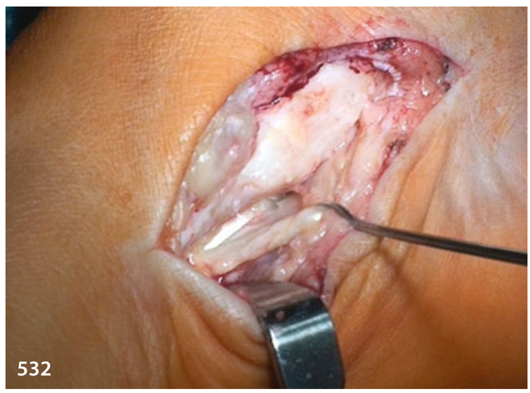
both ***long flexors of the toes***,



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the ***medial aspects of the subtalar, the talonavicular, naviculocuneiform, and eventually the first tarsometatarsal joint,***

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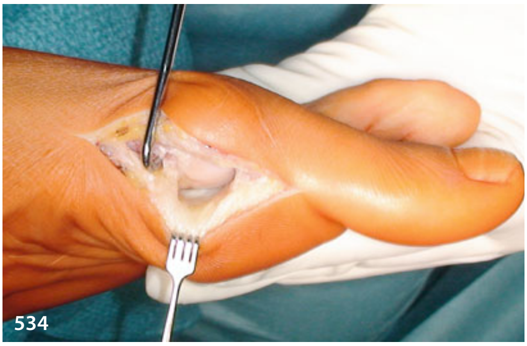
including the ***metatarso-phalangeo-sesamoid joint***.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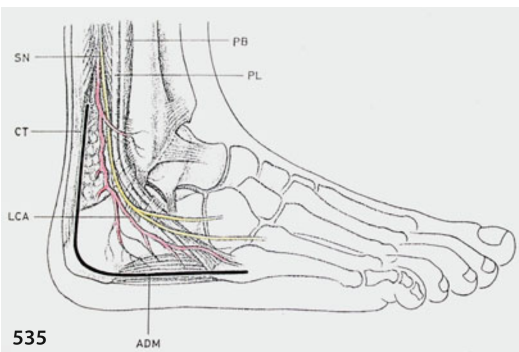
Lateral hindfoot

The lateral hindfoot approach discovers the lateral wall of the calcaneus, which allows for open reduction and fixation of fractures and osteotomies ***(T610)***. It follows the perfusion of the local tissues, which is linked to ***the lateral calcaneal artery.***



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The approach thus produces a ***cutaneo-subcutaneo-periosteal flap*** (34) ***(F456).***

Lateral midfoot

The apex of the acetabulum pedis is located in the lateral midfoot. Here, the four bones – calcaneus (anterior process), cuboid, navicular (lateral part), and talus (lateral head) – can be presented through a single approach ***(T541)***. Described in a more extended version by Ducroquet and Launay (31), it allows for all bony and ligamentous reconstructions, osteotomies, and fusions of the lateral midfoot.

The skin incision is inclined 45 degrees to the lateral edge of the foot sole and is ***centered on the crucial angle of Gissane.***


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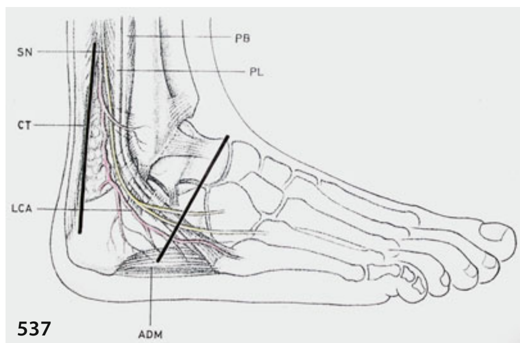
It can be performed ***together with the postero-lateral approach.***



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The ***sural nerve*** must be protected.

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The ***extensor digitorum brevis is reclined distally*** and allows for safe, well-vascularized coverage.

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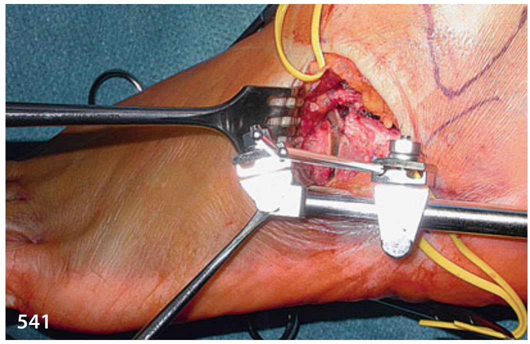
A ***local distraction device*** allows for eventual articular revision.



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Medial tarsometatarsus

The tarsometatarsal region medial to the anterior neurovascular bundle is best visualized ***between the long and the short extensor tendons of the big toe***.

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The insertion of the anterior tibial tendon, which covers the whole medial aspect of the joint, remains untouched. Exposing the first intermetatarsal space is interesting to achieve fusion between the first two medial metatarsals. In cases of subluxation of the first metatarso-phalangeo-sesamoid joint, the distal part of the incision is used to ***visualize the lateral***

aspect of the first metatarsal head and the first phalanx of the big toe ***(T662)***.


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Central tarsometatarsus

Both second and third tarsometatarsal joints belong to the "navicular foot" and are located lateral to the anterior neurovascular bundle. This approach is interesting at its proximal end for ***visualizing the second and third tarsometatarsal joints (T672)***


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for eventual fusions or arthroplasties. For proximal metaphyseal osteotomies, the approaches can be limited to a ***direct subcutaneous access*** for each ray separately.


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Lateral tarsometatarsus

The fourth and fifth tarsometatarsal joints belong to the "cuboid foot" and can be ***exposed together*** for eventual osteosynthesis or arthroplasty ***(T680)***.


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Because of the flexibility of the lateral foot, they are considered essential joints and should not be fused.

Central metatarsus

Both second and third metatarsi belong together anatomically. To visualize the corresponding diaphysis for osteosynthesis or osteotomies ***(T692)***, a longitudinal incision is made exactly between the two bones. The interosseous musculature remains untouched, and both metatarsi are presented separately ***on the lateral aspect of the corresponding long extensor of the toes*** and without dividing any intrinsic muscle.

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The intermetatarsal musculature and neurovascular structures remain within their "fatty atmosphere" to avoid secondary rigidity and dysesthesia.

Fourth metatarsus

The fourth metatarsus belongs to the "cuboid foot." The incision is lateral to the fourth metatarsal. The incision allows for a direct approach to the fourth metatarsus, such as for osteotomy.

Both incisions to ***expose the central and the fourth metatarsi can be performed simultaneously.***

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At the midlevel of the metatarsus, the long extensor muscle tendon of the fifth toe crosses the field and must be protected.

Fifth metatarsus

The fifth metatarsus must be approached laterally for osteotomy ***(T711)***, which reorients the bone in adduction. The approach is logically performed passing on the lateral aspect of the bone, ***above the abductor digiti quinti muscle***.

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Lesser toes

Toes 2–5 must be approached for dorsal metatarsophalangeal arthrolysis and extensor tenotomies, proximal interphalangeal fusion ***(T757)***, and flexor tendon transfers onto the first phalanx for active stabilization of the toes. The ***logical approach is thus dorsal***.

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The flexor tendons can be harvested passing close to the bone toward plantar, at the level of the proximal interphalangeal joint ***(O403)***.

The distal interphalangeal joint can be specifically visualized by a ***transverse incision*** at the level of the joint.

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3 Postoperative care

Divided biological tissue usually consolidates both rapidly and safely following ***interfragmentary strain***. Skin is less demanding than bone, which means that relative motion between the edges of the divided skin may admit strain up to 100% (38). The best healing, though, is obtained by reducing the strain of the soft tissues after surgical trauma. Jones introduced this concept in foot and ankle surgery more than 100 years ago. Today, sterile, packed soft padding of the whole foot and ankle, when covered by plaster of Paris ***(F501)***, does reduce to a minimum the soft tissue strain (38). The multiple joints are thus immobilized, which allows for safe blood supply and constant safe venous drainage. Skin and subcutaneous healing takes about ***2 weeks*** to consolidate to allow motion.

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The first wound dressing change is thus performed 2 weeks after surgery.

4 Bone and joint reconstruction and alignment

Supramalleolar osteotomy

The aim is to redirect the upper ankle joint in a congruent tibiofibular malleolar fork to achieve perfect horizontality of the talar dome within the frontal plane. Consequently, both tibia and fibula are always osteotomized ***(O197)***. To limit harm to the soft tissues, the safest approach to the tibia is anterior. The tibia is exposed medial to the anterior tibial muscle and lateral to its tendon (more distal), thereby protecting the anterior tibial artery and the deep fibular nerve. The fibula is best approached from a posterolateral direction as for malleolar fractures. Thus, the anterior fibular artery is protected, as is the superficial fibular nerve. If the anterior cutaneous conditions are critical, the approach to the tibia is from posterolateral. The fibular vessels are then visualized and protected while the tibia and fibula are addressed through the same approach ***(O193)***.

Plane-cut osteotomies

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not only allow for angular correction but also for axial rotation as well as transverse shifting. No relevant length discrepancy should be feared with this technique. Overhanging bone about the medial malleolus is trimmed down to avoid soft tissue strains. The tibia and fibula are fixed by plates and screws. The osteotomy of the tibia is thus situated about 3 cm proximal to the anterior articular rim and the fibula slightly more proximal. This allows for a straight plate fixation on the fibula with a sufficient lever. The bone wedge is first removed on the tibia because the control of the osteotomy planes is optimal in mechanically still conditions.

Any undesired angulations of the osteotomies in the sagittal plane must be avoided to achieve a stable montage. At this stage, the fibula can be cut.

In corrections aiming in varus, the ***fibula will be cut obliquely,***

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and the osteotomy surfaces will glide upon each other. ***The tibia is fixed first*** with an L-shaped plate allowing for at least two sagittal horizontal screws within the distal fragment. Two screws within the proximal fragment secure the angulation within the frontal plane.

The fibula is adapted ***by a flexible tubular plate.***

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The soft tissue layers of the supramalleolar region, or more precisely the distal third of the lower leg, are known to be generally critical. Closing wedge osteotomies are therefore safer to achieve, especially the corrections into valgus. In corrections aiming in valgus, the ***fibula will undergo a resection*** about a centimeter or two above the tibial osteotomy with the making of two ***parallel cuts***.


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The ***interosseus membrane thus remains intact***.


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The correction of each supramalleolar osteotomy relies on the adaptation of the tibia osteotomy. The fibula is then aligned using a thin straight plate and four screws ***(T555, T556)***.

Lateral malleolus osteotomy

Such osteotomy is indicated in malunions of malleolar fractures ***(O199)*** in which the articular congruence of the malleolar fork is lost. The distal fibula should regain functional congruence with the upper ankle joint, which had been lost through the previous trauma.

Generally, as in all fractures, there has been a loss of length that has to be regained. When the most frequent malleolar fractures that singularly involve the fibula are considered, the medial malleolar joint space seems to be increased, thus demonstrating the anterior opening of the joint. With the shortening, ***the broken distal fibula undergoes an additional angulation in external rotation and abduction***


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together with the whole underlying foot.

The contralateral radiograph is used as a template for the correction.


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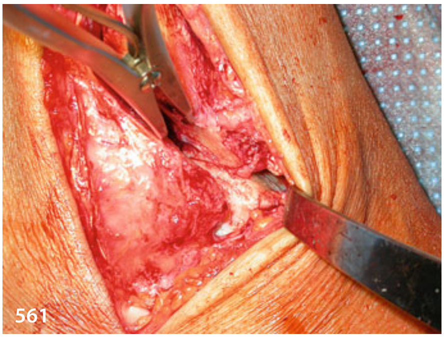
The aim is thus to regain length, internal rotation, and adduction of the distal articular fragment, which will reduce the talus beneath the tibia and correct the abnormally increased joint space of the medial malleolus. ***The osteotomy follows the former fracture plane.***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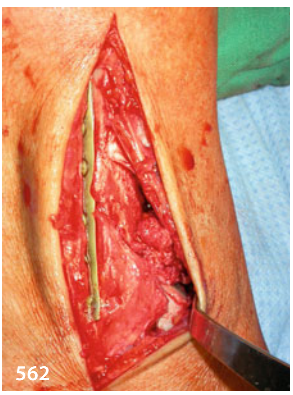
The plate is fixed onto the distal fragment and is used as a lever to achieve anatomic length.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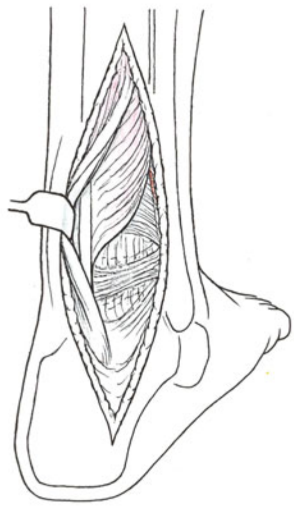
Upper ankle fusion

The upper ankle is wide in the front and narrow in the back. Degeneration of the joint is therefore accompanied by an anterior shift of the talus within the mortise ***(O229)***. The logical pathway to correct the position is the posterolateral approach ***(T515)*** to "open" the posterior space, pushing the talus backward for fusion to the tibial plafond. The posterolateral approach is done vertically, which avoids problems when length must be gained. The optimal way is between the sural nerve lateral and the heel cord medial. Keeping within the same plane, the deep space is safe, and the flesh of the ***flexor hallucis longus is kept medial*** and the fibular muscles lateral.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The fibula is divided above the syndesmosis, taking away a segment corresponding to the shortening induced by the arthrodesis and occasional valgus correction, thereby avoiding fibula-calcaneal impingement. The joint is opened and distracted. A distractor occasionally helps when placed medially between the tibia and the calcaneus, thus ***avoiding the feared varus malunion***.

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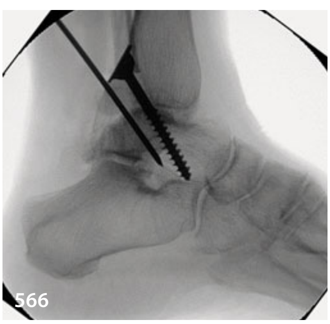
The entire joint can be seen, and debridement is performed. The talus is placed judiciously beneath the tibial plafond with a discrete shift posterior to its normal position. A ***strong screw helps pull it backward*** when placed in the same oblique vertical plane as the surgical approach. This plane cuts the head of the talus. An ***optional wide washer*** achieves sufficient hold on the posterior aspect of the distal tibia.



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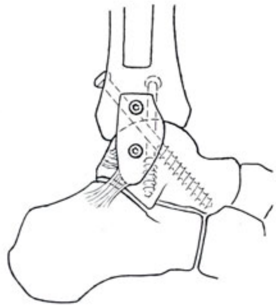
A second screw is placed percutaneously from medial and above the malleolus to the posterolateral aspect of the talus. The ***syndesmosis can be used together with the fibulotalar joint as fusion surfaces*** that are compressed by two thinner screws.



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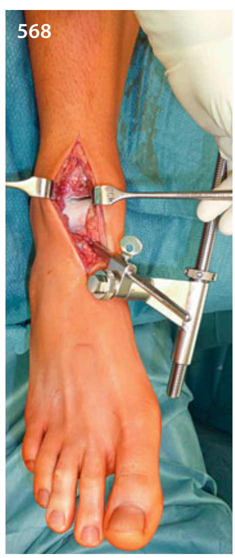
At the end, the foot must be perfectly vertical to the lower leg and the heel lateral to the original upper ankle joint or similar to the other foot (39) ***(O232)***.

Osteochondroplasty of the talus

In symptomatic, adult osteochondritis dissecans of the talus ***(O179)***, autologous osteocartilaginous transplants from the ipsilateral femoral condyle give long-lasting and very good results (21). After either anteromedial, anterolateral, or posterior arthrotomy of the upper ankle joint, the joint is visualized by mechanical joint distraction using a ***distraction device anchored within the tibia and the talar body;***



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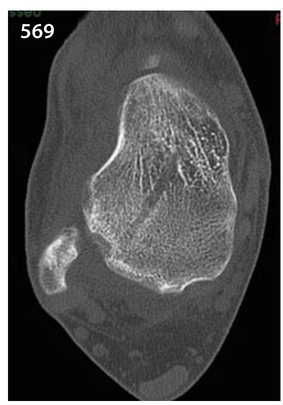

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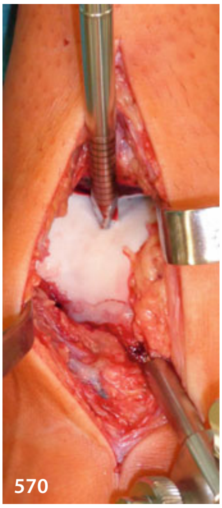
the ***avascular fragment is enucleated or drilled out;***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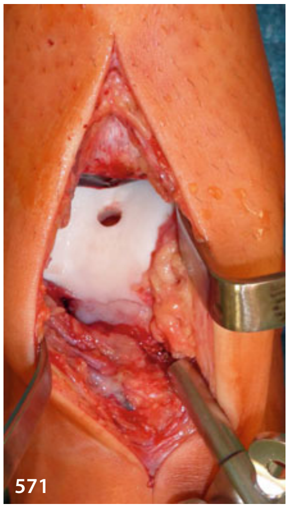
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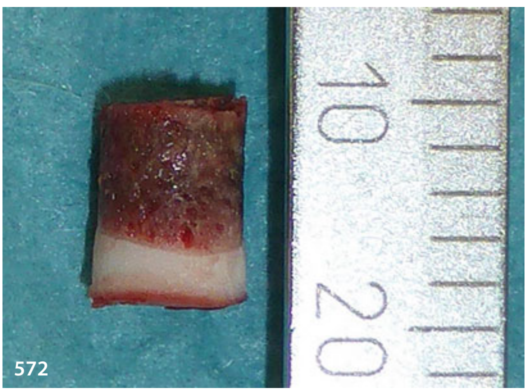
and the needed transplant is evaluated. The ipsilateral medial femoral condyle is exposed and the ***transplant taken from the medial edge***,



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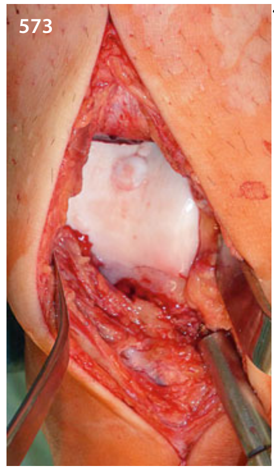
following the shape required by the recipient.

The specific tubular osteotomies and shanks are indispensable for achieving a ***stable transplant (O180)***.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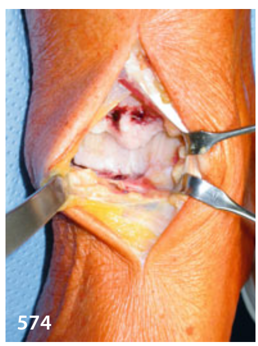
Cheilectomy of the upper ankle joint

When removing articular impingements of the joints, the stability of the joint should always be considered. Within the upper ankle joint, arthrosis, with its impinging osteophytes, may already be linked to a causal instability that should not be made worse by bone resection. At the anterior aspect of the joint, such ***bone resection is thus preferably performed on the talar side (O184).***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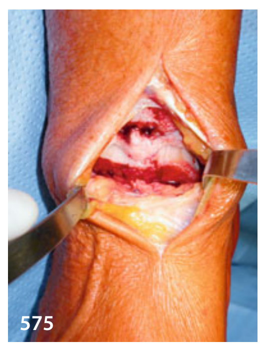
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Soft tissue impingements of the anterior and posterior aspects of the joint are relatively frequent and should be removed if clinically relevant. The anterior approach is parallel to the lateral edge of the anterior tibial tendon. Posteromedial and lateral impingements (e.g., free talus fragments) ***(O186, R162)*** are removed through the ***posterior medial approach***, leaving the neurovascular bundle anterior to avoid any vascular disturbance to the talus.

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The calcaneal branch of the tibial nerve is also protected.

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The pathway is located ***between the tibial nerve and the flexor hallucis longus*** tendon.

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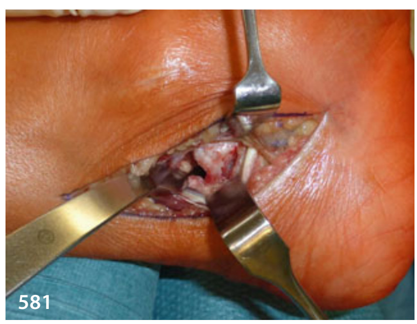
Both ***tibiotalar and talocalcaneal joints*** are opened, and



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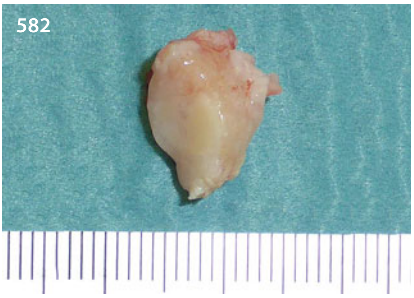
the free-moving ***fragment is enucleated.***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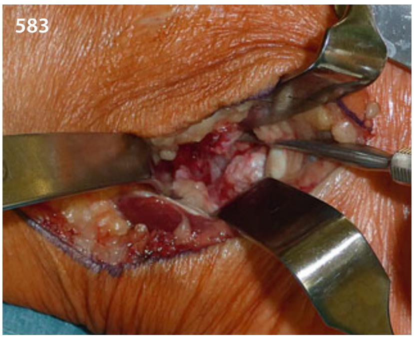
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A pointing ***posteromedial process also undergoes resection.***


584

Posterolateral impingements are removed in select cases through the posterolateral approach (39) (***E100***).

Cheilectomy of the lower ankle joint

Peripheral fractures of the talus often impede articular function of the subtalar joint and provoke joint degeneration. Multifragmentary fractures of the lateral process of the talus that are obviously avascular are best removed, taking care to not jeopardize the joint's stability ***(F450)***. If untreated, these fractures often result in chronic pain due to the malunited impinging bone. Impingement may also occur after any surgical procedure of the sinus tarsi, such as central calcaneus osteotomy ***(O251)*** to repair pes planus abductus.

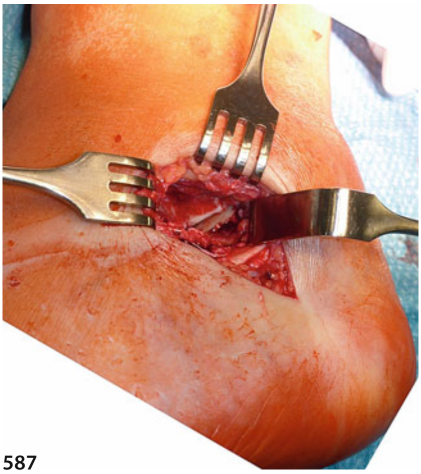
The impingement corresponds to the ***abutment of the processus lateralis tali onto the critical angle of Gissane of the lateral calcaneus***


585

in eversion of the foot ***(O316)***. Secondary resection helps in restoring normal motion of the coxa pedis. ***Cheilectomy*** on both talar (processus lateralis tali) and calcaneal sides (critical angle of Gissane) ***improves subtalar motion***.


586

The optimal approach is the ***oblique anterolateral approach*** due to the local vascularity of the soft tissues (31). The short extensor muscle of the toes is detached and reclined distally.



587

Traumatic lesions including subtalar subluxations and dislocations may end in painful medial impingements located about the sustentaculum tali. The best approach for debridement and arthrolysis is centered on the sustentaculum between the flexor digitorum longus and the flexor hallucis longus ***(E96)***.

Reorientation arthrodesis of the subtalar joint

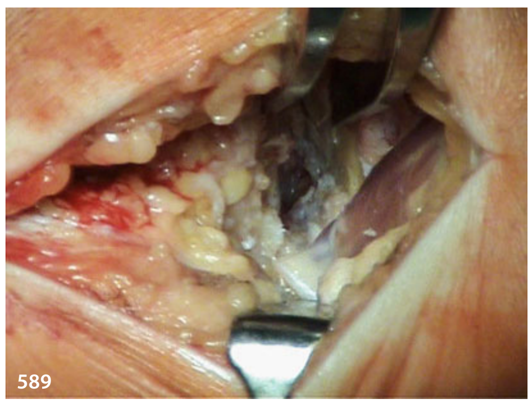
Malorientation and secondary subtalar joint degeneration after trauma most often causes a dorsal extension of the talus. The aim is to align the axis of the talus to the axis of the first metatarsus within the sagittal plane ***(R149)***. The approach is clearly best performed ***from the posterolateral plane*** because the largest mobilization of all tissues (bone and soft) is located behind the joint **(*T564*)**.

Additionally, the frontal alignment must be controlled at all times, and this is possible only from behind using a distracting device in select cases. The patient lies on the contralateral side with a tourniquet on the thigh. This allows for very convenient radiologic control using vertical fluoroscopy and by bending of the knee joint **(*T565*)**.

Skin incision is lateral and parallel to the heel cord.

588

The plane of approach is strictly vertical and sagittal, remaining at all times posterior to the sural nerve close to the skin and lateral to the flexor hallucis longus in the depth ***(T564)***. Its muscle belly, protecting the neurovascular bundle, is held toward medial with a ***smooth rectangular retractor (Langenbeck).***

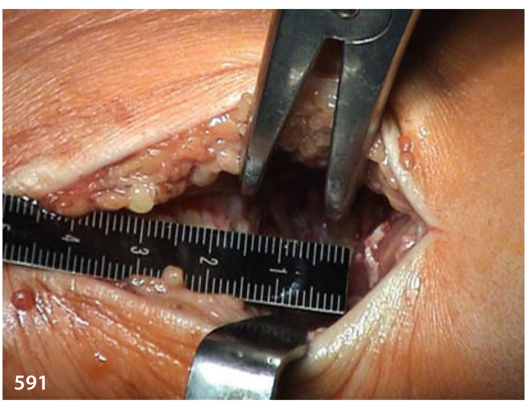


589

The fibular tendons are the lateral limit of the approach. The joint is opened and the occasional osteophytes removed. Opening the joint space is often difficult due to the articular destruction with occasional impaction of the talus within the calcaneus. In these cases, a Schantz screw is fixed in the tuber calcanei and another is placed in the tibia, and a distraction device (distractor) is installed parallel to the lower leg ***(T565)***. Most often, the joint is more difficult to mobilize medially, and to avoid any varus malunion of the heel, the device is placed on the medial aspect of the leg. In addition, the talus and calcaneus are progressively separated from each other using a distraction forceps (laminar spreader) while the remnants of cartilage and the subchondral bone are removed using a ***curved Lambotte osteotome.***

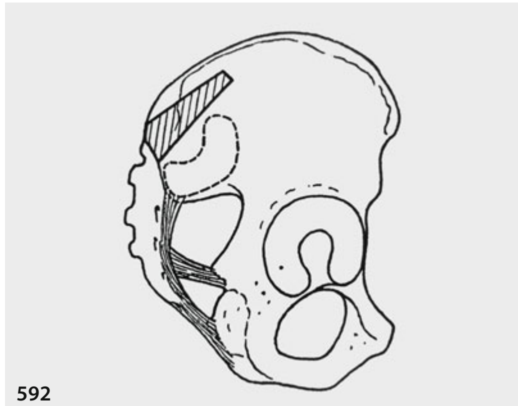
590

The entire posterior subtalar space is thus exposed. Orientation of the talus can be controlled by an adequate "joystick" pin. The joint capsule must be opened medially and laterally to allow for reorientation within the frontal plane. The physiologic valgus of the heel is checked clinically, and the divergence of talus and calcaneus is verified on lateral fluoroscopy. The ***height and depth of the space*** between the talus and the calcaneus is evaluated and measured.



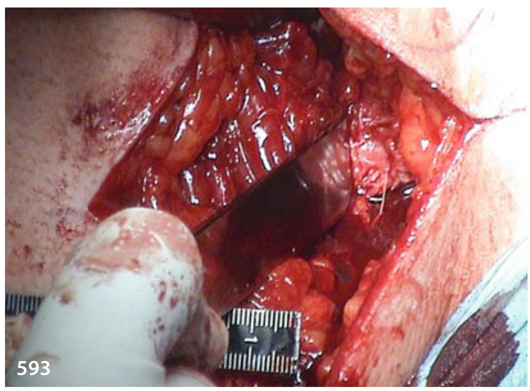
591

The ipsilateral ***posterior pelvic bone*** is considered for harvesting a tricortical bone block.



592

The tourniquet is released temporarily and the incision is vertical, centering the posterior iliac spine. The bone is harvested beneath the spine using a ***straight osteotome to avoid heat necrosis***.

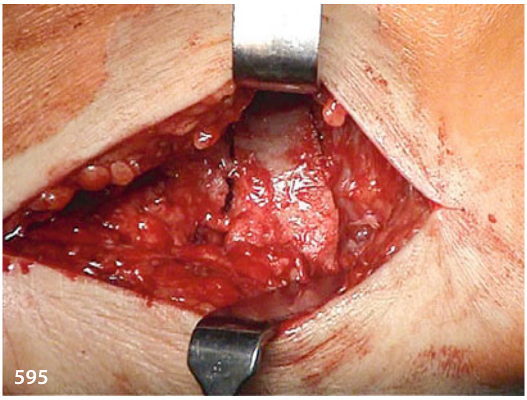


593

The bone block is ***trimmed to the exact dimension,***

594

which most often includes a higher medial wall of the transplant than lateral, and it is ***wedged in the posterior subtalar space (O238).***



595

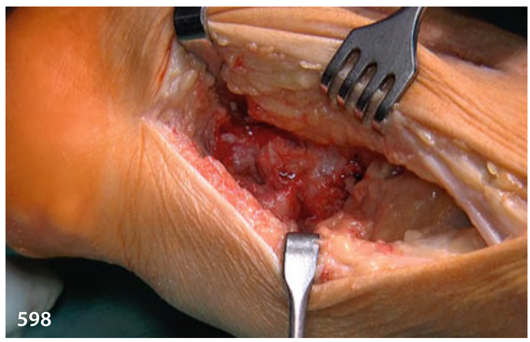
Spontaneous stability should be achieved, while fixation by two screws protects the montage against eventual medial–lateral stresses within the frontal plane. The axes of these screws preferably ***cross the natural axis of the subtalar motion*** for optimal counteraction of any eventual destabilizing stresses.

596

Tibiotalocalcaneal arthrodesis

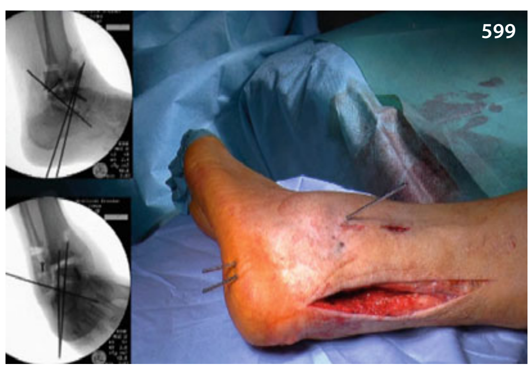
If both upper and subtalar joints are destroyed for any reason and require fusion, the need to achieve a stable normal axis of the hindfoot or at least a similar orientation to the contralateral foot becomes greater than ever ***(E37)***. Both joints must be mobilized to allow for free angulation and shifting in any plane. To achieve good function, the aim is a slight, augmented external rotation of the foot in relation to the knee axis. To resect the remaining cartilage and the occasional bone, the ***posterolateral approach*** is probably the most accurate pathway in the majority of cases (***T564***).

597



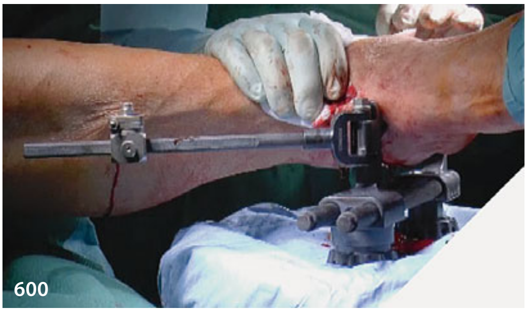
598

The patient is thus in ***true lateral position with vertical radioscopic control*** available. The talus is centered beneath the tibia or slightly shifted posteriorly, and the heel is aligned beneath the tibia in the desired alignment (physiologic valgus) and ***fixed temporarily with transfixing Kirschner wires.***



599

The frontal alignment of the lower leg and the axis of the foot to the knee axis are controlled clinically and radiologically. Within the sagittal plane, a perfect orthogonal position at the right angle of the plantar surface to the lower leg must be checked. The **circular curve** crossing the tuber calcanei, the posterior subtalar joint facet, the center of the distal tibial joint surface, and the distal tibial metaphysis is found ***(O242)*** virtually using an ***external frame under radioscopy***.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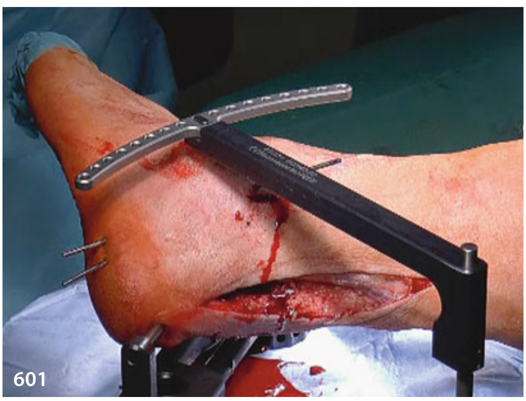
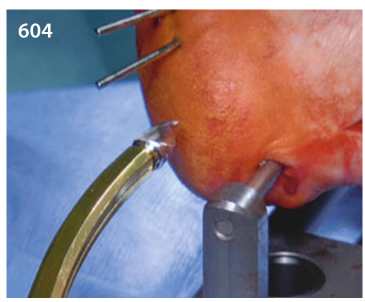

601

A ***drill bit*** attached to a flexible motor axis is ***fixed within a rigid curved hull***


602


603

and is ***rotated around the center of the arc*** to drill through the three bones and achieve the ***circular curved bone tunnel***.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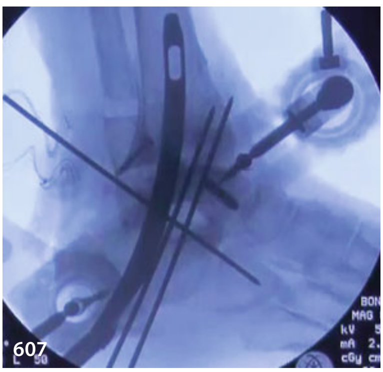
605

A corresponding ***curved nail is smoothly impacted*** in the opening following precisely the predrilled hole, thus achieving immediate optimal stability ***(O244)***.


606


607

Rotational stability of the subtalar joint and the nail is achieved through a screw ***securing the nail against backing out.***


608

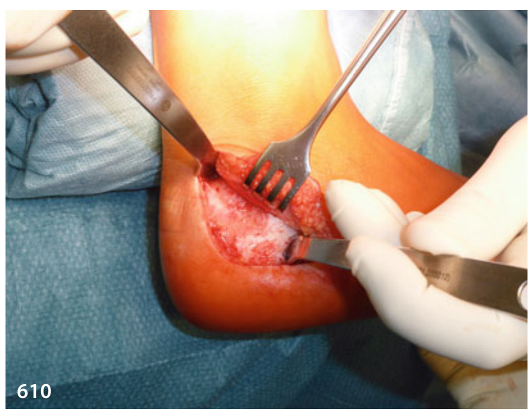
Rotational stability of the upper ankle joint is secured by a locking screw within the distal tibia, crossing the nail through a hole that ***allows for impaction of the nail*** toward the tibia.


609

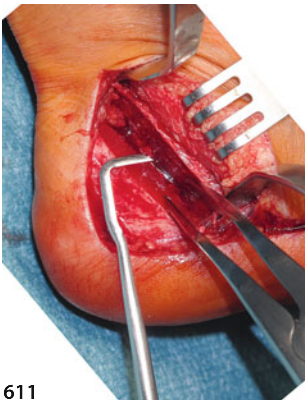
The construct thus defines a central load transmitter that intimately contacts the cancellous bone of the three bones of the hindfoot ***(O245)***.

Osteotomy of the tuber calcanei

In pes cavus varus adductus, the varus and adductus components are corrected by lateralizing the tuber calcanei ***(O204)***. ***The approach is lateral***


610

but smaller than for calcaneus fractures because only the tuber calcanei is exposed ***(T455)***. The osteotomy is oblique from posterodorsal to anteroplantar, joining the calcaneus spur to the anterior aspect of the pre-Achillean bursa. The course of the osteotomy avoids jeopardizing the neurologic pedicle on the medial aspect of the hindfoot. Distraction of the fragments precedes indirect release of the soft tissues on the medial aspect using an ***angulated periosteal elevator.***



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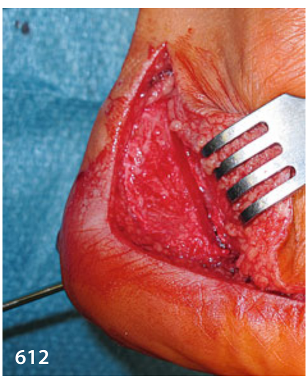
The tuber is ***shifted laterally*** about 1 cm to a maximum of 1.5 cm for optimal correction.



612

Stability is secured using two 3.5-mm screws to avoid shear and axial rotation. Interfragmentary functional compression is secured by the heel cord and the plantar fascia.

In the rare indications requiring a shift of the mechanical axis <u>toward medial</u> beneath the upper ankle joint, the tuber calcanei is moved medially through the oblique tuber calcanei osteotomy. This correction allows for ***moving the weight-bearing axis of the upper ankle joint toward medial***. The procedure is similar to the lateral shift of the tuber ***(O218)***.

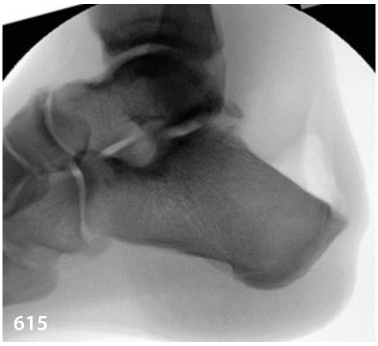
613

Posterior calcaneal ostectomy

Repetitive hammering of the posterosuperior apophysis of the calcaneus on the distal Achilles tendon triggers a chronic pre-Achillean bursitis (20) ***(O174)***. A tendinitis component may also occur. The aim of treatment is to remove the causal osteophyte. The most efficient resection removes all bone at the dorsum of the calcaneus ***(O177) that might interfere with active flexion and extension***.

614

A straight, virtual line connecting the insertion of the Achilles tendon and the posterior aspect of the subtalar joint is a good ***landmark for bone resection***.

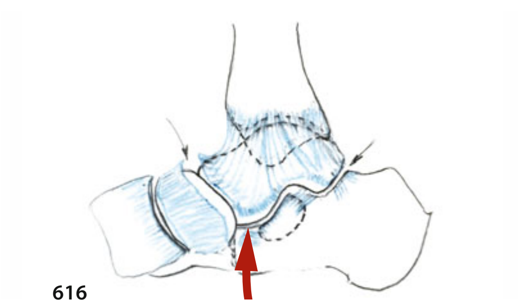

615

The lateral vertical approach at the lateral edge of the heel cord at about 6 cm is optimal because of the lateral position of the tuber calcanei.

Arthrolysis of the talocalcaneonavicular joint

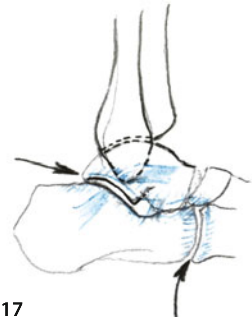
Arthrolysis opens contracted, closed, and often rigid joints in, for example, congenital club feet. The lower ankle joint is essentially made up of the talocalcaneonavicular joint. A closed talocalcaneonavicular joint corresponds to a pes cavus varus adductus in which the navicular bone is very close to the calcaneus, including a short ligament linking those bones ("spring ligament"). This pathological joint has the tendency to dislocate: The talar head is uncovered at the dorsolateral aspect of the foot. It is the dysplastic coxa pedis.

The first move to correct such a deformity is to open the calcaneonavicular space or acetabulum pedis ***(O282)***. The approach is thus longitudinal medial ***(T531)*** to avoid problems in soft tissue healing. In addition to ***dividing the spring ligament***,


616

a tenotomy of the posterior tibial tendon is indicated for eventual lengthening. Through the same approach, keeping close to the bony roof of the approach, the medial aspect of the calcaneocuboid joint is visualized and opened.

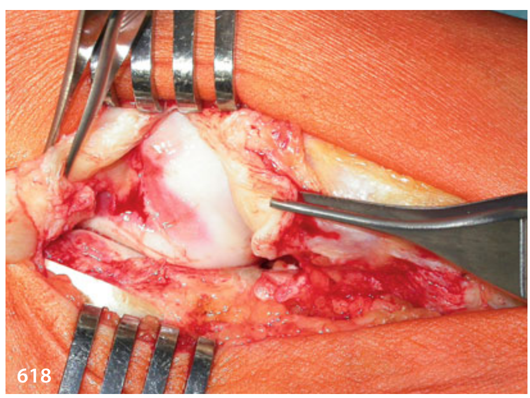
In select cases on the lateral aspect of the foot, the ***calcaneocuboid joint will also be opened***


617

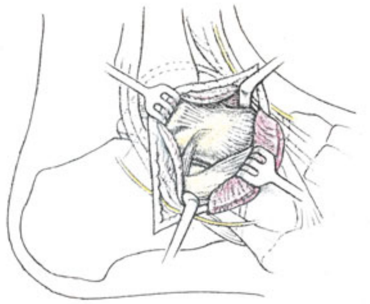
to allow for aligning the lateral wall of the calcaneus with the fifth metatarsus within the horizontal plane.

Central talus osteotomy

In mobile, flexible pes cavus varus adductus ***(E85, E91, O277)*** in which the arthrolysis is not sufficient for correction due to bony deformities, opening the acetabulum pedis by moving the head of the talus medially is a very strong move toward morphologic correction ***(O278)***. The first approach is longitudinal medial on the level of the subtalar joint. The posterior tibial tendon is released from its navicular insertion, and the spring ligament is divided after ***opening the medial aspect of the articular capsule.***

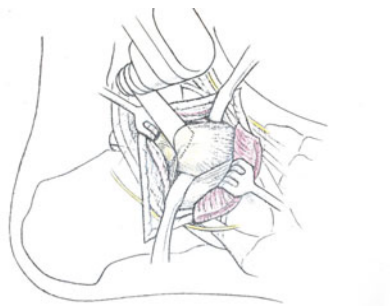

618

In addition to the medial longitudinal approach, a small ***anterolateral approach (T540)***



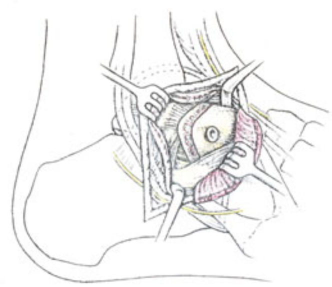
619

allows for optimal positioning of a talar neck osteotomy ***(O276)*** (41) at the level of the canalis tarsi ***in front of the processus lateralis tali***.



620

The talar head thus gets ***pushed toward medial*** onto the sustentaculum tali ***(O278)***,



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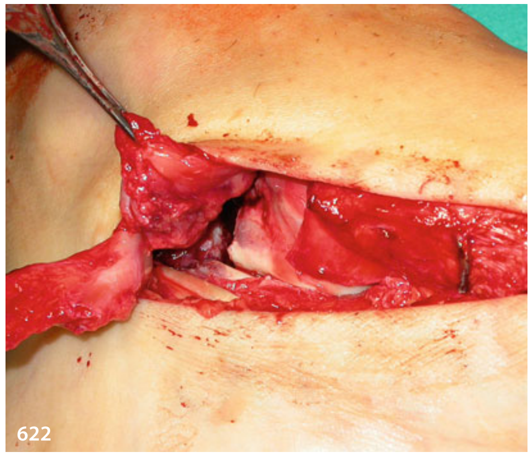
pushing the navicular bone distally and laterally. Seen from the medial side, the talar head ***occupies the space between the navicular and the sustentaculum tali,***



622

staying above both long flexor tendons of the toes and the tenotomized posterior tibial tendon.

In severe cases, this effect is increased by interposing a tricortical bone graft within the osteotomy.

Central calcaneus osteotomy

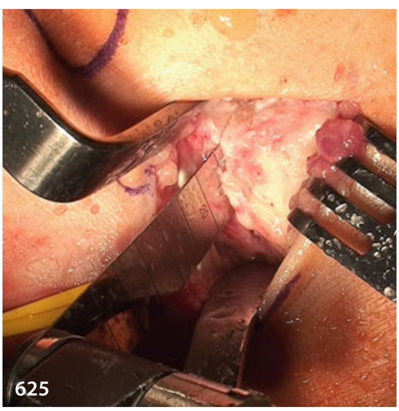
Symptomatic pronated feet with or without abductus may be corrected by central calcaneus osteotomy ***(O246)*** (27). The approach is anterolateral and oblique, ***centering the crucial angle of Gissane (T540)***.

623

The ***sural nerve***


624

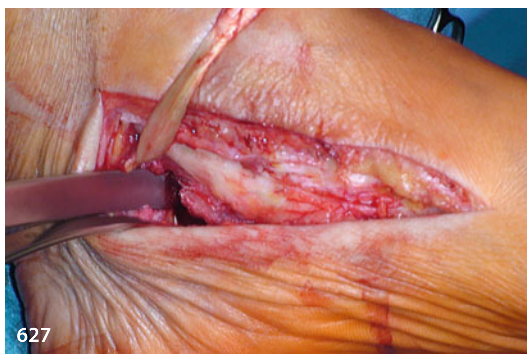
and the fibular tendons are protected. The short extensor muscle of the toes is detached from the calcaneus and reclined toward distal. The anterior aspect of the posterior facet of the calcaneus is shown while opening the joint. The osteotomy from lateral is ***partial and straight*** and does not cross the whole calcaneus body ***(O250)***, ***starting at the crucial angle of Gissane***. The osteotomy is made using a precise narrow oscillating saw, ending its course precisely at the medial edge of the posterior facet.


625

At this stage, the medial approach is performed longitudinally between the first cuneiform and the posterior aspect of the talus. The tendon of the long flexor of the toes is exposed through the "master knot" (47) ***(T532)*** and cut. ***The sustentaculum tali is exposed, especially at its posterior aspect***.


626

Using a curved osteotome in a vertical fashion, the medial part of the osteotomy ***starts from behind the sustentaculum tali***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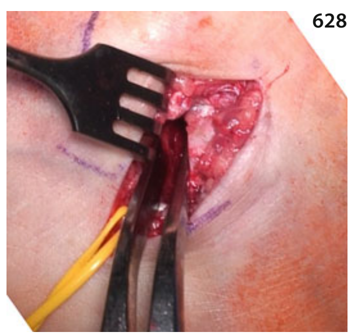
and joins the osteotomy previously performed from the lateral aspect ***(O250)***. A lengthening of the calcaneus and angulation of the heel is then made by ***distracting both bony edges of the osteotomy at the lateral aspect***

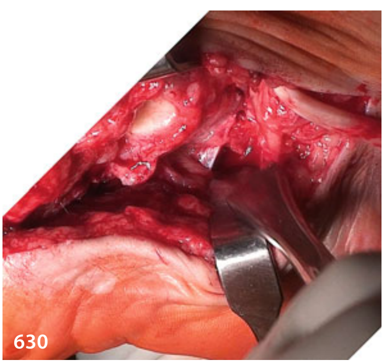

628

and behind the sustentaculum tali ***on the medial aspect of the calcaneus (O254).***

The talus undergoes reorientation within the sagittal and horizontal planes until reaching its anatomic alignment with the first metatarsus. This alignment is controlled within the horizontal and sagittal planes by fluoroscope within the dorsoplantar and lateral projection, in orthograde position of the foot. Any overcorrection must be avoided because it is generally not well tolerated. At this stage, the tourniquet is temporarily opened, and the ipsilateral anterior iliac crest is addressed in order to harvest the desired tricortical blocks. After returning to the foot, the soft tissues are trimmed away from the grafts and inserted to ***replace the distraction clamps on the lateral wall***


629

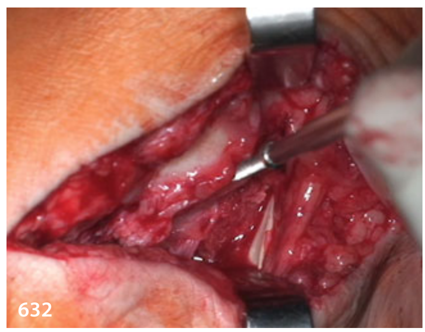
and the ***medial aspect of the calcaneus***.


630

At this point, the montage is ***spontaneously mechanically stable***, allowing for free manual motion of the talocalcaneonavicular joint.


631

Fixation is ***secured by one or two small interfragmentary screws***


632

from the sustentaculum tali toward the greater tuberosity.

Triple arthrodesis

Fusing all four bones of the hindfoot (talus, calcaneus, cuboid, navicular bone) allows for comprehensive reorientation of any deformity located at the lower ankle joint ***(O286)***. Two approaches are mandatory for safe control of the correction: the longitudinal medial approach from the medial cuneiform to the sustentaculum tali ***(T531)*** and the anterolateral approach ***(T536)***. For ease, the patient is secured with contralateral buttresses allowing the table to be inclined up to about 40 degrees.

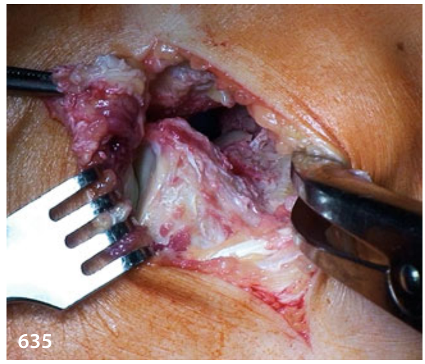
From the medial approach, the posterior tibial tendon is exposed, and the talonavicular joint is opened. For reorienting a cavus–adductus deformed foot, the tendon is divided for lengthening in order to avoid recurrence and to allow for correction of the length of the medial column. The talar head is exposed by opening the subtalar joint. The plantar calcaneonavicular ligament (spring ligament) is divided for optimal mobilization. The cartilage is removed using the osteotome and the rongeur to avoid any heat-induced bone lesion. Curved osteotomes (Lambotte) are easier to handle within these curved joint surfaces. For safe consolidation, the well-vascularized subchondral bone is exposed. More posteriorly, the ***anterior and medial joint facets*** are treated in a similar way.


633

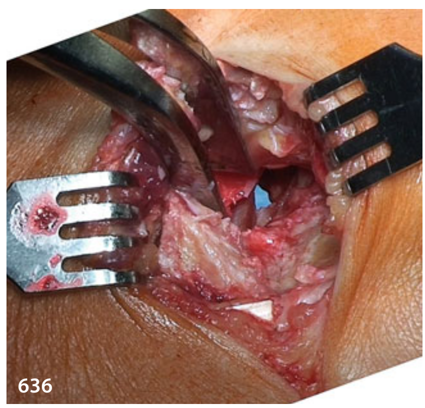
From the lateral approach, the subcutaneous tissue is divided carefully because all essential structures such as the sural nerve and the superficial fibularis nerve cross the approach at about a right angle. The entire space ***between the fibularis tertius and the fibularis brevis tendons*** is exposed.


634

The retinaculum, together with the insertion of the short toe extensor muscle, is mobilized and retracted toward distal, exposing the sinus tarsi and the anterior process of the calcaneus. This allows for opening of the subtalar joint beneath the lateral process of the talus, ***the calcaneocuboid joint***,

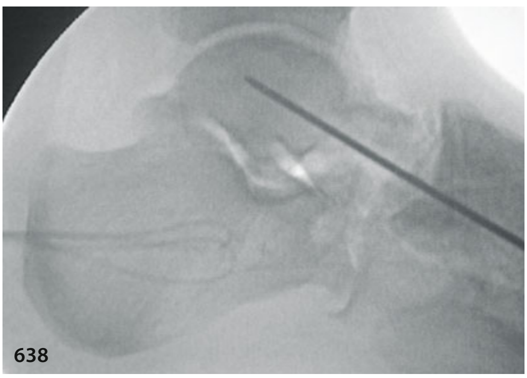

635

and the lateral aspect of the talonavicular joint. All these joints are progressively mobilized while the articular cartilage is removed using the curved osteotome. To ease access to the subtalar joint, a bone spreader is used in different positions. This allows for visualization of and access to all the subtalar joint space to remove the cartilage and to align the four bones as desired. At full mobilization, the flexor hallucis longus tendon is observed in the back, and toward medial only the flexor digitorum longus tendon crosses the view through the foot. For reorienting the four bones of the hindfoot, special attention is given to the ***full free view through the subtalar space*** between the two surgical approaches.


636

Full, free motion is also needed between the talar head and the navicular bone. If the main reorientation is performed within the horizontal plane, first alignment is performed between the talar head and the navicular bone: The talar head is taken manually through both surgical incisions and seated properly at the desired place within the navicular "cradle." Temporary fixation is performed with a ***transarticular Kirschner wire***.

637

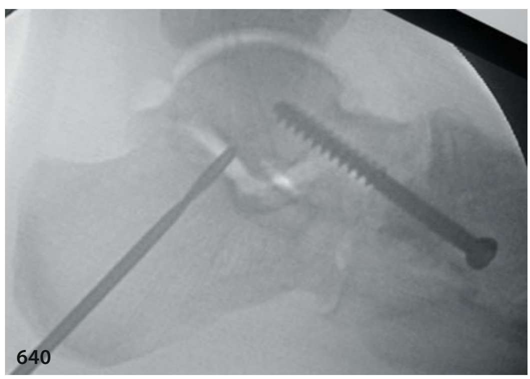


638

If the main reorientation is performed within the sagittal plane, the talus is "lifted" up along the posterior facet of the subtalar joint until the optimal position is reached. The bone spreader is useful if placed between the anterior process of the calcaneus and the lateral process of the talus for best positioning. The optimal desired position is secured by percutaneous fixation using a Kirschner wire through the heel.

With the foot held in orthogonal position, the desired valgus between the heel and the axis of the lower leg is controlled. At this stage, the calcaneocuboid joint should, in most cases, be adapting spontaneously. Any residual exaggerated adductus is corrected by shortening the anterior calcaneus, and the pronation/supination of the midfoot is controlled through this joint. The calcaneocuboid joint is optimal for correcting the position of the foot within the frontal plane because the joint is located within this plane, and gliding the cuboid on the calcaneus rotates the foot around the talometatarsal axis. At this point, it may be wise to check the orientation of the four bones by fluoroscopy in dorsoplantar and lateral incidences. Definitive fixation of the medial column by means of talonavicular fusion is performed using one screw from distal to proximal centering the talus body. Through a ***small skin incision on the heel***, ***calcaneotalar fixation*** is performed using one screw driven through the center of the subtalar facet into the talar dome.

639



640

A final screw is introduced through a small skin incision above the lateral tarsometatarsal joints pointing at the calcaneus along its long axis, thus fixing the calcaneocuboid joint. The drill enters the cuboid from the top and ***centers the anterior process of the calcaneus***.

641

This ***three-screw montage***

642

643

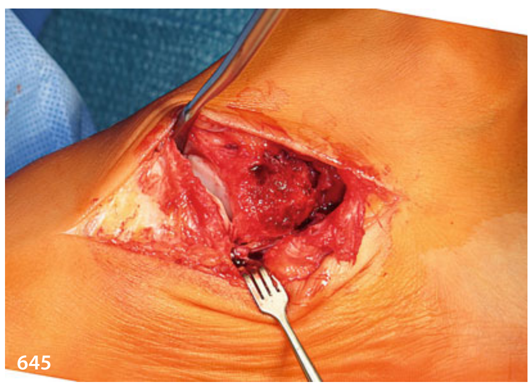
does not need an additional bone graft because it forms a mechanical chain that is closed anteriorly by the cuneocuboid anatomic fixation.

Naviculocuneiform arthrodesis

In pes planus and/or abductus in which the deformity or sag is located at the naviculocuneiform joint, correcting fusion is indicated ***(O294)***. The ***approach is longitudinal (T530)*** and medial behind the anterior tibial tendon.

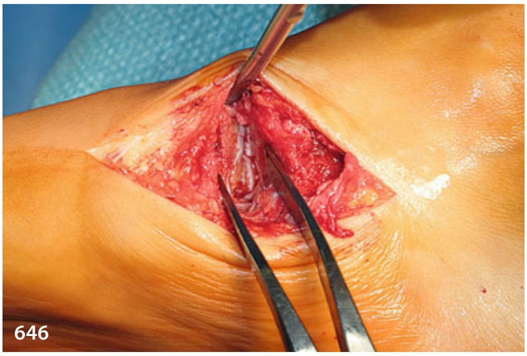
644

After arthrotomy, an ***occasional associated os naviculare accessorius is resected.***



645

The cartilage and subchondral bone are removed on the first and second joints, keeping in mind the “conical” type of resection that corresponds to the desired correction (plantar resection to correct pes planus, ***medial resection to correct pes abductus***).



646

Temporarily holding the ***corrected position***,

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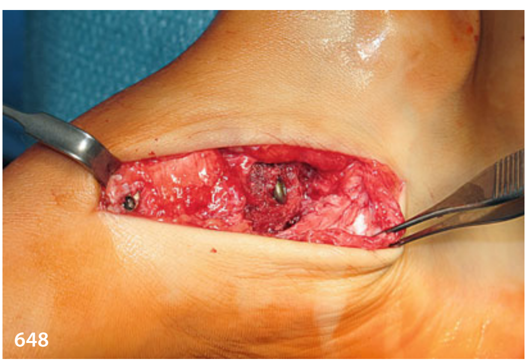
fixation ensues with ***two inclined screws (O298)***.

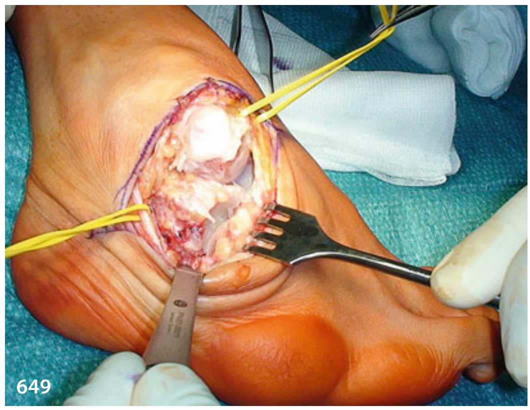


648

More mechanically demanding fixations – such as for heavy, noncompliant patients with flat feet – are stabilized with a plantar plate joining the navicular bone to the first cuneiform. This plate can be very thin because it acts as a plantar tension band (42) ***(O308)***.

Dorsolateral tarsectomy

This correction has great potential in severely disabled feet ***(O324)***. It corresponds to a subtracting dorsolateral wedge osteotomy of the midfoot about the “Chopart” joints. The approach goes through ***an extended oblique anterolateral incision (T535).***



649

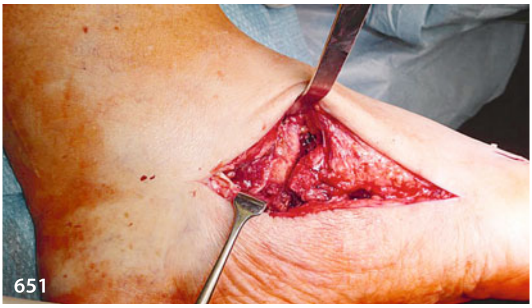
An essential part of the intervention is the ***correction of the muscle balance,***

650

aiming at empowering the pronators (tibialis anterior) with a possible fibularis longus and flexor hallucis longus tendon transfer onto the lateral aspect of the foot.

Talometatarsal arthrodesis

This procedure is the most stabilizing operation of the medial column of the foot. It corrects uncontrollable instability of the talonavicular and distal joints ***(O315)***. The ***approach goes through the medial utility***


651

and additional ***percutaneous limited incisions to insert the implants,***


652

which are often massive. A ***second axis of fixation*** is essential to catch the torque around the medial column of the foot.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654

There are no articular compensatory mechanisms left, and only a very strict respect for ***stable alignment*** allows for good motion of the upper ankle joint.

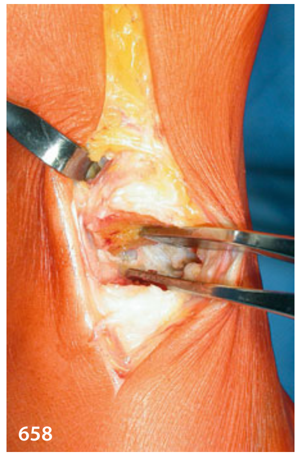
655

656

657

Fusion of the first tarsometatarsal joint and first intermetatarsal space

The approach is dorsal to the first ray, lateral to the extensor hallucis longus tendon ***(E25, E62, E113, O347, T542)***. The first cuneometatarsal joint and the space between the first metatarsus and the second cuneiform is visualized. The neurovascular bundle, which is held laterally, is protected. The joint is opened and the cartilage removed using a curved Lambotte osteotome. A thin layer of the subchondral bone is removed to avoid excessive shortening, but the amount of bone removed determines the desired reorientation. A thin but strong laminar spreader is introduced into the joint to enable ***visualization of the long fibularis tendon fibers at the bottom of the joint***.



658

By twisting the spreader, ***the first metatarsus is moved medially,***

659

and the ***lateral condyle of the bone can be precisely removed*** with a straight and thin osteotome.

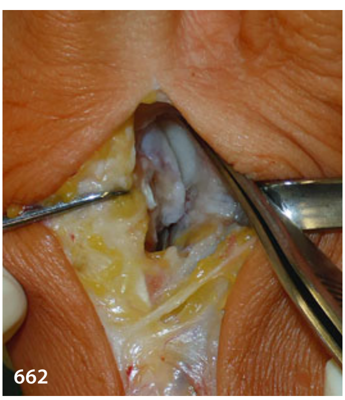
660

Continuing to hold the neurovascular bundle laterally, the periosteum of the medial basis of the ***second metatarsus*** is scraped down, and the ***first layer of the cortical bone is removed*** using the thin osteotome on about 1 cm^2.


661

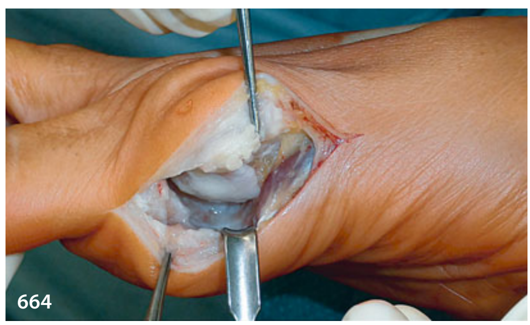
The horizontal correction of the first metatarsus is prepared by doing a resection of the corresponding bone on both the first cuneiform and first metatarsus.

In the case of a relevant additional horizontal malorientation of the metatarso-sesamoid-phalangeal joint, the skin incision is prolonged distally to the dorsolateral aspect of the first metatarsal head. The small dorsolateral nerve is held laterally to expose the joint capsule. By stretching the big toe toward medial, the arthrotomy is performed horizontally until the lateral sesamoid bone is visualized. The capsule is divided from the first phalanx to the posterior part of the metatarsal head, thus allowing the metatarsus to sit properly on both sesamoid bones. In some cases, ***an occasional lateral osteophyte*** is ***removed from the metatarsal head***.


662


663

The medial aspect of the metatarsophalangeal joint is approached through a second incision of about 5 cm ***(T534)***, avoiding the dorsal and plantar nerves of the hallux. ***The medial capsule is divided and mobilized*** from the metatarsus.


664

An occasional pseudoexostosis is removed, and the synovialis is removed if irritated.

Under visual control through both approaches, a blunt elevator is moved about 3 cm between the metatarsal head and both sesamoid bones. No proximal dissection beneath the metatarsus is performed to avoid harming the subcapital blood supply to the head.

The first metatarsus head can now be positioned on the top of both sesamoids and at the correct height. This positioning is done together with the ***impaction of the base of the metatarsus within the metatarsus 2–cuneiform 1 angle***.

665

Provisional 1.6-mm Kirschner wires hold the position, and an occasional reduction clamp helps if positioned in between the metatarsal neck and percutaneously lateral to the third metatarsus. The vertical adjustment is best achieved by ***sliding the first metatarsus up or down on its cuneiform*** counterpart.

666

The position is secured with a 3.5-mm cortex screw driven percutaneously from the proximal metaphysis of the first metatarsus to the proximal epiphysis of the second metatarsus within the horizontal plane. A second, similar screw is driven obliquely from the top of the first cuneiform to the plantar aspect of the first metatarsus ***(O348)***. Three bones are fixed: the first metatarsus, second metatarsus, and first cuneiform ***(O347)***. The anteromedial angle of the foot is thus stabilized, providing for new articulation with less amplitude: ***the joint between the three mutually fixed bones and the second cuneiform*** (29).

667

In large feet and if the patient is heavy and/or not reliable, the fixation is doubled (four screws). In revision cases, eventual ***length discrepancy between the first two metatarsals (E44, T493)***

668

may have to be corrected by lengthening the first ray. An ***autologous bone block from the pelvic crest is properly placed between the first cuneiform and the first metatarsus.***


669

Screws are used for the fixation.

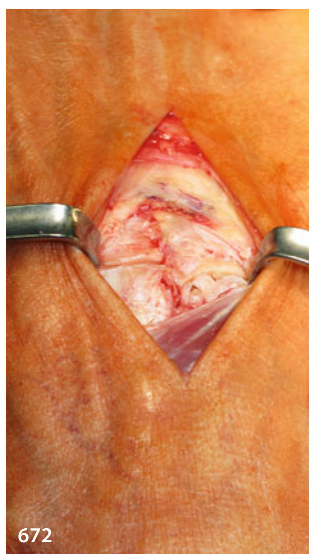
670

Second and third tarsometatarsal arthrodesis

Fusion of the central tarsometatarsal joints is done together because of their synergy. It is also indicated in most cases together with the stabilization of the first ray ***(O332)***. The surgical approach is dorsal in between the two corresponding rays ***(T547)***. A small branch of the fibularis superficialis nerve may cross the field and must be recognized and protected. ***On the medial side, the dorsalis pedis neurovascular bundle is also protected***.


671

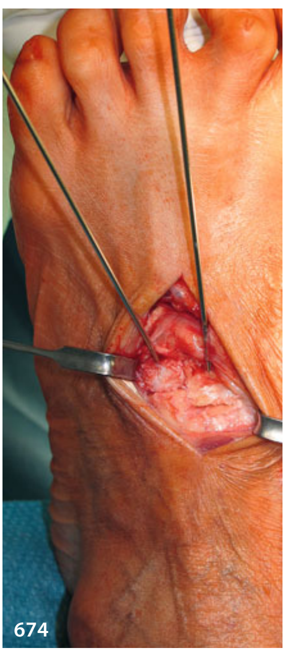
The cuneiform 2–metatarsus 2 and the cuneiform 3–metatarsus 3 ***joints are opened,***


672

and the ***cartilage with subchondral bone is removed***.

673

The bone surfaces are approximated with the desired angulation, especially in the sagittal plane, and the corresponding level of the metatarsal heads is checked. Releasing the space between the third and the fourth metatarsi allows for length adaptation during this fusion; this is especially true in relevant shortening. ***Temporary fixation allows for definitive position control***.



674

Fixation occurs with screws, preferably from proximal to distal.

Eventually, the medial side of the metatarsus 2 basis is also approached, removing the cartilage and the corresponding lateral side of the first cuneiform for fusion. Fixation occurs from the medial plane, applying a screw through a stab incision on the proximal medial aspect of the first cuneiform. Its course follows the Lisfranc's ligament: oblique from medial toward distal lateral, catching the basis of the second metatarsus.

In cases of inflammatory or degenerative articular degeneration, ***all three medial tarsometatarsal joints are fused,*** including or otherwise a relevant reorientation ***(O338)***.

675

Optimal approaches add the longitudinal approach to the first tarsometatarsal to the basal intermetatarsal approach for the second and third rays. The means of fixation involves a number of 3.5-mm ***screws (two to five) placed percutaneously from medial,*** joining the first metatarsal to the third cuneiform and the first cuneiform to the third metatarsus, and ***eventual plates***.


676

When higher stability is required, shorter screws are placed that cross single cuneometatarsal joints. These approaches allow the dorsalis pedis neurovascular bundle to be protected and leave the insertion of the anterior tibial tendon untouched.

Fourth and fifth tarsometatarsal arthroplasty

The skin incision lies exactly in between the proximal metaphysis of the fourth and fifth metatarsi ***(O343, T546)***. After identification of the joints, the cartilage is completely removed, leaving in place the subchondral bone layer. ***The plantar capsular ligaments are preserved***.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Both long ***extensor tendons are then harvested,***


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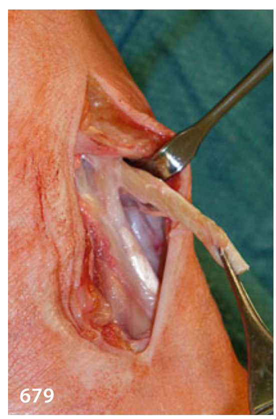
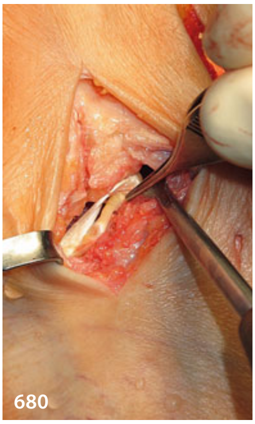

679

and the distal limb is adapted to the corresponding short fourth extensor tendon. The ***tendinous material is laid together smoothly in the groove***


680


681

separating the cuboid bone from the metatarsi.

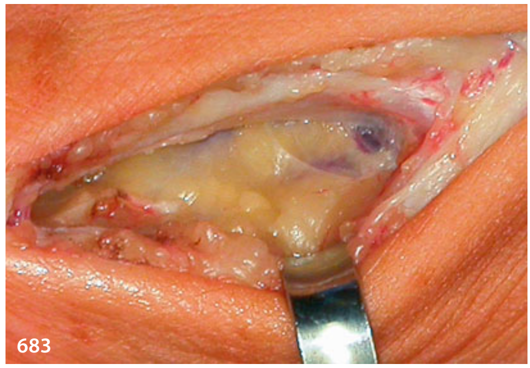
The ***short extensor muscle and subcutaneous layer*** are adapted onto the plasty followed by the skin closure.


682

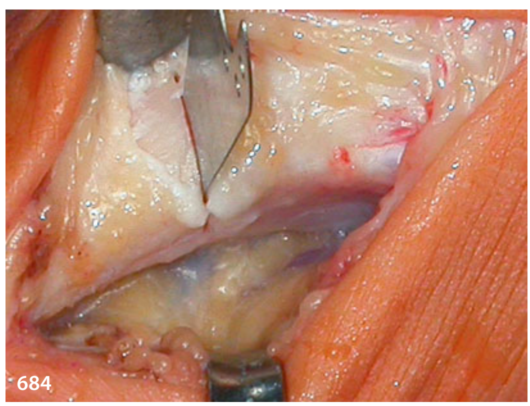
This montage tends to be ready for immediate, full weight bearing using a rigid-soled shoe.

Diaphyseal osteotomy of the first metatarsus

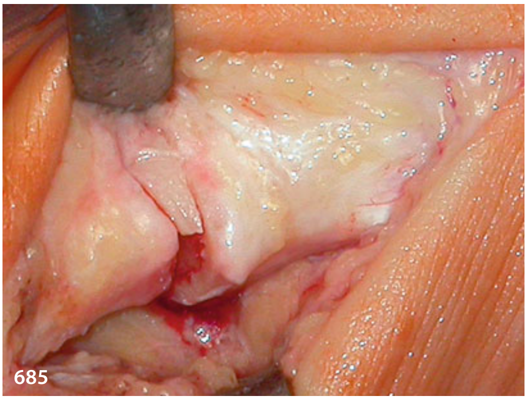
The incision is made on the medial side of the metatarsus along the "medial utility line" ***(O368)***. The abductor hallucis is pushed toward plantar, and the ***plantar aspect of the first metatarsus is exposed*** epiperiosteally.


683

The neck of the bone is not exposed because the major nutrient vessel entering the bone lies about 1 cm proximal to the posterior edge of the articular cartilage. If only shortening is the aim, the plate is adapted to the concave shape of the bone. If extension is desired, less or even no adaptation of the shape of the plate is needed. The second screw hole from proximal is drilled and the plate removed. The ***performance of the proximal osteotomy is incomplete, and a blade is inserted*** for orientation.


684

The second, distal osteotomy is performed either completely parallel for shortening or as a ***dorsal subtraction wedge*** for dorsal extension.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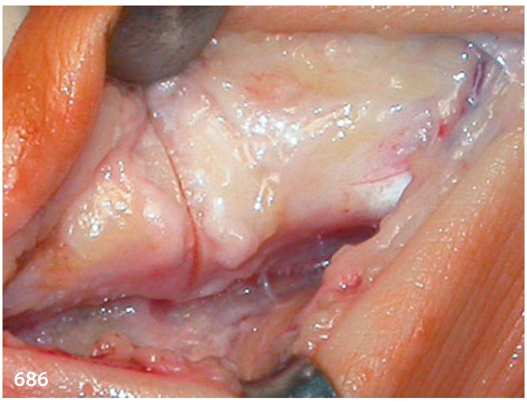
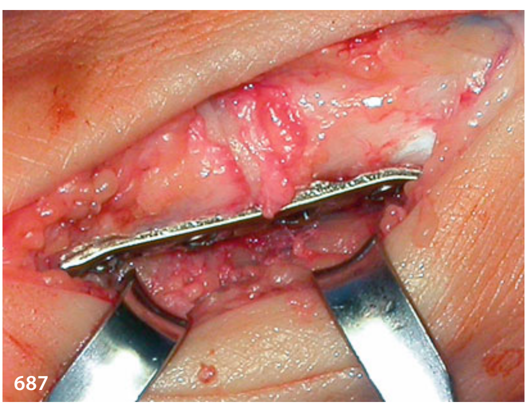
The wedge is removed and ***both fragments adapted***.


686

The plate is applied using the previously drilled bore hole and a screw. The ***other three screws*** are placed.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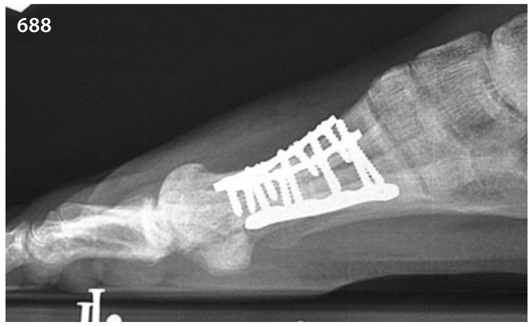
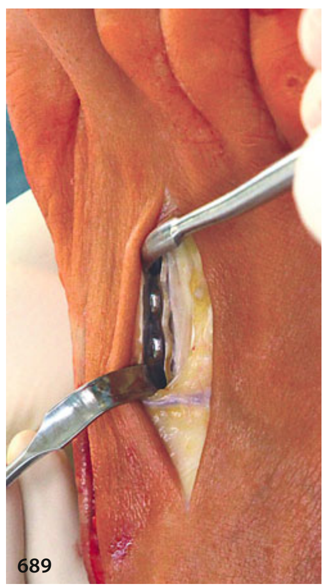
The plate is in a tension band position and is ***stable for full weight bearing***.

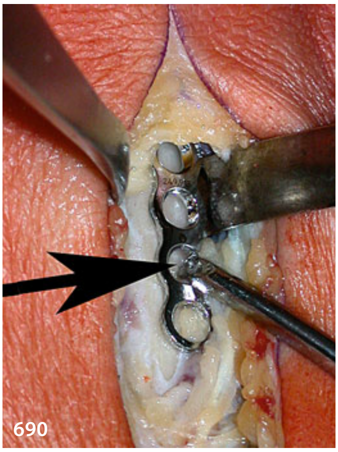

688

Diaphyseal osteotomy of the second and third metatarsus

The approach is dorsal in between the second and third metatarsus ***(E46, O352)***. This incision is perfectly compatible with concomitant stabilization of the first ray. Beneath the skin the dissection is directed individually to both metatarsi, sparing a thin branch of the superficial fibular nerve. In fact, a dorsal nervous branch often lies within the soft tissue layer in between the bones. The dorsum of the metatarsus is prepared epiperiosteally, and a ***small plate with four holes*** is applied and adapted anatomically using pliers.


689

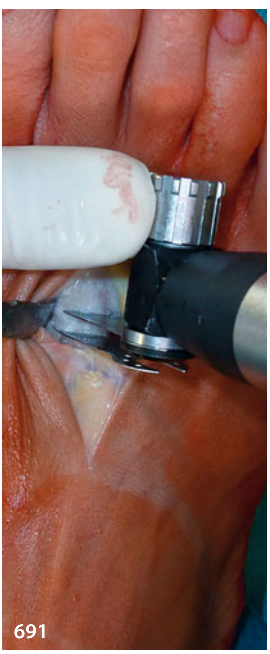
The ***second screw hole, numbered from proximal***, is drilled and the screw prepared.



690

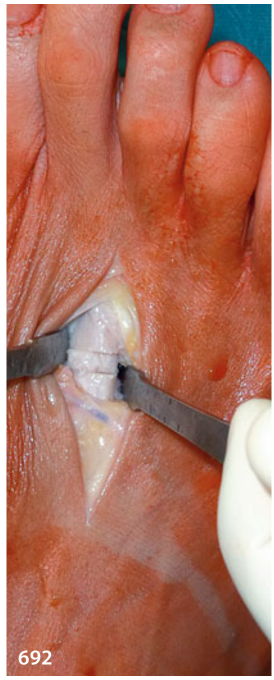
This allows rapid and safe application of the plate after the osteotomy.

Removing the periosteum precisely at the desired osteotomy, two bone levers protect the soft tissues from the oscillating saw. The proximal cut is performed incompletely, and a free saw blade is inserted to indicate the plane of the cut. This allows ***the second cut to be made under stable conditions.*** This cut is completed, following the aim of shortening, flexing, or extending the metatarsus.



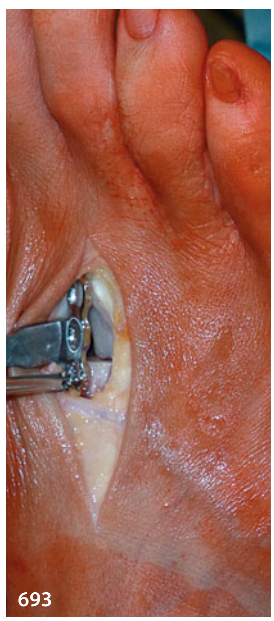
691

The proximal cut is then completed under stable conditions. ***Shortening of up to 10 mm is not a problem***.



692

The plate, where necessary, is bent to achieve flexion or extension and is ***fixed to the proximal fragment*** using the prepared screw.



693

The assistant then holds the distal fragment of the metatarsus with the two bone levers while the osteotomy planes are approximated. The second screw hole is drilled preferentially in an ***eccentric fashion through the plate hole*** (43),

694

695

thus approximating the osteotomy planes and applying interfragmentary compression by the plate. This strengthens interfragmentary stability. The other osteotomized metatarsus is then fixed following the same procedure. The ***dimension of the plate should be adapted*** to the dimension of the bone.

696

Securing the plates through the ***remaining plate holes***

697

completes the fixation.

698

Such a montage ***allows full weight bearing*** after surgery.

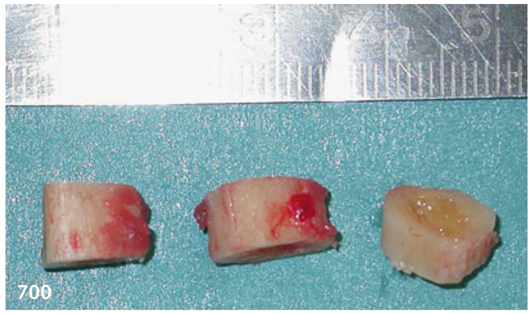
Eventual additional osteotomy of the fourth metatarsus is performed through a separate skin incision on the lateral aspect of the bone.

Diaphyseal osteotomy of the fourth metatarsus

In select cases of metatarsalgia 2–4, correction osteotomies aiming at shortening and/or extension are performed ***through two separate incisions (T548)***.

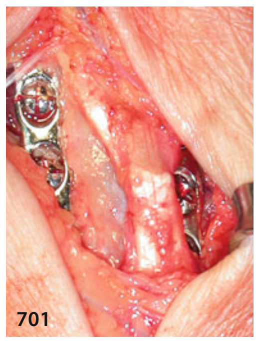
699

To allow more freedom to the osteotomized bones, ***all sections*** are performed before any fixation.



700

Due to the central position of the bones, **osteotomy and fixation are achieved from the dorsal plane**.



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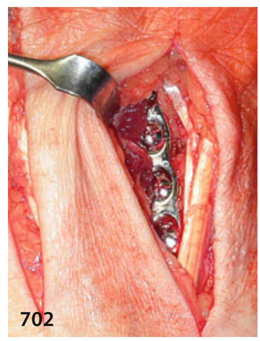


702

Together with and thanks to the strong intermetatarsal soft tissue connections, multiple osteotomies fixed by dorsal plates **allow for immediate full weight bearing** in the postoperative phase.

703

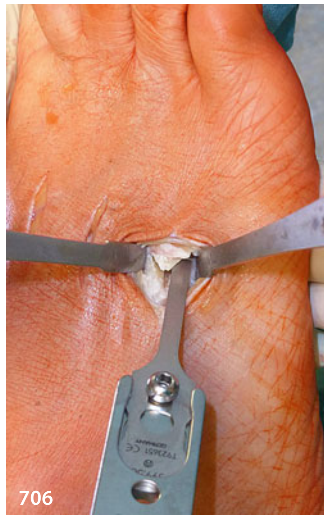
704

Proximal metaphyseal osteotomy of the second, third, and fourth metatarsus

The skin incision is about 2.5 cm in length, right over the proximal metaphysis of each metatarsus ***(O363)***. The bone is exposed subperiosteally with a narrow periosteal elevator in an oblique fashion on each side of the bone, directing from dorsal toward distal plantarward. A 2-mm drill hole is made in the same angle at the middle of the bone. Using a very small saw blade and obliquely positioned narrow retractors, a chevron-shaped osteotomy is performed following the defined inclination and ***confluent proximally with the central bore hole***.


705

Using a clamp and/or a thin, small osteotome, the distal part of the metatarsus is mobilized from the adherent soft tissues ***to allow gliding of the osteotomy planes*** on each other dorsally and proximally.


706

Sharp bone edges may jeopardize the skin and ***are removed***.


707

The procedure is the same for all three metatarsi and does not imply any fixation means. Postoperatively, however, the patient bears his or her whole weight immediately on a plantar orthosis including a retrocapital elevation and a shoe with a rigid sole ***(O365)***.

Diaphyseal adduction osteotomy of the fifth metatarsus

The incision is lateral to the fifth metatarsus ***(O361, T549)***, and the muscle belly of the abductor digiti quinti is ***retracted plantarward***.

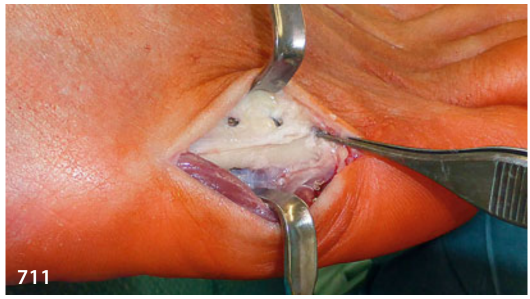
708

The osteotomy is horizontal, dividing the oblique metatarsus by a large osteotomy plane. The distal fragment is ***rotated in adduction*** on this large bony surface and is fixed by two 2.0-mm screws ***(O362)***.

709

710

Cortical bone edges are removed using a rongeur



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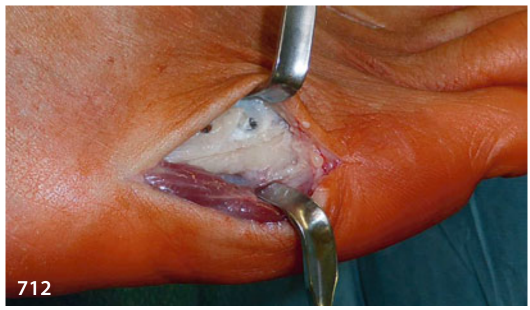


712

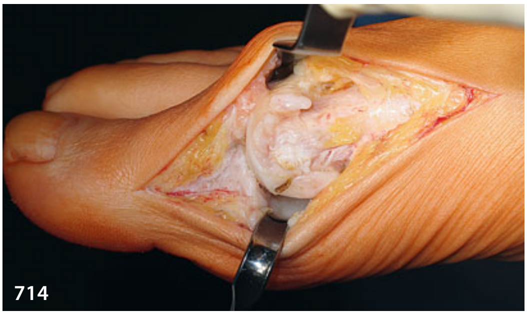
to avoid painful spots beneath the skin.

Intracapital extension osteotomy of the first metatarsus (Watermann)

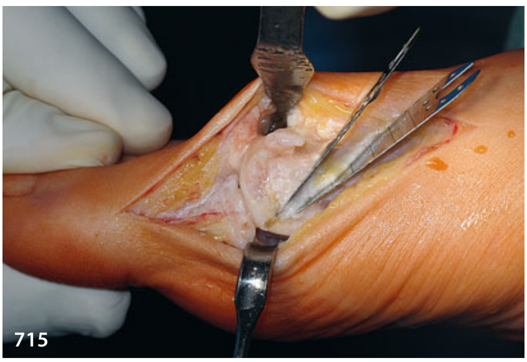
The ***approach is medial*** to the first metatarsophalangeal joint, between the dorsomedial and the medial plantar nerves ***(O370)***.

713

The arthrotomy demonstrates the metatarsal head. The slight change in curvature of the cartilaginous layer that separates the metatarsophalangeal from the ***metatarsosesamoid joint is marked***.


714

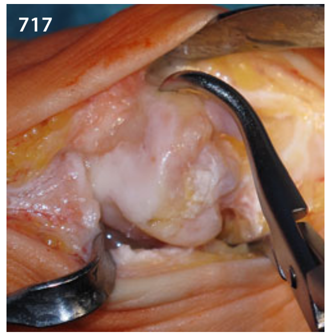
An oblique V-shaped ***dorsal subtracting osteotomy*** is performed using a micro oscillating saw.


715

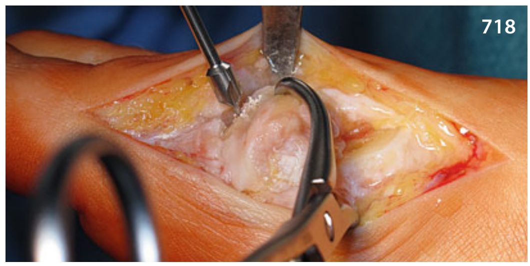
The cartilaginous layer is not cut. After removal of the intercalary bone, the distal fragment is carefully ***reclined toward posterior***,


716

hinging at the cartilage using small reduction forceps.


717

Fixation is performed with a 2-mm screw from dorsal that is ***countersunk deep into the cartilaginous layer (O370)***.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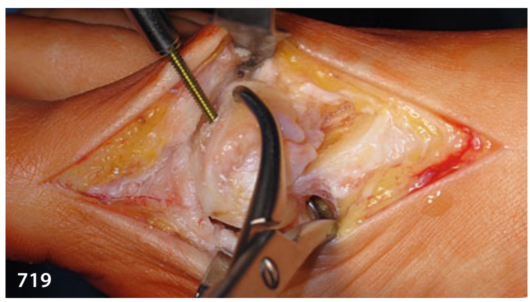
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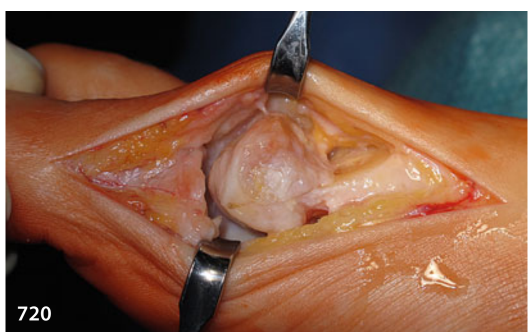
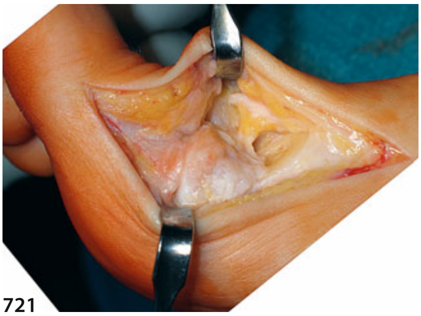

720

Sagittal ***mobility is increased*** due to the reduced dimension of the metatarsal head.



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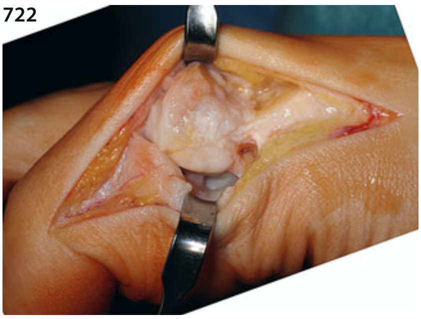


Intracapital extension osteotomy of the second and third metatarsus (Gauthier)

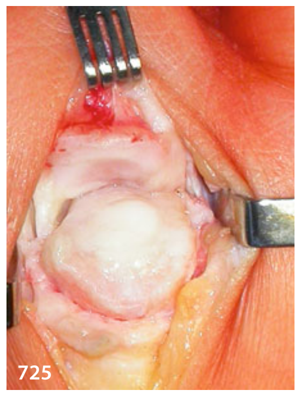
The incision is located above the metatarsal head (30) ***(O379)***. The best access is ***between the long and the short extensor tendons*** to avoid shortening through scarring.

723

After arthrotomy, which spares the plantar plate, the ***arthritis and joint destruction are evaluated***.

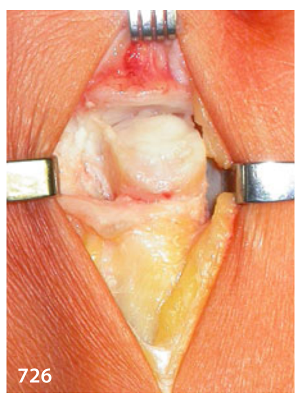
724

Manual distraction reveals the articular damage and demonstrates ***the intact plantar part*** of the head.



725

The ***lateral and medial osteophytes of the metatarsal head are carefully removed***.

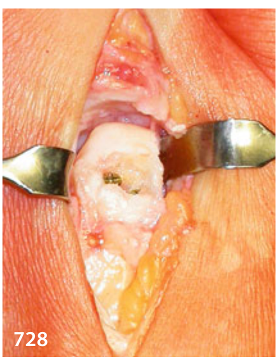


726

An oblique osteotomy from distal dorsal toward the neck of the metatarsus is performed incompletely to evaluate and perform a ***vertical osteotomy that converges*** with the first cut.


727

The first cut is then completed. Care is taken not to divide all the soft tissue attached to the metatarsal head. The dorsal subtracting wedge measures about 45 degrees. The ***head is then reclined in extension*** using a thin joystick, bringing the intact plantar articular surface to face the articular surface of the phalanx. Fixation is secured by one or two 1.0-mm inclined ***screws that are countersunk*** into the cartilaginous layer ***(O380)***.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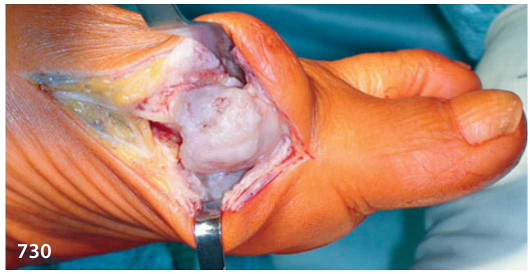
729

First metatarso-sesamoid-phalangeal joint fusion

The skin incision measures about 6 cm and lies on the medial utility line between the dorsal and the plantar medial nerves of the hallux, starting 1 cm distal to the joint ***(O375)***. ***The joint is opened,***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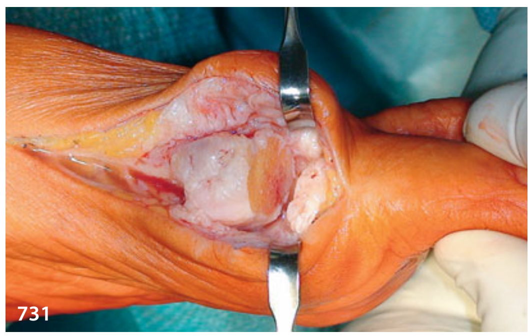
and the adductor hallucis is held toward plantar. The ***joint surfaces undergo resection using an oscillating saw,*** avoiding heat necrosis.


731

Any significant shortening should be achieved at the phalangeal side because the metatarsal head is essential for anteromedial weight bearing and the metatarsosesamoid fusion surface. The orientation of the first phalanx is crucial for smooth function. The aim is to achieve an ***exact horizontal***

732

733

and slight valgus position of the phalanx for optimal push-off. Shifting the phalanx on the frontal osteotomy plane of the metatarsus in all directions is a good option to achieve optimal position of the big toe. The plantar aspect of the metatarsal head is exposed behind the condyles. Temporary fixation is secured using an ***axial K-wire*** driven from proximal to distal.

734

The horizontal orientation is verified with a vertical beam of a fluoroscope. Definitive fixation is secured using a 3.5-mm or 4.0-mm screw driven through the head of the metatarsus distally in the exact axis of the first phalanx. The condyles of the metatarsus act as an ***optimal countersink for the head of the screw***.

735

A second parallel screw, smaller in diameter if necessary, replaces the K-wire and secures the ***rotational stability*** of the montage.

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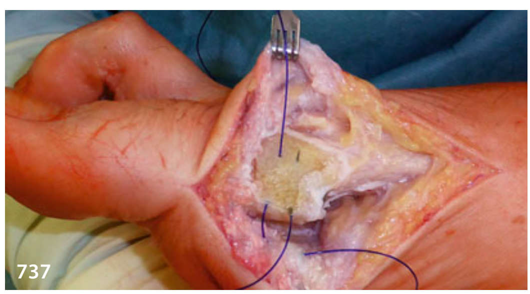
The medial and dorsal overreaching bone is removed. The cartilaginous layer on both sides of the metatarsosesamoid joint is then removed. A ***strong osteosuture***



737

crossing the metatarsal head ***holds the sesamoid girdle*** for safe consolidation.

738

This fixation is ready for full weight bearing with a rocker-bottom walker. In revision cases that include ***relevant bone loss, such as arthroplasties,***

739

an ***autologous bone block harvested at the pelvic crest is interposed (T594).***

740

This restores physiologic length and thus allows for ***physiologic push-off***.

741

Osteotomy of the first phalanx of the big toe

The skin incision lies on the medial utility line between the dorsal and the medial plantar nerves of the hallux ***(O368, T534)***. The first metatarsophalangeal joint is opened plantarward. The osteotomy is placed at the basal third of the phalanx due to the larger cross section of the bone and the cancellous bone-easing consolidation. In shortening or angulation osteotomies, the proximal cut remains incomplete until the distal osteotomy is achieved because of the need for stability of the fragment during the cut. The ***shape of the bone to be removed is thus decided with the distal osteotomy***. The proximal osteotomy is then achieved.

742

Approximation of the fragments is held with a ***temporary oblique K-wire***.


743


744

A 2.0-mm screw secures the fixation starting at the plantar aspect of the ***proximal medial subchondral bone*** and directing the medial distal condyle.


745

This fixation is stable for ***full weight bearing*** using a protective shoe.


746


747

Shortening osteotomy of the first phalanx of the lesser rays

The skin incision lies ***dorsal to the toe (O419)***.


748

The metatarsophalangeal joint is opened to ensure sufficient flexion of the toe. The whole phalanx is drilled using a 2.0-mm drill starting at the joint surface ***(T756)***. The middiaphyseal bone is divided using a micro oscillating saw. The ***shortening length is determined by the proximal osteotomy.***

749

Fixation is secured using a ***straight-profiled resorbable pin*** driven through both approximated fragments.

750

751

Proximal interphalangeal fusion

The skin incision lies on the top of the toe ***between the intermediate phalanx and the head of the metatarsus (O393)***.

752

The metatarsophalangeal ***joint is opened wide,*** leaving just the plantar plate of the joint capsule.

753

The ***proximal interphalangeal joint***


754

undergoes resection, aiming at a slightly ***physiologic angle in flexion*** of the fusion.


755

A 2.0-mm drill hole is made within the intermediate phalanx and through the first phalanx ***from the joint surface distally***.


756

A curved-profile resorbable pin ***(F442)*** is driven by gentle hammering through a guiding sleeve from the joint through the first phalanx and ends ***within the intermediate phalanx***.


757

The proximal ***overhanging extremity of the pin is resected flush*** to the cartilage surface of the joint.


758

This montage achieves ***immediate rotational functional stability*** in an anatomic orientation.


759

Distal interphalangeal fusion

The incision is transverse above the distal interphalangeal joint. The cartilaginous layers undergo resection. Through a stab incision beneath the toenail, a 1.5-mm screw is inserted into the distal phalanx and driven to the middle phalanx in a slightly functional flexion ***(O407)***.

ORIF of multipartite sesamoids

Multipartite sesamoids are mostly due to an acute or fatigue fracture ***(E47)***. Assessment is by computed tomography for ***evaluation of the number, shape, and dimension of the fragments as well as of the bone density***.


760

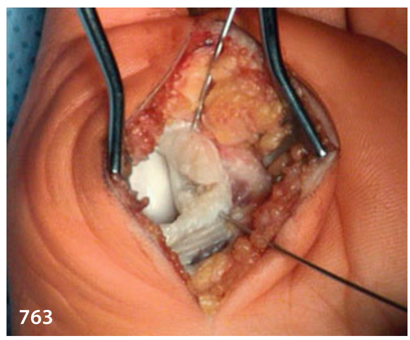
Eventual bone graft is indicated (44). The medial sesamoid fracture is approached from the medial utility line ***(T534)*** and the metatarsophalangeal arthrotomy. The ***lateral sesamoid is approached from the plantar plane***, with the patient lying prone.


761

The articular layer is inspected and the ***quality of the cartilage*** evaluated.


762

Eventual necrotic bone is extracted after lifting the cartilaginous layer and is replaced by cancellous bone harvested at the metatarsal head. Reduction is eased by using ***joysticks*** (K-wires).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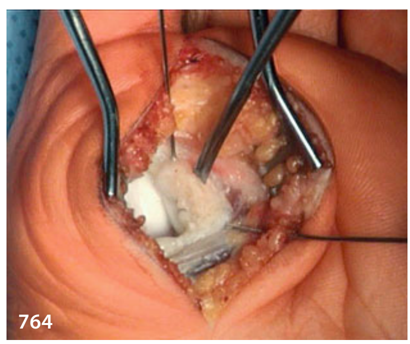

764

The fragments are definitively ***fixed using 1.5-mm screws***.


765


766

The skin is closed with anatomically adapting single stitches that remain for 3 weeks. This technique ***avoids any step between the edges of the scar.*** Such a scar would remodel badly and remain painful.


767

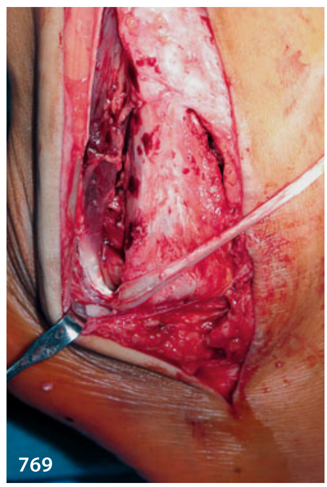

768

5 Ligamentous reconstruction of the ligaments of the ankle joints

Syndesmosis

The aim is to restore the mobility and stability between the distal tibia and fibula ***(E79)***. The most logical approach is to reconstruct all three ligamentous components of the syndesmosis by means of the posterior, intermediate, and anterior tibiofibular ligaments ***(O221)***. As most cases are at the chronic stage and the local ligamentous structures are absent ***(O219)*** or insufficient, the best material in the vicinity is the tendon of the musculus fibularis longus. To reconstruct the syndesmosis, the lateral aspect of the malleolus is exposed (22).

The graft is the anterior third of the tendon. The incision along the tendon runs up to 12 cm proximally, and the graft is cut to obtain a ***distally pediculated graft beginning 10 mm below the tip of the fibula***.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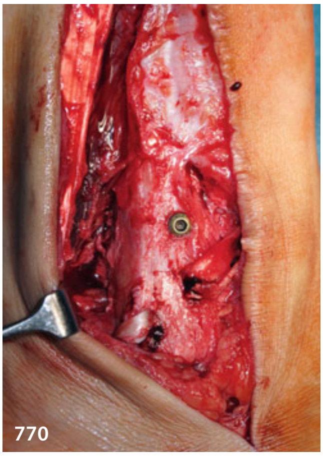
Exposing the posterior aspect of the distal fibula, a 4.5-mm hole is drilled through the lateral aspect of the distal fibula, aiming at the posteromedial edge of the bone. Another hole is drilled through the fibula about 1.5 cm above the first hole, running slightly posteriorly, entering the posterolateral extremity of the tibia. Another short hole is drilled from the posterior aspect of the tibia, converging with the first bore hole. The graft is passed from the posterior aspect of the tibia (reconstructing the posterior syndesmosis) and exits at the lateral wall of the fibula. This second part of the graft reconstructs the intermediate ligament. A "syndesmosis clamp" helps adjust the fibula within the syndesmotic gutter ***(T507)***. It is placed between the tip of the fibula and the medial malleolus. The graft is then pulled tight, directed toward the anterior aspect of the tibia onto the tuberculum of Chaput, and fixed with a screw or a bone anchor. This ***completes the reconstruction*** of the anterior part of the syndesmosis.



770

A screw replaces the clamp and secures the position of the fibula in its tibial concavity ***(O222)***.

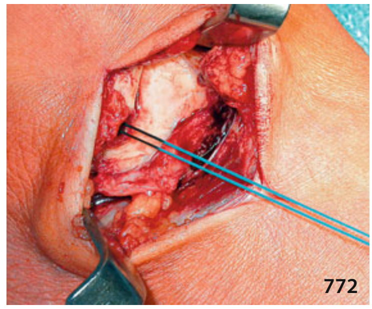
Anterior fibulotalar ligament

Repair

The reconstruction of the anterolateral ligament ***(E80)*** of the upper ankle joint, e.g., the anterior fibulotalar ligament, is a keystone for rotatory (internal rotation of the talus) and sagittal (anterior shift for the talus) ***(E84)*** stability. The approach is either longitudinal or oblique (anterolateral approach), with no obvious general advantage of one over the other. The traumatized ligament is always ***stripped off its fibular origin***

771

and in some cases attached to a bony avulsion of the fibula. This occasional fragment is obviously avascular and is advantageously removed. Attaching nonresorbable sutures to the fibular side of the ligament, preferably ***through an anchor***,



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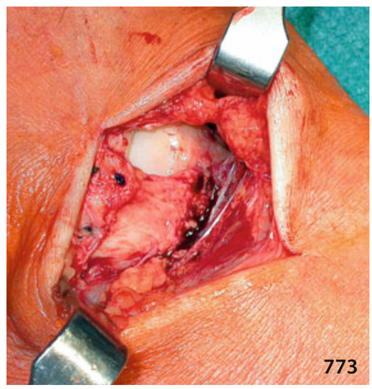
the ligament is taken and ***sutured in external rotation*** of the talus to the fibula (23).



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Augmentation of this suture is performed taking the proximal edge of the ligamentum frondiforme (retinaculum) and attaching it with the same sutures (Gould).

Plasty

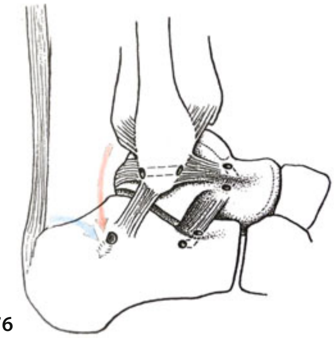
In the absence of the ligament, a rational choice should be made for a biologic autologous transplant. There are two reasonable choices: If the caliber of the transplant is essential, the ***anterior part of the short fibular tendon*** is a good choice. It runs close to the posterior aspect of the fibula exactly ***at the insertion of the fibulocalcaneal ligament***.

774

In cases in which the dimension of the transplant is not essential, the plantaris longus is a good choice, reducing the skin incision. The ***plantaris longus tendon is taken at the medial aspect of the heel cord***, leaving it attached to its insertion using a ***tendon stripper.***

775

An oblique bore hole through the calcaneus brings the transplant exactly ***to the insertion of the fibulocalcaneal ligament***.



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The transplant is secured at the insertion of the fibulocalcaneal ligament onto the calcaneus using a bony anchor. A horizontal bore hole is drilled from the origin of the fibulocalcaneal ligament on the fibula through the bone within the sagittal plane. Tightened between the bone anchor and the fibular hole, the transplant ***anatomically reconstructs the fibulocalcaneal ligament***.

777

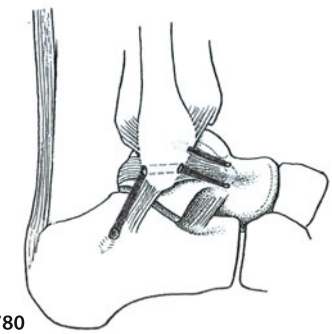
The sagittal bore hole is aimed at the origin of the anterior fibulotalar ligament. From there, the ***transplant is directed to the talus***

778

at the insertion of the anterior fibulotalar ligament (laterodorsal edge of the talar neck). Two 90-degree-angulated short holes are placed at the natural insertion of the ligament. Passing within the bone, the rest of the transplant is pulled back to the anterior aspect of the fibula. It thus ***replaces the anterolateral ligament with two limbs***.


779

Back to the fibula, the transplant is ***secured with a bony anchor***.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781

Cervical talocalcaneal ligament plasty

When there is a need to substitute the cervical ligament at the lateral aspect of the sinus tarsi, a ***free transplant of the plantaris longus*** tendon is adequate.

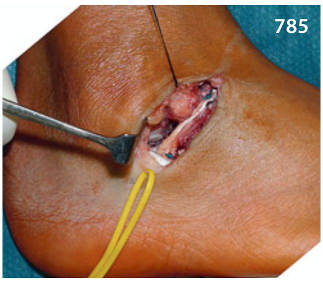

782

The transplant is pulled across the sinus tarsi, crossing two 90-degree angulated bore holes at the ***anterior aspect of Gissane's angle***


783

and through two similar 90-degree angulated holes at the ***lateral neck of the talus.***

784



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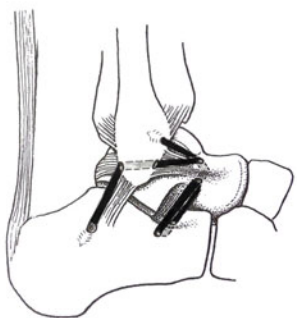
The upper and lower ankle joint ***stabilization can also be combined***.



786

6 Tendinous balance reconstruction

Heel cord lengthening

The patient is supine, with the contralateral leg a little lower. The heel is placed on a small, hard pillow to allow full freedom to the calf musculature. The incision is placed medial to the heel cord to avoid painful dorsal scarring and to preserve the lateral horizontal nutrient vessels to the subcutaneous tissues. ***An incision of about 8 cm is made along the medial edge of the heel cord***, with the incision in the same plane as the peritenon ***(O165)***.

787

The occasional plantaris longus tendon is cut. Using a large blade, a ***frontal incision*** of the tendon in its exact middle is made to achieve two equal anterior and posterior limbs. The ***distal part of the cut ends anteriorly.***

788

The posterior limb is thus distal and the anterior limb is proximal, thereby achieving the best conditions of vascularity, and the contact surface between the two limbs is maximized. The ***final length of the heel cord is carefully adapted*** by playing with the upper ankle joint.

789

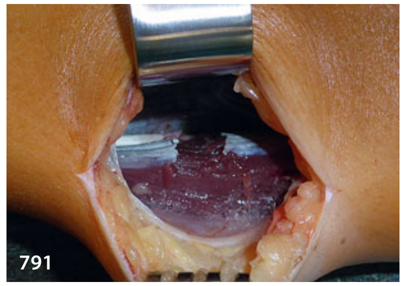
Three adaptive isolated sutures are placed with slow-resorbing material closing the knots anteriorly. The peritenon is adapted with fine suture material, with continuous stitches in the skin.

Gastrocnemius fasciotomy

The patient is supine, with the heel placed on a solid cushion. The shape of the musculus gastrocnemius is evaluated because its extension is quite variable. The ***skin incision is longitudinal, measuring about 4 cm at the distal portion of the medial musculus gastrocnemius.***

790

An incision is made at the fascia cruris at the same level. Applying digital dissection, the separation of the soleus muscle and gastrocnemius medialis is found and visualized to their merging point distally. At about 4 cm from its insertion, the ***ventral fascia of the gastrocnemii is incised transversally*** along the whole width of the muscle ***(O166)***.



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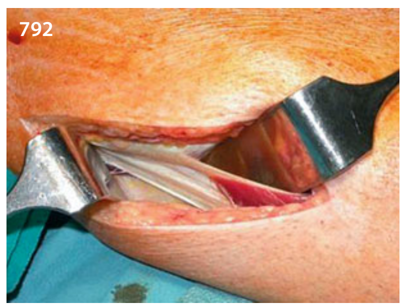
Care is taken not to cut any muscle fibers. The foot is extended forcefully toward the dorsal plane to achieve about 3–4 cm of structural elongation.

Gastrocnemius tenotomy

The patient is positioned and the calf approached as before. After the gastrocnemius insertion is visualized, the posterior aspect of the musculus gastrocnemius is bluntly dissected. The ***sural nerve*** is palpated, visualized, and ***protected by a blunt retractor***.



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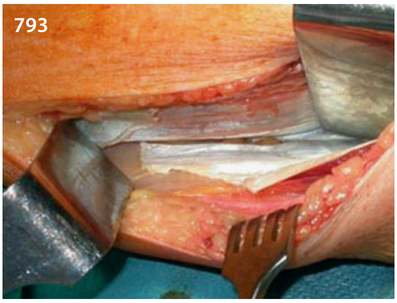
The gastrocnemius tendon is cut by scissors along its whole width ***(O167)*** (45). Extending the foot fully, the ***muscle bellies retract automatically***.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Suture of the heel cord

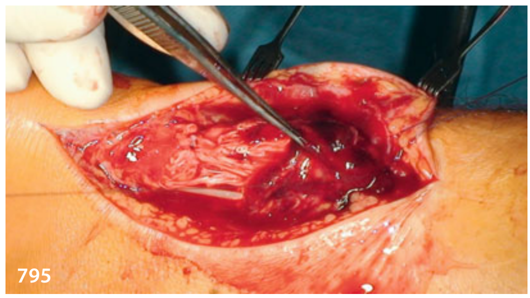
Rupture of the Achilles tendon rarely occurs within a full and healthy tendinous structure. A vascularity problem or chronic tendinitis is often involved. If there is doubt regarding a relevant vital problem of the tendon, an exam using magnetic resonance may indicate either direct surgical adjustment of the physiologic length of the tendon or an additional vascular supply implementing a muscle plasty.

The heel cord region is delicate with regard to the blood supply to the skin, which runs horizontally from lateral and medial. However, a straight, vertical medial skin incision is a very safe approach. This, in particular, allows the surgeon to keep away from any problem involving the sural nerve, which might be endangered by a blind percutaneous technique. The patient is placed prone with both legs lying on a transverse roll to have both feet hanging free. A tourniquet is placed on the thigh. Directly beneath the subcutaneous tissue, ***the peritenon is evaluated. No static distraction is applied to the skin.***


794

If it is intact, a longitudinal incision is carefully performed until the stumps of the tendon are visualized. A strong, single suture with slow-resorbing material is used to approximate the stumps of the tendon (Kessler). Tension of the tendon after suturing determines the rehabilitation capacity of the triceps surae. The spontaneous equinus is observed carefully and evaluated with the contralateral foot, which should demonstrate the same angulation. This corresponds to the elastic recoil of the triceps surae, which is always present under physiologic conditions.

At this stage, knowing the essential nature of the peritenon to the regeneration of tendinous tissue (46), ***the peritenon is adapted with a fine resorbable continuous suture over the sutured tendon***.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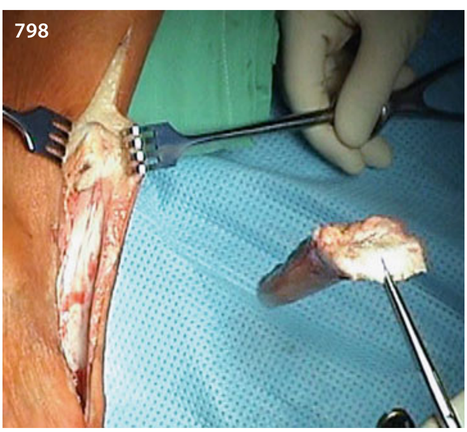
Stability of the montage is checked by holding the foot manually in orthogonal position. Careful soft tissue handling allows for rapid rehabilitation, and muscular power should be ***close to normal at 3 months.***


796

Heel cord plasty

In poorly perfused soft tissue ***(E16, R159)***, including the tendon itself, it may be wise to look for a good vascular supply that can be brought to the tendon as a reconstructive muscle flap. Indeed, in the depth of the heel cord, the muscle belly of the flexor hallucis longus runs behind strong fascia. This muscle belly usually reaches the posterior aspect of the talus and is well vascularized. It can therefore be harvested to run alongside the original heel cord from the distal musculus suralis to the dorsal aspect of the tuber calcanei.

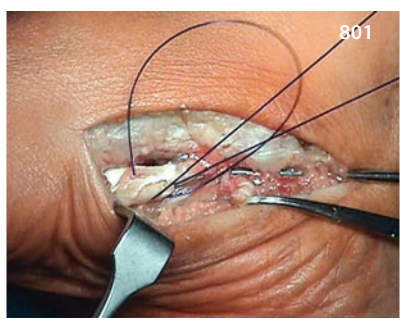
The patient lies supine. The approach to the heel cord is performed longitudinally, medial to the tendon. After open inspection of the Achilles tendon, a definitive indication for muscular flap transposition to the heel cord is decided. The ***tendon is debrided*** from all pathological and necrotic tissue and ***is sometimes excised entirely***.



Lateral to the neurovascular bundle, the strong fascia of the musculus flexor hallucis longus is incised.

At this stage, the midfoot is approached from medial (medial utility; ***T532)***. Keeping close to the bone and remaining above the adductor hallucis longus, the "master knot" described by Henry (47) is incised, and ***the flexor hallucis longus tendon is identified***.

The flexor hallucis longus tendon is tenotomized proximal to its expansion to the flexor digitorum longus tendon. The distal limb of the tenotomized tendon is pulled proximally, provoking flexion of the hallux, and is ***sutured through a hole cut through the flexor digitorum longus tendon***.



Returning to the first approach, the tenotomized ***tendon is pulled out*** of its pulley at the posterior aspect of the talus.

802

until its transposition to the posterior aspect of the calcaneus does ***not cause a relevant angulation (kinking)***

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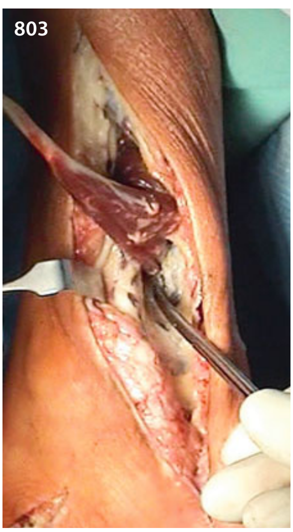
The tendon and its muscle are then detached progressively toward proximal. Attention is given to protect the fibular vessels located on the posterior aspect of the interosseous membrane. The muscle is ***mobilized proximally***



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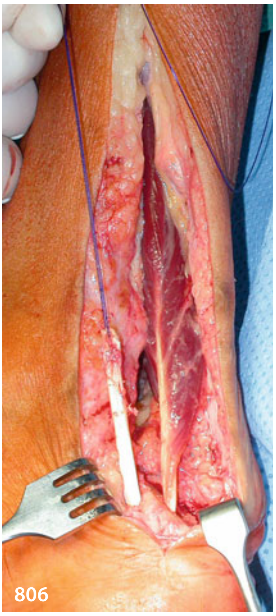
and its tensionless adaptation to the soleus muscle is possible. An ***8-mm hole*** is made from the top to midsubstance of the calcaneus at the ***most posterior aspect of the bone***.

805

A horizontal joining hole is made from the medial aspect. The ***tendon is pulled through*** and pulled toward the proximal direction



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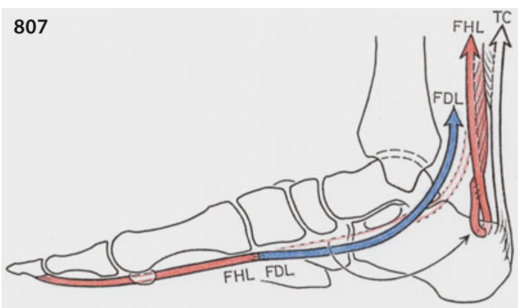
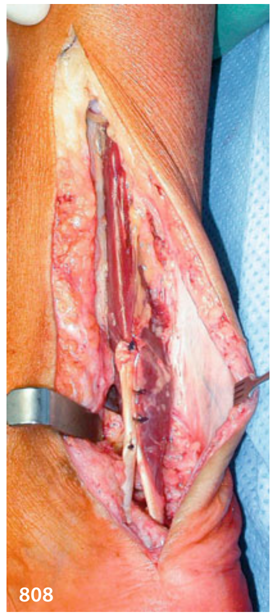
to be ***attached to the musculotendinous junction or more proximally if possible***.

807



Attention is given to the ***tension of this attachment***: It should be done in a slight equinus of the foot



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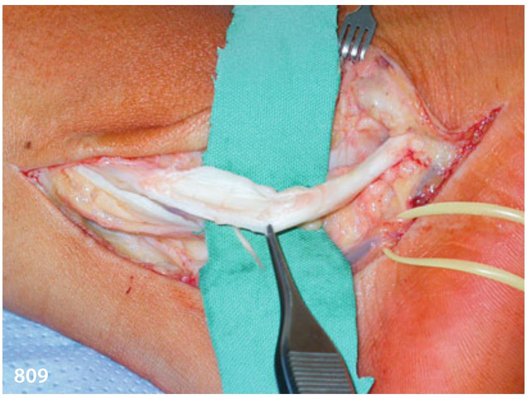
such as to allow relevant pretension of the muscle when the foot is manually put in an orthogonal position. The soleus muscle is then adapted to the transposed muscle.

Reconstruction of fibular tendons

These tendons rarely rupture acutely without prodromal symptoms or morphologic abnormality. They are overloaded in pes cavus varus; in this case, the muscle and tendon are constantly under tension to equilibrate the foot in pronation. Chronic overload and tendinitis ensue, provoking irreversible lesions. These lesions are very different from those encountered at the posterior tibial tendon. Here, the tendon does not undergo hyperplasia but presents with ***longitudinal splits and flattening,***



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which may occur all along its course along the lateral aspect of the hindfoot. It also may separate into different parts without augmenting its diameter. Repair of the tendons includes a longitudinal suture (continuous) to ***restore their original tubular shape***.

810

The underlying cause of the chronic overload must always be evaluated before surgical treatment. Treatment may include morphologic stabilization of the hindfoot by, e.g., lateralizing the heel, and it includes the functional stabilization of the hindfoot by powering the fibularis brevis muscle through the addition of the fibularis longus muscle and tendon to its insertion. In very severe deformities, which most often are linked to relevant neurologic disease, pronation is powered by transferring the flexor hallucis longus tendon to the insertion of the fibularis brevis tendon.

Posterior tibial tendon repair

Similarly to the heel cord, this tendon rarely ruptures without underlying pathology. Experience shows, however, that the purely traumatic ruptures occur at its insertion site, and degenerative ruptures occur more proximally, in the retromalleolar region. The acute, traumatic ruptures may respond well to a direct suture and careful after-treatment. The degenerative ruptures are due to a lack of blood supply and a chronic inflammatory status that causes microruptures and results in a ***larger tendon by hypertrophic scarring***.

811

The volume of such a tendon sometimes increases dramatically. The function of the muscle is then further impeded, often considerably, causing a secondary opening of the acetabulum pedis medially and plantar. A corresponding elongation or rupture of the plantar calcaneonavicular ligament ensues. Plantar protrusion of the head of the talus goes together with a corresponding malposition of the whole hindfoot ***(E42)***: The midtarsal lever is no longer efficient to transmit push-off. The distal part, especially the medial aspect of the foot, extends, abducts, and inverts, while the talus and the calcaneus, pulled by the triceps surae, flex, adduct, and invert. The hindfoot thus positions increasingly in equinus. The talus slides medially until its lateral process abuts onto the calcaneus about the critical angle of Gissane or floor of the sinus tarsi. Conventional radiographs demonstrate a disturbed alignment of both the talar and first metatarsal axes ***(R142, R150)***.

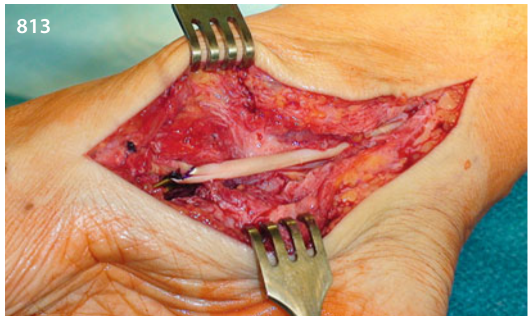
At this stage, reestablishment of normal mutual osteoarticular orientation is clearly indicated to avoid degenerative diseases of the joint surfaces ***(O254)***. If this has already occurred, fusion of the four main bones of the hindfoot cannot be avoided in order to reestablish the needed orientation of the foot beneath the upper ankle joint ***(O286)***.

In all stages of this degenerative disease ***(E105)***, it is logically wise to reestablish the normal equilibrium of the extrinsic musculature and tendons. The tendon that runs closest to the posterior tibial tendon is the flexor digitorum longus ***(O265)***. It has the advantage of not being essential in its function of flexing the tips of the toes. The anatomy demonstrates the tendinous link originating from the flexor hallucis longus tendon and connecting more distally to the flexor digitorum longus of the plantar aspect of the cuneiforms. Harvesting the flexor digitorum longus at this spot is thus very compatible with normal foot function. The approach is longitudinal medial between the basis of the first metatarsus and the talonavicular joint ***(T533)***. In cases in which the posterior tibial tendon must be replaced, the approach is ***extended proximally to the retromalleolar region***.

812

The transferred tendon then ***substitutes entirely for the absent or resected posterior tibial tendon***

813

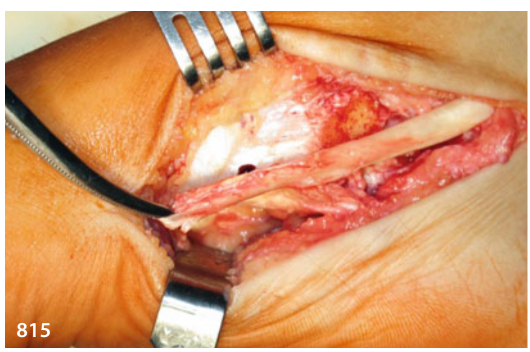


and is attached proximally with its muscle.

Leaving the adductor hallucis plantarward, the roof of the medial arch allows the “master knot” to be opened (47), disclosing ***the chiasma of the long flexors*** of the toes.

814

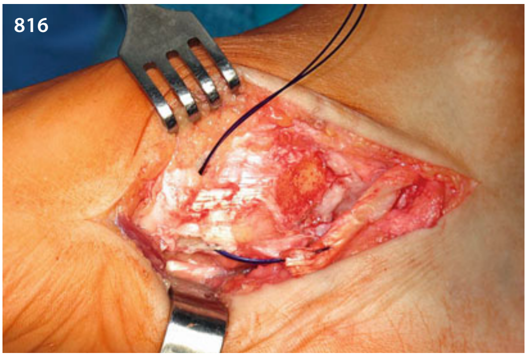
The flexor hallucis longus sends strong fibrous extensions to the distal part of the long flexors of the toes; therefore, ***harvesting the flexor digitorum longus***



815

does not imply any relevant functional limitations.

A 4.5-mm bore hole is made from plantar to midsubstance of the first cuneiform, and another joining hole is made from medial through the same bone. The tendon is mobilized and ***pulled through the hole*** and sutured on itself.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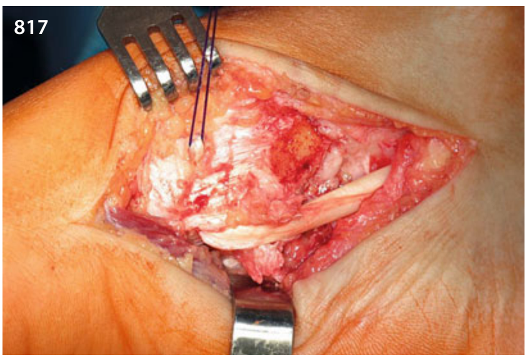

817

The length of the harvested tendon allows for this transfer, and it secures the naviculocuneiform joint in addition to the sagging talonavicular joint.

Anterior tibial tendon repair

Ruptures of the anterior tibial tendon seldom occur, but they often follow local injections of corticoid solutions causing necrosis. If the patient receives attention within a reasonable time, the stump may be found, and ***reinsertion is anatomically feasible (E93)***.


818

Because of the “missing structure” after such necrosis, and also for secondary retraction in patients who did not seek immediate orthopedic assistance, it is wise to look for a strong tendon substitute. The long extensors of the toes may be harvested easily at the metatarsal level and brought together to be fixed at the anatomic insertion site of the anterior tibial tendon. To save the functional stability of the toes, the distal limbs of the tendons are fixed individually onto the corresponding short extensor tendon of the toes.

Posterior tibial tendon transfer onto the dorsum of the foot

The patient lies supine with the contralateral leg slightly lowered. Four skin incisions are required. The tendon is harvested through a medial utility incision centered on the medial navicular bone, including a small extension distally. After tenotomy of the posterior tibial tendon and without harming the plantar extensions, the master knot is divided, and the flexor digitorum longus is harvested at the chiasma of the tendon with the flexor hallucis longus. A second incision is performed at the posteromedial crest of the tibia at about two-thirds of its length. The posterior tibial tendon and muscle are identified and pulled out. Leaning against the tibial cortex, the interosseus membrane is found and opened to at least 8 cm in length. A third incision is made about halfway between the second incision and the upper ankle joint, just lateral to the anterior tibial crest. Again, leaning against the tibial cortex, the slot within the interosseus membrane is found, and the ***tendon is pulled through anteriorly***.


819

At this stage it must be verified that the muscle and tendon do not present any angulation or kinking at this rerouting. From this point toward distal, the tendon will be driven through the subcutaneous tissue for optimal force transmission and gliding. A fourth incision is made on the top of the foot at the cuneiform level. For optimal "neutral" function, the second cuneiform is chosen for insertion of the tendon. ***A large bore hole of about 8–10 mm in diameter is drilled from the top of the foot to the medial plantar aspect of the foot***,


820

corresponding to the first cuneiform.

The flexor digitorum longus tendon is pulled through the bore hole from plantar to the top of the foot for substitution of the harvested tendon. The posterior tibial tendon is pulled from the top to the bottom of the foot, thus crossing the other tendon. Tightening and fixation of both tendons is performed in a perfect neutral, orthogonal position of the foot in the sagittal and frontal planes ***(O168)***.

Long toe extensor transfer onto the dorsum of the foot

The approach to the dorsum of the foot is located at about the cuneiform level, allowing identification of the five tendons. At about the neck of each metatarsus, the long extensors are tenotomized, and the distal limb is fixed without tension onto the respective extensor digitorum brevis tendon. The long ***extensor is then pulled out*** toward the proximal direction.


821

A second incision is made on the plantar medial aspect of the midfoot. A ***bore hole is drilled*** from the desired insertion spot of the transfer to the plantar medial aspect of the first cuneiform.


822

All of the tendons are then ***pulled through***

823

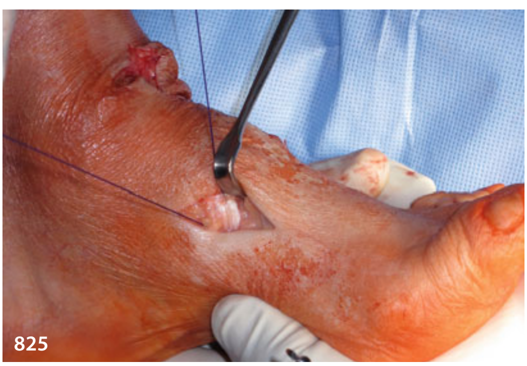
824

Fibularis longus tendon transfer onto the fibularis brevis

Such a transfer ***(O214)*** is quite simple, requiring only one skin incision. The approach is thus lateral to the foot about 5 cm proximal to the basis of the fifth metatarsus. The fibularis brevis tendon is identified, and a central hole is made. Beneath this tendon and beneath the cuboid bone more proximal, the fibularis longus ***tendon is identified while turning in its plantar tunnel***.

826

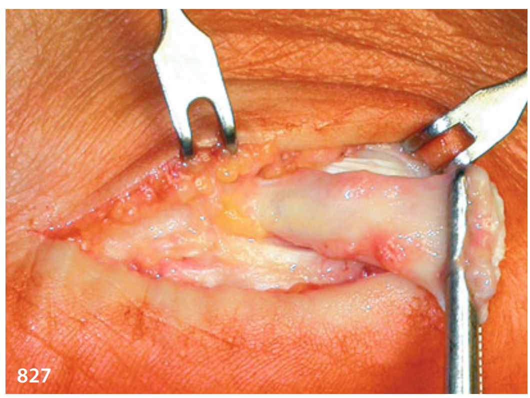
and ***fixed at the plantar side*** of the cuneiform, or to the extensions of the anterior tibial tendon ***while the foot is held in orthogonal position (O171)***.



825

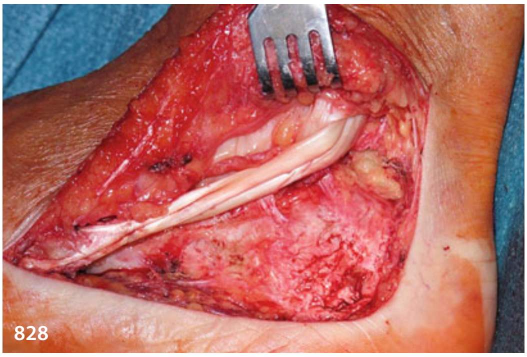
An eventual os peroneum is removed by enucleation.

The tendon is cut at this level and ***rerouted through the fibularis brevis tendon*** at its insertion.



827

Tendon repair **and** transfer need a ***wider exposure,***


828

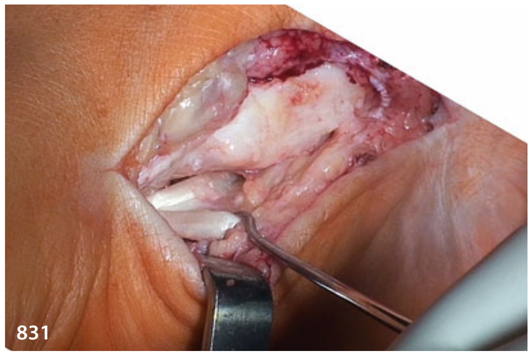
which heals uneventfully when the ***posterolateral flap is respected.***


829

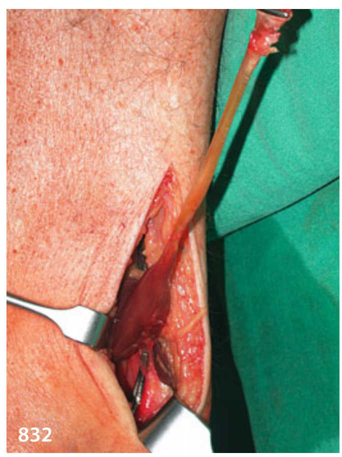

830

Flexor hallucis longus tendon transfer onto the fibularis brevis

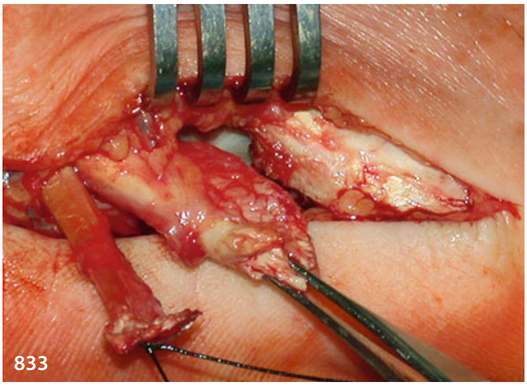
The rerouting of the flexor hallucis longus tendon to the lateral aspect of the foot ***(O215)*** requires three incisions. The first approach is along the medial utility line at the cuneiform level. The master knot is divided, and ***the tendon is identified distal to its crossing with the flexor digitorum longus tendon.***


831

The distal part of the tendon is secured before tenotomy and attached under tension to the flexor digitorum longus tendon, provoking a hallux flexus. This flexion allows for efficient functional flexion of the hallux after healing and will resolve aesthetically after a few weeks. A posteromedial approach is performed medial to the heel cord. ***The tendon is pulled out posteriorly***.


832

The fibular tendons are identified, and the retinacula are opened longitudinally from the posteromedial approach. On the lateral aspect of the foot, a third incision is made at the insertion of the fibularis brevis tendon. To maximize active pronation, ***both flexor hallucis longus and fibularis longus tendons are transferred***.



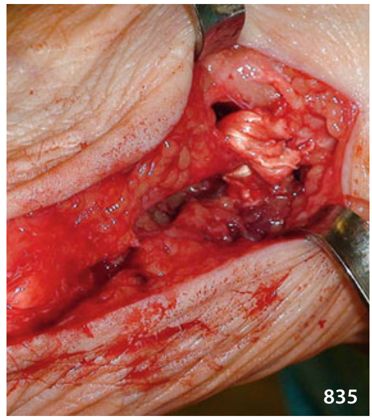
833

Here, too, the retinacula are opened proximally. The transplant is pulled through to the fibularis brevis tendon, where it is anchored under slight pronation of the foot, allowing for a certain pretension of the tendon.

Flexor hallucis longus tendon transfer onto the basis of the first metatarsus

This is indicated particularly in neurologic and muscular diseases ***(O344)***, including metatarsus primus elevatus. The approach is longitudinal medial between the first metatarsus and the first cuneiform. Leaving the adductor hallucis plantarward, the flexor hallucis longus tendon is followed distal from the chiasma of the long flexors of the toes. The ***tendon is then cut*** to be transferred to the basis of the first metatarsus. The limb is pulled through a 4.5-mm bore hole drilled within the sagittal plane through the basis of the first metatarsus. The ***tendon is then attached to itself and to the insertion of the anterior tibial tendon***.

834



835

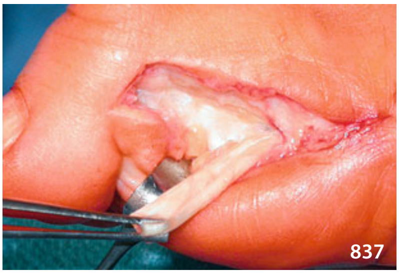
The joint surface is more or less even, and the function of the muscle is to hold the first metatarsal down, thus limiting shear motion toward the dorsum of the foot. Care must be given to the metatarsophalangeal and the interphalangeal joints because they lose their main dynamic flexor. The distal limb of the tendon is therefore attached to both short flexors proximal to the sesamoid bones.

Flexor hallucis longus tendon transfer onto the first phalanx

The approach is along the ***medial utility line*** in between the dorsal and medial plantar nerve branches.

836

The concavity of the plantar aspect of the first phalanx is visualized. The underlying tendon is dissected about 1.5 cm distally and ***cut***.



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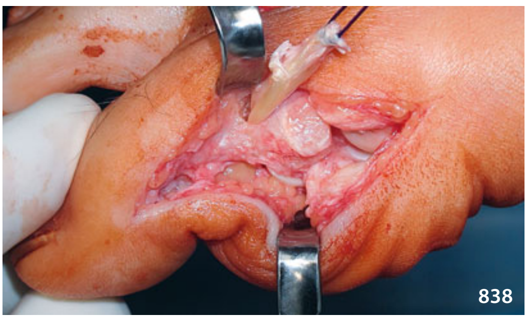
A 4.5-mm hole is drilled from medial through the first corticalis. The second hole is drilled from the plantar aspect of the basis of the phalanx. The ***tendon is pulled***



838

through this angulated channel and ***sutured on itself.***

839

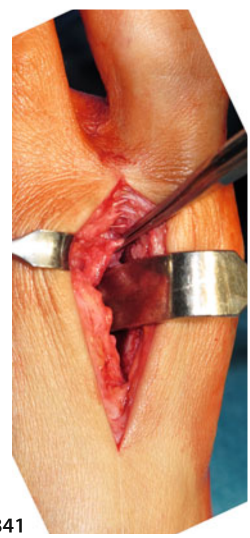
The transferred tendon must allow ***immediate stretching of the toe***.

840

The dorsum of the toe thus remains untouched with its extensor tendons.

First dorsal interosseus transfer onto the first phalanx of the hallux

The skin incision lies dorsolateral to the distal aspect of the first metatarsus ***(E52, O411)***. The dorsolateral nerve branch of the hallux is identified and protected. On the lateral aspect, the second metatarsus is palpated through the soft tissue, and the small muscle belly of the first interosseus muscle is identified. The muscle fibers are all protected and followed distal to the tendon, which is ***cut at the level of the second metatarsal head***.



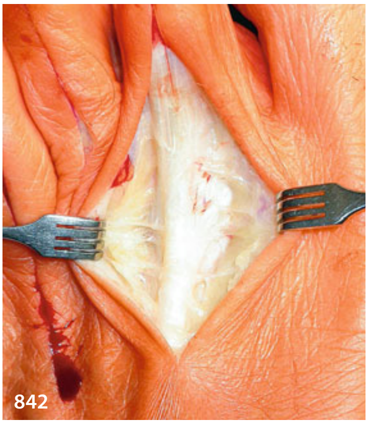
841

The muscle is carefully mobilized and directed toward the lateral aspect of the first phalanx of the big toe. The joint has been previously mobilized by arthrotomy. The tendon of the first interosseus muscle is then attached to the first phalanx of the big toe by transosseous sutures.

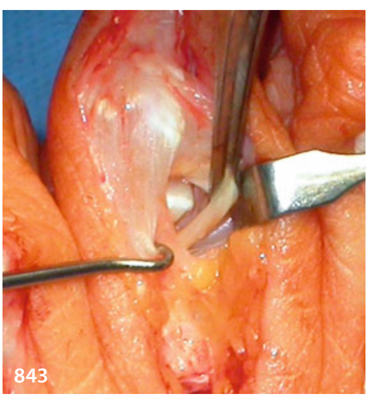
Flexor digitorum longus tendon transfer onto the first phalanx

The ***approach is dorsal*** from the intermediate phalanx to the neck of the metatarsus.

6


842

The extensors of the toe are divided for elongation, and the joint is opened, leaving only the plantar plate of the capsule untouched. Choosing one side of the toe and leaning against the bone and the first interphalangeal joint capsule, ***the flexor tendons are identified*** and caught on a smooth hook. The long flexor (which perforates the short flexor tendon) is cut and pulled back to the midlength of the first phalanx. At this stage, the tendon, which has a double string shape, is ***divided to obtain two limbs***.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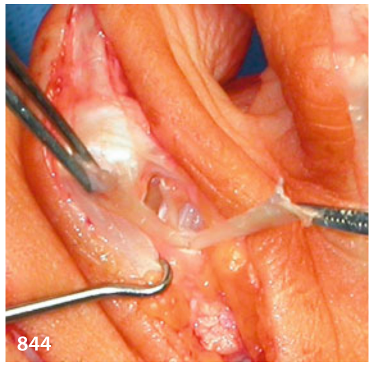
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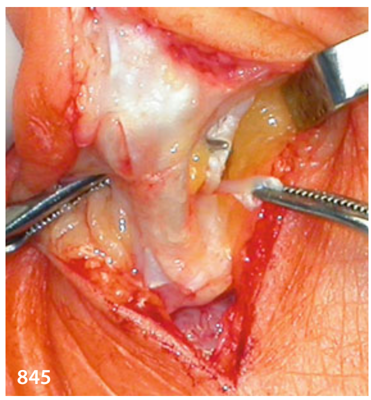
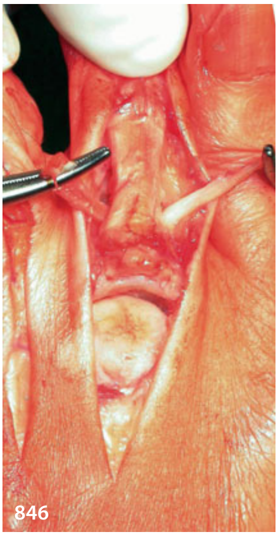
One limb is caught beneath the phalanx using a mosquito clamp introduced ***from the opposite side of the phalanx***.


845

The result is that the two limbs of the long flexor tendon are ***pulled dorsally*** on each side of the first phalanx of the toe. The ***toe is then pushed*** *plantarward*, and the occasional subluxed or dislocated toe is reduced at the metatarsophalangeal joint.



846

The two limbs are then ***sutured together*** on the dorsum of the phalanx ***(O387)***. This procedure is done ***on all lesser toes*** because of the common pull of the long flexor (48).

847

Therefore, adapting all of the toes at similar flexion while suturing the flexor tendon is indicated. The aim is ***firm contact of all tips of the toes with the floor***.

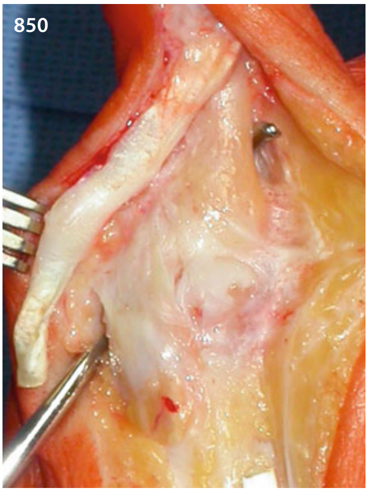
848

Extensor digitorum minimi transfer onto the abductor digiti quinti

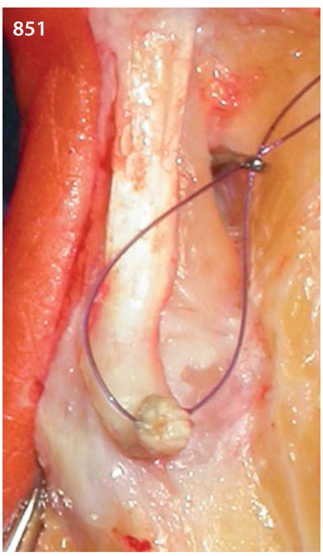
The tendon ***(O413)*** is ***divided at the level of the metatarsal,***

849

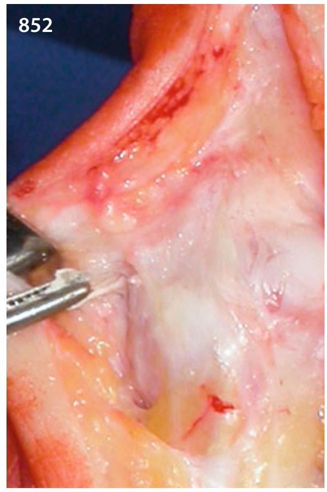
and an ***oblique plantar tunnel*** is prepared at the level of the metatarsophalangeal joint.

850


The distal limb of the ***tendon is taken***

851


and passed within the oblique path, arriving at the basis of the ***lateral aspect of the metatarsal head***.

852


The tendon is sutured to the lateral ***tendinocapsular hood*** of the fifth metatarsal head.

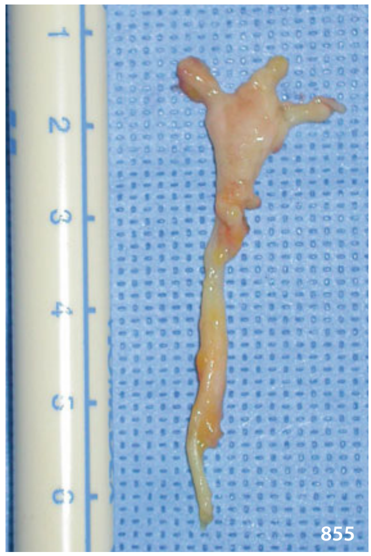
853


7 Intermetatarsal Neurectomy

The approach is performed to reduce collateral damage to a minimum. The involved nerves are located plantar to all osteoarticular structures and just deep to the plantar fascia. The incision is therefore performed plantar on a length of about 7–8 cm between the metatarsals. Staying within the sagittal plane and dividing the fibers of the plantar fascia longitudinally, the nerve is identified just beneath this layer. Magnifying glasses and instruments for microdissection help free the nerve and present the ***pseudoneuroma***, which is located at the level of the metatarsal heads ***(R164)*** (7).

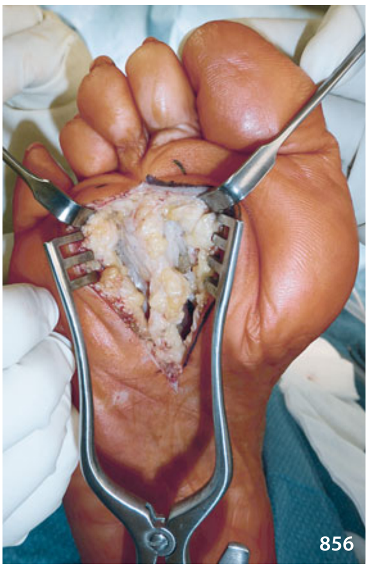
Dissecting distal to the tumor, both plantar digital nerves are presented on a few millimeters and cut sharply. The removal of the nerve and neuroma is then eased going proximally as all collateral nerve fibers situated plantar to the intermetatarsal ligament are also lifted and removed. The ligament is an important structure and is not incised. The nerve is dissected and ***removed proximally together with the accompanying vessel,*** which is cauterized where it crosses the intermetatarsal ligament. The nerve is then cut proximally at the level of the intrinsic musculature.


854



855

The stump neuroma will thus be clinically irrelevant, and weight bearing will not cause tingling pain. Cauterizing the small vessels is more precise with bipolar cautery. The skin layer is closed using simple single stitches to bring the edges of the skin to the same level. A step at the level of the skin is not well tolerated. In the rare case of two pseudoneuromas located in adjacent intermetatarsal spaces, the cut is ***centered on the corresponding metatarsus,***

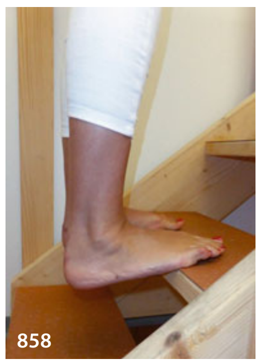

856

and the dissection diverges beneath the dermis to allow ***uneventful healing of the plantar skin***.


857

8 Stretching

In cases of calcaneodynia or heel cord tendinitis ***(E16)***, the concept of stretching the plantar fascia and the Achilles tendon is a keystone of nonoperative treatment. The inflammatory process affects vessels and increases local perfusion. By stretching the aforementioned structures, the vessels are tensed and their caliber diminishes, reducing the inflammatory vicious circle. Efficient stretching of the heel cord can be performed standing with the forefoot at the edge of a step, leaving the heel without support and the hindfoot joints in ***maximal passive dorsal extension.***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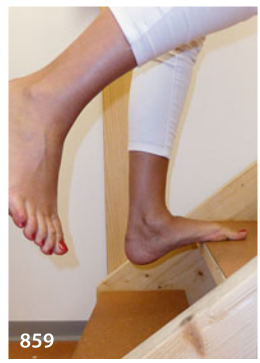

859

Efficient stretching of the plantar fascia can be performed on the sitting patient, who lies with one foot on the contralateral knee and, with his or her hands, pulls all ***toes in maximal dorsal extension.***


860

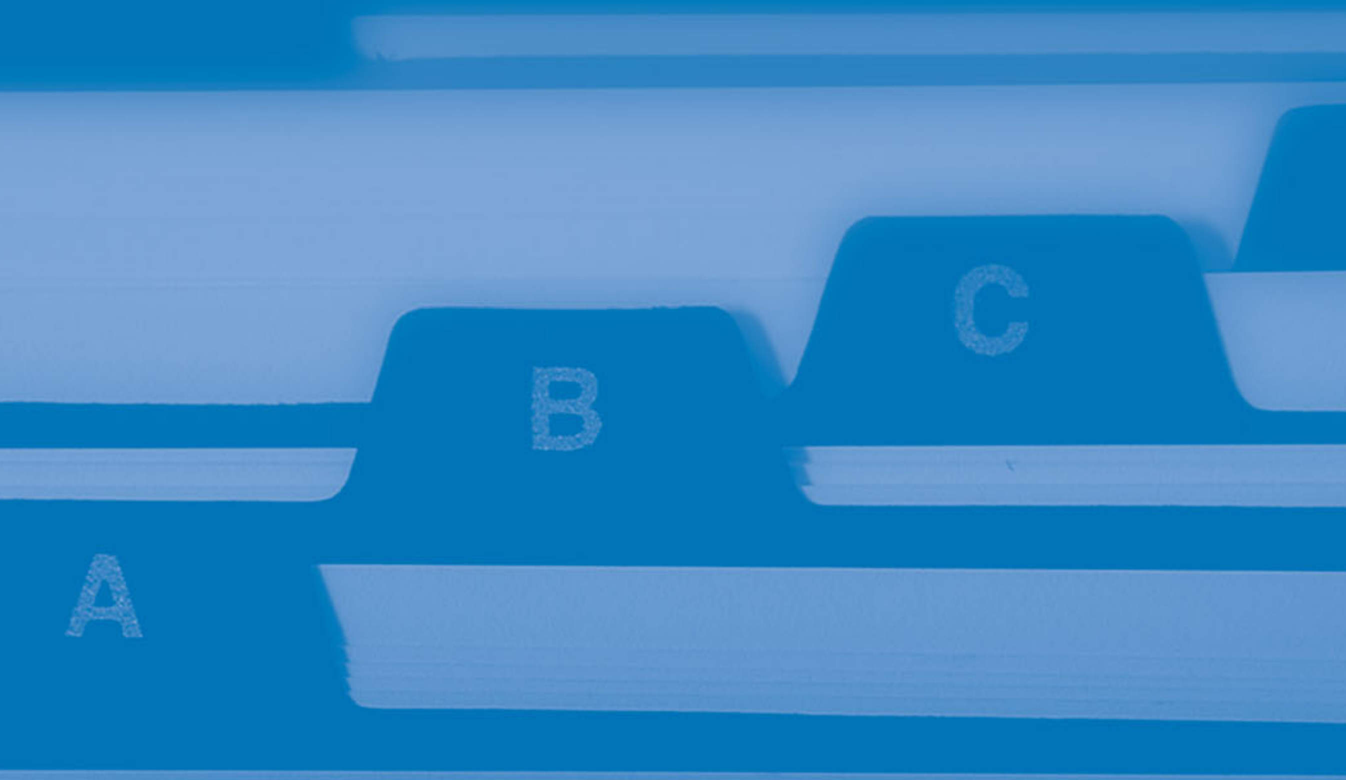
9 Orthoses

The weight-bearing area of the foot is quite variable. In cavus feet, it is reduced; this can be overcome by using a plantar support that increases the area by reproducing the anatomic shape of the sole of the foot. Diabetic feet suffer from fragility of the skin and local overload after dislocation of, e.g., joints of the midfoot (diabetic arthropathy). Microcirculation also reduces stress resistance to the skin. The aim is to reduce the peak loads using plantar supports equalizing the plantar load distribution. To achieve reliable and constant corrective support, the orthosis should have a ***stable plane surface facing the shoe sole***.

861

To relieve overload from the central metatarsal heads causing metatarsalgia, load sharing to the metatarsal shafts can be introduced by so-called retrocapital supports.

Service Part



K. Klaue, *The Foot*,
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Subject Index

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Efficient learning and creation not only strives for the cutting edge of knowledge but should also cultivate a close interest in the non-related fields of art and science.

We should remind any newcomer in research of the maxim : “If you follow the flock, you’re likely to step into shit”.

Recognizing the likelihood of interconnection between unrelated fields is what can be called “horizontal learning”.

This attitude might be most profitable and efficient for everyone and it provides the most fun.

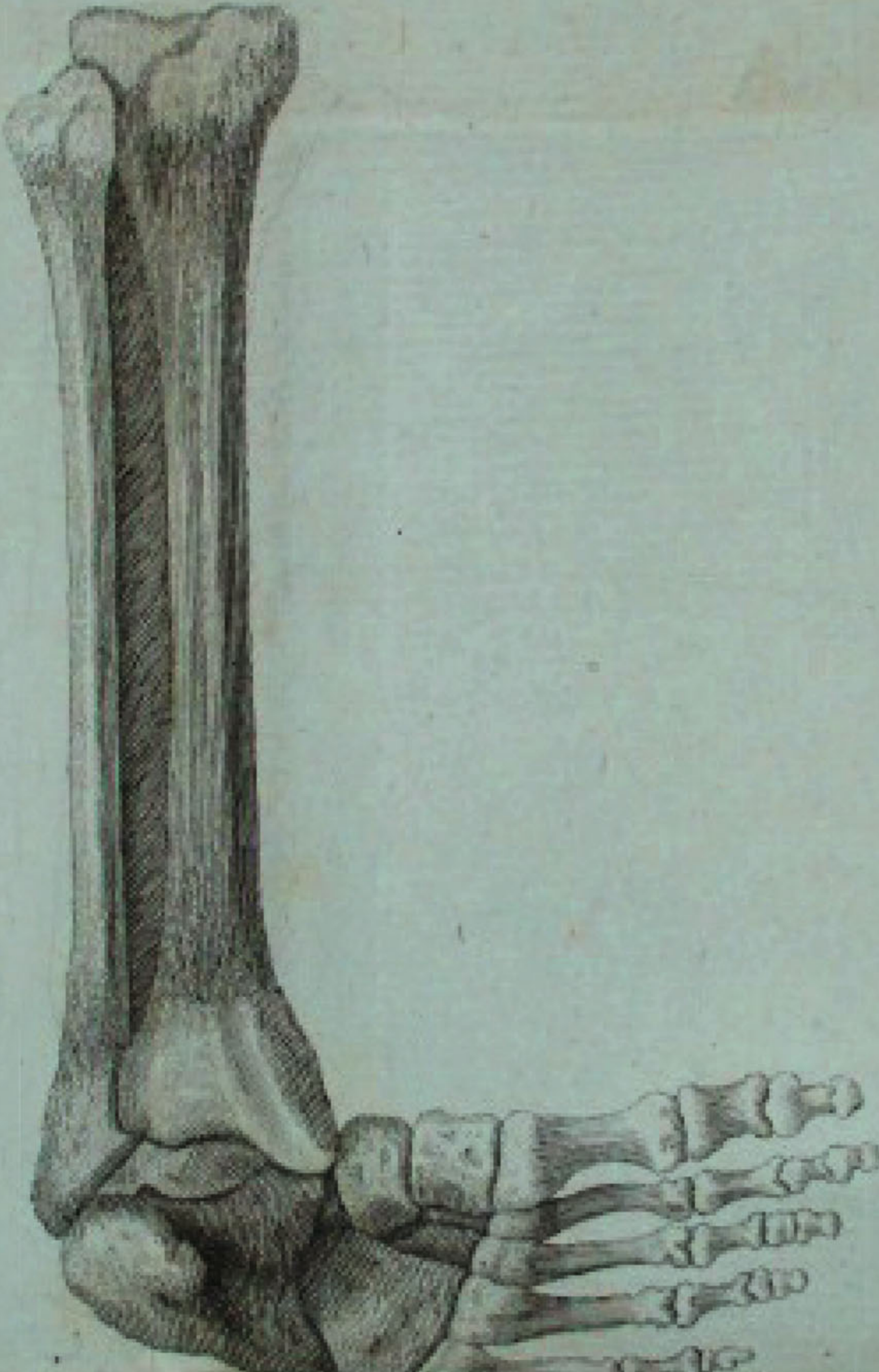

Fig. II.