The Foot

From Evaluation to Surgical Correction

Kaj Klaue

Second Edition

Springer

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Preface to the Second Edition

The aim of the first edition of this book was to expose a rational link between symptomatic dysfunction of the foot and ankle and pathology so that logical surgical treatment could follow with more ease. I found it encouraging to hear colleagues express surprise at the extended chapter on clinical examination. Back to the root, I would answer. How many times do we see patients in our office carrying a bunch of radiographic images of examinations which show "pathologies" irrelevant to their actual problems? In the field of foot and ankle surgery, examination of statics and function should be the primary guide to diagnosis and treatment. This new edition is the result of refining descriptions of pathological conditions and the corresponding imaging, which may be unclear in the first edition. It also contains a new chapter on comprehensive complex reconstructions. This chapter exposes the approach to frequently occurring conditions such as the "diabetic foot" and foot conditions after failed surgical treatment. The important reconstructive aspect in amputations closes this edition. Again, I would acknowledge the influence of Professor Stephan M. Perren on my vision in reconstructive surgery of the locomotor system. A special mention also goes to Dr. Sigvard T. Hansen who first showed me a logical and comprehensive approach to foot pathology. Again, this book has not the pretention to claim originality nor exclusivity but proposes pragmatic and efficient treatments which are logically linked to pathology.

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November 2021

Preface to the First Edition

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 analyse biological and mechanical pathways. Every step of the protocol is based on secured knowledge. As a clinician, I learned the basics of efficient surgical treatment based on an understanding pathology. I grew up in a mechanical automobile engineering environment and during high school I became interested in biology which led to a natural interest in applying mechanics to 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. The atmosphere following the moon landing undoubtedly boosted my curiosity in this field. Meeting Professor Stephan M. Perren at this time was decisive in me having the opportunity and the freedom 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 and has developed because of historical rather than rational reasons. Interestingly, the spectrum of surgical care in this field today quite probably demonstrates the widest variation in all medicine. Textbooks reflect this variation and often set the reader in front of multiple different possible and praised treatments for single pathological entities. As a reader I often remain puzzled for two reasons: I miss the rational link between symptomatic dysfunction and pathology and I am disappointed not to find the logical treatment to pathology based on biological and mechanical rules. This book strives to be evidence against obscure and irrelevant treatments. It has not the pretention to claim originality or exclusivity but proposes pragmatic and efficient treatments which are logically linked to pathology.

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Introduction

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K. Klaue, *The Foot*, https://doi.org/10.1007/978-3-662-64001-2_1

This book should provide the reader with Ariadne's thread, from the symptoms through to the surgical solution. The reader should be driven by an interest in logical thinking and rational handling. Remaining attentive to this process, the reader will be entertained by the history of pathology while learning about pathogeny. This is "Edutainment", a concept found in schools and professional training. The reader will notice some repetition in the book. There are concepts which merit repeating when discussing clinical examination and surgical correction. The intention is to outline a specific aspect of the pathological significance found during clinical examination and which is raised again when describing the surgical treatment. By combining entertainment with education, the reader is made aware of the continuous evolution in knowledge and teaching following the concept of lifelong learning.

The approach to foot and ankle pathology begins with the inquiring and focused case history. This dialogue raises suspicion in the search for diagnosis and is therefore followed by the focused clinical examination. The clinical exam is divided into different sections, the study of the statics of the lower limb being, in most cases, fundamental. This usually leads the physician, in more than 90% of the cases, to a reliable diagnosis. The reader is then referred to the eventual paraclinical evaluation (conventional radiographs) or more sophisticated exams such as computerized tomography (CT), magnetic resonance imaging (MRI), scintigraphy or combined exams such as Pet-CT, SPECT-CT or SPECT-MRI. From here the reader moves on naturally to the surgical orthopaedic treatment which is a rational and generally complex, multifactorial correction. The approaches to traumatic pathologies which include mainly fractures and tendon ruptures are treated in the subsequent chapter. This chapter deals with the most common traumatic lesions and therefore may seem incomplete at first sight. In those selected injuries, we emphasize the essential aspects of the treatment which may not correspond automatically to anatomical restoration. We aimed to present one approach to treatment which is based on a logical reflection to achieve long-lasting painless function. The operative techniques of the single steps to achieve surgical corrections are then reviewed within the next chapter. The chapter starts with a comprehensive list of the surgical approaches thus emphasizing the relevance of the soft tissue structures including vascular supply and nerves at risk. Crossing the soft tissues to reach the injured structures requires a desire to achieve the least "expensive" trajectory. At this point, we would remind the reader of Bernhard Georg "Hardi" Weber's teaching of "MiniMax" meaning the minimal surgical investment to a maximal mechanical and functional effect. A critical view onto the so-called "minimal invasive techniques" is thus often indicated. To complete the manual, the chapter titled "Complex reconstructions" describes a vision of orthopaedic surgical reconstructions of the foot and ankle and includes additional factors that may puzzle the surgeon. In the first subchapter, the reader will find the judicious association of hind- mid- and/or forefoot operations treating cavus and planus feet with or without stabilizing soft tissue correcting means. The following subchapter deals with the complexity of the multifactorial aspects of the diabetic foot. The third subchapter demonstrates the unique difficulty of treating complications after previous surgical interventions. Finally, we attempt to demystify the oldest surgical actions known to man, amputations, insisting on the final function rather than on anatomical integrity.

Throughout the manual, the reader should find an answer to most of the practical questions which arise when preparing and executing surgical corrections about the foot and ankle. More precisely, this manual adheres to the principle that says "question everything", asking "why?" for any step on the path to diagnosis and particularly for anything related to the treatment. Being a critical thinker should be one of the characteristics of the orthopaedic surgeon. He/she should be aware that the orthopaedic surgeon, besides being etymologically the doctor of growing children, shares with the common family doctor the capacity of managing musculoskeletal issues, mental health and social concerns as a whole over generations of patients. In an inquiring way, this book avoids the ambiguous suggestions introduced by the words "you can also do this, you might do that" which is of no help to the surgeon who is looking for a fully rational path to improve his treatment of pathological conditions. Rational surgery on the foot and ankle results in a list of procedures which can correct the orientation, the stable load-bearing ability and the propulsive function of the complex osteo-articular framework of the foot and ankle.

References to further reading within the book is noted by ***(A)*** medical history, Anamnesis ***(E)*** clinical examination, ***(R)*** Radiological Screening, ***(O)*** basic surgical orthopaedic treatment, ***(F)*** surgical treatment of traumatic lesions, ***(T)*** operative techniques and ***(C)*** complex reconstructions. Figures and Illustrations are noted by Arabic numbers. The references are thus specified by the chapter (letter: ***A, E, R, O, F, T, C***) and the figure number.

1.1 General Considerations

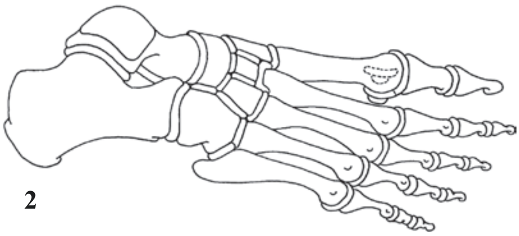
Bipedalism first appeared in the phylogeny of mankind about 3–4 million years ago [1]. Recent research suggests that the rigidity of the longitudinal arch of the foot, which is specific to our species, has been part of the very early time of phylogeny [2,3]. This evolution, although obviously helpful for the further development of the species, was a real mechanical challenge to the foot and ankle. ***The support polygon, by means of the horizontal surface over which the centre of mass of the body must lie, to achieve static stability***

1

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. It also demonstrates a slow (and sometimes insufficient) adaptation of the anatomical 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 and as such, instability is a subjective notion. We would therefore distinguish instability from hyperlaxity which may occur and remain asymptomatic throughout life and as such is an objective observation. Instability can therefore occur without hyperlaxity. Instability usually causes pain and/or apprehension and if not treated, may lead to articular lesions and destruction.

The foot has a structure inherited from 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, the foot became 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 at about 32–36 joint surfaces***.



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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 [5]. Essential joints may be defined by their indispensable role for a specific task in walking or running while adaptive joints are defined by a low arc of motion, linking bones by a tremendously strong ligamentous system assisted by intrinsic and extrinsic [6] 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 this way, we aim to achieve a judicious balance between a multi-articular frame and a number of extrinsic muscles. Instability due to foot and ankle pathology might be corrected by re-orienting osteotomies and/or by fusing adaptive joints together with muscle tendon transfers in order to achieve an equilibrated muscular system (motor propulsion and active suspension).

1.2 Anamnesis

Ideally, the podologic patient who suffers from foot pain should be seen first by his/her family physician who would exclude the major "extrinsic pathologies" such as compressive neuro-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 the cases [5].

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

1.2.1 Subjective Disorders

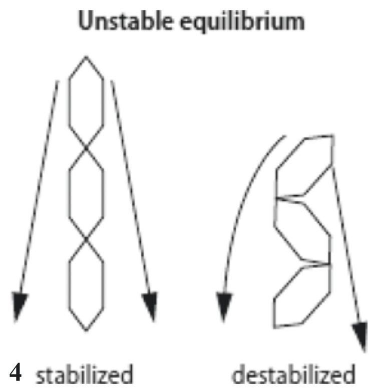
1.2.1.1 Pain

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 towards a degenerative disease. Pain can, conversely, increase during activity which would lead the diagnosis towards an osteo-articular malorientation or a musculo-tendinous problem. Pain can also arise without weight-bearing and at night which may be linked to a neurological problem. Pain can have different characteristics. Pain can be reported as sharp or precisely located in a joint problem, dull in a degenerative disease, or wandering, diffuse, inconstant, burning, including "electric discharges" in neurological diseases. Precisely located plantar pain very often indicates a local overload and thus an osteoarticular imbalance of the foot. It may also indicate a malalignment of the whole lower limb.

Pain might be linked to footwear. For the Foot and Ankle surgeon, it is essential to know if 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 fifth metatarsus, the medial process of the navicular bone and at the level of the insertion of Achilles tendon. When considering pain linked to footwear the adaptation of the footwear to the particular anatomy of the foot must first be discussed. Orthopaedic 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 practise of plastic and aesthetic surgery.

1.2.1.2 Instability

Instability is a subjective feeling experienced by the patient. Hyperlaxity is an objective sign which 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 either as pain and/or apprehension. It is often linked to traumatic lesions of the ligamentous entity of a local osteo-articular 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 osteo-articular structures in the forefoot and midfoot follows the rules of an unstable equilibrium which is stabilized by a specific musculature [6]. As such, ***a minute imbalance of muscular antagonists***



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causes a slight deformity which, 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 either by pain and/or apprehension. The patient often reports a trauma in the past.

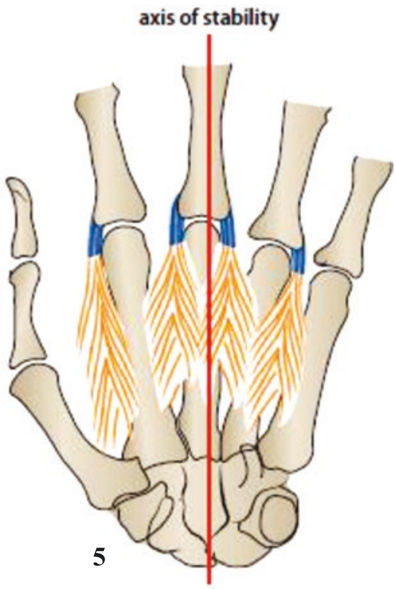
In the hind foot, the instability causes pain either lateral, at the antero-lateral corner of the upper ankle joint or medial, at the level of the posterior tibial tendon and/or anterior to the medial malleolus. Apprehension is most critical when dealing with hindfoot instability.

In the mid-foot, pain due to instability might be centred 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 tarso-metatarsal (TMT) joints and/or at the plantar level of the metatarsal heads. Static buttress and dynamic push-off are basically influenced by the mobility of the TMT joints and the relative length of the metatarsi.

1

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



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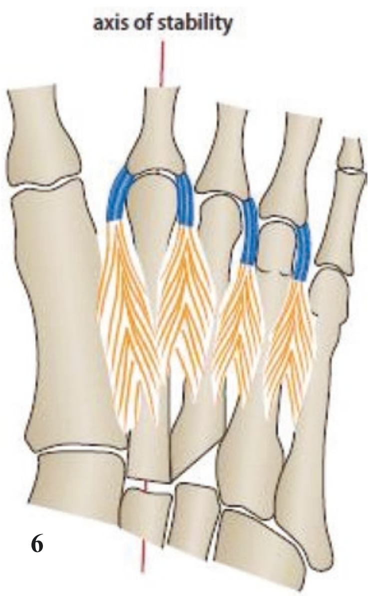
to the second ray (foot).



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

Since the recent time of homo erectus existence (about 3–4 million years), there has been insufficient 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 lacks a ligamental hold to the lateral metatarsi. This characteristic jeopardizes the stability of the foot in weight-bearing, walking, running and jumping. Instability of the first TMT joint reduces the antero-medial 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 (2 (and/or 3)) metatarsi***

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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 anatomic ***separation between the "navicular" and the "cuboid" forefoot***

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and where the intermetatarsal mobility is highest. This causes the nerve and surrounding tissue to thicken, undergo fibrosis and to be destroyed.

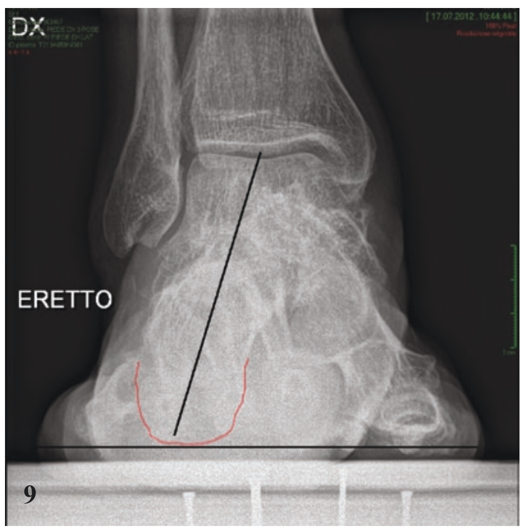
1.2.1.3 Impaired Function

The function of the feet is to give the body stability while standing, walking and running, though due to the bipedalism of the human species, functional stability is, in fact, a real challenge. The most frequent trauma encountered in clinical practise is the sprained ankle. Impaired function might be due to recurrent sprains or other post-traumatic conditions. A considerable number of people, however, suffer from a morphological disposition causing a state of dynamic imbalance of the foot thus impairing function. Such unfavourable morphology originates either from a congenital disposition or, more rarely, from 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 which should be assessed and treated by the foot and ankle surgeon.

1.2.2 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 which changes length or angulation of the osteo-articular structures changes the weight-bearing pattern of the foot which might be unable to compensate.

The patient might indicate precisely the **localization** of the pathology easing the pathway to diagnosis. On the other hand, he/she might indicate diffuse pain or 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 those joints must be oriented and stabilized by the combined effect of connective tissue and muscles. These levers, besides being multi-articular, are oriented in a ***helicoidal fashion***, starting at the (posterior) heel in a ***slight oblique plane*** (valgus talus-calcaneus) and ending in a perfectly ***horizontal plane***



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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 upon **physical activity**. The relation between musculo-skeletal activity and pain, instability or impaired function, will inform about the origin of the disorder. Physical activity clarifies such information. If running and/or jumping causes trouble, walking and standing alone might not cause any discomfort. Change of the gait perimeter is a reliable factor in assessing foot function. Pain at rest is difficult to interpret and may be related to neurological, 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 dependence of 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 in improving pain, instability and impaired function. The contralateral foot might help in finding the cause of the disorder. Previous re-orienting procedures (osteotomies and arthroplasties) located proximal to the ankle may influence foot function.

Check for updates

Clinical Examination

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K. Klaue, *The Foot*, https://doi.org/10.1007/978-3-662-64001-2_2

2.1 Observation

2.1.1 Statics

Statics is the mainstay of the clinical examination of the foot and ankle. From the time of *Homo erectus*, statics became essential to the survival of mankind. The aforementioned support polygon ***(A1)*** is responsible for the equilibration of the whole body to this sudden challenge. If the bony and articular alignment of the lower leg and the foot does not follow a few simple rules of statics, function is likely to be jeopardized and painful degeneration follows. In general, when comparing the foot to the vertebral column, human bipedalism is stabilized by the musculature while the ligaments are secondary.

The first static examination is performed while looking at the patient from behind while he/she is standing on an elevated ***platform of about 1 square metre*** (examination cube) [7].

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

2.1.1.1 Pelvis - Lower Leg

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

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The level of the knees gives information about potential 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.

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13

Genu valgum may be compensated by a varus of the hindfoot. Such a morphotype may cause a clinically relevant instability if associated with internal rotation and shortened gastrocnemii ***(E93-94) (T888-889).*** Genua vara, in the presence of a neutral axis of the foot or in varus, represents a challenge to stability in itself. If the problem is one of instability, surgical angular correction may be indicated at the proximal aspect of the leg ***(O220).***

The ***perimeter of both calves***

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is measured because it is a very sensitive parameter for evaluating atrophy of the extrinsic foot musculature 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 which coordinate and motorize the foot. The triceps surae is the most powerful. In the normal foot, the torque measured around the ankle joint is four times greater for the flexors than for the extensors. Around the lower ankle joint, the supinators have twice as much power in torque when compared to the pronators [6]. The relationship between the power of these muscle groups is both essential and very sensitive. The natural difference between the agonists and antagonists in 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 or central neuropathies, selective electroneurography is indicated.

2.1.1.2 Hindfoot and Midfoot

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

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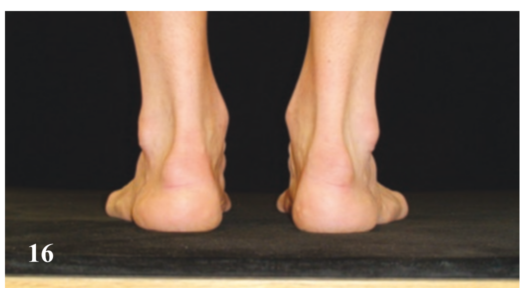
The axis between the upper ankle joint and the heel (tuber calcanei) is carefully evaluated (hindfoot axis). A stable lower limb includes a ***discrete valgus of the hindfoot*** axis (about 5–11 degrees).



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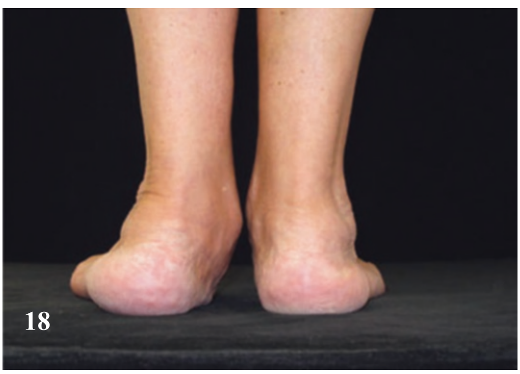
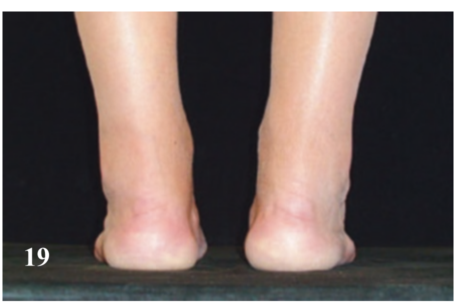
Symmetry of both heel cords is evaluated. ***Eventual irregularities***, which may be painful at palpation, may hide chronic tendinitis ***(R186)***.

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



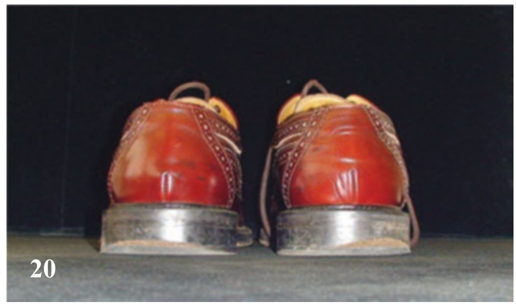
(E59) in case of a chronic rupture of the posterior tibial tendon ***(T905)***.

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



which should always be considered together with the angulation of the lower leg. Modifying the frontal angulation of the lower leg may be a powerful means for correcting an occasional instability of the hindfoot **(O220)**.

The lower leg axis (genu valgum/varum) together with the hindfoot axis determines the weight-bearing pattern of the heel and the ***wear of the shoes.***



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

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

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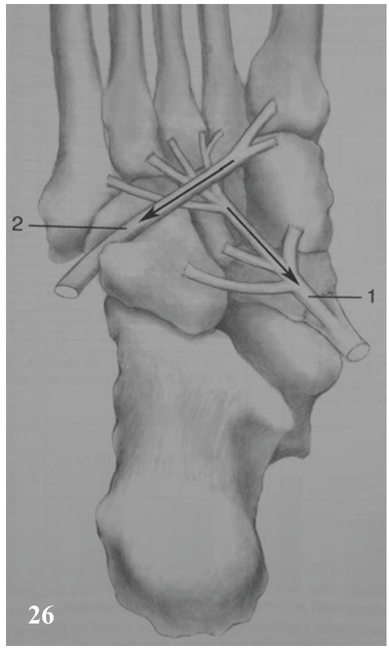
The longitudinal arch of the foot is specific to *Homo erectus*, although it really should be termed the longitudinal "arc" because of the structural components of which it is composed. An arch in ancient architecture holds by pure static rules and the so-called "keystone" distributes weight onto the pillars. The longitudinal arch of the foot is more complex and possesses additional means to be stabilized. The arch is under tension through the plantar fascia which allows for ***the windlass mechanism during gait and which elevates the midfoot from the floor*** [8].

It also includes active means such as two essential muscles which cross their distal tendons at the "plafond" of the foot: ***the posterior tibial tendon (1) and the fibularis longus tendon (2). These act as active "suspenders" of the arch***.



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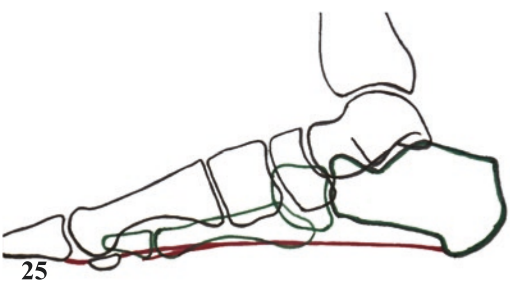
Considering now the three-dimensional aspect of the arch, we note that the arc appears relevant at the medial side of the foot while the lateral column of the foot (calcaneus-cuboid-fifth metatarsus) is generally buttressing the floor ***(E31)***. The geometric figure we thus see at the plantar aspect of the foot is a part or ***truncated cone, with a large opening to the medial side of the foot.***



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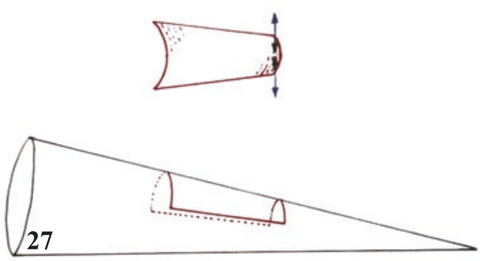

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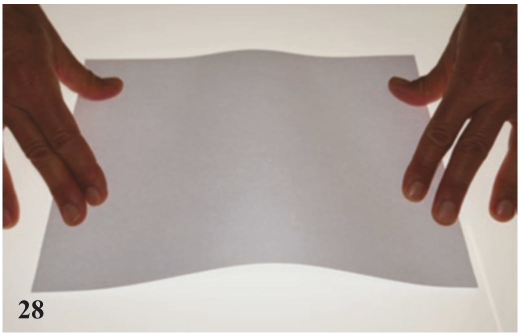
Schematically, one can demonstrate such three-dimensional variations using a single sheet of paper from the top, the bottom edge of the paper representing the medial column and the top edge the lateral column, ***the wave simulating the longitudinal arch of the foot.***



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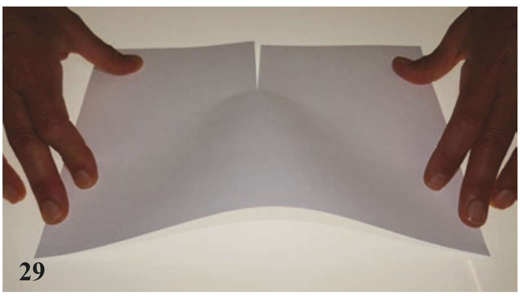
By cutting the top edge (lateral column) and ***distracting the cut, the medial column rises up***



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and by ***overlapping the cut edges, the medial column*** drops.

30

A surgical armamentarium to regulate the height of the longitudinal arch of the foot in defined pathological situations is thus of interest. Considering the geometric aspect of the longitudinal arch which is lowest (in most cases flat) on the lateral aspect of the foot (lateral column), the height of the medial side of the arch can be modified by altering the length of the lateral edge of the aforementioned truncated cone ***(E27)***. Shortening the lateral border of the foot should thus bring down the medial arch ***(O319,O361)*** while the foot turns in abduction. Lengthening the lateral border of the foot instead will raise it up, turning the foot inwards in adduction. Due to the flexible connected chain of bones of the medial column of the foot (talus-navicular-cuneiform-first metatarsus) which is still held on the plantar aspect by the plantar fascia and transiting musculature, the medial aspect of the longitudinal arch will be lifted ***(O307-O294)***.

Symptoms of an exaggerated eversion or inversion of the foot are the indications for treatment. Symptomatic eversion in flat feet is mostly due to a painful abutment of the lateral process of the talus onto the anterior process of the calcaneus ***(E110) (O244)*** and eventual tendinopathy of the posterior tibial tendon ***(E127-128) (T905-906)***. On the other hand, symptomatic inversion (pes varus adductus) is mostly linked to functional instability during stance and walking (including, for example, multiple ankle sprains) and painful overload of the lateral column of the foot ***(E78) (O255)***.

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 parallel to the fifth metatarsus ***(E33)***. Pes abductus (***R169)*** and adductus present a relevant horizontal angle between the calcaneus and the fifth metatarsus ***(C969)***. Interestingly, an abductus angle may partially compensate a varus of the hindfoot and improve functional stability. On the other hand, an adductus angle (pes adductus), in which the foot is angled medially at the TMT joints ***(O369)***, tends to worsen the functional instability of a hindfoot varus.

2.1.1.3 Footprint

The weight-bearing pattern of the foot corresponds to the vertical projection of the foot with its specific longitudinal arch. It is 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 ***(A9)*** (metatarsal heads). As both heel and anterior heel have contact with the floor, the ***most usual footprint***

31

includes the 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). In addition, all tips of the toes should be pressed naturally onto the ground due to the windlass mechanism of the plantar fascia ***(E25, E71-72)***. The footprint is the interface between the body and the ground and as such it determines the aforementioned ***"support polygon" (A1)***. This geometric figure is defined by a line joining the points of the print of both feet creating the largest area of a ***polygon***.

In stable static stance, the vertical line that passes through the centre of gravity of the body crosses the support polygon.

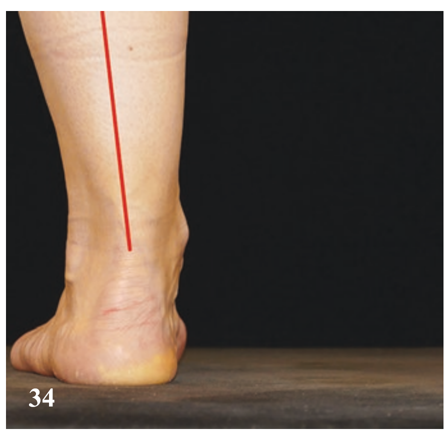
Since the development of *Homo erectus* about four million years ago, the support polygon has drastically reduced. Consequently, potential instability of the body in statics but also in motion has increased exponentially. Thanks to the precise phylogenic installation of the heel posterior and lateral to the lower leg [9] which is vertical, static (bipodal) and dynamic (unipodal), equilibrium became safe. All alignments which do not conform to physiological valgus of the foot are potentially unstable. Unipodal static equilibrium does not modify the axis of the hindfoot. Due to the ***drastic reduction of the support polygon in unipodal stance***,

32

it is the ***axis of the lower leg*** which changes due to the ***shift of the body from bipodal***

33

towards the unipodal support



34

and thus accommodates the vertical line passing through the centre of gravity.

The anterior heel should have a homogeneous weight-bearing print across the whole width of the forefoot [4,10]. If the ***antero-medial aspect of the footprint indicates reduced weight-bearing,***


35

this might be a sign of an unstable first ray and an overloaded second metatarsus (left side) ***(O397)***.

Occasional instability of the first metatarsus ***(E138)*** disturbs the homogeneous load distribution of the anterior heel. By ***"escaping" in extension, selected cases present a pronounced "metatarsus elevatus".***


36

Most often, the metatarsus "escapes" also in ***adduction presenting a "metatarsus adductus" (R173)***.


37

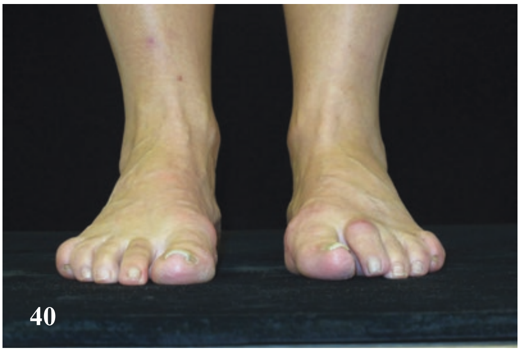
The first metatarsus leaves the stiffest rays on the TMT level to take the resulting overload [4]. This overload results in ***striking callosities beneath the corresponding central metatarsal heads leaving the first ray with obvious unloaded plantar skin***.


38


39

Plantar pain under the central metatarsals is the main sign of instability of the first ray ***(A7)*** [4,11].

Such imbalance and local overload end in a degenerative lesion of the "plantar plate" situated beneath both central metatarsal heads. The plantar plate comprises the confluent distal fibres of the plantar fascia and the inter-metatarsal ligament and thus reinforces the corresponding articular capsule. If such a plantar "tear" is big enough that it is no longer possible to hold the toe to the ground, the toe undergoes ***dorsal subluxation***


40

and the tip of the toe no longer touches the ground ***(O429).***

Observing the ***dorsal aspect***


41

of the metatarso-phalangeal joints allows the assessment of an eventual subluxation or a true dislocation due to a "torn plantar plate" ***(E148.149).***

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


42

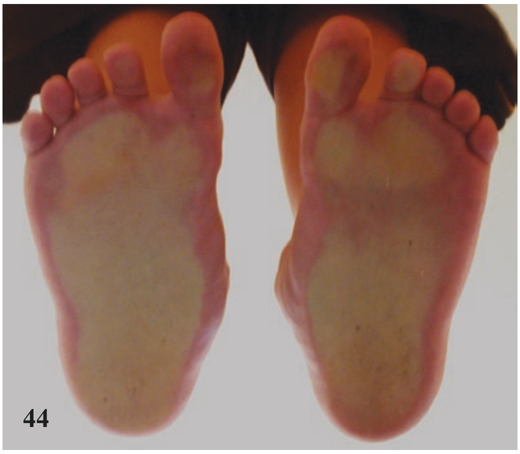
on the footprint is testimony to the imbalance of the anterior heel and the radiograph shows the ***overlap of the second metatarsus with the basis of the first phalanx***.


43

In a stable, normal foot, the midfoot demonstrates a narrower contact surface to the floor which is located at the lateral edge of the foot

(E31). 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).

If the foot collapses at midfoot level, it will ***demonstrate a wide footprint***.



44

In contrast, the cavus foot will logically demonstrate a smaller footprint. The often-associated change of orientation within the frontal plane also modifies the weight-bearing pattern: an increased varus position ***enhances the buttress of the lateral column of the foot*** (arrow) ***(E55-56*** same feet***)***.

45

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

46

In this morphotype, the lateral column does ***not demonstrate any plantar buttress.***

47

In such feet, local pressure is increased in inverse proportion to the weight-bearing area [6].

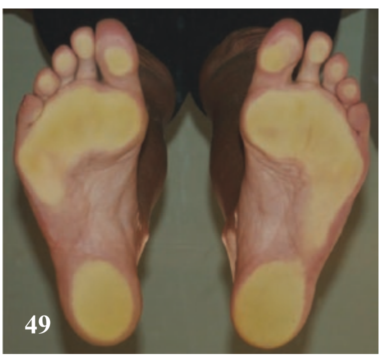
Local overload may occur with corresponding lesions (calluses, open wounds, unstable scars).

2.1.1.4 Tiptoe

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


48

A **normal foot demonstrates a varus** of the hindfoot, assessing a good functioning of the talocalcaneo-navicular joint and the functional motor muscles by means of the musculus tibialis posterior ***(E127)*** and musculus fibularis longus ***(E134)***. If the patient indicates apprehension while standing on tiptoe, the stability of the hindfoot must be investigated closer by assessing the axis of the hindfoot, the ligaments and the extrinsic musculature. Here, the patient is asked to turn around towards the examiner to assess the weight-bearing action of the plantar tip of the toes. Despite the functional varus of the feet, ***the forefoot is loaded more on the medial aspect in tiptoe stance.***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50

The hindfoot axis adapts to this modification of the support polygon ***by positioning the heel in varus*** and the long fibular muscle ***tendon forces the forefoot in pronation.***

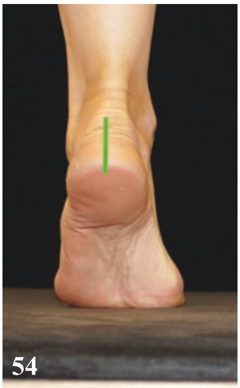

51


52

Lifting one foot in digitigrade position ***does not alter the corresponding footprint significantly (E50)***


53

but the hindfoot adapts to this further reduction of the support polygon with a ***slight valgus of the heel***



54

which is a sign of stabilization due to the missing contralateral foot.

The body searches spontaneously to find its equilibrium which is achieved when the vertical line through the centre of gravity crosses the weight-bearing surface now limited to one single forefoot.

Body weight is 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 [12].

The unilateral cavus foot ***(E45)*** changes its weight-bearing pattern considerably with ***a different orientation within the frontal plane, when compared to the other side.***

55

Standing on tiptoe, this weight-bearing pattern is noted by observing the ***asymmetry of plantar skin about the lateral column*** (arrow).

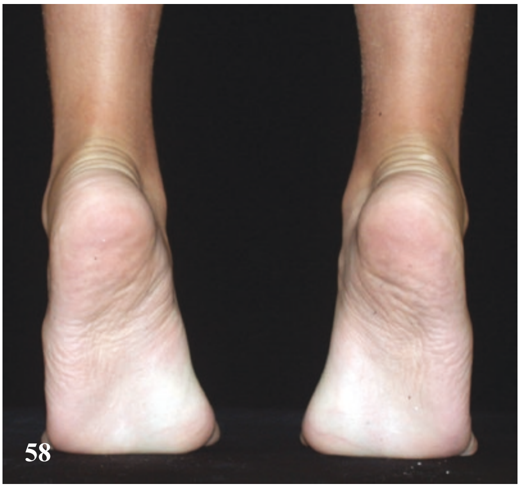
56

With these signs, it becomes clear why feet such as these are more prone to suffer traumatic lateral ligament tears of the ankle as the vertical passing through the centre of gravity passes close to the lateral aspect of the support polygon.

The asymptomatic mobile, flexible flatfoot with a ***collapsed midfoot (E44)***

57

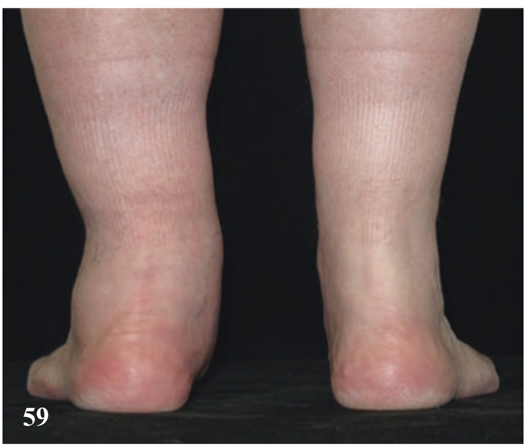
is not linked to a missing varus of the heel while on tiptoe but ***demonstrates a strong inversion of the foot.***



58

This foot has a wide range of movement within the talo-calcaneo-navicular joint demonstrating sufficient power of the posterior tibialis musculature. This asymptomatic foot does not require medical, surgical or orthotic care.

Frequent pathology includes the chronic rupture of the posterior tibial tendon ***(E129,(T906)***. Specific muscular function through holding the foot medial beneath the upper ankle joint is thus missing and the static examination demonstrates a ***pes "ad latus"***



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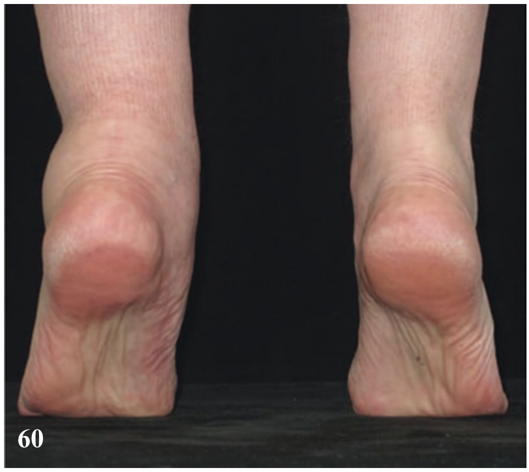
as well as a ***missing varus of the hindfoot in the digitigrade position***



60

(E52).

If the patient reports pain about the anterior heel, the sagittal alignment of all metatarsal heads must be assessed (metatarsalgia) ***(E139)***.

Occasionally, metatarsalgia increases when standing on one foot. ***Discrepancy of the metatarsal length***

61

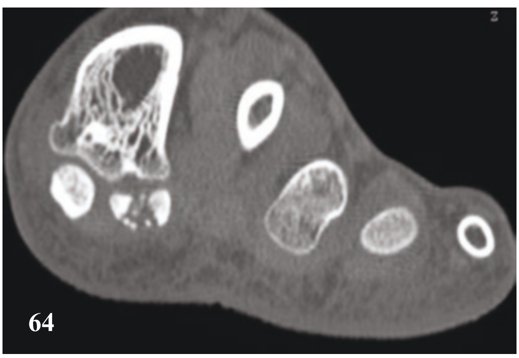
can explain any ***pain experienced during push-off or standing on tiptoe.***

62

63

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 ***(O464-456)(T803)***.

In other morphologies in which the first metatarsus is longer, pain can concentrate beneath the first ray. ***Pathological overload of the sesamoid bones (R157)*** may reveal eventual fractures ***(F574)***.



64

2.1.1.5 Forefoot

The standing patient is asked to turn again towards the examiner who can precisely evaluate the alignment of the forefoot from the front. In case of a varus of the hindfoot, the heel appears as a sunrise behind the medial, vertical aspect of the midfoot ("peek-a-boo" sign, [13]).

65

(E19)

Varus of the heel is a morphological component of the symptomatic static instability of the hindfoot and should be corrected surgically ***(O234-235) (T678-682).***

Anterior view allows for rotational evaluation of the toes. The big toe, the second and the third toes are generally in a "neutral" position evidenced by the orientation of the toenail (horizontal). The ***fourth and the fifth toes*** belong to the calcaneus foot ***(A8)*** and ***are usually turned slightly in supination.***

66

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

67

there is a likelihood of a painful buttress of the outer edge of the nail which may need correction ***(T942-946)***.

The origin of toe malalignment must be established radiographically for causal treatment.

Rotation of the lower leg and hindfoot is considered with reference to the knee axis. ***Focusing the attention on the patellae***

68

which are positioned within the frontal plane, 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) varum. ***External rotation of the feet***

69

may be augmented by excessive pronation of the lower ankle joint (flat feet).

2

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

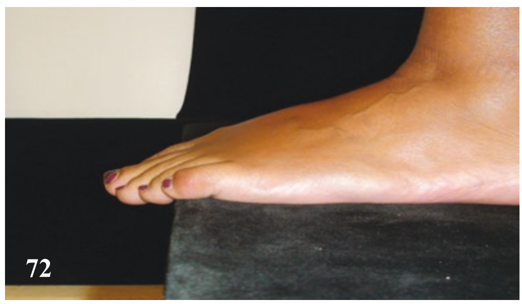
is one such iatrogenic misalignment.

This deformity is generally not tolerated due to pain and discomfort ***(O456-458)***.

The patient is then evaluated *from the side*. All toe pulps should touch the floor and the inclination of the tip of the toes to the bearing surface is critical because of the push-off function of the toes. 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 [8] 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

Asking the patient to ***stand at the edge of the examination cube*** having all the toes free should, in the healthy foot, demonstrate 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 metatarso-phalangeal joints*** results [8].



Spontaneous plantar flexion of the toes under such conditions demonstrates the natural "pre-stress" of the toes under weight-bearing conditions.

2.1.1.6 Heels Standing

The integrity of the anterior tibial muscle is tested by asking the patient to extend his foot dorsally. The forefoot is inverted by the muscle action.

Rupture of the anterior tibial muscle tendon

73

causes eversion of the forefoot through the lower ankle joint due to the singular activity of the fibularis tertius muscle to raise the forefoot. Rupture of the anterior tibial muscle tendon rarely occurs, however, and is mainly the result of cortisone injections ***(E116)***.

Attention is given to the simultaneous activity of the tibialis anterior and the extensors of the toes. During the 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 a recruitment of the long extensors of the toes. This is also evident in the case of shortening of the calf muscles ***(E93-94)***. It results in a strong pull on the toes, resulting in ***dorsal extension at the metatarso-phalangeal*** and plantar flexion at the proximal interphalangeal joints ***(E80)(O435).***

74

This position of the toes may become chronic and irreducible and the condition is termed: "***hammer toes***". While this condition should occasionally be investigated on the neurological level, from the orthopaedic aspect, it is often the expression of a chronic lesion of the metatarso-phalangeal plantar plate ***(E148)*** and a progressive functional loss of the intrinsic and especially interosseus musculature. Often, a pes cavus is associated. Besides treating the origin of the pathology, morphological and functional reconstruction may be indicated ***(O429-432).***

2

2.1.2 Nonstatic Observation

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

75

2.1.2.1 Unloaded Alignment

This position corresponds to hip and knee both flexed. Any length discrepancy of the thighs is best seen in this position. Asking the patient to hold his/her feet horizontally, the anatomical 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.

76

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 ***(E68).***

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 foot dorsally.

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

77

2.1.2.2 Foot Sole

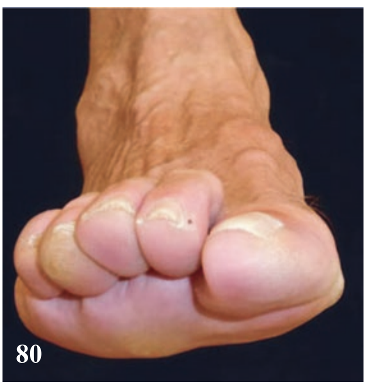
Still seated as above and in front of the examiner, the plantar skin is visualized. The plantar skin reacts to chronic and repetitive pressure by thickening the epidermis of the skin and forming ***calluses***.

78

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 **(C975-976)** and eventually ***skin breakdown*** (ulcers, malum perforans). This is particularly the case in motoric and sensory neuropathies (Charcot-Marie-Tooth disease) and diabetes mellitus ***(C1037)***.

79

The anterior heel corresponds to the horizontal alignment of all metatarsal heads [10] ***(A8)***. 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*** within the frontal plane.



80

In such cases, there is often an unstable first ray and the corresponding lack of the anteromedial buttress of the foot, with calluses beneath the central (second and third) metatarsal heads which demonstrate the secondary local overload. Those calluses are painful at palpation ***(E138) (O340)***.

Diabetes mellitus causes a peripheral neuropathy in which deep sensibility is lost, probably along with a reduced activity of the intrinsic musculature [14]. Concentration of bearing load and callus formation in diabetic patients is considered the precursor to skin breakdown and the appearance of ***malum perforans***.

81

Sensitivity of the skin about the foot should be tested for all dermatomes: on the lateral aspect for the nervus suralis, on the dorsal aspect for both nervi fibularis superficialis and profundus, and on the medial aspect for the nervus saphenous. The plantar aspect should be checked with respect to the nervus plantaris lateralis and medialis. Local breakdown of the neural function is generally assessed visually and by palpation of a ***dry and squamous skin***.

82

In diabetic patients, the particular red-coloured and warm skin is correlated to the associated microangiopathy and diabetic sympathectomy.

When the pulps of the toes do not make contact with the ground for whatever reason, 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.***

83

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

84

This may also occur after transferring the long flexor of the toe to the first phalanx for treating symptomatic hammer or claw toes [15]. If the interphalangeal joints are hypermobile (hyperlaxity), the first and the second interphalangeal joints barely resist passive extension of the toe ***(O440).***

Interdigital calluses may form at the level of the interphalangeal joints. Rigid flexion of the distal interphalangeal joints (claw toes) may cause ***subungueal calluses***

85

which is due to shortening of the long flexor tendons and may have traumatic (calcaneus fractures including compartment syndrome of the foot) or neurological causes. Calluses around the toes are usually due to a mechanical dysfunction and are very painful ***(O450)(F521).***

2.2 Palpation and Joint Mobility

The founder of osteopathy, Dr. Andrew Taylor Still (1828–1917), first declared: "Motion is life and life is motion" [16]. Walking, jumping, running belong to the physiological action of motion. The foot, originating from the hand includes 28 bones and more than 36 joints. The hand requires this number of joints because it is the organ of prehension. With "*Homo erectus*", the hand lost its function of loading e.g.

carrying part of the body's weight. The foot began to use the morphological heritage of the hand to bear all the body's weight and lost any prehensile function. Due to this very rapid adaptation in a phylogenetic view, the morphological changes seem to lag behind. The mobility of the joints experienced an adaptation to the new task and today we talk about "essential" and "less essential" or "adaptive" joints in reference to the foot when considering the amplitude of their motion [5]. Below we will refer to this kind of assessment when considering the diverse joints to be examined.

2.2.1 Heel Cord

The patient is lying relaxed on his chest and his knees are passively flexed by having his shins lying on a soft roll. 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 ***(E17)***. Peritendinous edema might give the feeling of a "crisp dry sponge" on palpation (tendinitis). Pain at palpation is the driving point. The fulcrum of ***pain can be located at the insertion of the heel cord***

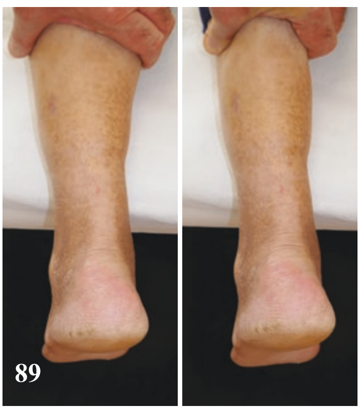
at the back of the tuber calcanei (enthesopathy ***(O202)***).

If the soft roll is removed and both knees fully straightened with the feet over the edge of the examination surface, both gastrocnemius muscles are in tension due to their insertion on the back of the distal femur. Both feet should ***show a slight plantar flexion and varus.***

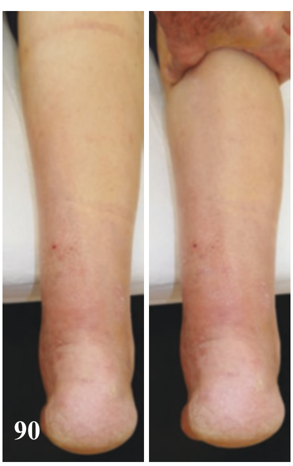
If, however, one foot demonstrates a ***neutral position without flexion***


88

there is a strong suspicion of a ruptured heel cord. By squeezing the calf muscles the consequent muscle shortening provokes ***passive flexion of the foot*** in normal conditions.


89

If this manoeuvre does not occur, the ***heel cord is certainly ruptured*** (Thompson test) ***(F471).***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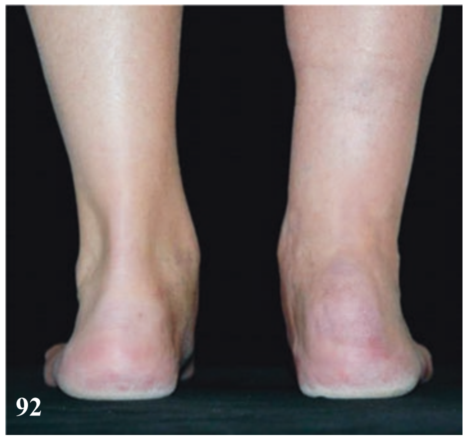
Ruptures of the tendon at this location may be secondary to ***corticoid injections.***


91


92

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


93

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

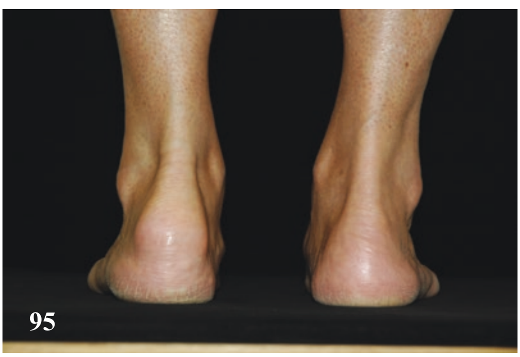
Normal conditions allow the ankle to be moved 20-30 degrees in extension. Still holding the lower leg but the ***knee straight***,

94

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 [17] ***(T858) (T793).***

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

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



95

(Haglund) [18] ***(O204)(T706-707)***

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

96

2.2.2 Heel

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

97

This pressure elicits pain in cases of calcaneodynia. Additionally, the proximal medial aspect of the fascia plantaris will also be tender on palpation ***(T963)***.

2

2.2.3 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.*** 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** [19] ***(R192)***.

2.2.4 Upper Ankle Joint

The tibio-fibulo-talar joint is usually called the ankle joint. Mechanically, this joint moves in flexion extension following a slight conical path with the centre of the cone being medial. In fact, this motion of the talus within the malleolar fork is due to the shape of the talus: the joint surface gliding beneath the tibia is shaped as a truncated cone in which the largest diameter is located on its lateral aspect, facing the distal fibula. To rationalize 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. Considering the action of acceleration in running and jumping, upper ankle motion belongs to the "essential joints". Due to the conical shape of the joint, plantar flexion will guide the foot in adduction and dorsal extension includes a slight abduction of the whole foot.

2.2.4.1 Lateral Ankle

Both tibia and fibula are connected by a strong, three-part ligament: the tibio-fibular syndesmosis. Traumatized, non-fractured ankles may result in painful insufficiencies of the syndesmosis. ***Forced external rotation of the foot in a neutral position or dorsal extension*** may rupture the anterior syndesmosis, and the passive stress test in this direction is painful. The talar joint facet is largest in its anterior part and in this position, all ligaments of the malleolar fork are tight. 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 ***(O251).***

Beneath the upper ankle joint, the fibula is connected to the talus by two rather lax, lateral fibulo-talar and fibulo-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 aspect of all joints is tight and less prone to giving way than the lateral aspect of the limb. We can thus talk about the fixed medial reference and the mobile lateral adaptive play of the joints. The lateral condyle of the femur glides on the tibia while the medial condyle rotates on the tibia. The upper ankle joint is lax on the lateral side and the talus does not have a relevant sagittal play beneath the medial malleolus. Furthermore, the subtalar joint is tightly fixed on the level of the sustentaculum tali with more mobility on its lateral aspect. The fibula constitutes a "guiding rod" which is not prone to bear loads. It is rather part of a muscular, tendinous, ligamentous and bony structure which guides the talar body within the ankle mortise.

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

Following a sprain of the hindfoot, the lateral ligaments, especially the ***ligamentum fibulo-talare anterius***

100

is usually first to sustain a tear ***(T868-870)*** in a typical flexion-inversion trauma of the hindfoot in which the narrower part of the talar joint facet lies within the malleolar fork.

Palpating the origin of the ligament on the fibula

101

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

102

may remain painful for longer if the ligament is insufficient ***(T875-876).***

Forced supination of the foot thus stresses the anterior fibulo-talar ligament which may rupture and leave the talus, while held firmly on its medial aspect with an ***exaggerated antero-posterior drawer.***

103

104

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 followed by insufficient healing of those ligaments may cause functional incongruencies of the upper ankle joint surfaces which are painful, leading to apprehension, "giving way" and post-traumatic joint degeneration ***(R167)***. The talus is not held anymore by the lateral ligament and shifts anteriorly. Chronic static shift of the talus towards anterior is due to the conical shape of the talar dome which is wide anteriorly and narrow posteriorly.

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

2.2.4.2 Medial Ankle

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

The anterior fibres 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 (supination) excessively within the malleolar fork. A supination trauma includes internal rotation and flexion of the talus within the malleolar fork. The antero-lateral ligaments of the upper ankle joint rupture first. If the rotation goes further, especially in flexion, the anterior part of the deltoid ligament also ruptures. A lesion of the ligamentum deltoideum signifies a severe sprain in which only the posterior fibulo-talar ligament might have resisted. Together with the anterior dislocation of the talus, dissociation between the medial malleolar and the talus may bring the rotating talus to shear off the posterior tibial 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 due to the rupture of the "fixed medial reference".

2.2.4.3 Posterior Ankle

Posterior impingement may be symptomatic in ***passive hyperflexion of the upper ankle joint***.

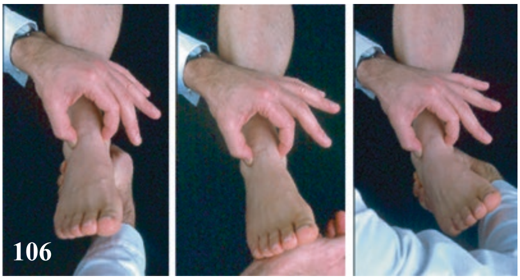
105

The resulting pain may be due to a bony impingement by a long posterior apophysis of the talus which may be broken ***(R189)***.

2.2.5 Lower Ankle Joint

2.2.5.1 Motion

The inversion of the subtalar joint stresses the fibulo-calcaneal ligament which may yield under excessive load. The mobility of the lower ankle joint is tested specifically ***between the talar neck and the heel***,



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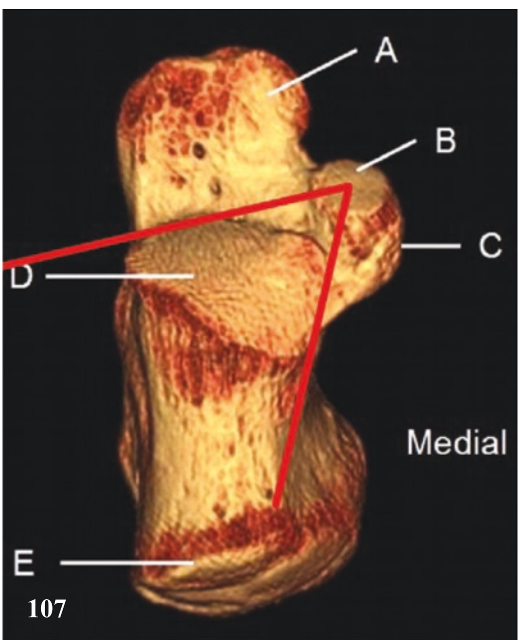
thus evaluating the arc of the joint beneath the talus: the talo-calcaneo-navicular joint. This joint shares its exceptional mobility with the hip joint and must be considered here as an essential joint, being the only joint beneath the hip joint having a play within the frontal plane. To be precise, the path of motion of the calcaneus beneath the talus follows a helix situated on an ***inclined, conical flattened joint surface, the posterior facet of the calcaneus.*** This facet is part of a cone (D), the apex of which is located at the level of the sustentaculum tali (B).



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The axis of the cone is oblique from postero-lateral to antero-medial.

The cone is flattened on its supero-lateral 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

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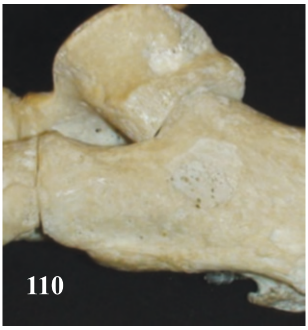
which includes pronation and ***moves towards anterior during push-off***

109

and includes supination of the talo-calcaneo-navicular joint ***(E111)***. Push-off, induced by the strong triceps surae and the heel cord thus flexes the upper ankle joint and pushes the calcaneus forwards which slides down the posterior facet of the talus.

At heel strike, the lower ankle joint undergoes maximal pronation and the talus abuts the calcaneus laterally (angle of Gissane).



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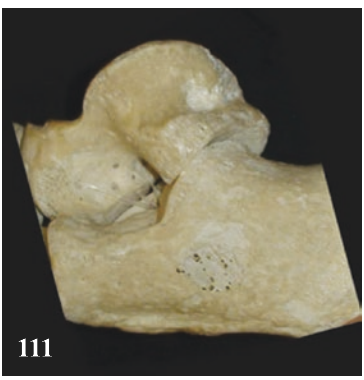
Such abutment between the lateral process of the talus and the anterior process of the calcaneus may become painful (impingement) ***(O244)*** and the described test in extension-pronation reproduces the pain while walking. Local resection arthroplasty may relieve the problem completely ***(O247-248).***

At the same moment of pronation, within the horizontal plane, the calcaneus moves in external rotation, being pushed posteriorly by the talus.

At push-off, in maximal supination of the coxa pedis,



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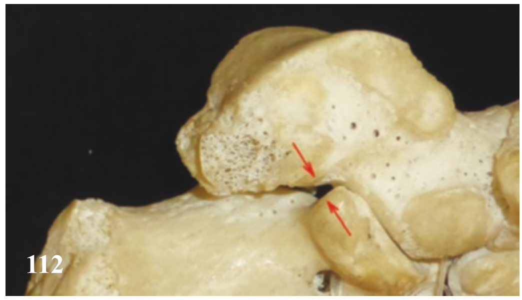
the talus abuts the calcaneus medially (119) (sustentaculum tali).



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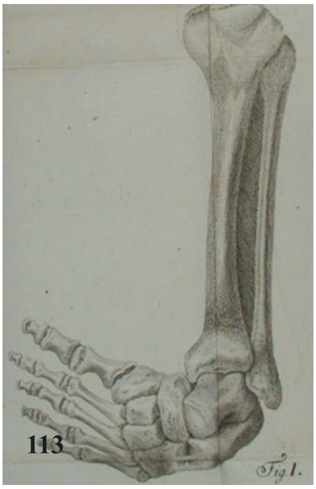
At push-off, the calcaneus moves in internal rotation, sliding down the posterior facet of the talus, taking with it the whole foot in slight supination.

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).

In summary, articular play of the talo-calcaneo-navicular joint occurs between two articular stops. Abutment of the talus onto the calcaneus in functional pronation of the foot might result with invalidating pain at the lateral aspect of the hindfoot ***(O244)*** precisely at the sinus tarsi. Conversely, abutment of the talus onto the calcaneus in functional supination of the foot is much rarer and might result with invalidating pain at the medial aspect of the hindfoot precisely at the sustentaculum tali ***(E119)***. This sign occurs after occasional post-traumatic lesions of the subtalar ligaments.

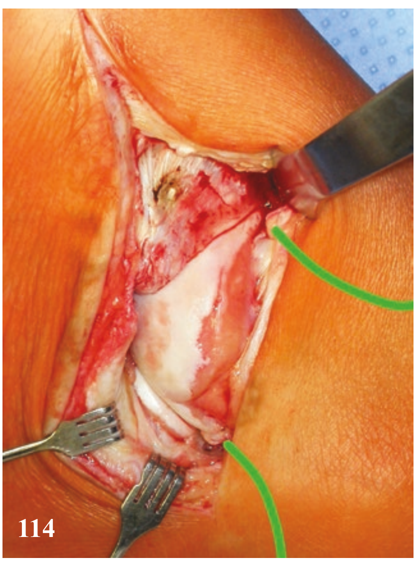
The articular play of the navicular and the sustentaculum tali (calcaneus) around the talar head very much resembles the rotation of the extended hip joint ***(E114)***. The shape and configuration of the navicular joint facet and the antero-medial calcaneal joint facets are ***very similar to the coxal acetabulum***. Both anatomical structures are also spanned by the transverse ligament at the hip and the deep plantar calcaneo-navicular ligament at the foot (spring ligament).

Antonio Scarpa [20] noted this morphological and functional resemblance, especially in relation to pathology such as the club foot which demonstrates ***subluxation of the talo-calcaneo-navicular joint.***



113

He named the talo-calcaneo-navicular joint the **"coxa pedis"**. The mainstay of the acetabular arch is made up of the calcaneo-cuboidal joint which allows some motion between both the anterior (navicular) and posterior (sustentaculum tali) acetabular walls. The morphological similarity becomes eye-striking observing ***a right foot in a vertical fashion (toes up, heel down)***



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in which the image evokes a ***left hip seen from the front*** (femoral/talar neck with green lines).

Again, to rationalize the important and complex articular mobility of the hindfoot, we call this joint, together with the posterior subtalar joint, the "lower ankle joint". In its exceptional mobility within the frontal plane, the lower ankle joint must be considered as an "essential joint".

The anterior part of the lower ankle joint is made up of the navicular bone. The navicular bone is basically a transversal bone which 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. Those opposing functions occur depending on the position of the joint.

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

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are 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 first cuneiform and first metatarsus. In case of instability of the first ray due to hypermobility, it may be that the increased mobility between the cuneiform and the metatarsus results in painful enthesopathy of the anterior tibial tendon. ***Rupture of the tibialis anterior tendon***

116

is common after local cortisone injections which can cause necrosis. The consequent functional disability is obvious ***(E73) (T912-918)***.

Different locations on the lower ankle joint may demonstrate specific pathological conditions: Loaded pronation may stress the dorso-lateral edge of the talo-navicular joint. An osteophyte ensues on the dorso-lateral aspect of the talar neck. Loaded pronation of the lower ankle joint and the osteophyte at the talar side of the joint resembles strangely the osteophyte occurring at the antero-lateral corner of the femoral head in coxo-femoral impingement. We call this impingement the "coxa pedis conflict" ***(O280-281)***.

2.2.5.2 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.

While Antonio Scarpa observed a "dislocation" of the talo-calcaneo-navicular joint or coxa pedis in the congenital club foot, we can talk about a "protrusio" of the same coxa pedis in the pronated foot ***(O293).*** In pronated feet ***(R177)*** pain may be the result of talo-calcaneal impingement ***(E110).*** Along its spiral and pronating motion beneath the talus, the calcaneus stops its movement abutting the lateral process of the talus. Fortunately, in normal feet, there are different soft tissue structures which slowdown the 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***

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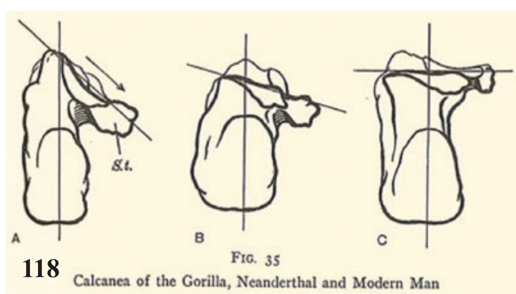
by impingement ("snow-boarders fracture") ***(E110) (F502-507)***.

Subtotal subtalar coalition (bar) ***(R185)*** may cause pain while palpating the sinus tarsi due to the logical asymmetric load and consequent pathological talo-calcaneal micromotion.

2.2.5.3 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*** of the foot ([4, p. 63] with permission). This arch was built up gradually within the family of primates.



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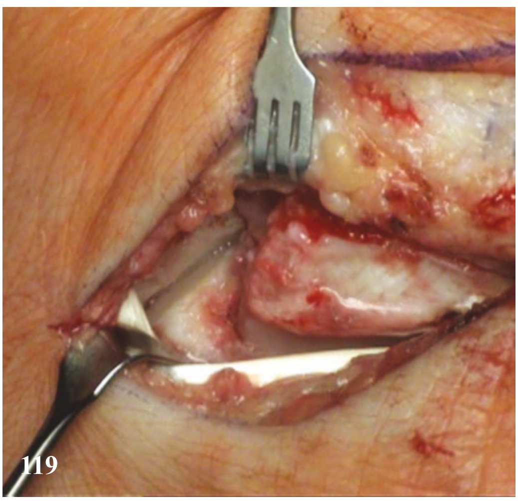
The plantar arch (or arc) is actually specific to "homo sapiens", beginning with "*Homo erectus*" [9].

The sustentaculum tali lifts the talus phylogenetically and with this move, it is assisted functionally by the tibialis posterior and long fibular muscle and tendon such as a plantar staple to the midfoot ***(E26).***

The calcaneus, through the sustentaculum tali is tightly fixed to the above lying talus by a strong capsule and by ligaments. This medial spot is much more protected than the lateral aspect of the ankle. 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 postero-medial tubercle of the talus, thus closing the canalis tarsi ***(E112)***. ***Post-traumatic osteophytes*** (after subtalar subluxation or dislocation) ***at this location*** may induce invalidating pain by ***medial subtalar impingement*** (left foot).



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2.2.5.4 Talo-Navicular Joint

Pain at palpation can be due to arthritis and joint degeneration. Diagnostic articular anesthetic infiltration may confirm such a suspicion. As principal actor of the lower ankle joint, the talo-navicular joint must be considered an essential joint. In fact, blocking the talo-navicular joint results in reducing to nearly zero motion of the talo-calcaneal joint [10]. This joint may also be blocked by a congenital coalition which reduces considerably hindfoot motion ***(C996-1002)***.

2.2.5.5 Posterior Subtalar Joint Facet

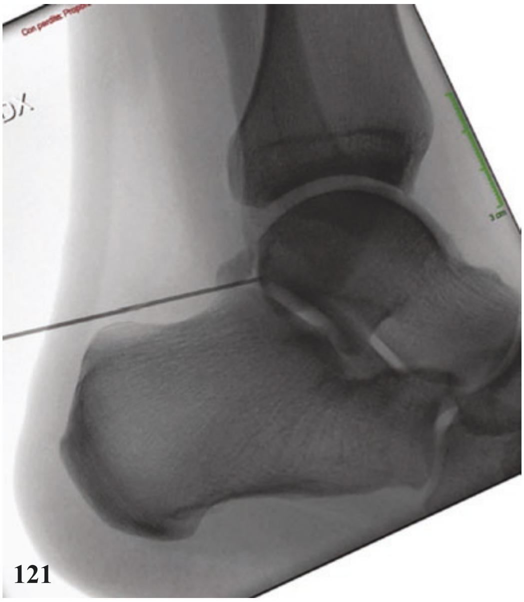
The postero-lateral border of the subtalar joint may be palpated behind the fibular tendons. It is at the base of the aforementioned cone which guides the helicoidal articular path of the calcaneus beneath the talus. This spot is especially painful in subtalar arthritis due to arthrosis which might be 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) ***(E105)***. Passive hyperflexion of the foot may be irritating and painful. There are three bones in close proximity to each other here and the intermediately placed talus may suffer through a ***large postero-lateral or –medial tubercle***

120

which may fracture or present an impinging os trigonum ***(R189)***.

2

Diagnostic anesthetic infiltration indicates surgical treatment ***(O215-216)***.



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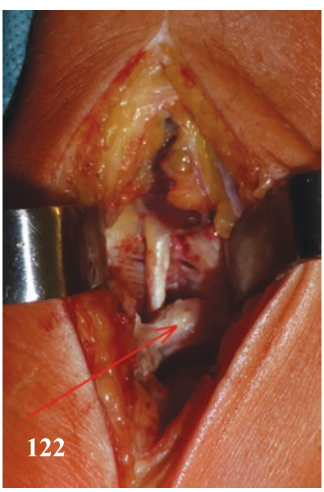
It may also be due to a soft tissue impingement involving the upper or lower ankle joint.

Exceptional cases involve congenital malformations such as additional muscle bellies (fibularis quartus or accessory soleus muscles) ***(E155)(R190)***. Some of those abnormal muscles and tendons may insert into the posterior aspect of the talus.

This condition might cause neurological symptoms while compressing the nervus tibialis ***E153)***.

On the medial side and on the same level, the impingement may involve the flexor hallucis longus tendon between both posterior talus tubercules which present a ***restricted passage to the tendon.***



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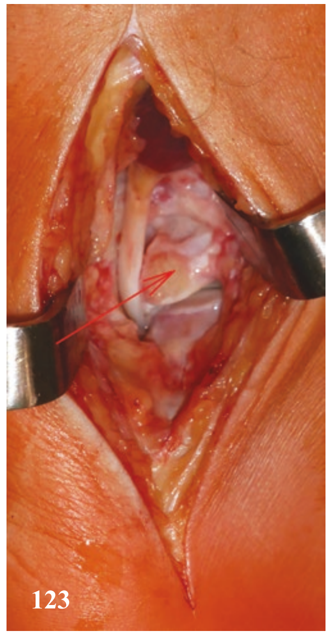
Operative revision and ***liberating the passage*** may be helpful in selected cases.



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2.2.5.6 Posterior Tibial Tendon and Navicular Bone

Mobilizing passively the lower ankle joint, the ***medial aspect of the navicular bone***

124

is palpated without difficulty.

The importance of its prominence is critical. Abnormal pain at this point may be a sign of a morphological particularity such as an ***accessory navicular bone*. *(O330-331)*.**


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The accessory navicular bone may be unstable and create with the navicular a painful pseudarthrosis (type 2 and 3) [21]. The posterior tibial tendon is attached to this unstable fragment and thus is not very efficient in lifting the medial longitudinal arch. The posterior tibial muscle and tendon lift the longitudinal arch of the foot in synergy with the long fibular muscle. Both muscle tendons insert spider-wise on multiple bones about the plantar aspect of the midfoot ***(E26)*** and thus maintain the motor function of the plantar vault of the foot which is pre-tensioned by the plantar fascia.

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.***


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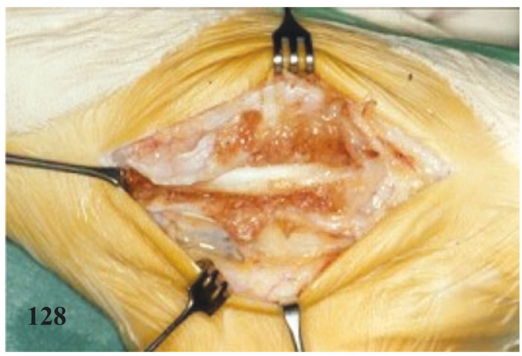
During this manoeuvre, the examiner opposes resistance to the motion of the foot and with one finger palpates the retro- and inframalleolar space in which the tendon glides. This tendon is poorly vascularized [22] and frequently undergoes chronic degeneration or ruptures in elderly patients and in pathological 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 such cases, the tendon rupture is located about the retro-malleolar region. Palpation may demonstrate no supination power and sub- and retro-malleolar pain ***(E60)***.

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


128

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

2

Scarring of the tendon increases the diameter of the tendon which may ***rupture preferentially about the posterior aspect of the medial malleolus (R188) (T906).***

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Traumatic ruptures are less often seen and usually occur more distal, closer to the navicular insertion.

2.2.6 Processus Anterior Calcanei

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 of the toes. This might be the location of ***traumatic avulsion***,

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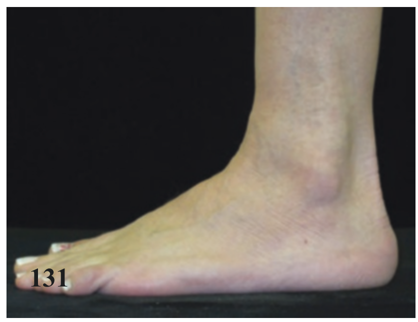
which may or may not involve bone, after sustaining a forced supination trauma.

2.2.7 Calcaneo-Cuboidal Joint

The calcaneo-cuboidal 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 calcaneo-pedal unit [23] at heel strike, while on the medial plantar aspect of the midfoot, the plantar calcaneo-navicular ligament (spring ligament) takes up the tension. The lateral aspect of the calcaneo-cuboidal 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.

2.2.8 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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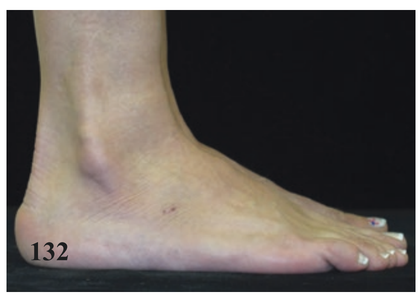
to pop out occasionally,



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though this is most often a benign particularity which does not cause any pain or discomfort.

Phylogeny demonstrates the progressive division of a common fibular tendon into two parts [6], together with the creation of the longitudinal arch of the foot**.** 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 to the musculus tibialis posterior ***(O298).*** The musculus fibularis longus is essential for holding the medial longitudinal arch of the foot ***(O238)*** by inserting into the plantar aspect of the first cuneiform and first metatarsus. It flexes the medial TMT joint using a lever corresponding to the distal oblique path of its tendon between the first metatarsal base and the cuboid where the tendon is reflected, joining the short fibular tendon. It acts as an antagonist to the musculus tibialis anterior.

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

133

while the examiner, opposing resistance with his hypothenar, palpates the course of the tendons about the lateral infra- and retromalleolar space.

The *musculus fibularis longus* is tested similarly to the musculus tibialis anterior, its antagonist, by ***asking the patient to flex strongly his first metatarsus*** towards the plantar plane

134

without moving his foot at the talo-calcaneonavicular joint.

The action of the fibularis longus tendon is palpated at the retro-malleolar space.

The critical locations on the tendons which may be linked to pathology (longitudinal splits) ***(T904)*** 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 abnormal large dimension and be very painful at 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 ***(E19) (O236)***.

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

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.

2.2.9 Naviculo-Cuneiform Joints

Pain on palpation can be due to arthritis and joint degeneration. Instability due to hyperlaxity may be assessed radiologically (plantar articular gap) or during surgery ***(O299-300).***

2.2.10 Second and Third Tarso-Metatarsal Joints

The 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 ***(A5-6)*** [4,24]. Painful palpation of the central Lisfranc joints may be linked to a degeneration of those joints. In this case, it is common to palpate a pre-eminent osteophyte at this location. The majority of rheumatoid arthritis cases are linked to this kind of symptom. Post-traumatic conditions including lesion of the cuneiform 1 – metatarsus 2 ligament (Lisfranc's ligament) may cause clinically relevant subluxation which is difficult to assess radiologically ***(F557)***.

2.2.11 Fourth and Fifth Tarso-Metatarsal Joints

The lateral TMT joints are essential joints and are more mobile than the first TMT joint [24]. 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 and is frequently seen after reorientation of the axis of the foot (e.g. correction of pes planus). Changing the weight-bearing axis of those joints can provoke such irritation while articular desensitization or interposition arthroplasty may considerably improve the condition ***(O377-379)***.

Metaphyseal fractures of the fifth metatarsus may be the result of supination trauma but this also includes fibularis brevis and fibularis tertius tendons. This results in a mechanically unstable situation which requires very stable fixation for successful healing (Jones fracture) [25].

2.2.12 First Tarso-Metatarsal Joint

Mobility of this joint was reduced considerably during evolution from the prehensile organ (hand) to a weight-bearing organ (foot) [1]. 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 generally causes an angulation towards medial (adduction) and dorsal (extension) [26] ***(O384)***. 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 which has undergone a local compartment syndrome [27] or a simple trauma. As a physically unstable construction which is stabilized by balanced agonists and antagonists, the forefoot may then develop a rapid deformity at the first TMT joint ***(E36-37)*** due to the absence of strong ligamentous structures which are missing because of phylogenetic reasons.

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

136

may accompany instability of the first TMT joint. Such instability may trigger an eventual painful enthesopathy of the anterior tibial tendon ***(E115).***

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

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

138

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 antero-medial buttress of the foot during gait and push-off [4]. Similar to the sagittal "Lachmann" test of the knee, it demonstrates the stability of this part of the foot. The fulcrum of rotation (or deflection) is more 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**.** As with the Lachman test of the knee, the stiffness of the sagittal path seems relevant for the assessment. We thus distinguish a sharp stop from a progressive, rather cushioned path of the first metatarsus [28].

2.2.13 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. In fact, physiological distribution of static load is shared between the tuber calcanei and the metatarsal row that we call the anterior heel ***(A9)***. Within the anterior heel, load is equally distributed on the six aforementioned bony prominences [10].

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

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(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 metatarso-phalangeal joint becomes unstable due to the ***rupture of the plantar plate (O383)***.

The ***dorsal aspect of the joint also becomes painful***

140

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 and thus their relative length, especially in relation to the first metatarsus, is critical. Radiological 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 (arrow), pain on palpation and on motion***

141

may be the clinical expression of a ***metatarsal head necrosis (Morbus Freiberg) (T835).***

142

2.2.14 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.

2.2.15 Lesser Intermetatarsal Plantar 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 due to 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 pseudo-neuroma [29] ***(T948)*** which may cause burning pain. Squeezing all metatarsi within the sagittal plane may elicit the same pain. This pain is increased with additional ***intercapital digital pressure.***


143

Tactile sensation between the toes may be reduced due to the auto-destruction of the nerve ***(R191)***. It must be noted, however, that the presence of the pseudo-neuroma on magnetic resonance imaging does not necessarily imply corresponding symptoms.

2.2.16 Metatarso-Phalangeal Joints

2.2.16.1 First Ray

Push-off is the major compound movement of the foot in moving the body forwards. It begins with a "rigidification" of the mid- and forefoot to form a beam or lever to the calf muscles. At the end of the movement though, when the forefoot only touches the ground, all the remaining power is transmitted to the big toe. The mobility of the first metatarso-phalangeal joint in plantar flexion is thus essential for the ultimate push-off.

Energy for this function is provided by the flexor hallucis longus muscle and tendon. ***Passive plantar flexion of the first metatarso-phalangeal joint***


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should be evaluated in the orthogonal position of the whole foot. Clinical evidence tends to show that insufficient active plantar flexion of the first metatarso-phalangeal and interphalangeal joints leads to functional plantar pain beneath the corresponding metatarsal head.

Palpatory pain, dorsal pain during passive flexion of the first metatarso-phalangeal joint together with an ***evident dorsal osteophyte (left foot)***


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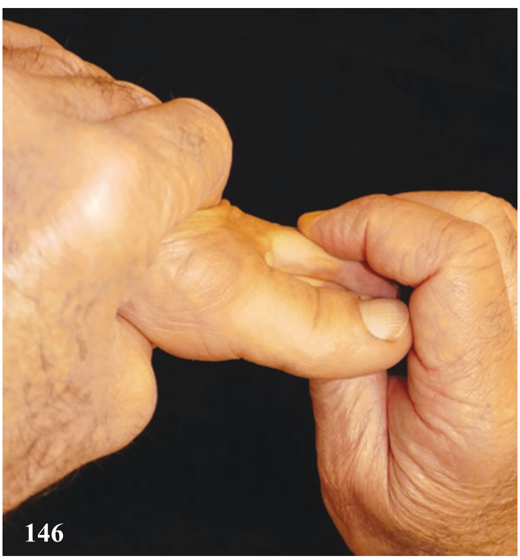
2

of the first metatarsal head (***O420)*** is often the clinical manifestation of hallux rigidus. Mechanical prerequisites which combine to bring about an increase in functional overpressure within the MTP1 joint are that 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 ***(O413)***. Surgical correction in all stages is usually helpful ***(O414,O416,O418)***. The *long flexor of the hallux* is tested while opposing resistance to the flexion of the end phalanx.

2.2.16.2 Lesser Rays

Stability within the sagittal plane is tested to verify the integrity of the plantar plate. Degenerative lesion of the plantar plate is mostly and logically due to insufficient buttress of the first ray. Secondary overload of the second ray results. Lacking the plantar hold, the metatarso-phalangeal joint experiences an abnormal path within the sagittal plane at every step. Palpation of the dorsal rim of the first phalanx becomes very painful ***(E140).*** The lack of plantar stabilization of the joint allows for a positive ***"Lachmann-test" of the lesser metatarso-phalangeal joint.***



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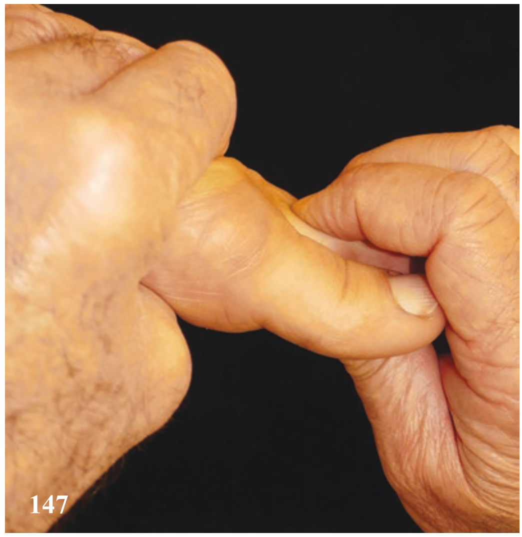

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Surgical exploration through a dorsal approach aiming at stabilizing the joint allows for grasping directly the flexor tendons through a ***wide-open lesion of the plantar plate***.

148

The *long flexors of the toes* are tested easily as the patient is asked to flex his toes towards 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. Dysfunctioning 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 metatarso-phalangeal joint (O429-432)***.


149

Dysfunction of the stabilizing intrinsic muscles may appear as insufficient local metatarso-phalangeal flexion.

2.2.17 Sesamoids of the First Ray

Painful plantar palpation of the sesamoids may be due to an articular pathology of the metatarso-sesamoid joint. Multi-fragmentary sesamoids are reputed to be more frequent in those who play football [30]. Trauma may cause acute fractures of the sesamoid bones ***(F574-580)***. The patient often presents late to his doctor at the painful, non-union stage.

2.2.18 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 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 neurological disease. *Intrinsic muscles of the foot* are very sensitive to plantar hematoma or any cause of augmented pressure within the plantar muscular compartments [31]. Those compartments are separated by very tight fascia and have very little option to expand. Very frequently, following a foot trauma including a simple, slightly displaced calcaneus or a metatarsal fracture which has not been treated by open reduction and internal fixation, hammer toe is likely to occur. The metatarso-phalangeal joint rests in an exaggerated dorsally extended position, together with a progressively ***ankylosing flexion of the first interphalangeal joint***


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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 is ***tethered in flexion***


152

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

2.2.19 Sensitivity

The anatomical distribution of skin sensitivity is divided across the dermatomes of the nervus fibularis superficialis, the fibularis profundus, the saphenus, 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 tumours such as ***ganglia*** [32]


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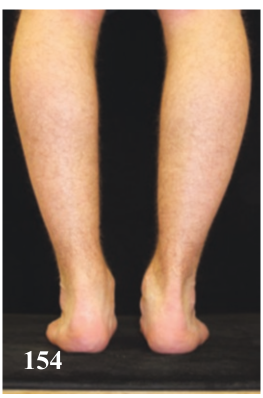
or anatomical malformations such as ***abnormal, additional muscles (left medial ankle).***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2.3 Active Joint Mobility and Functional Exam

2.3.1 Active Joint Mobility

2.3.1.1 Upper Ankle Joint

The patient, still sitting on the edge of the examination cube, faces the seated examiner. After checking the motors of the foot, 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 heel on the knee of the examiner thus relaxing all his 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 between the tibia axis and the posterior lateral edge of the foot***,


156

which corresponds to the level of the calcaneus.

Flexing then the foot, the same landmarks are considered to ***quantify flexion.***


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2.3.1.2 Lower Ankle Joint

Quantifying active motion of the lower ankle joint is difficult ***(E106)***. A good alternative for verifying relevant mobility of the lower ankle joint is to ask the patient to describe the largest circles he may draw in space with his big toe. To do this he will mobilize both his upper and lower ankle joints at their maximum. A valuable alternative for this coordinating motion is to ask the ***patient to lie prone on the examination table***


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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 within the orthogonal position of the upper ankle joint.

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

2.3.2 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 by a strong hindfoot valgus and/or a pronounced external rotation of the feet ***(E69)***. This rotational component may be located within the lower leg and the amount of rotation may be quantified statically ***(E68)***. Four exercises, discussed in the following sections, with progressive difficulties verify global foot and ankle balance.

2.3.2.1 Walking Tiptoe

Performing the exercise standing, the patient is asked to walk on the tip of his toes. The tuber calcanei will be pulled medially by the synergic activity of the triceps surae and the musculus tibialis posterior. Prerequisite to this function is a stable coordination of the extrinsic musculature. The agonist-antagonist coordination between the musculus tibialis posterior and fibularis brevis as well as between the fibularis longus and tibialis anterior is verified. Absence of the varus of the heel while rising on the tip of the toes may be linked to several pathologies such as a coalition ***(R185)*** between two or more of the four bones of the hindfoot or insufficient function of the musculus tibialis posterior ***(E60)***.

2.3.2.2 Walking on the Heels

Normal anatomical conditions should allow anyone to raise the forefoot and walk, bearing all weight on the tuber calcanei. Nonexecution can be related to an insufficiency of the extensor musculature due to either local traumatic pathology (rupture of the anterior tibial tendon) or neurological problems such as a lumbar radicular compression of the motor fibres of L5. The metatarso-phalangeal joints may be excessively extended due to an excessive ***"recruitment" of the long extensors of the toes*** (right foot).


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

2.3.2.3 Hopping on One Leg

Jumping on one leg gives a good picture of the function of the gastrocnemius (jumper's muscle) because it works over 2 main joint groups, the knee joint and the upper and lower ankle joints. With this anatomy, extending the knee joint powered by the quadriceps, the gastrocnemius muscles are tensioned, thus multiplying the action of the gastrocnemius alone in flexing the ankle joints.

Additionally, this exercise shows the ability of coordinating the extrinsic musculature and the potential of amortizing 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 a normal foot anatomy. A lack of mobility at an essential joint such as a subtalar coalition is markedly demonstrated during this test.

2.3.2.4 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 tip of the toes and balancing on one leg is the most difficult physical exam as it involves the proprioception and coordination of all 10 extrinsic muscles of the foot.

Radiological Screening

Contents

K. Klaue, *The Foot*, https://doi.org/10.1007/978-3-662-64001-2_3

3

3.1 Conventional Radiographs

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

3.1.1 Hindfoot

3.1.1.1 Antero-Posterior 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 the 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

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 though the axis of the tibia is not relevant in itself due to evident mechanical reasons.
2. The shape of the fibula is critical in reduced malleolar fractures. Anatomical congruency of the tibiotalar joint through the distal fibula is essential for functional stability ***(O230)***.
3. The plantar edge of the tuber calcanei shows the exact weight-bearing spot of the heel. In a stable hindfoot, the centre of the tuber must be located lateral to the centre of the talar dome [33] ***(A9)*** ***(E18)***.

Hindfoot Varus

The image of the tuber calcanei is situated medial of or on the vertical line passing through the middle of the talar dome ***(E19)***.

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

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


163

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***


164

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


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3.1.1.2 Lateral View (Sagittal Plane)

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

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


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

3.1.2 Foot

3.1.2.1 Antero-Posterior (Dorso-Plantar) 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 centred 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 and 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. By 'index metatarsus' the relative length of the metatarsi 1 and 2 is meant ***(R174-175)***. The alignment of the metatarsal heads should run on a parabolic line [34].

Pes Abductus

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

If the abductus is ***located at the talo-navicular joint,***


169

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

The abductus may be ***centred on the TMT joints***


170

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

Unstable First Ray

The unstable first ray demonstrates a sagittal hypermobility which reduces the antero-medial weight-bearing ability. Consequently, ***the second metatarsus***, which is strongly fixed at its base, takes the functional load and ***undergoes hyperplasia*** [4].


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Splay Foot

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


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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 metatarso-phalangeal joint is subluxed due to the insufficient first ray and the consecutive local overload on the second metatarsus ***(E43)***.

The relevant congenital pathomorphological 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.***

173

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***

174

and is shorter. This foot may thus present an overloaded second (and third) metatarsus which is larger [4] ***(E61-63)***.

Index Metatarsus Plus

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

Here, the big toe is also longer than the second toe. This constellation jeopardizes the first metatarso-phalangeal joint which may be overloaded and undergo premature degeneration ***(O413-414)***.

3.1.2.2 Lateral View (Sagittal Plane)

This view should always be taken from medial to lateral and the plane includes the lateral edge of the hindfoot (calcaneus). In cases where the mid-foot or forefoot is deformed, it is advisable to achieve a true lateral incidence to the hindfoot as a reference. 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.

Within the sagittal plane, a flat foot may demonstrate a ***sag at the talo-navicular joint.***

The talus protrudes the acetabulum pedis. A curved dorso-lateral osteophyte (dorsal beak) of the talar head is a sign demonstrating the pathological motion of the navicular on the talar head ***(O239)***. 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 naviculo-cuneiform and cuneo-metatarsal joints***

should be noted. A sag such as this is very common in Charcot diabetic arthropathy [14] ***(C1041)***.

3

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

179

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

The ***anterior pes cavus***

180

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

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

3.1.3 Special Incidences

3.1.3.1 Oblique

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


181

The calcaneo-navicular space (coalitions) and the lateral TMT joints are seen better.

3.1.3.2 Brodén View

This view [35] is not made under weight-bearing conditions. The foot is held in an orthogonal position and the beam is inclined towards proximal by about 20–40 degrees.

The whole leg is internally rotated about 45 degrees and the beam is ***centred on the sinus tarsi***

182

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

3.1.3.3 Forefoot Axial

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

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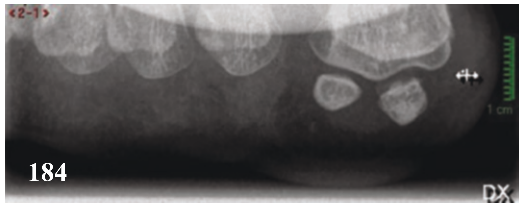
The radiological beam is conducted horizontally [36] from the back towards the toes and the film is placed vertically in the frontal plane in front of the foot. The objective is to demonstrate the ***vertical alignment of the metatarsal heads***



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

3.1.3.4 Stress Views of TMT Joints

In rare cases in which the post-traumatic stability of the TMT joints are questioned, the forefoot can be stressed in adduction or abduction under a dorso-plantar radiological incidence. This test can be performed under fluoroscopy to adjust the view axis.

3.2 Computed Tomography

As computed tomography (CT) is not yet commonly 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 the deformities such as ***subtalar coalition***

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or impingements.

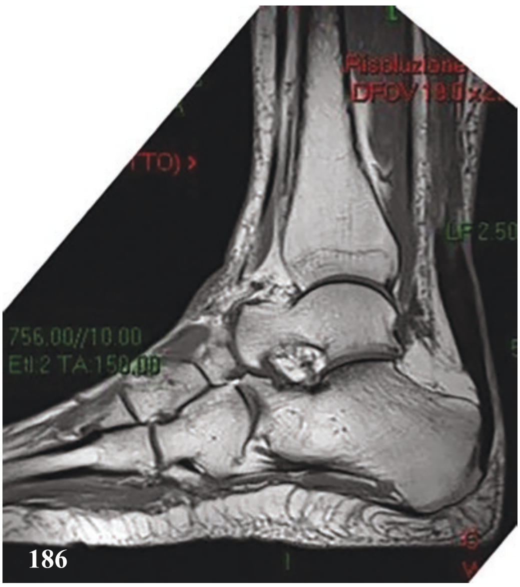
Intra-articular disorders may be best visualized by intra-articular contrast with CT. Intra-articular bodies and osteochondritis tali are good indications for this technique.

3

3.3 Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) should be done in the same position as the CT. This exam shows qualitatively soft tissue lesions or abnormalities within the joint (cartilage) or without (tendons, tumours, nerves, joint capsules) but lacks precision in demonstrating bone necrosis.

Achilles chronic degeneration can be visualized in detail ***(E17)***



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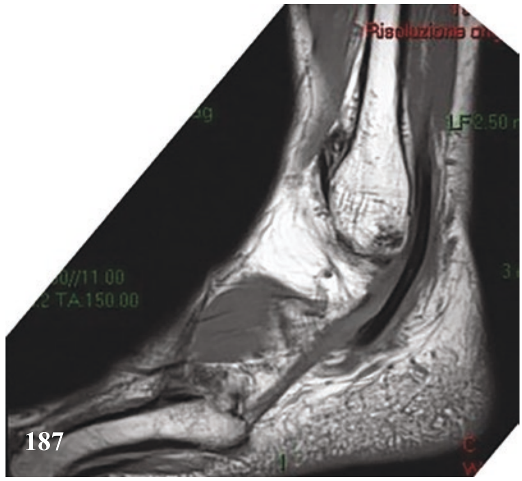
as well as

chronic fibularis tendon lesions (T903) and



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posterior tibial tendon degeneration and scarring ***(T906)***.

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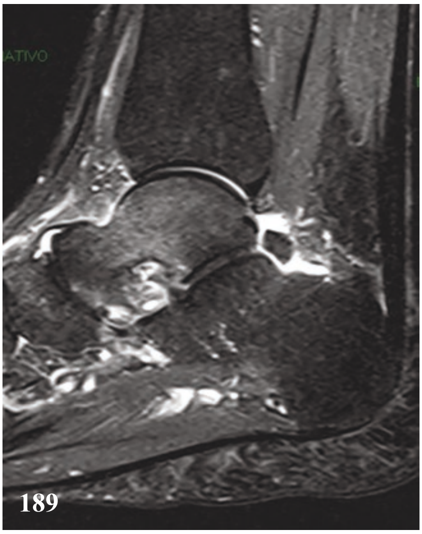
Fractured postero-lateral process of the talus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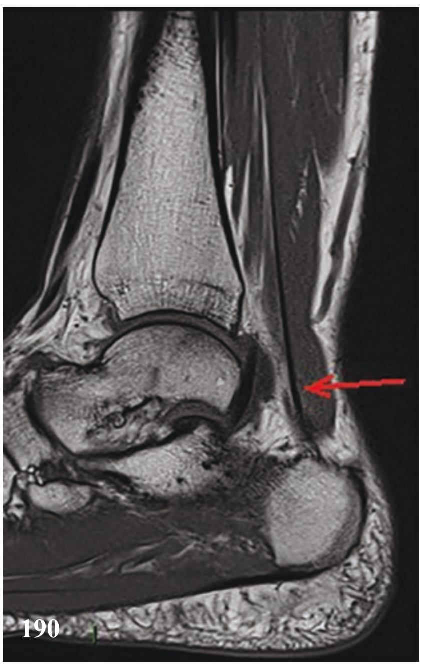
may be evaluated in the context of tibio-talar and talo-calcaneal impingement ***(T668-669)***. Soft tissue abnormalities such as an occasional ***musculus soleus accessorius*** (red arrow)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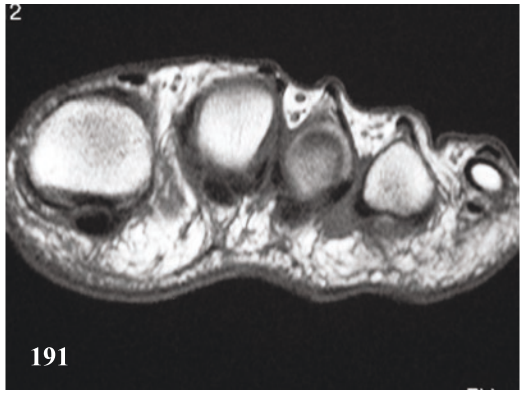
located anteriorly to the normal soleus and inserting into the medial aspect of the tuber calcanei ***(E155)*** and ***pseudoneuroma***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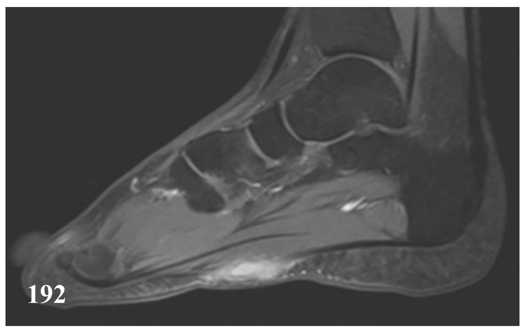
between the third and the fourth metatarsal heads ***(E143)*** are best seen with this technique ***(T947)***.

The plantar fascia is also well visualized and can reveal occasional fibromatic lesions. Such fibromatosis is mostly localized at the ***medial edge of the fascia (E98).***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Basic Surgical Orthopaedic Treatment

Contents

K. Klaue, *The Foot*, https://doi.org/10.1007/978-3-662-64001-2_4

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 a weight-bearing and a locomotor function [1].

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 observed that every operative reorientation of the foot and ankle is amplified distal to the surgical site and may, without other means, create secondary imbalance.

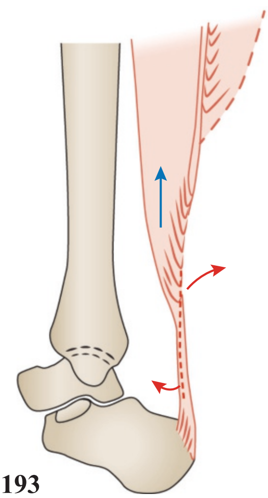
The muscular balance of the foot is essential for secure acceleration and deceleration of the body. Considering the relationship between the vertical position of the body and its relatively small support polygon ***(A1)***, it becomes evident that occasional muscular imbalance is crucial for equilibrating the whole body. Muscle and tendon action closely depend on the lever arms to the joints. Correcting the morphology, those lever arms are modified and thus the action of the muscle tendons change drastically. At this point, it is for the surgeon to evaluate if a muscular imbalance persists which would indicate a need for a rebalancing of the delicate agonist-antagonist system by tendon transfer(s) [37,38]. Surgical treatment of foot and ankle disorders most often includes a whole "menu" of different measures combining structural and motor means which converge to a comprehensive aim. Those aims and the rational treatment are described below. Surgical correction of foot axes should always be considered from proximal to distal. In comparison with a tree (when viewed upside down) in which the trunk determines the orientation of the branches, orientation of the foot and ankle depends on the orientation of the whole lower limb. The power of any modification of orientation is strongest at the root of the limb. ***(O218)***. Adapting to achieve a stable equilibrium of the body lies with the articular freedom of the multiple joints about the foot and ankle.

In this chapter, the comprehensive principles of surgical corrections about the foot and ankle are outlined. The techniques to achieve those aims are described under "surgical techniques" and both principles and techniques of multifactorial problems located on different levels of the foot are described under "complex reconstructions".

4.1 Functional Correction of the Hindfoot in the Sagittal Plane

4.1.1 Muscle Balance

Hindfoot equinus is a major sign of many foot diseases. It concentrates on the adaptive shortening of the calf musculature. True equinus, which includes shortening of the musculus suralis, involves all three muscles and thus is best treated by ***elongation tenotomy of the heel cord. (T884-886)***.



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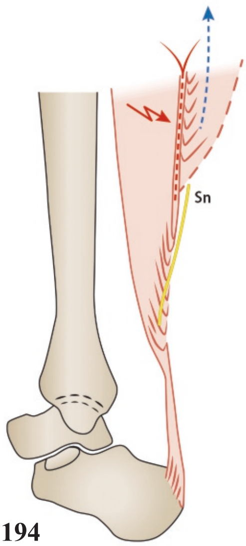
Functional equinus which appears clearly only with the extended knee joint ***(E93-94)*** is best treated by selective elongation of both gastrocnemii muscles because those muscles insert on the femur. The suralis muscle which inserts on the lower leg then preserves its integrity and function. Mild adaption of this problem is best resolved in young, elastic musculature by anterior ***fasciotomy of the ventral muscle fascia of both gastrocnemii (T888).*** (Sn: sural nerve).



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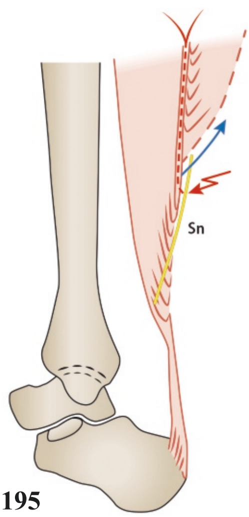
In older, stiff and/or severe cases, the ***tenotomy of both distal gastrocnemii (T889-890)***



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

Paralytic pes equinus of the hindfoot must logically be treated by muscular substitution to reanimate extension of the foot. Following the clinical and eventual electro-neurological status, different tendons are prone to be transferred to act as extensors. The most suitable muscle to be transferred is the ***musculus tibialis posterior onto the dorsum of the foot (T912).***

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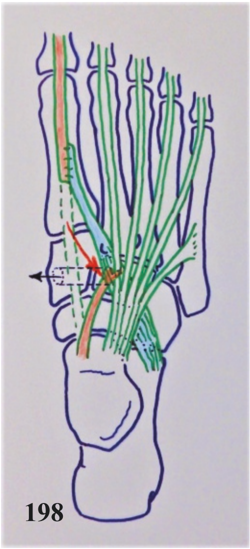
197

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 by the flexor digitorum longus to avoid the risk of secondary collapse of the foot in pronation ***(T908-911).***

If the posterior tibialis muscle is insufficient or inadequate for other reasons, ***the extensor digitorum longus and hallucis longus are transferred*** on the dorsum of the foot ***(T914-916)***.



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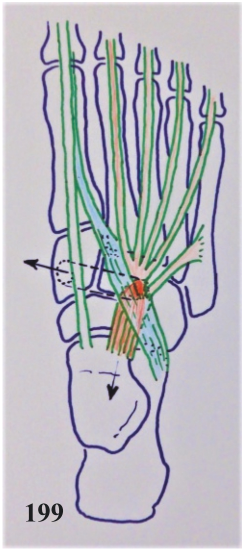

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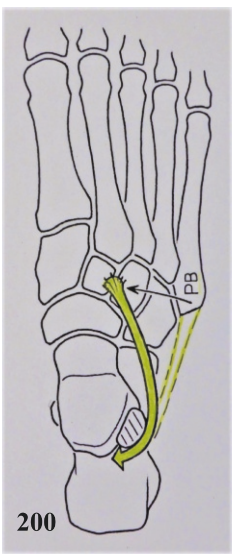
If functional, ***the musculus fibularis brevis is also transferred***.



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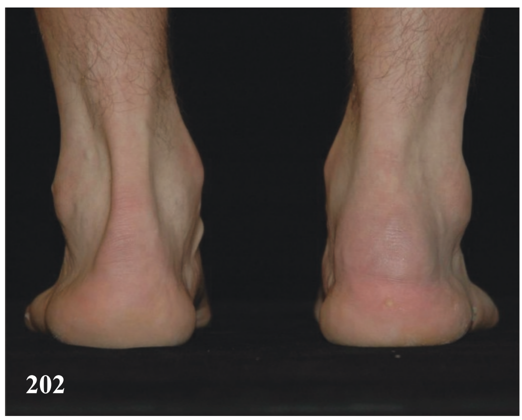
Hindfoot talus is linked to neurological diseases which include pathological weakness of the flexors. After evaluation of the relevant power of the foot extensors, those are ***transferred to the heel through the interosseus membrane.***

201

Such a transfer is usually enough to position a foot plantigrade but is insufficient to substitute 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 [18]. A tendinitis component may also occur. The aim of the treatment is to ***remove the causal osteophyte (T706-707)***



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to avoid recurrence of the bursitis. If the accompanying tendinitis has ***evolved towards irreversible changes within the Achilles tendon*** (calcifications),


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combining the ***removal of the osteophyte with the removal and substitution of the tendon***


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is a rational and gratifying decision [39] ***(T902)***.

4.1.2 Upper Ankle Repair

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

4.1.2.1 Cartilage Repair

Osteochondritis dissecans is a disease of the adolescent and young adult. It must be stressed that in those patients, spontaneous healing of osteochondritic fragments is frequent. Such fractures may often consolidate spontaneously and thus never require surgical treatment.

Long-lasting instability of the ankle joint may cause ***osteochondral lesions***

208

including necrotic bone fragments which behave like ***articular sequesters***.

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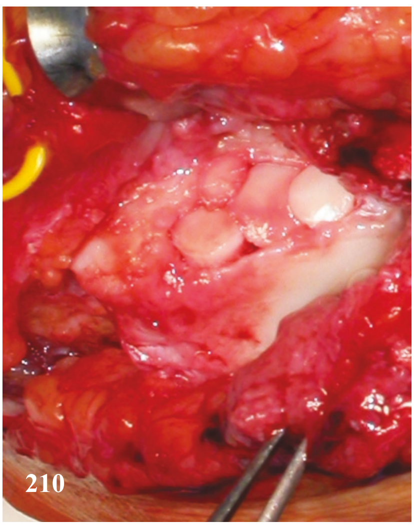
Surgical correction includes alignment, stabilization and articular repair. *Cartilage repair* includes removal of the necrotic osteochondral tissue and substitution by means of ***autologous osteochondral transplants*** [40] ***(T660)***.



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The instability referred to above must be corrected by eventual static (reorientation osteotomy ***(T681)*** and/or ligamentous (***ligament reconstruction***) ***(T876)*** means.

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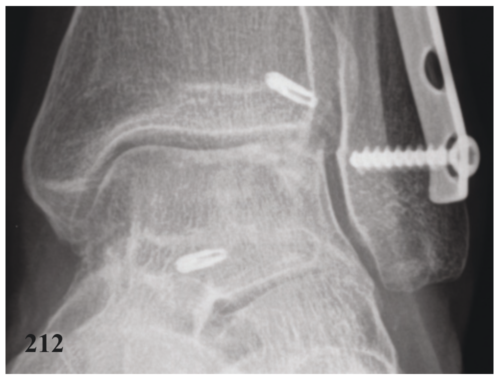

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4.1.2.2 Anterior Cheilectomy of the Upper Ankle Joint

Osteophytes About the Anterior Upper Ankle Joint

213

represent an impingement by abutment and/or secondary joint incongruency which reduces articular mobility. They accelerate joint degeneration by impeding function and should be removed. Their origin is mostly due to an abnormal motion and instability between tibia and talus caused by insufficient ligamentous structures after trauma. The containment of the joint must be respected for antero-posterior stability and thus the ***osteophytes located on the talus are addressed in priority.***

214

The osteophytes on the tibial side are left in place or removed with care only if the joint is mechanically stable. ***(T662-663)***

4.1.2.3 Posterior Cheilectomy of the Upper Ankle Joint

Posterior impingement of the upper ankle joint involves the tibia, the talus and the calcaneus ***(E105)***. The flexion of the hindfoot is impeded by pain and morphological anomalies while the impingement is often triggered by trauma in plantar flexion. The posterior debridement concerns ***the posterior process of the talus***

215

which might be fragmented ***(R189)*** or the flexor hallucis longus tendon and its passage between both posterior talar tubercles ***(E122-123)***. Anatomical abnormalities such as additional muscles ***(E155)*** may be involved too though this is rare. This surgical approach is exclusively ablative ***to remove the impinging structures***.

216

4.2 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 ***(E55) (R161)***. 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 ***(R163-164)*** is mechanically unfavourable 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 ***(R161)***. Excepting the rare post-traumatic malunions about intra-articular fractures of the distal tibia or fibula (malleolar fractures), reorienting the upper ankle joint addresses naturally both tibia and fibula.

If the axis of the lower leg presents a relevant angulation within the frontal plane (genu or crus varum) ***(E19)(E69)***, 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 including a ***varus alignment of the talus within the frontal plane***

217

may result in a relevant deformity proximally. The case may include an unfavourable axis about the knee that includes a ***genu varum with a medial overload of the knee joint.***

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Such comprehensive evaluation would indicate for a ***valgus correction at the proximal end of the lower leg.***


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In cases in which the lower leg is vertical, the valgus correction is best performed ***a few centimetres above the ankle joint (T642-643).***


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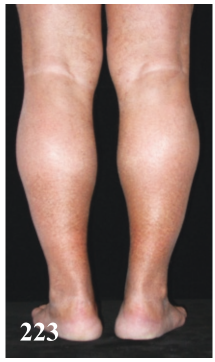
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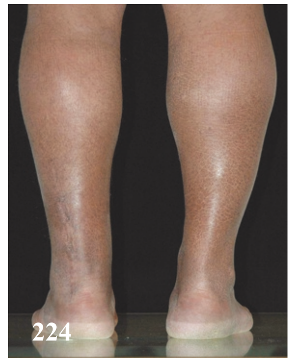
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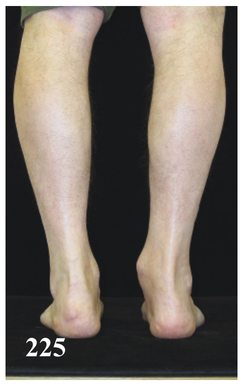
The converse is true for valgus malunion of the upper ankle joint in which the correction is logically performed ***at the level of the deformity*** and addresses naturally both tibia and fibula, for example in ***malunited malleolar fractures (T638-641)***.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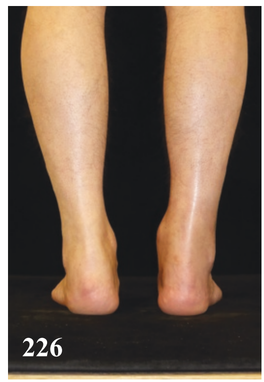
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Attention is given to the vitality and perfusion of the soft tissues: a ***closing osteotomy without a lengthening of the convex side*** of the correction is always safer.

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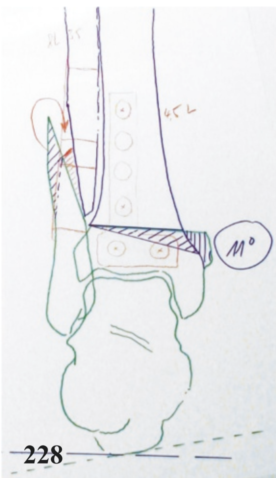
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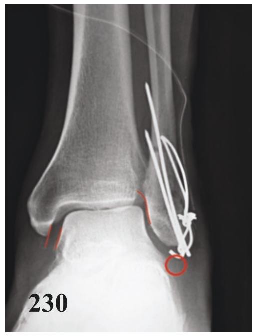
Attention should also be given to the function of both bones of the lower leg: The tibia is the load-bearing structure (“pilon”) and the fibula is the mobile guide of the upper ankle joint. Correction of the fibula osteotomy is therefore essential in length, axial rotation and orientation within the frontal plane. It only serves the congruency of the joint mortise which must accommodate the truncated cone of the talus.

Isolated malunions after fractures of the distal fibula must be identified radiologically ***(T644)***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and a ***correction osteotomy at the fracture site (T646-648)***


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allows for stabilization through corrected joint congruency and functional restoration.

4.3 Alignment of the Heel in the Frontal Plane

Referring to the conventional antero-posterior radiograph of the hindfoot under weight-bearing conditions and provided that the talar dome is horizontal, the tuber calcanei is, for natural stability, better situated lateral to the centre of the talus by about 2 cm ***(R161)***.

Hindfoot varus is most often the cause of chronic varus instability ***(E19)*** including recurring sprains and torn ligaments which lead to joint degeneration. Cartilage wear, osteochondritis dissecans and loose cartilage fragments are the results. The axis of the heel within the frontal plane is modified if the ***tuber calcanei is translated within the frontal plane.***

234

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These modifications can be performed through an osteotomy which divides the bone behind the posterior facet of the subtalar joint ***(T678-682)***.

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***.

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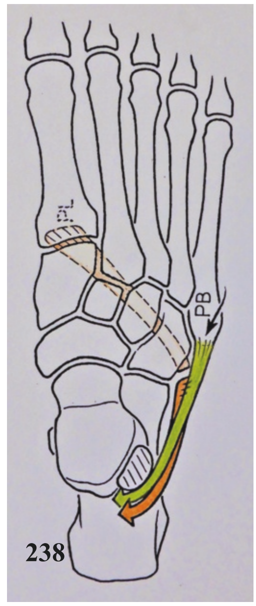
The motor counterpart of such correction is done by ***transferring the fibularis longus tendon*** to the insertion of the fibularis brevis ***(T919-920)***.



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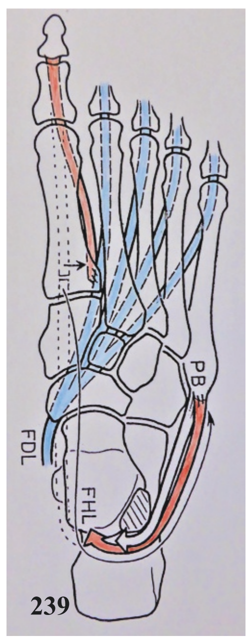
The plantar flexion of the first ray is weakened and the pronation torque around the lower ankle joint is increased because the fibularis longus inserts on the plantar aspect of the first metatarsus and cuneiform. If a shift of the pronators is not yet sufficient, ***transferring the flexor hallucis longus to the basis of the fifth metatarsus (T924-926)*** logically increases this action.



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If the patient demonstrates a *tight heel cord*, which is frequently the case, releasing the tightness achieves correction of the muscular imbalance. Clinical examination informs about the adequate level of the lengthening procedure ***(E93-94)***.

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.

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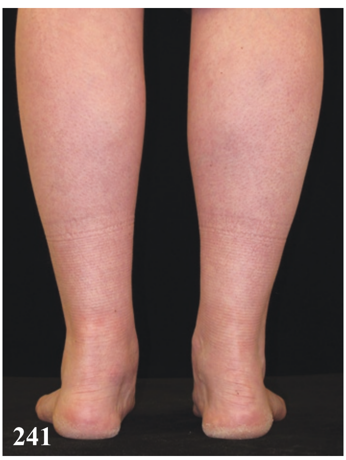
It results in an imbalance of the load and ***overloading of the lateral aspect of the upper ankle joint.***



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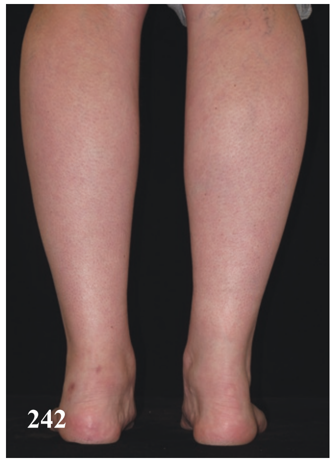
The prerequisite for successful treatment is a perfectly vertical lower leg without relevant talar tilt. ***Moving the heel towards medial (T683)***



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within the frontal plane also moves the load axis towards medial and thus corrects logically the load within the upper ankle joint.

4.4 Alignment of the Heel in the Sagittal Plane

The trajectory of the aforementioned osteotomy of the tuber calcanei allows for a third correcting orientation of the heel, this time within the sagittal plane. Posterior cavus ***(R179)*** jeopardizes functional stability of the hindfoot together with varus. Reducing the calcaneal pitch in cavus feet may easily be performed through the tuber calcanei osteotomy. Instead of being shifted towards lateral or medial, ***through a dorsal shift of the tuber, the talo-metatarsal axis of the foot***

243

may be lowered [41].

4

4.5 Lateral Subtalar Impingement

An unfavourable bony configuration of Gissane's angle of the calcaneus may cause a conflict between the lateral process of the talus and the anterior process of the calcaneus. A slight hyper-valgus of the hindfoot without frank posterior tibial muscle insufficiency favours this conflict.

The lateral aspect of the subtalar joint in hindfoot valgus is overloaded. There is an impingement by abutment between the processus lateralis tali and the anterior process of the calcaneus ***in pronation***

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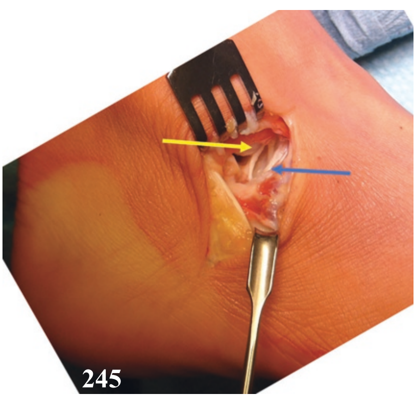
(right foot, yellow arrow: talus, blue arrow: calcaneus).

In supination, the talo-calcaneal conflict does not appear. The calcaneus ***glides*** beneath the talus on its posterior facet ***downwards thus opening the sinus tarsi revealing a torn ligamentum cervicale.***



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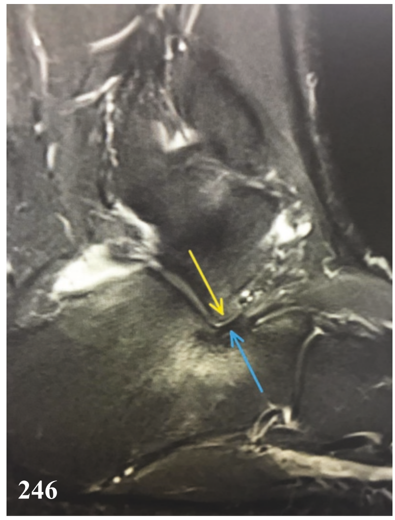
No lesion or insufficiency of the posterior tibial muscle/tendon must be associated. ***Osteo-articular alignment may be perfectly normal***.



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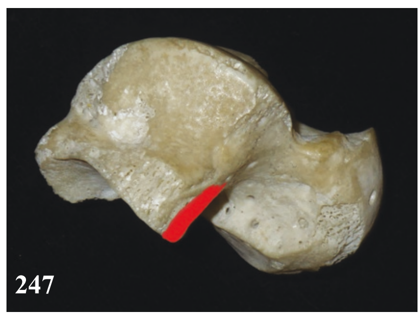
Pain localized precisely at the angle of Gissane ***(E110)*** while walking or running should be identified. Treatment consists of removing the parts of bone which are too close to each other by performing a resection arthroplasty ***on the talar side***



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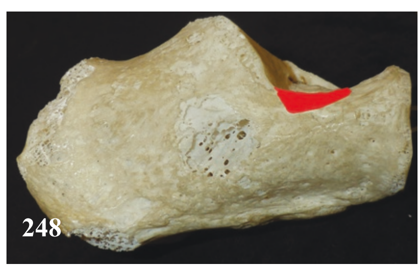
and the calcaneal side (T672-675).



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After bone resection, the new space between processus lateralis tali and processus anterior calcanei ***must be evaluated in pronation***

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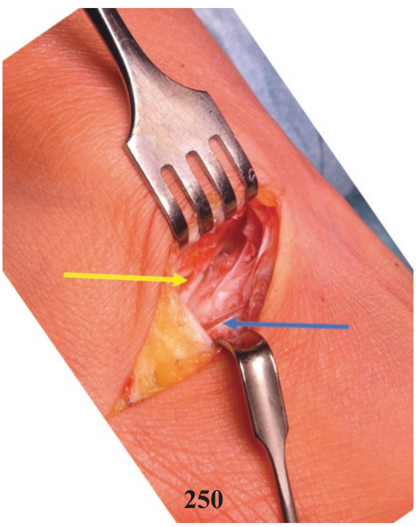
and in supination.



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4.6 Static Articular Stabilization of the Hindfoot

By static stabilization of the joints about the hindfoot we address inherent articular instabilities which jeopardize the integrity of the joints. Acting in the prevention of joint degeneration involves restoration of the ligamentous complex without altering the osteo-articular alignments. The *ligamentous repair* is mostly centred on the lateral aspect and must be based on the anatomic position and shape of the ligament to be repaired or replaced.

4.6.1 Syndesmosis Reconstruction of the Upper Ankle Joint

Forced external rotation of the foot beneath the lower leg stresses the antero-lateral ligamentous structures between the tibia and the fibula. The deltoid ligament is a very strong structure which 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: at the level of the anterior syndesmosis and the interosseous membrane. The acute rupture and unstable syndesmosis may be approached through an anatomic reduction of the distal tibio-fibular space ***(F490-494)***. The chronic ***insufficient (or absent) anterior tibo-fibular syndesmosis (E99)*** (right ankle seen from the front applying opening test of the tibio-fibular mortise)

251

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

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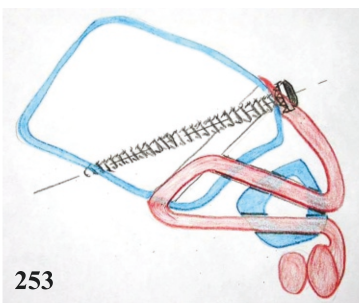
The best stabilization of the chronic insufficient syndesmosis is ***surgical reconstruction of all 3 of its ligamentous parts*** with the anatomical congruency of the fibulo-talar joint [42] ***(T866-867)***.



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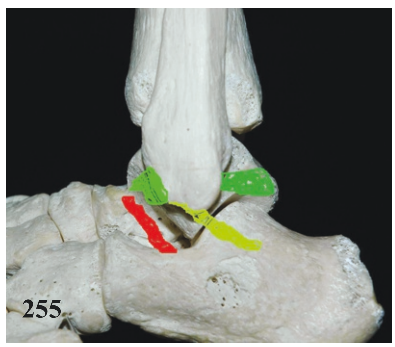
4.6.2 Ligament Reconstruction of the Ankle Joints

Traumatic internal rotation of the flexed hindfoot ("supination trauma") stresses the anterior fibula-talar ligament ***(E100)***. As acute surgical repair of this ligament is very rarely indicated specifically, surgical repair is indicated by chronic antero-lateral instability of the upper ankle ***(E104)*** due to an inefficient ligament. 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 fibulo-talar ligament. In the presence of a substantial ligamentous structure, its refixation on the anterior fibula is sufficient [43] ***(T868-870)***. If this substantial structure is missing, the ligament is best replaced by autologous, if possible local and pedicled tissue to achieve the most "biological" repair. It appears logical that the ***anatomical trajectory of the ligaments***



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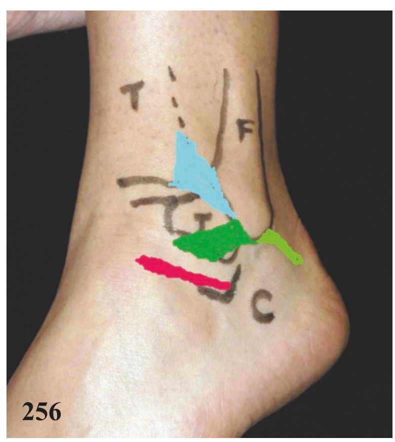

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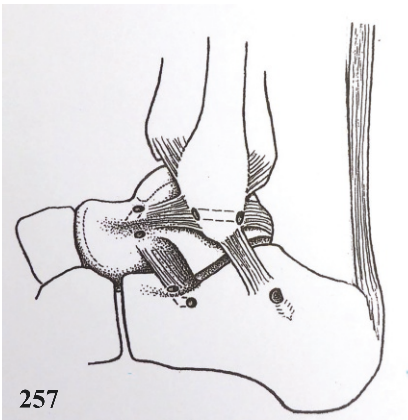
must be respected to achieve physiological conditions. Under this aspect, then, there are three ligaments which may be addressed for eventual reconstruction: the ***anterior fibulo-talar***, the ***fibulo-calcaneal (T877)*** and the ***cervical (T882)*** (antero-lateral talo-calcaneal) ligaments.



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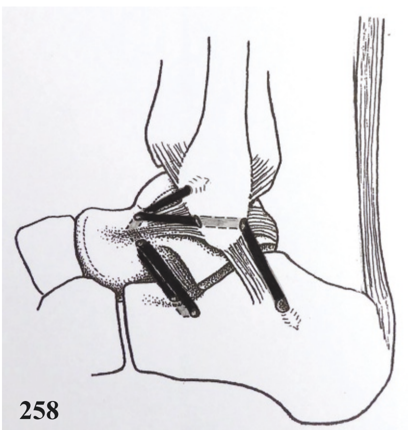

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The posterior fibula-talar ligament is intact and ruptures only in complete dislocation of the upper ankle joint.

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

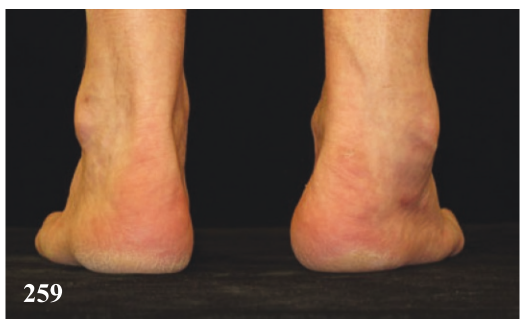
A complete rupture of the deltoid ligament is rare without complete dislocation of the joint. Optimal treatment is performed immediately after the trauma ***(F488).***

4.7 Arthrodeses About the Hindfoot

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

4.7.1 Upper Ankle Fusion

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



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

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Subtalar mobility should be painless but an additional subtalar arthrolysis with eventual osteophytectomy can help to limit the damage to the lower ankle joint and improve function. Fusion should be done with a very precise anatomical angulation between tibia and talus including a slight external rotation as after the fusion the foot is designated to scroll about the coxa pedis. Positioning the talus within the sagittal plane is also critical as, most often, destruction of the upper ankle joint goes together with ***anterior translation of the talus***

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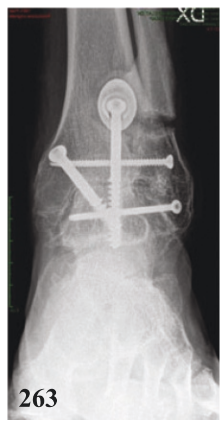
due to its conical shape within the horizontal plane ***(T651)***.

Shifting the whole foot towards posterior

262

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***



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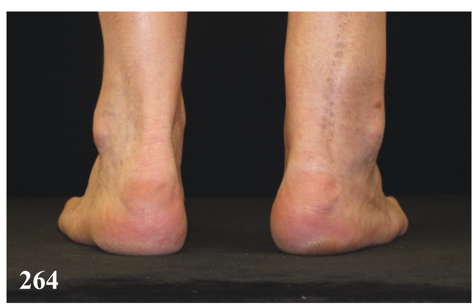
by at least the same amount to ***avoid secondary fibulo-calcaneal impingement*** [44] ***(T652)***



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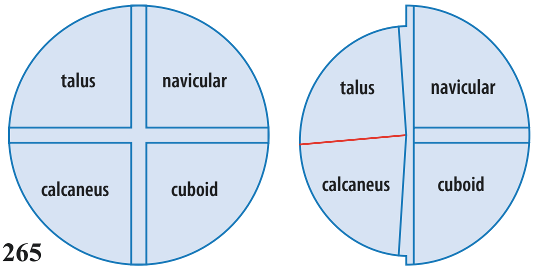
and fibular tendon dysfunction.

4.7.2 Subtalar Fusion

If the subtalar joint undergoes painful articular destruction limiting its mobility, fusion in anatomical axis is the logical treatment. All four bones of the hindfoot: talus-navicular-calcaneus-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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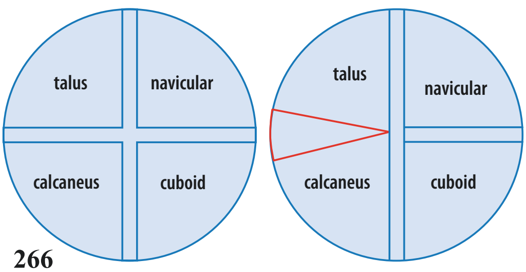
In such cases, an interposition spacer (autologous bone block) must be included to ***restore orientation of the hindfoot (686-687).***



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Fusing the subtalar joint alone significantly reduces and modifies motion at the talo-navicular joint.

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

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

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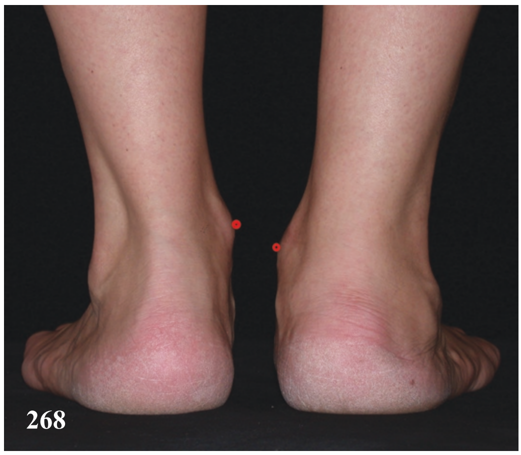
the whole ***ankle joint is maloriented***.



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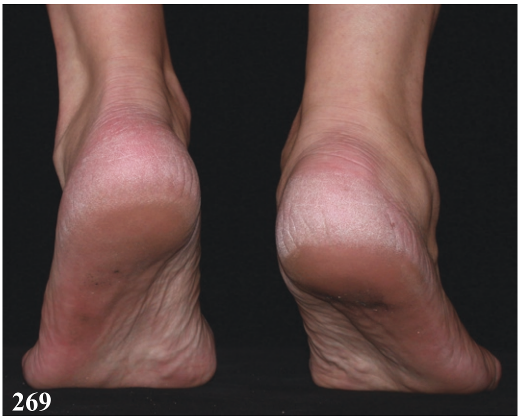
The clinical problem is that of pain due to a residual mobility within a destroyed joint, as well as to a lateral fibulo-calcaneal and an anterior tibio-talar impingement. ***Push-off is weakened***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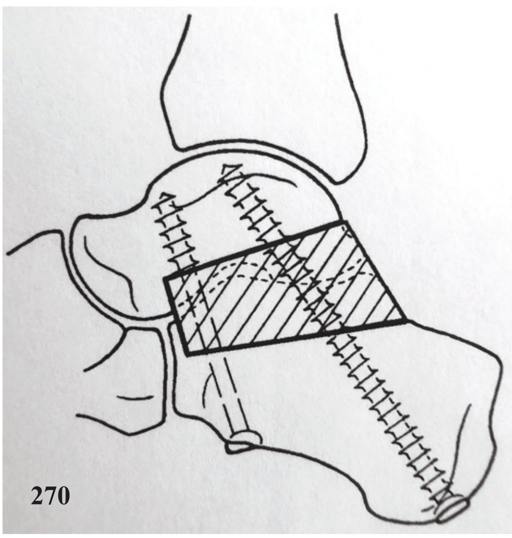
due to the reduced height of the ankle and the resulting relative lengthening of the heel cord. Reconstruction must involve a ***solid biological (autologous bone) spacer (T690),***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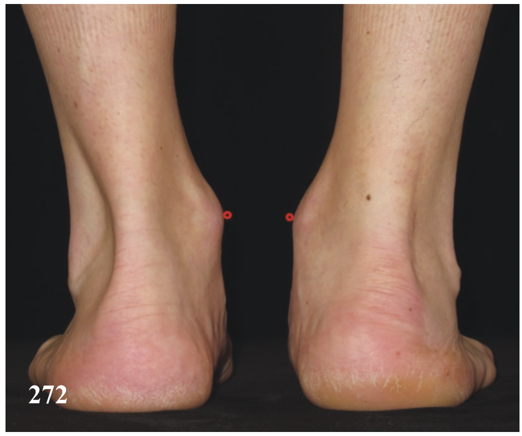
joining both talus and calcaneus to allow for a functional and impingement-free upper ankle joint. The ***height of the ankle joint is corrected***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and the ***push-off is restored.***


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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 post-traumatic situations the length of the heel cord is normal and should not be changed when correcting the equinus calcaneus.

4.7.3 Tibio-Talo-Calcaneal Fusion

If the painful articular destruction involves both the upper ankle and the subtalar joints (post-traumatic, 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 mid-tarsal 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 and the medial knee compartment. The same is true for revision cases after unstable/loose total ankle replacements ***(C1067-1070)***. 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 and 11 degrees [45]. In fact, considering the 3D environment, the ***anatomical trans-articular bony alignment of the weight-bearing heel to the distal tibia follows a circular arc***.


274

This circular arc lies within a vertical plane which cuts the tuber calcanei, the posterior facet of the subtalar joint and the upper ankle joint in about the centre of their articular surface. Such a circular arc is best visualized by the natural orientation of bone trabeculae of the distal tibia, the talus and the tuber calcanei [6]. The posterior facet of the subtalar joint is located slightly postero-lateral to the centre of the tibio-talar joint. Consequently, the aforementioned ***vertical plane is angulated inwards*** to about 15 to 20 degrees in relation to the sagittal plane.


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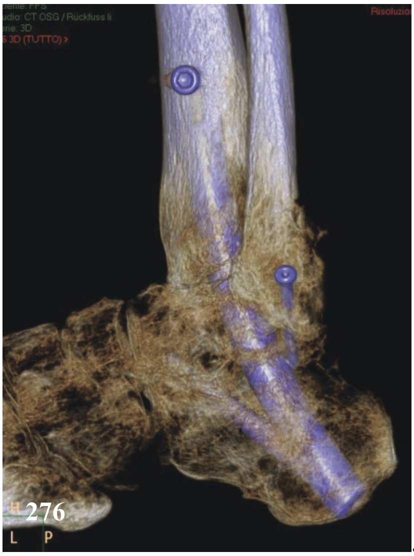
The most logical fixation device supporting the lower leg on the top of the foot thus follows this arc from the tuber calcanei to the metaphysis of the tibia and consists of a nail ***(T702)***.

This nail must be understood as a ***"bone" nail***



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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 and outer surface***

provided that a cavity with the same shape as the nail is drilled along its whole length ***(T699-701)***. Functional after-treatment allows for a more rapid consolidation and rehabilitation.

4.7.4 Talo-Navicular Fusion

Fusing the talo-navicular joint alone, both subtalar and calcaneo-cuboidal joint motions are reduced to an irrelevant magnitude and therefore such a procedure is seldom indicated.

4.8 Horizontal *and* Sagittal Correction of the Heel and Midfoot

This subchapter and the next two subchapters touch the "heart" of the overall orientation of the foot. We purposely put the correction of the sagittal plane together with the correction within the horizontal plane. This is due to the fact that altering the foot axis in one plane modifies its orientation within the other plane. This kind of correction alters the "twist" of the osteo-articular structures which are nearly aligned within the sagittal plane about the hindfoot and within the horizontal plane more distally about the metatarsal heads ***(A9).*** In pathology, we can observe the insufficient twist of the foot which results in a so-called cavus varus deformity and the converse, by means of an exaggerated twist of the foot in a so-called planus valgus deformity. Both extremes of the osteo-articular alignments, pes cavus and pes planus, present their specific symptoms such as instability and pain. In addition, the abnormal alignments may be located at different levels of the foot: the hindfoot, the midfoot and the TMT level.

In this subchapter, we will describe the surgical principles of correcting the pes planus valgus and the pes cavus varus proximal to the mid-tarsal joints. The corrections distal to the mid-tarsal joints and about the TMT joints will be discussed in ► Sects. 4.9 and 4.10 respectively.

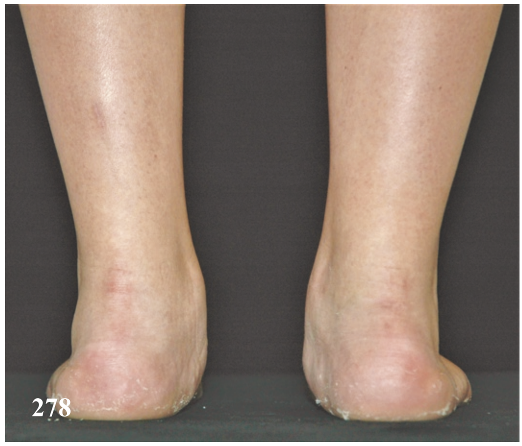
4.8.1 Correcting Eversion

Medial support of the hindfoot is provided by the sustentaculum tali ***(E118)*** 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 ***(R177)*** and the horizontal ***(R169)*** planes, both planes which indicate eversion. Within the sagittal plane one observes a flexed talus and calcaneus ***(O279)*** presenting a kind of hindfoot equinus while within the horizontal plane there is abduction of the calcaneus corresponding to an increased divergence between the axes of the talus and the calcaneus.

If for any reason the complex mechanism of the plantar windlass collapses ***(E44),*** we observe a deformity which is commonly called "flat foot". Here, the talo-calcaneo-navicular joint or coxa pedis undergoes a protrusion of the talar head within the calcaneo-navicular acetabulum. The lateral column appears short and the forefoot tends to abduct.

4.8.1.1 Central Calcaneus Osteotomy

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 ***(T715-733)***. A similar problem has been studied in treating hip dysplasia (coxa pelvis) [46]. A periarticular osteotomy, thus respecting the essential mobility of the joint, [47] allows for congruent articular motion of the hip together with a stable coverage of the femoral head by the acetabulum. The central calcaneal osteotomy [48] follows the same principle. It repositions the "calcaneopedal unit" [23] within the horizontal and sagittal plane over the talar head and thus corrects its bony coverage. The whole subtalar foot thus inverts. It secures medial stability without reducing the arc of motion of the coxa pedis ***(E158-159).*** Additional means include the shortening of the posterior tibial tendon and transferring of the long flexor of the toes to the plantar cuneiform to increase muscle power ***(T908-911).*** All these measures are effective to restore the longitudinal arch of the foot. At the end of this procedure, the length of the calf musculature has to be adapted to the new shape of the upper ankle joint ***(O192-194)***. ***Congenital flat feet***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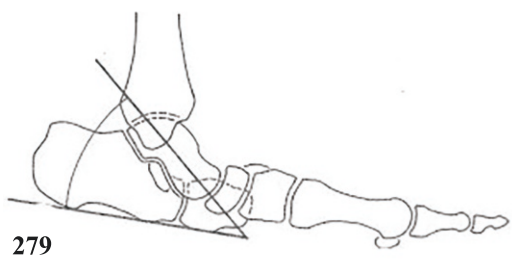
may be symptomatic medially at the insufficient posterior tibial muscle and tendon and laterally at the crucial angle of Gissane, thus causing an impingement such as that seen above ***(O244) (E110).***

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 [21] ***(E125-126)*** 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 may include an insufficient hold of the anterior talus on top of the calcaneus. More specifically, the ***sustentaculum tali is inefficient*** thus causing an ***increased divergence between talus and calcaneus.***

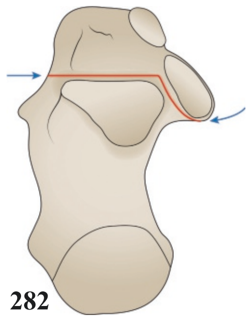
280

In young patients a congenital pes planus or flat foot protrusion of the coxa pedis (talo-calcaneo-navicular joint) often produces ***a dorso-lateral osteophyte of the talar head (arrow).***

281

This osteophyte resembles in its shape and localization the supero-lateral osteophyte on the femoral head found in dysplastic, retroverted acetabuli of the hip joint (coxa pelvis) [49]. In the hip, the corresponding osteophyte (or "bump") is the expression of the coxofemoral impingement, called also femoroacetabular impingement. Impingement is known to initiate articular degeneration with arthritis and arthrosis. The causal treatment in the hip is the anteversion periacetabular osteotomy to move the impinging anterior acetabular rim away from the femoral neck [50] or a cheilectomy of the femoral head [51]. The reorientation of the acetabulum through the periacetabular osteotomy resembles the reorientation of the talus through the central calcaneal osteotomy. The central lengthening calcaneal osteotomy moves the superior articular rim of the navicular bone away from the talar neck. The aim of the osteotomy is to restore the anatomical alignment of the hind- and midfoot together with normal motion of the coxa pedis. Lengthening of the lateral column of the foot thus alters the orientation of the foot within the horizontal ***(O308-309)*** as well as the sagittal planes ***(O293-294).***

The hold of the talus is secured by pushing the anterior part of the calcaneus beneath the talus ***(O286, T733).*** The obliquity of the talar axis within the sagittal plane is corrected, thus achieving a straight talo-metatarsal axis**.** The calcaneus is thus divided ***between the posterior facet and the sustentaculum tali (T725)***



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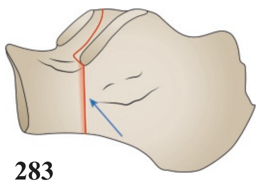

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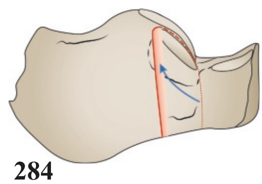

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and a bone block is interposed ***(T729)***. The ***calcaneus increases in length***.

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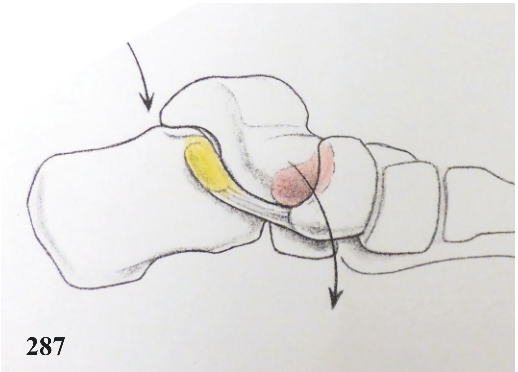
The talus is lifted and the foot turns towards medial: the calcaneus moves beneath the talus following a complex helicoidal motion ***(E108-111)***. ***The talus is raised in supination***.



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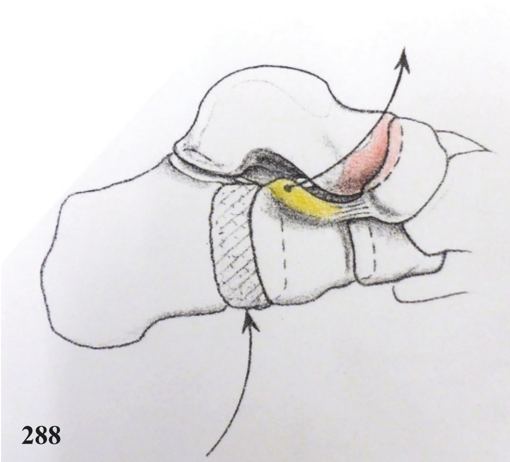

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The acetabulum pedis closes medially and the normal valgus of the heel can be restored.

The ***sustentaculum tali is pushed forwards***, beneath the anterior aspect of the talus (black arrow)

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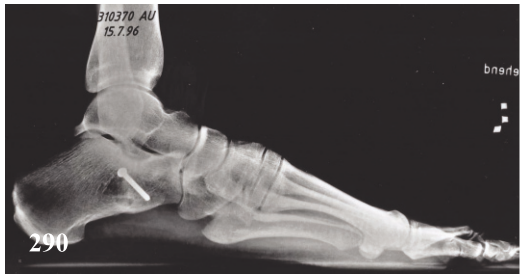
thus, restoring the ***straight alignment of the talus to the first metatarsus*** within the horizontal and sagittal planes ***(R168)(R176)***.



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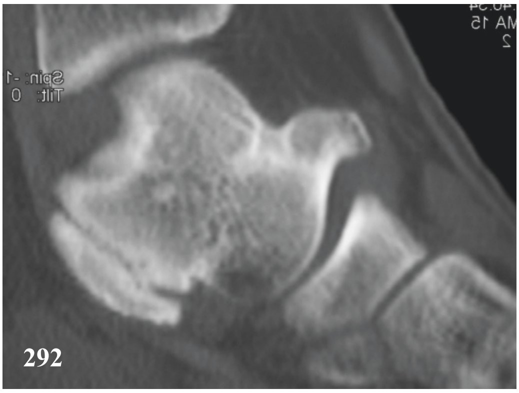
In rarer cases, misalignment may be due to a **subtalar coalition** ***(R185)*** which blocks normal motion of the coxa pedis. The missing motion of the subtalar joint increases the functional motion of the talo-navicular joint by a compensation mechanism. Such augmented motion, in association with the protruding talus within the acetabulum pedis, increases the formation of the dorso-lateral osteophyte resulting in a so-called ***"dorsal beak" onto the talar head (O280-281).***



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Radiographs under weight-bearing conditions demonstrate the ***sag of the medial column*** at the talo-navicular joint ***(R177).***

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In young and active patients, the blocking coalition must be evaluated precisely in localization and extension. Prior to elongation osteotomy, the calcaneus must be liberated from the talus to allow for ***reorientation within both transverse and sagittal planes***.

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

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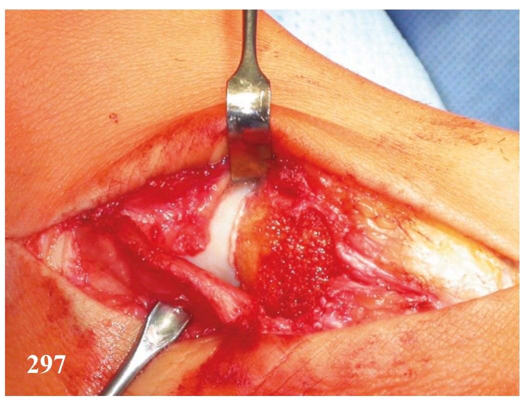
The resulting realignment must be held by a strengthened supinator muscle.

The motor counterpart of the above osteo-articular reorientation to treat the pronated foot includes powering the supinator muscles. This functional equilibrium means to assist the medial suspension provided by the posterior tibial muscle and tendon. The latter function may be impeded by the presence of an unstable accessory navicular bone ***(E125-126).*** In the usually classified type 2 and 3 [52], the accessory navicular causes medial foot pain in a pronated foot due to the inefficacy of the posterior tibial tendon. The logical pathway is to ***remove the accessory navicular, resect the remaining medial spur and re-tension the posterior tibial tendon onto the remaining "monobloc" navicular bone*** [21].



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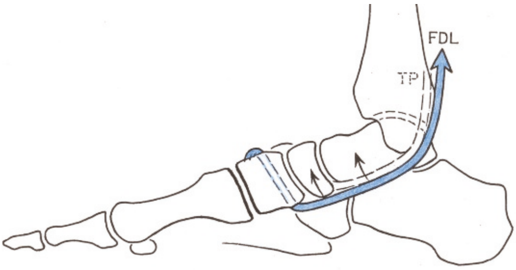
The flexor digitorum longus tendon follows the path of the posterior tibial tendon and receives about the midfoot a relevant tendon sheath from the flexor hallucis longus tendon [53]. Sectioning the tendon of the flexor digitorum longus proximal to this sheath and transferring it to the plantar aspect of the first cuneiform [54] ***(T911) empowers supination***



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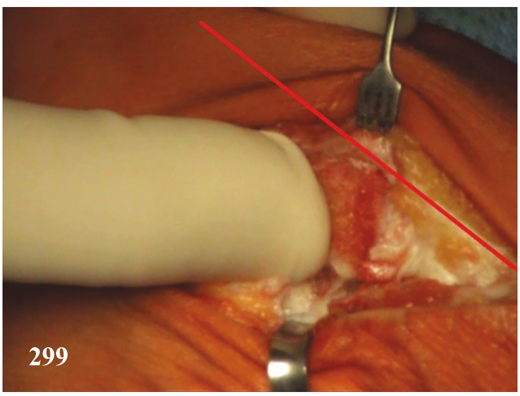
and does not result in sacrificing any relevant function to the toes. Transferring the tendon to the first cuneiform as well as the insertion of the posterior tibial tendon onto the navicular helps sustain the naviculo-cuneiform joint especially in hypermobile pronated feet [55]. Often this joint is also hypermobile as can be seen ***intra-operatively in flexion***



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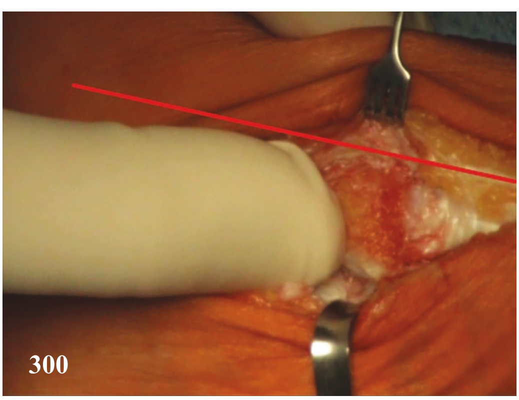
and may ***sag in extension*** (red line: axis of the first cuneiform).



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Following these procedures, the forefoot is aligned to the hindfoot and the equinus becomes usually very evident. Testing the effective shortening of the calf muscles ***(E93-94)***, the corresponding ***lengthening of the tendons*** is then achieved [56] ***(T884-890)***

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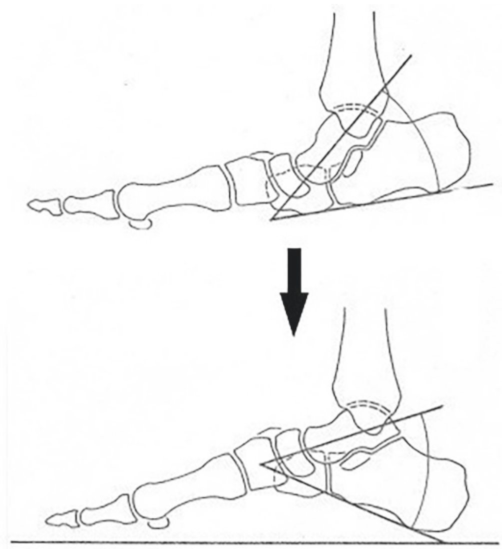
to realign the whole foot ***(O278)*** within the upper ankle joint ***in the sagittal plane.***



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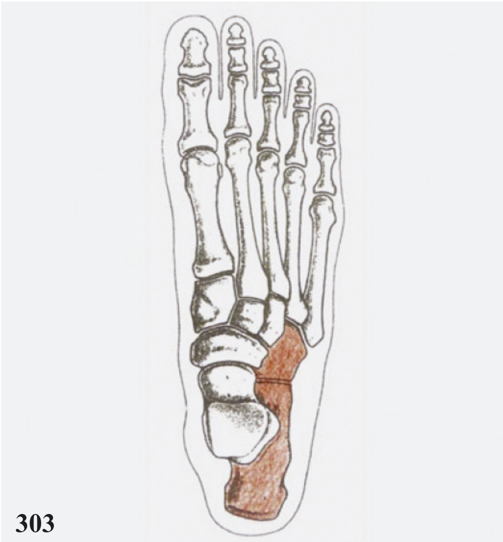
4.8.1.2 Calcaneo-Cuboidal Distraction Fusion

The "calcaneo-pedal unit" [23] 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.

Fusing the calcaneus to the cuboid



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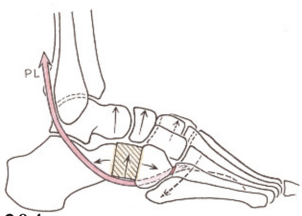
thus affects only some of the talo-calcaneo-navicular joint mobility, so little in fact that its clinical relevance is close to zero. However, the alignment between the calcaneus and the cuboid is essential for the whole hind- and forefoot alignment. Moving alignment upwards in particular increases pronation of the forefoot, while fusing it with an interposed bone block corrects eversion, elevates the medial column of the foot and puts the ***peroneus longus tendon under tension***. This effect pulls down the first metatarsus thus increasing the "cavus effect" on the medial arch ***(E29)***.



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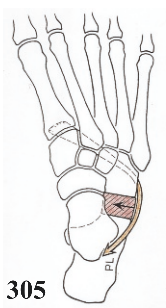

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Differentiating the localization of the cuboid on the anterior process of the calcaneus allows for rotation of the forefoot within a frontal plane. The centre of such rotation is the talo-navicular joint [6, p. 547]. Due to its simple lateral approach, this correction is justified in specific calcaneo-cuboidal misalignment, in local arthropathy (arthrosis) and in ***global correction of symptomatic eversion*** (pronation).

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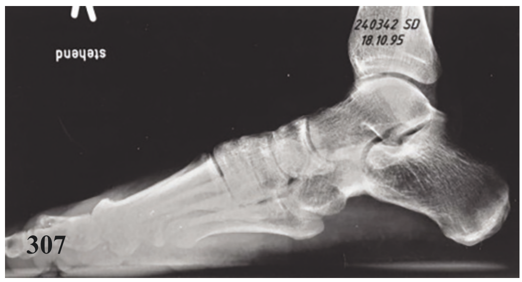

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4.8.2 Correcting Inversion

During normal gait and running, the non-weight-bearing foot is in slight inversion, ready to expand in eversion after heel strike and with progressive loading of the foot on its whole until the following step. In cases in which the supinators do not relax and/or the pronators by means of the musculus fibularis brevis and tertius are too weak, the resulting imbalance creates what is called pes cavus varus. This kind of imbalance is found in the deformities which are commonly called “club feet”. Those deformities cannot be attributed to a kind of “on-off” diagnostic evaluation. They simply spread off the range of normality and are clinically relevant when becoming painful and cause disabilities as well as causing progressive degenerative articular diseases. We discuss below the principles of the most frequent group of compensated cavus varus feet and move on to discuss the evaluation and therapeutic surgical approaches of the decompensated cavus varus feet under “complex reconstructions”.

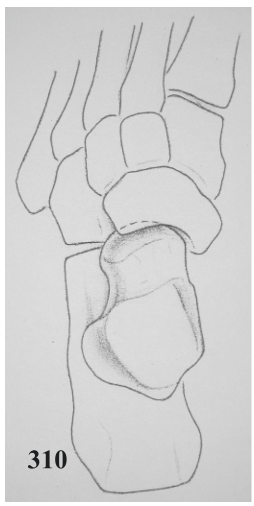
Certain joints, such as the naviculo-cuneiform and/or TMT joints are overloaded due to their unphysiological osteo-articular axes (***R178)***. Those joints undergo morphological degeneration. Depending on the stage of progression, the statics can be corrected by osteotomies (metatarsal, talus, calcaneus) or by reorienting fusions of non-essential joints (naviculo-cuneiforms, TMTs).

Depending on the etiology of the deformity, functional correction by tendon transfers is generally indicated. It has been established that pes cavus linked to hereditary motor and sensory neuropathies, an inherited genetic condition (Charcot-Marie-Tooth), recur after correcting triple arthrodesis if the balance of the musculature is not corrected [57].

It appears that comprehensive correction of this deformity must particularly respect multiple factors such as age, vascular and neurological status, functional expectations and compliance. The major clinical factors to be re-established are functional stability (standing on tiptoe on one single leg rise), along with full and equal weight-bearing on all tips of the toes. The radiological factors which are relevant are the horizontality of the talar dome within the frontal plane, the alignment of both talus and first metatarsal axes within the sagittal and the horizontal planes, and the parabolic alignment of all metatarsal heads within the horizontal plane.

4.8.2.1 Central Talus Osteotomy

Pes adductus is a relevant component of club foot deformity. In young patients suffering a pes cavus-varus-adductus ***(E23)*** without joint degeneration and good mobility, lengthening (and eventually rotating) the talar neck is a very powerful means to ***correct the adductus*** [58].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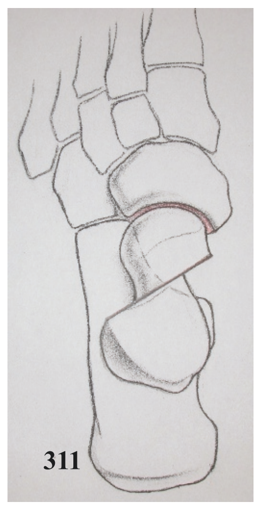
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In fact, this correction aims at restoring the normal divergence of the talus and the calcaneus. To do so, lengthening the medial column of the foot, together with the release of the adjacent soft tissues by means of joint capsules ***(T708-709)*** (talo-navicular joint) and tendons (posterior tibial tendon) ***pushes the forefoot in abduction (T713)***

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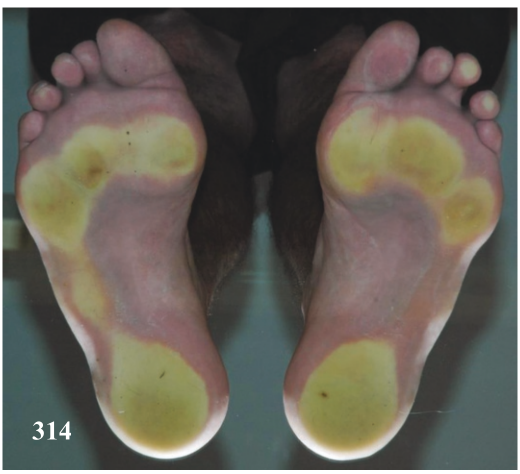
and ***increases the antero-medial weight-bearing*** of the foot (left foot).



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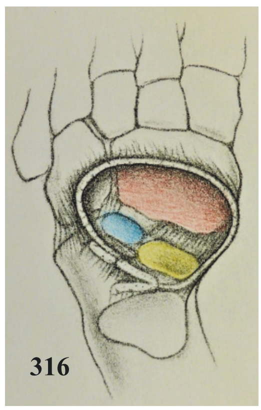
A prerequisite is safe vascularity of the soft tissues and good mobility of the joints. The intervention includes a complete ***medial opening of the acetabulum pedis (T708)*** [59].



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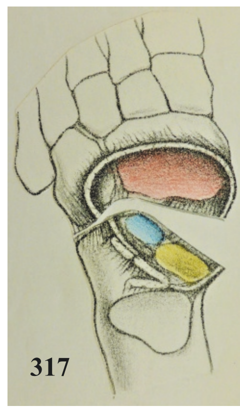

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The effect of the necessary release of the posterior tibial tendon may be increased by transferring it onto the opposite side of the foot (dorso-lateral) ***(T812)***.

4.8.2.2 Calcaneo-Cuboidal Shortening Fusion

An effective complement of medial opening of the acetabulum pedis is closing the apex of the acetabulum located laterally ***(E30)***.

At this location, this corresponds to ***shortening of the lateral column within the calcaneo-cuboidal joint (E30)***.


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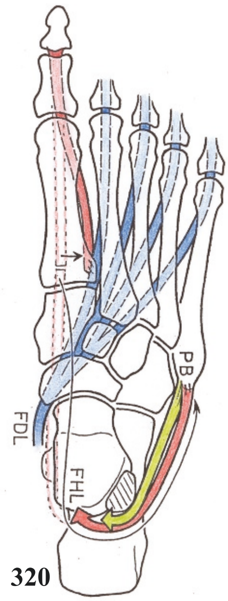
The calcaneo-cuboidal joint minimally affects the mobility of the lower ankle joint and its fusion is very well supported. This procedure limits the soft tissue strain on the medial side of the foot. Additional extending of the first metatarsus ***(O363)*** allows for pronation and lowering of the medial longitudinal arch. Fusing the calcaneo-cuboidal joint not only allows for shortening the lateral column of the foot. Due to its orientation, fusion may correct a supinated forefoot by sliding the cuboid upwards. The whole forefoot then turns inwards around the talar head within the frontal plane [6, p. 547].

According to the tridimensional character of the deformity, the exaggerated varus component is also corrected by a lateralizing tuber calcanei osteotomy ***(T682)***. The extension osteotomy of the first metatarsus reduces the antero-medial buttress of the foot.

The motor component of this correction is very important to avoid relapses because the aetiology is essentially neurological through a muscular imbalance which 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 ***(T812)***, a lateralizing transfer of the anterior tibial tendon, a transfer of the fibularis longus to the fibularis brevis tendon and transfer of the ***flexor hallucis longus tendon to the basis of the fifth metatarsus (T926)*** [38].



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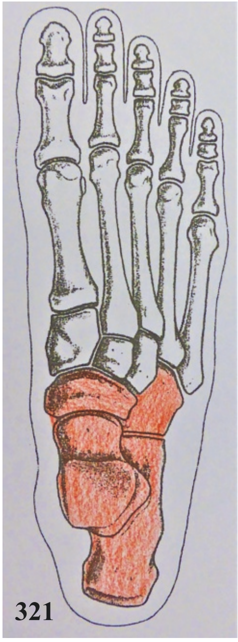
4.8.3 Correction by Global Fusion: Triple Arthrodesis

Triple arthrodesis fuses the talo-navicular, the talo-calcaneal and the calcaneo-cuboidal joints. Performing the arthrolysis and the removal of the joint surfaces of those joints along with fusing the corresponding ***bones***



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is a very efficient intervention which addresses painful degenerative and post-traumatic conditions. Any malorientation of the lower ankle joint which lacks in mobility cannot be reoriented with osteotomies and such correction must go through arthrolysis and fusions of the submalleolar joints. Malorientation may have multiple causes which include ***post-traumatic destructions after dislocations.***

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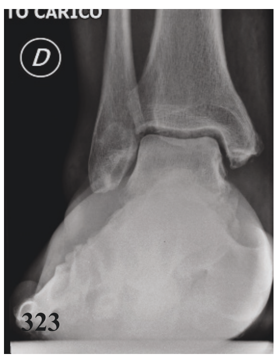

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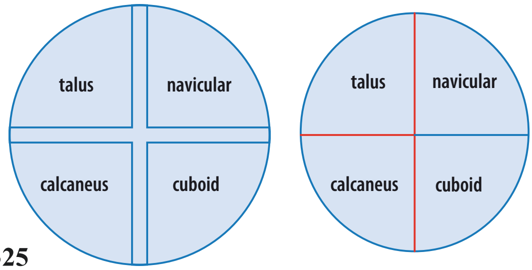
Treatment goes through free reorientation of the whole hindfoot and midfoot within the sagittal and the horizontal plane ***(T734-744)***. All four bones are mobilized completely and reassembled with the desired horizontal and sagittal orientation in a ***slightly reduced dimension***



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due to the removal of the joint surfaces. The ***talo-metatarsal axis is realigned*** within both sagittal and horizontal planes ***(R168-176)***.

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If the indication includes a deformation due to neuromuscular imbalance or degenerative insufficiency of the posterior tibial tendon, the corresponding imbalance must be corrected by the adequate tendon transfer. In some cases, the deformity recurs within the fusion if the imbalance persists. Such recurrences are particularly frequent in Charcot-Marie-Tooth diseases in which the muscular imbalance progresses step-wise [57]. Other expansion of this reconstruction occurs in selected cases of diabetic arthropathy in which the medial column of the foot, the talo-metatarsal axis, is malaligned. Here, the triple arthrodesis is associated with a talo-metatarsal arthrodesis ***(O355-356)***.

4.9 Horizontal *and* Sagittal Correction of the Midfoot

As mentioned above, this subchapter discusses the possibilities to correct the twist of the osteo-articular structures distal to the mid-tarsal joints.

4.9.1 Correcting Eversion

Eversion of the mid- and forefoot corresponds mechanically to a collapse of the longitudinal medial arch of the foot ***(O279)***. These feet also belong to so-called "flat feet" but their morphological defect is slightly more distal which excludes the morphological disorders at the talocalcaneal alignment. An occasional accessory navicular bone is testimony to a certain posterior tibial muscle/tendon insufficiency ***(E126)***. Surgical correction begins in weak posterior muscle function by removing the accessory navicular bone and retensioning the tendon onto the "monobloc" navicular [21] with eventual support given by a transfer of the flexor digitorum longus tendon [54] ***(T911)***.

In essence, pronated feet have to be observed in the three planes of space and only then can be quantitatively evaluated. There are deformities which are more clearly expressed within the horizontal plane (abduction) and others which 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.

4.9.1.1 Talo-Navicular Fusion

The talo-navicular 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 mobility. This is due to this joint being essential for the functional hindfoot motion.

4.9.1.2 Naviculo-Cuneiform Fusion

Pes pronatus or planus may present its main deformity distal to the mid-tarsal joints, or more precisely the talo-navicular joint. The ***abnormal abduction and extension (eversion) of the forefoot***

may concentrate on the naviculo-cuneiform joint.

In the horizontal radiological view of the weight-bearing foot, for which the interpretation together with the contralateral foot is essential, the talus is well covered by the navicular bone and ***the pathological angle in abduction is more distal***.

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The relationship with the accessory navicular bone demonstrates the inefficacy of the posterior tibial muscle. ***Orientation within the sagittal plane though*** is less affected.

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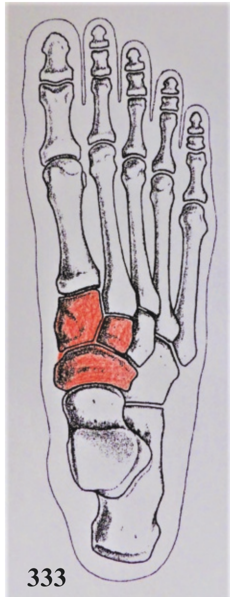
The "talar foot" of the first 3 rays are corrected surgically in either plantar flexion, thus correcting the deformity within the sagittal plane, and/or in adduction within the horizontal plane. Both sagittal and horizontal components are more or less pronounced either way. The naviculo-cuneiform joints are not essential for foot function and are thus ***destined for correcting these deformities*** [60] ***(T749)***.



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Essential is the corrected, ***symmetrical aspect of the long axis of the foot in relation to the knee axis (O329) (E68)(E76).***

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In cases where the sagittal sag of the medial column is located at the talo-navicular joint *and* the naviculo-cuneiform joint, the naviculo-cuneiform fusion is associated with the central calcaneal osteotomy ***(O288)***. One thus achieves simultaneously: ***sagittal correction of the talo-metatarsal axis***

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and ***correction of the abduction***


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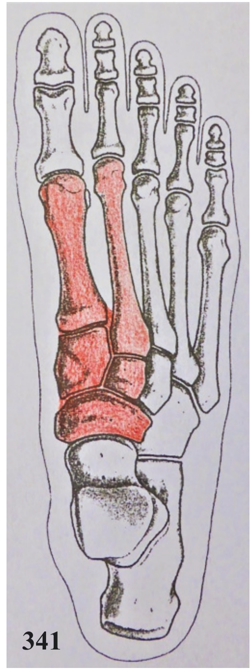
within the horizontal plane while preserving all essential articular mobility of the foot.

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

4.9.1.3 Naviculo-Cuneo-Metatarsal Fusion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In cases of degenerative deformities, the instability is frequently located at the naviculo-cuneiform level as well as more distal at the cuneo-metatarsal 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. Radiological verification demonstrates the ***sagittal sag of both naviculo-cuneiform and cuneo-metatarsal joints***.

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

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As non-essential joints, the medial tarsometatarsal joints are fused and arranged in both ***horizontal (adduction)*** [61] ***(T771).***

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and ***sagittal (flexion) planes*** to re-establish anterio-medial buttress of the foot ***(T769)***.

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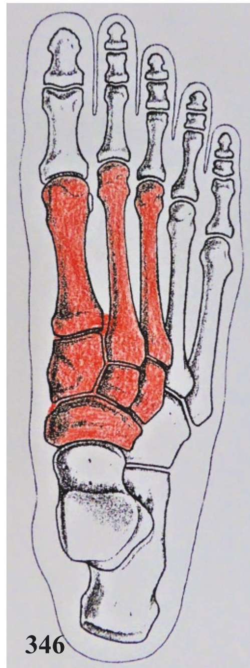
The motor counterpart of the correction of imbalanced pes pronatus is logically corrected by either powering the supinators ***(O298)*** or powering the flexors of the first ray ***(O380).***

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 naviculo-cuneiform 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 naviculo-cuneiform*** level and in ***abduction eversion at all three medial tarsometatarsal joints.***

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

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4.9.1.4 Talo-Naviculo-Cuneo-Metatarsal Fusion

If the articular degeneration includes the whole first ray, reorientation is done by ***fusing the metatarsus in straight alignment with the talus.***


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This fusion is justified if the misalignment is symptomatic as it can occur after trauma or diabetic arthropathy. Involvement of the ***talo-navicular joint and its axis within the sagittal plane***

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must be verified. An obvious misalignment has immediate consequences onto the talo-calcaneal joint and a ***secondary antero-lateral impingement (E110)(O244).***


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The insufficient talo-metatarsal axis must be fixed straight and the pro/supination must be locked. The simplest locking is achieved through a second ***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 of stabilizing the axial rotation within the subtalar joint, which is indicated if there is a clinical hyperlaxity in heavy patients and/or ***progression of a diabetic arthropathy.***


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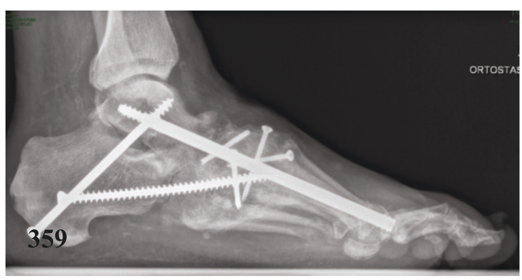
The end result then corresponds to an association of a ***first ray stabilization with a triple arthrodesis (O325)***.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4.9.2 Correcting Inversion

These feet belong to what are commonly called cavus-varus feet.

4.9.2.1 Calcaneo-Cuboidal Extension Fusion

Triple arthrodesis is a very good tool to correct any deformity of the hindfoot situated beneath the upper ankle joint. Fusing the calcaneo-cuboidal joint alone allows for a localized shortening of the lateral column of the foot ***(E30)*** and thus a specific ***abduction of the midfoot*** which can be scaled by the quantity of bone removed.

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Gliding dorsally the cuboid within the fusion adds a relevant pronating component within the correction [6, p. 547].

4.9.2.2 First Metatarsal Extension Osteotomy

Structural supination of the foot should also be investigated on the metatarsal level. A plantarflexed first metatarsal is then easily corrected by the aforementioned extension osteotomy of the first metatarsus ***(T788-793).***

Diagnosing an isolated anterior pes cavus ***(R180)*** correction of an associated central metatarsalgia is logically approached ***through correction of the medial anterior heel on the metatarsal level.***

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Extending the medial correction on the central metatarsus ***(O409)*** induces the ***associated and desired pronation***

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4.10 Horizontal and Sagittal Correction of the Metatarsus

As mentioned above, the pathological and symptomatic planus or cavus of the foot may be located at the TMT level.

4.10.1 Medial and Central Tarso-Metatarsal Fusion

4.10.1.1 Pes Adductus

Pes cavus adductus may be located specifically at the ***tarsometatarsal joints***. The three medial and particularly the second and third TMT joints can be considered non-essential joints. They all belong to the "talar foot" having one more joint on the foot axis than the lateral column of the foot. They are also responsible for the stability of the medial aspect of the longitudinal arch. Fusion of those joints is thus perfectly compatible with a normal foot function. In the example of ***pes adductus at the level of the TMT joints***

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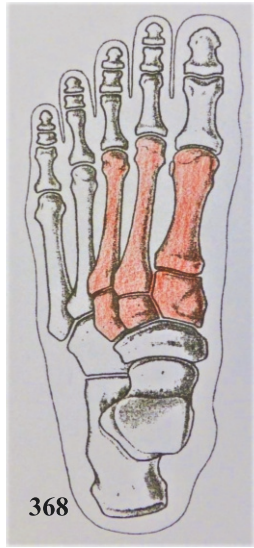
the whole gait may be altered, though without relevant metatarsalgia. The logical treatment is the abduction arthrodesis of the ***first three tarsometatarsal joints***.



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The fourth and fifth tarsometatarsal joints may spontaneously follow the correction. In severe cases, 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 the 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 morphological result ***(T776-781)***.

4.10.1.2 Pes Abductus

Pes planus abductus occurs frequently in polyarthritis and or in degenerative ***destruction of the medial tarsometatarsal joints***.

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In this case, the foot ***collapses antero-medially***.

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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 ***restoring the medial arch*** of the foot.

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Arthrodesis at the corresponding tarsometatarsal joints is the optimal point 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***

376

and the medial metatarsus in slight flexion ***(E80)***. This treatment is very efficient because the correction is performed at the base of the bones.

4.10.2 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" and should be considered essential. They require a wide range of functional adaptation during gait and are provided with one joint less than the medial three rays. If the horizontal orientation of the medial rays is modified by selected TMT arthrodesis, the whole forefoot will also be modified within the frontal plane. Such a change modifies the orientation of both fourth and fifth TMT joints which often results in painful arthritis of those joints. The simple complete arthrolysis of the two joints allow the fourth and fifth metatarsi to follow the corrected axis of the third tarsometatarsal joint. If the deformity is very severe or the ***fourth and fifth tarsometatarsal joints are arthritic,***


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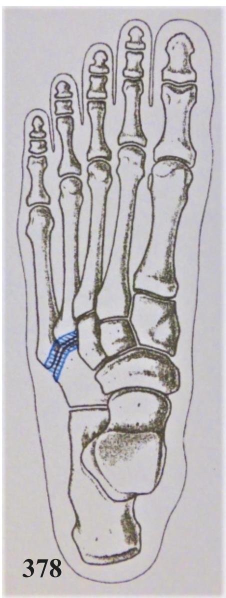
arthroplasty of the two joints by ***resection of the subchondral bone*** and interposing chondrogenic soft tissue (autologous tendons) ***(T782-787)***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provides for a ***painless, functional and stable reconstruction***.


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The plantar articular and ligamentous layers remain intact, acting as plantar tension bands**.** 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 may solve the articular and the weight-bearing problem 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.

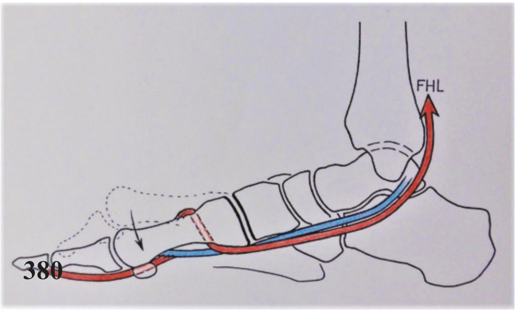
4.11 Correction of the Anterior Heel

Weight-bearing problems of the anterior heel are due to a functional mismatch of load distribution on the sesamoids and the lesser metatarsal heads ***(A9)(E38-39).*** The problems discussed in this sub-chapter are directly linked to the uneven weight-bearing pattern of the metatarsal heads. The primary role is played by the unstable first ray and the consequences of this instability [4] ***(E136-140)***. From this point of view, one should recall the anatomical symmetry of the foot which moved towards medial from the original hand ***(A5-6).***

4.11.1 Muscle Balance

Powering the flexors of the first metatarsus should help to achieve a better antero-medial buttress of the foot and to 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 (T927-928)*** is sufficient to re-establish 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 and therefore a bony stabilization is most often required.

4.11.2 First Tarsometatarsal and First Intermetatarsal Space Fusion

The alignment of the metatarsal heads and sesamoids is critical for smooth push-off and gait ***(R184).*** By alignment of the metatarsus, we mean the sagittal as well as the horizontal (Lelièvre's parabola [34]) and rotational alignment of the metatarsal heads. As a rule of thumb, the radiological axis of the first metatarsus should be aligned with the axis of the talus in both sagittal and horizontal planes.

Restoring a functional antero-medial buttress of the forefoot is indicated in frequent instability of the first ray ***(E36-37)*** which is characterized by a hypermobile first tarsometatarsal joint in the sagittal and also in the horizontal plane and probably along its own axis [11]. The clinically relevant aspect of the pathology corresponds to the painful overloaded second and third metatarsal heads. The corresponding TMT joints are much stiffer and cannot "escape" functional load. Aim of the treatment is to regain and secure the absent/lost antero-medial weight-bearing of the first ray which can be seen when ***comparing the corresponding plantar skin of the non-operated (right foot) and 2 years after the operative correction (left foot)*** of the same patient.

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The problem is resolved definitively by three-dimensional re-orienting the first metatarsal and reducing the destabilizing hypermobility of the medial ray. The radiographic image under weight-bearing conditions of the unstable first ray often reveals a widened space between the first and the second metatarsus and between the first cuneiform and the second metatarsus ***(R171)***. The cuneo-metatarsal and the metatarso-phalangeal joint are often of the ***condylar type*** and ***second metatarsal hyperplasia*** is the rule for clinical relevancy.

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The lateral incidence often demonstrates a **plantar opening of the medial** TMT **joint**.


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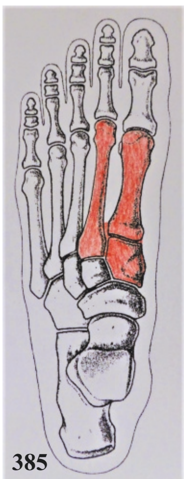
Re-orientating the first metatarsus and fusing it to the second metatarsus and the first cuneiform [62] creates a ***new functional and less mobile entity***: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the three bones ***articulate around the second cuneiform*** and thus limit, but not block, the functional sagittal mobility of the first ray.

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The function of this "new" joint can be evaluated in a ***conventional radiograph at more than 2 years follow-up.***


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The first tarsometatarsal and intermetatarsal 1–2 arthrodesis provides by its congruency the lowest probability of a recurrence of metatarsus adductus/elevatus ***(T758-772)*** and an ***equilibrated anterior heel at long term (case E36).***

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4.11.3 Extension and Shortening Osteotomy of the Central Metatarsals

Symptoms of the missing antero-medial buttress is logically linked to the compensatory overload of the neighbouring metatarsals. The ***second and third metatarsals are considered to be the central axis of the foot (A6)***

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with a 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 ***(E62-63).*** The importance of the aforementioned Lelièvre's parabola becomes clear at this point. If the alignment does not follow the parabola ***(E61)***, 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 metatarso-phalangeal joints ***(E148)***. 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 the alignment of the lesser metatarsal heads: either a central diaphyseal ***(O396)*** or a basal metaphyseal osteotomy [63] ***(O411)***. The basal metaphyseal osteotomies allow for a local spontaneous stability of the corrected position of the metatarso-phalangeal joint which is due to the action of the interosseous musculature which attaches on the metatarsal diaphysis. Furthermore, the intermetatarsal ligament holds the lesser metatarsals together. Distal metatarsal osteotomies may be located distal to the intermetatarsal ligament and thus do not benefit from the mentioned anatomical stabilizers. The desired alignment cannot be secured. Intra-articular, horizontal osteotomies to shorten the metatarsal have minimal or no effect within the sagittal plane. Metatarso-phalangeal joint motion has been reported to be reduced significantly after this treatment [64].

Last but not least, vascularity and thus ***vitality of the metatarsal*** head may be jeopardized after this treatment.

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4.11.3.1 Diaphyseal Osteotomy

The diaphyseal osteotomy allows for an immediate, highly precise correction. At first sight, this technique seems somewhat invasive as it includes implants ***(T799)***. In practise though, respecting the soft tissues, healing is generally secure. Correction is free in all planes: the metatarsus can be extended, flexed, shortened, lengthened or rotated without anatomical limitations and without disturbing the adjacent joints. As mentioned above, this correction is most often ***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 a chronic 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 which is accompanied by a corresponding plantar callus. In these cases, a precise osteotomy fixed definitively by plate can produce the desired harmonious functional weight-bearing pattern of the anterior heel.

The unstable, hypermobile first ray is not always linked to the flexible, rather flat foot. It may occur within an anterior pes cavus by means of a plantar ***concave talo-metatarsal axis (R180)***.

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The logical answer to this often-symptomatic static problem consists of associating the extension osteotomies of the second and third metatarsals with ***an extension-abduction arthrodesis of the first ray***.

404

Metatarsus quintus abductus is sometimes associated with imbalanced medial metatarsi (splay foot) ***(R172)***

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and the problem is relieved by orienting the metatarsus ***on the diaphyseal level (T816-819).***

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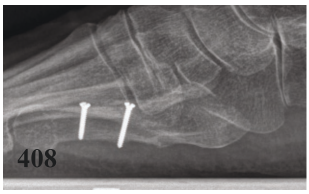
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4.11.3.2 Basal Osteotomy

The basal osteotomy, although less invasive, allows for approximative physiological adjustment of the metatarsal head by weight-bearing ("self-adjustment") [63]. The sagittal guided slide of the bone is assured by the ***inclined "chevron-like" shape of the osteotomy (T810-814).***


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The important mechanical solidarity between the metatarsi (intermetatarsal ligament) remains intact.

Essential components of the treatment are the post-operative plantar orthosis (***retrocapital cushion or "pelote"***), while the interosseous musculature (dorsal and plantar musculi interosseii), which remains intact, ***cushions and limits the sagittal bony correction***.


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411

Additionally, the said musculature avoids any rotational malunion which 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 upwards allowing for ***adequate shortening***.


412

This procedure is less predictive than the diaphyseal osteotomy because it is self-adjusting and thus is well indicated in the elderly who cannot handle crutches easily and the osteoporotic, non-compliant or smoking patient with local vitality problems including peripheral arteriosclerosis.

4

4.12 Correction of the Metatarso-Phalangeal Joints

4.12.1 First Ray

The first metatarso-phalangeal joint may experience local overload over time. Certain morphology, including a relatively long first metatarsus (index metatarsus +) and an Egyptian morphotype favour joint degeneration ***(R175)***.

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

4.12.1.1 Joint Decompression

If the joint surface is acceptable in a young person and there is the combination of an Egyptian morphotype and an index metatarsus +, the pressure within the joint is reduced by ***shortening the first metatarsus (T788-793) andlor the first phalanx (T846-851).***

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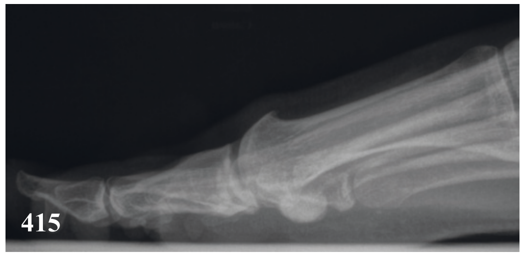
4.12.1.2 Metatarso-Phalangeal Joint Reorientation

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 intra-articular wedge-shaped osteotomy (T820-829).***

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4.12.1.3 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*** [65].

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Neither of the above principles affects the metatarso-sesamoidal joint.

4.12.1.4 Metatarso-Phalangeo-Sesamoidal Fusion

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


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and ***involvement of the metatarso-sesamoidal joint***,

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a ***fusion*** is indicated.


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The first phalanx should be ***oriented horizontally*** [66] ***(T837-845)***.

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This is well tolerated in the first ray, allowing for most sports activities including when the correction is performed bilaterally. Functional ***buttress of the tip of the toe***


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


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4.12.2 Lesser Rays

Lesser metatarso-phalangeal joints (2–5) are essential joints which 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 which protect the long flexor tendon. Local overload may be due to discrepancy of anterior heel alignment. Lesion and rupture of the plantar capsule (plantar plate) and its consequences ***(E148)*** ensue. In fact, this is a very frequent pathology which is best treated logically by removing the causal factor which is the axial and sagittal correction of the metatarsus on the extra-articular level ***(T808)***. The general aim remains always the equilibrated weight-bearing pattern of the forefoot ***(A9)***. Motion between the metatarsus and the first phalanx is essential for a smooth gait. Repeated intra-articular surgery, especially of the bone and articular joint may lead to limited mobility, ankylosis and painful degeneration with osteophytes.

4.12.2.1 Subcapital Extension Osteotomy

Metatarsus 2 or 3 ***cephalic osteonecrosis*** (Morbus Köhler-Freiberg [67,68])


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is best approached by an extending re-orienting osteotomy. In fact, the local anatomical 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 (T830-836)***.

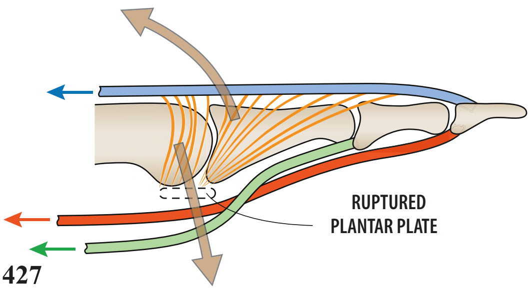

426

Such a procedure brings the basis of the first phalanx to face an intact cartilaginous layer on the metatarsal side [69].

4.13 Functional Reorientations of the Toes

4.13.1 The 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 ***(E71-72)***. 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 ***(E25)*** [8]. Weight-bearing leaving the toes free causes a passive plantar flexion at the metatarso-phalangeal joints. When the plantar plate of the metatarso-phalangeal joint is torn by chronic overload ***(E148)*** or iatrogenically after plantar fasciotomy or local injections of corticosteroids, this ***mechanism is disturbed.***



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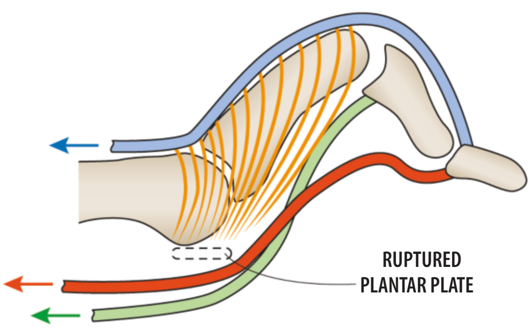
The ***first phalanx is extended and the second phalanx is flexed***.



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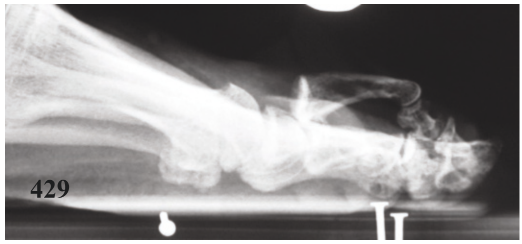
The result is a "hammer toe". At the end of the process, due to the torn plantar plate of the metatarso-phalangeal joint, ***the toe dislocates dorsally***.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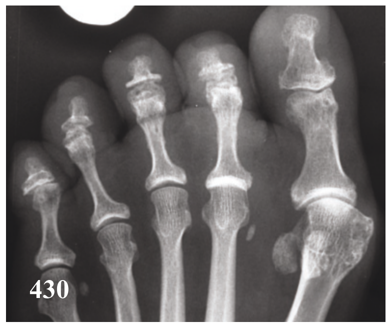
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The aim is thus to restore active metatarso-phalangeal flexion ***to relocate the toe, facing the metatarsal head.***


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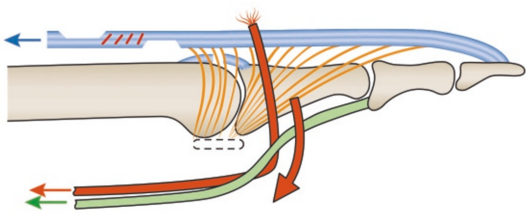
Apart from the reorienting and stabilizing procedures on the metatarsal level ***(O396)(O411)***, reducing the metatarsophalangeal dislocation is indicated. Restoring the axis of the first phalanx by plantar flexion requires an active force pulling the first phalanx plantarwards, such as that provided by a tendon transfer.

4.13.1.1 Tendon Transfer

There are 2 flexor tendons which present sufficient power to reduce the metatarso-phalangeal joints. The short flexor tendon is the weakest but the most accurate muscle-tendon unit to reduce a chronic metatarso-phalangeal dislocation. If the proximal interphalangeal joint is flexed and the distal interphalangeal joint is free and extended, ***transferring the short flexor tendon to the basis of the first phalanx***



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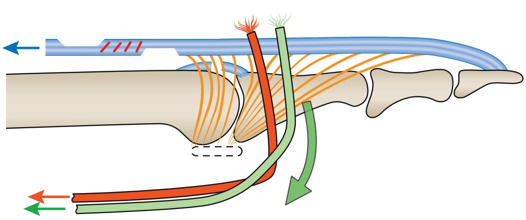
looks to be the most efficient and logical approach [70]. The short flexor is in fact bundled to act synchronically onto the lesser toes. Consequently, the transfer should be performed on all corresponding toes.

In severe cases, with chronic dislocations of more than one joint and where there is a rigid flexion of the distal interphalangeal joint and a verified absence of hyperextension, additional ***transferring of the long flexor*** tendon onto the first phalanx



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may be justified [15]. The muscle power is higher and thus the reduction of the metatarso-phalangeal joint is safer with limitations.

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

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does not correct with passive extension of the hind-foot which tensions 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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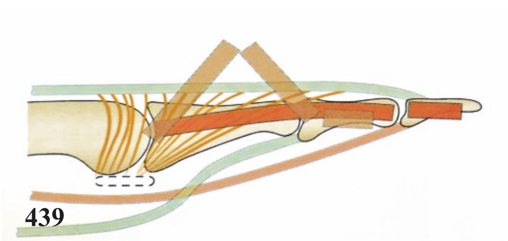
This correction must then be performed on all toes ***(T935-941)*** because of the strong mutual functional interference of the flexors between the toes. In cases where passive extension of the distal interphalangeal joint is hyperlax and allows for passive extension of more than 20 degrees, removing the long flexor tendon from the end phalanx may result in painful hypercorrection of the hammer toe and absent buttress of the tip of the toe. This complication produces a swan-neck deformity of the toe ***(E83-84).***

4.13.1.2 Proximal Interphalangeal Fusion

In cases of hyperlax toes, a ***fusion of the proximal interphalangeal joint (T856-863)***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allows for the essential flexion power to be left to the hypermobile distal interphalangeal joint. ***Stabilizing the toe in the correct axis***

440

avoids secondary imbalance and the aforementioned swan-neck deformity.

The functional aim is a relevant buttress of the ***tip of the toes pressing against the floor within an adequate angle.***


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This procedure alone, however, does not allow the reduction of a dislocated metatarsophalangeal joint.

If the ***metatarso-phalangeal joint is dislocated and the proximal interphalangeal joint is ankylosed in flexion,***


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both ***proximal interphalangeal joint reorienting fusion and long flexor tendon transfer to the first phalanx*** restore good function with a corrected morphology. This is particularly the case in revisions after previous surgical attempts for correction and chaotic malorientations of the toes.


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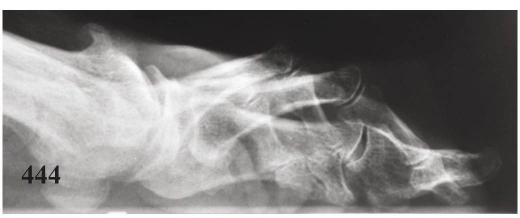
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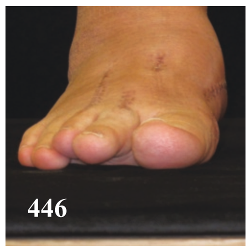
4.13.1.3 Skin Plasty

In order to achieve a functional push-off, the toes must touch the ground at their pulp and the angle of the toe in the weight-bearing foot is relevant ***(E71).*** 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 metatarso-phalangeal joint undergoes relative shortening, pulling the toes in extension. If systematic stretching of the joints in plantar flexion is not sufficient, lengthening plasty (e.g. ***Z- or V-Y plasty***) of the dorsal skin corrects the position of the toes ***(T589-595)***.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4.13.1.4 Distal Interphalangeal Reorientation of the Lesser Rays

The pulp 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. A localized hyperflexion of a toe which appears in children is mostly linked to a ***shortening of the corresponding long flexor of the toe***.


448

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


449

is also indicated.

In cases of painful degeneration of the joint and, particularly, hyperlax distal interphalangeal joints, the buttress is transferred proximally causing pain and discomfort. In the case of a (often unrecognized) compartment syndrome of the foot, retraction of the long flexor of the toes causes a flexion contracture of the distal interphalangeal joints which may become rigid. Ectopic calluses are testimony to such conditions. Reorientation of the pulp of the toe is best performed through a ***fusion*** in the correct position ***of the distal interphalangeal joint (T864-865)***.


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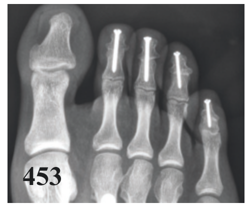
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4.13.2 The Horizontal Plane

4.13.2.1 Osteotomy of the First Phalanx of the Big Toe

In what is 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 a painful chronic conflict with the second toe including ulcers or soft corns and impede function of the long flexor tendon. Alignment through a ***diaphyseal adduction osteotomy*** corrects impingement and function ***(T851).***


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4.13.2.2 Tendon Transfer

Surgical release of the metatarso-sesamoido-phalangeal joint including tenotomy of the m.adductor hallucis may cause a secondary imbalance of the toe in varus ***(E70)***. 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 (T934)***.

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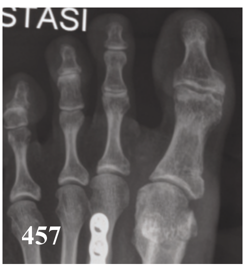
A complete ***medial arthrolysis*** of the joint must accompany this procedure.



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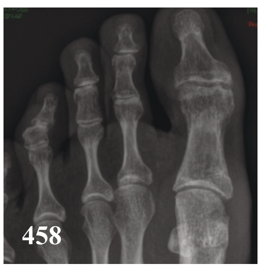

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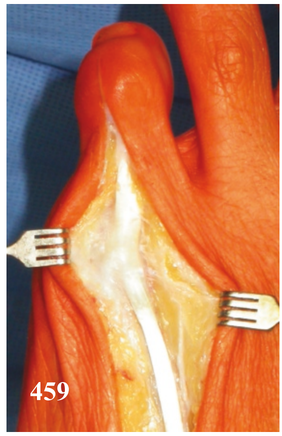
Supination of the last toe may result in very painful conditions while bearing weight ***(E67)***. Active pronation can be found using the power of the corresponding extensor muscle. Even though the short extensor does not exist, harvesting the distal limb of the ***extensor digitorum longus tendon***



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and connecting it to the abductor digiti minimi [71] do not result in functional insufficiency ***(T942-946)***.

4.13.2.3 Axial Correction

Discrepancy of the lengths of the toes and the metatarsi may occur together and cause an ***imbalance of the forefoot during push-off*** **(*E62-63*)** when the metatarsus is vertical.

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The aim is then to restore a ***morphological harmony of the levers*** of the toe pulps.

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

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Precise shortening ***osteotomies of both the metatarsi (T803) and the basic phalanges (T853)*** may resolve this problem.

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465

Check for updates

Surgical Treatment of Traumatic Lesions

Contents

K. Klaue, *The Foot*, https://doi.org/10.1007/978-3-662-64001-2_5

5.1 Healing of Traumatized Biological Tissues

In foot and ankle surgery, soft tissue is relatively thin and requires particular care. Attention should be focused on the direct approach to the underlying structures to be treated. Undermining the thin soft tissue and using steady retractors harm the perfusion and jeopardize healing. Multiple incisions to the skin are not a problem per se. On the other hand, periosteo-fascio-cutaneous flaps can be created if the rule of thumb relating to centrifugal distribution of the vascular supply around joints is respected. This may help a lot when choosing approaches, especially in trauma.

Strain, or relative motion between fractured or ruptured biological tissues in general, limits healing of all living tissues [72] which react differently with regards to each other.

5.1.1 Bone

Direct bone healing only occurs if interfragmentary strain (or relative motion) is less than 2%. In mechanical conditions which include higher strain values, ***indirect bone healing*** occurs: bone resorbs at the extremities of the bone fragments (e.g. fracture site) [73]. The increased distance between the fragments while the 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 those natural means, non-union and pseudarthrosis ensue. This may be the case in single, simple fractures: strain due to relative motion between two single fragments concentrates in a single spot. If the environment of the bone extremities is non-vital or necrotic, natural stabilization cannot occur and the non-union remains atrophic. The same principle applies in arthrodesis. Fusing a single joint when a neighbour joint has been fused previously may be indicated about the foot and ankle. This condition renders the desired treatment more difficult due to the concentration of strain and should alert the surgeon to the need to optimize the biomechanical environment of the arthrodesis to avoid the dreaded non-union.

5.1.2 Cartilage

Cartilage does not heal if the tissue layers are submitted to a strain higher than 10%.

5.1.3 Granulation Tissue

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 during a relevant period of time [74] ("fracture disease"). Mobilization of joints soon after fractures forms the basis of internal fixation of fractures and continuous passive motion (CPM) [75] considerably reduces this invalidating condition. In the particular 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 which can be addressed to **reduce strain of the soft tissues by immobilization**. Optimal immobilization seems to be achieved by the ***Jones' dressing cast*** [25,76]. The idea is to keep the surgical situs within a sterile environment together with a minimal relative motion of the skin and subcutaneous tissues. The quality of the rigid "shell" that is applied onto a compressed soft and sterile padding is probably very relevant. Plaster of Paris fulfils the requirements thanks to its moulding properties.

The principle of the original dressing popularized by Sir Robert Jones is completed by the resilient stability provided by the plaster without harm to the soft tissues.


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The multiple incisions about the foot and ankle are covered by moist, gel medicated gauze pads 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 [38]. The first look at the operative wounds in programmed cases thus occurs after 2 weeks ***(T637)***.

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


468

which allows for partial or full weight-bearing by ***reducing the mechanical lever*** on the foot by a convex sole. Walking 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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Air-proof coverage such as polyethylene folders should be avoided all times because of the immediate creation of wet chambers.

5.2 Tendon Ruptures

5.2.1 Achilles Tendon Rupture

Ruptures of the Achilles tendon rarely occur within a full and healthy tendinous structure. There is often a vascularity problem involved or chronic tendinitis. A healthy, young heel cord holds in at least 1500 Newtons in a static mode. In dynamic load (e.g. running), the stress supported by the tendon can reach up to 8000 Newtons. Physiological data support that full weight-bearing of the lower limb and walking does not imply evident muscular activity of the gastrocnemius musculature. The scope of the treatment is thus the firm anatomical adaptation of the separated limbs of the tendon and firm hold of the upper ankle joint using a cam walker. Such treatment allows for full weight-bearing during the phase of consolidation. Secondary lengthening of the tendon after suture does not depend on a post-operative weight-bearing regimen [77].

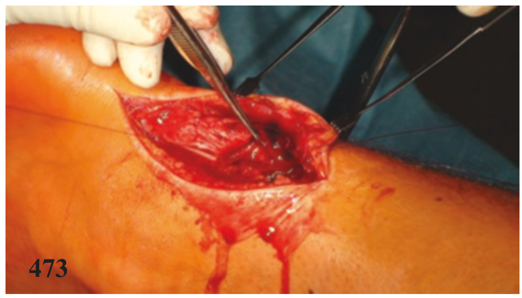
The Achilles tendon is covered by very thin subcutaneous and skin layers. This region makes it very vulnerable to perfusion of the local soft tissues. Local skin microvascularity seems to follow a "horizontal" pattern between a strong medial (posterior tibial artery) and a lateral (peroneal artery) along the axis of the hindfoot [78]. The patient is placed prone with both legs lying on a transverse roll to have both feet hanging free. The tourniquet is placed on the thigh. Directly beneath the subcutaneous tissue, ***the peritenon is evaluated. No static distraction is applied to the skin.***

471

It is safe to incise the skin along the long axis of the heel cord taking care not to touch the posterior crest of the underlying tendon which is poorly supplied by the arterial network. ***Skin incision is therefore positioned about 1.5 to 2 cm medial from the posterior crest.***

472

This approach allows the surgeon to keep away from any problem involving the sural nerve which might be endangered using a blind, percutaneous technique. At this point, the tendon ends are brought close together achieving at least a slight equinus of the foot that can be seen on the contralateral side ***(E88)***. This corresponds to the elastic recoil of the triceps surae which is always present under physiological conditions. Closing this suture should allow for positioning the foot in a plantigrade position with a slightly superior force as needed on the contralateral foot. A few reinforcing sutures complete the mechanical fixation. At this stage, knowing the essential nature of the peritenon to the regeneration of tendinous tissue [79], ***the peritenon is adapted above the tendon using a fine continuous suture thus closing the tendinous compartment***.



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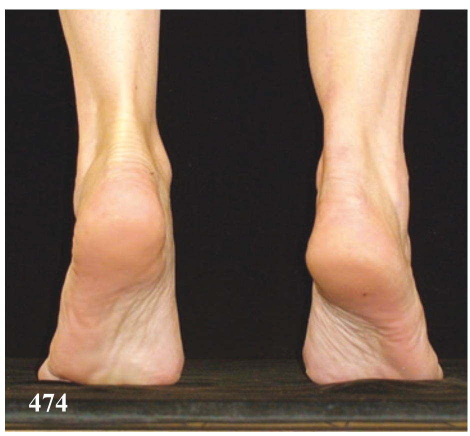
Tension of the tendon after suturing determines the rehabilitation capacity of the triceps surae. Stability of the montage is checked by holding the foot manually in orthogonal position. Final fixation will be using a closed lying cast in orthogonal position of the foot for 2 weeks.

Careful soft tissue handling allows for rapid rehabilitation and muscular power should come ***close to normal at 3 months.***



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5.2.2 Anterior Tibial Tendon Rupture

Ruptures of this 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 (E116)***.


475

Due to the "missing structure" after such necrosis, and also to secondary retraction in those cases that do not seek immediate orthopaedic 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 anatomical insertion site of the anterior tibial tendon. In order 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.

5.2.3 Posterior Tibial Tendon Rupture

Although uncommon, and particularly underdiagnosed, the traumatic posterior tibial tendon rupture occurs mainly in active, middle-aged patients. Rupture occurs at plantar reception from a fall from a relevant height. The foot gets stressed in forced abduction, pronation and extension. Such as in many traumatic ruptures of the heel cord, there is probably no clearly definable degenerative aspect of the tendon prior to trauma. The consequence to this often-unrecognized pathological entity is a rapid alteration of the normal alignment of the foot, along with pain and joint degeneration.

5.3 Fractures

A fracture is a traumatic solution of continuity of the bone. As such, the anatomical restoration of the bone is clearly the optimal treatment. As a biological structure, the fractured bone causes immediate discharge of blood which accumulates as haematomas within generally confined spaces. Within the foot, there are a number of relatively small compartments which are separated by strong fibrous tissues. Those compartments contain muscles (intrinsic) and nervous structures which are very sensitive to hydraulic pressure and a fresh haematoma due to, e.g. a displaced fracture is likely to produce a local compartment syndrome with deleterious consequences [31, 80]. It is probable, though, that severe fracture-dislocations rupture most of the relevant intercompartmental walls and produce swellings which may jeopardize the vitality of the skin. In both cases, the hemodynamic, "hydraulic" period lasts up to 6 hours and surgical removal of the haematoma should be considered, if possible, together with the definitive bone and joint repair. Not to operate a malleolar fracture because of the swelling is unjustified if it is possible to start surgery within the first 6 hours after the trauma. After this period, the metabolic action of tissue oedema may put the soft tissues at risk when involving open surgical approaches because the swelling is intracellular and cannot be removed by open surgery.

Fractures about the foot most often involve joint surfaces. When evaluating those fractures and elaborating a plan of treatment, it is mandatory to know if those joints are essential or not for function. Essential joints should be reconstructed anatomically while non-essential 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, the shape and dimensions of the bone are essential to restore after trauma.

Fracture treatment by means of reduction and fixation in the foot and ankle is thus mainly a matter of surgical approaches (cf next chapter), chronology (strategy) and rational tips and tricks.

5.3.1 Ankle Fractures

Malleolar and pilon fractures may safely be fixed by using one to three simultaneous open surgical approaches [81].

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


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The *tibio-talar 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 [81] and thus allows visualizing and correct reduction of the crucial ***anterior arch of the medial malleolus***.


477

The posteromedial approach of the distal tibia, between the neurovascular bundle and the flexor hallucis longus allows visualizing and reduction of fractures of the posterior rim of the tibia ***(T611)(T667).***

5.3.1.1 Malleolar Fractures

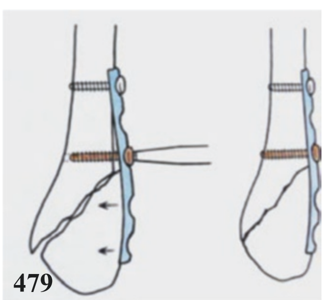
The malleolar fracture is a lesion of the stabilizing part of the ankle joint. Due to the strong mechanical interaction between bone and ligaments, it may be important to interpret conventional radiographs to understand the comprehensive osteo-articular lesion which includes bone fractures and torn ligaments. As mentioned above, (p.33) the medial malleolus is the main and steady pillar of the ankle joint. The lateral malleolus plays the role of semi-mobile guide of the talus which might yield in traumatic external rotation.

If the external rotation trauma occurs in a plantar-flexed upper ankle joint, the narrow part of the talus is located between both malleoli and the talus and exerts a strong sheer onto the tip of the fibula. The fibula thus yields with an oblique fracture ***starting below the anterior tibio-fibular ligament and ending posteriorly about 1–2 cm above the joint***.


478

In most of the lateral malleolar fractures, the distal fragment goes posteriorly, together with the usual shortening of the bone along the oblique course of the fracture.

Reduction goes through the opposite way to the fracturing, by sliding the distal fibula along the oblique fracture site. The fixation means aim at avoiding recurrent dislocation. Plates may function as fixing devices ***acting like springs***: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their wide application surface reduces the pressure on fragile bone which has to be reduced. The postero-lateral 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 pressing safely the more fragile distal malleolus ***in the desired antero-medial direction*** [82].


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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 completely out of the malleolar mortise. The first aim is thus ***to reduce the dislocated joint***

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and to fix the medial malleolus anatomically. The approach is ***antero-medial***, parallel to the saphenous vein ***(F477)***.

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


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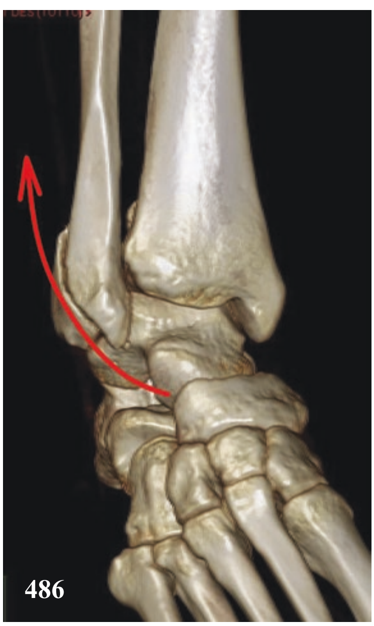
using screws, wires and/or pins, the fibula is then reduced and fixed through a postero-lateral approach ***(T613)***.

Fracture-dislocations of the upper ankle joint may include a partial or full lesion of the deltoid ligament without fracture of the medial malleolus.

This may be the case if the external rotation trauma is more violent, pushing the talus posteriorly, hinging more or less on the medial ligamentous structures. The talus thus pushes against the posterior aspect of the tibial plafond which yields under a load on a level which depends on ***the axis of the applied force within the sagittal plane.*** This axis correlates logically with the inclination of the shear fracture of the fibula.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Interestingly enough, the anterior, intermediate and posterior tibio-fibular ligament (syndesmosis) ***(O255-256)*** may remain intact together with the anterior fibula-talar ligament. The foot moves with both fibular and tibial fragments as single unit in external rotation.

The deltoid 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 anatomical sites. Accidental interposition of ligamentous structures within the joint must be looked for and removed. Healing occurs through scarring in an uninterrupted orthogonal position of the hindfoot. Useful ***suturing of the deltoid ligament is illusory***.


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5.3.1.2 Rupture of the Distal Tibio-Fibular Syndesmosis

If the forced external rotation applied on the foot occurs in a “locked” ankle position, in which the wide part of the talar dome lies between both malleoli (dorsal extension of the joint), ***the anterior tibio-fibular ligament (syndesmosis) is torn, most often through an avulsion on the fibular side*** [83].


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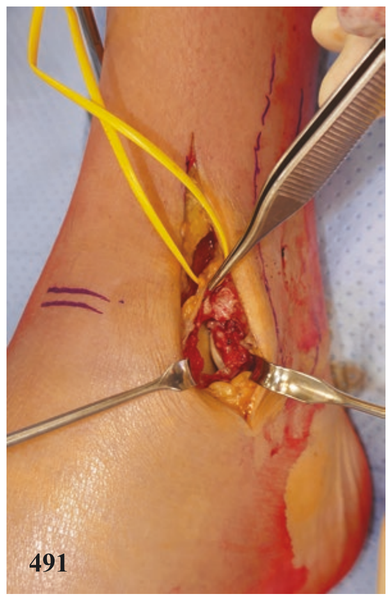
This can occur with or without a fracture of the distal fibula. The lesion which is linked to the tibio-fibular syndesmosis may run proximally through the interosseous membrane, dissociating the fibula from the tibia. This lesion ends with a fracture on the proximal aspect of the fibula.

Logically, such a fracture can be located on any level above the upper ankle joint. The rotation and length of the fibula is best performed through open reduction and internal fixation of the fracture. In selected cases though, including fractures located at the proximal epiphysis of the fibula, the best option to avoid jeopardizing the fibular nerve is to concentrate surgical care to the lateral aspect of the upper ankle joint. Anatomical reduction of the distal fibula onto the lateral aspect of the distal tibia and lateral talus is best controlled by direct visualization. At this location, ***the superficial fibular nerve crosses the field and is best protected by a loop***.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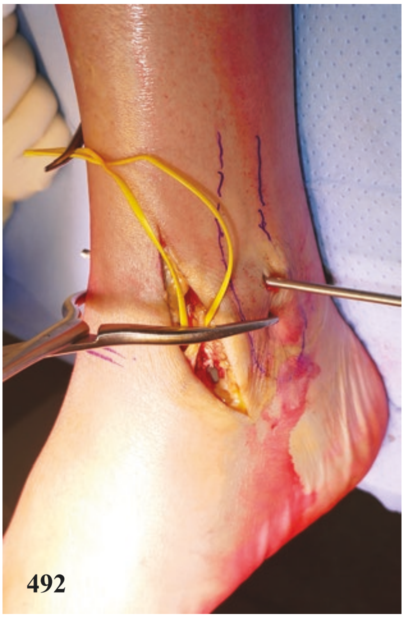
In any case, the lateral malleolus must be secured back to its buttressing position of the lateral talus.

An efficient procedure is to compress the distal fibula against the tibia horizontally at the level of the syndesmosis using ***forceps (T588) between the tibia and the fibula***



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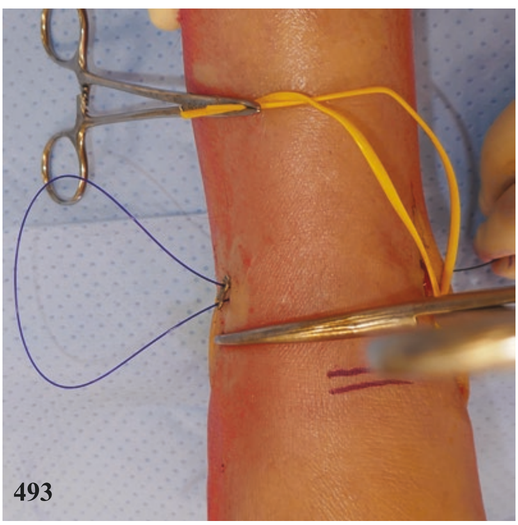
at the level of the syndesmosis. Optimal fixation of the syndesmosis takes into consideration the relative physiological mobility between tibia and fibula. A trans-syndesmotic strong suture is ***inserted as a loop***



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which holds the medial cortex of the tibia and the lateral cortex of the fibula, pulling down the distal fibula within its tibial gutter.

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5.3.1.3 Pilon Fractures

The 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 anatomical restoration of the peripheral edge and border of the joint surface. The lateral pillar of the tibia by means of the antero-lateral corner of the joint which carries the tubercle of Chaput is one of the critical locations. The ankle is poorly covered by soft tissue and therefore surgical approaches are essential to avoid eventual necroses. In general, up to three approaches can be used simultaneously to safely fix a pilon fracture [81]. A ***longitudinal incision centred on Chaput's tubercle***


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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 ***(T605)***. This artery perforates the interosseus membrane at about 2 cm above the anterior syndesmosis and ***runs antero-laterally to join the sinus tarsi vessels***.


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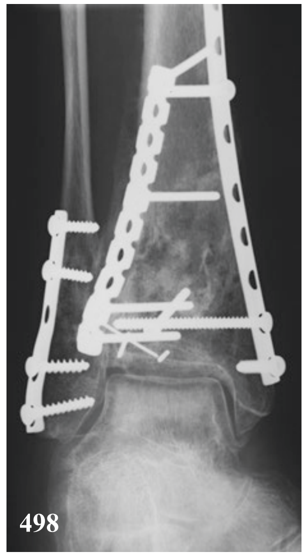
Buttressing the antero-lateral pillar of the tibia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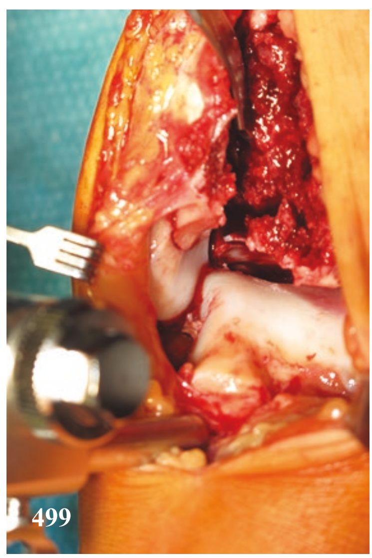
by a more proximally anchored plate avoids secondary impaction of the joint surface. Such impaction causes a peripheral joint incongruency which destabilizes the joint and leads to post-traumatic arthrosis.

In pilon fractures, of which there are several, particularly centrally dislocated fragments, steady intra-operative joint distraction by a ***"distractor"*** locked ***in the tibia and the talus*** allows for instrumental space to reduce the fragments of the joint surface ***(T655)***. This is particularly useful laterally, for antero-lateral impaction of the Chaput's tubercle or medially, ***at the anterior aspect of the medial malleolus.***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A second rationale vision of the pilon tibial is performed through a ***postero-medial approach (T608-611)***.

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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. This pathway allows for saving the arterial supply of the talus. The flexor hallucis longus muscle can be retracted laterally from the approach to the bone. In complex intra-articular fractures, which completely separate the joint surface from the proximal tibia, the posterior direct visualization and anatomical reduction of the posterior articular edge of the tibia shall be the first step to the reconstruction of the joint.

As a second step, still under joint distraction, alignment of the anterior part of the articular fragments from the anterior aspect of the joint is eased considerably.

The fractured fibula is approached through a third and separate incision which runs preferentially ***posterior to the lateral crest of the fibula***

501

to avoid painful scarring ***(T613)***.

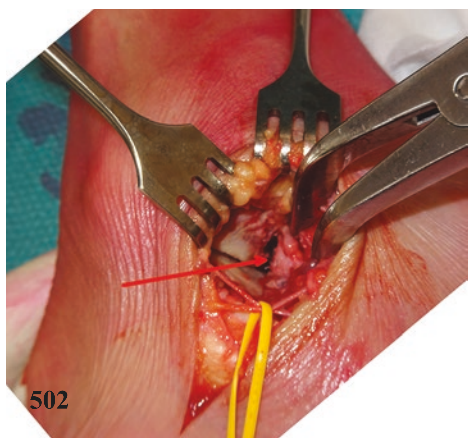
5.3.2 Fractures of the Talus

The talus acts as the intermediate link of a cardan joint. The two corresponding joints are the upper ankle joint and the talo-calcaneo-navicular joint or lower ankle joint. This unique position within the human lower leg means the bone is covered by about 80% cartilage of four major joint surfaces. It is thus clear that the integrity of the cartilage layers, their position and their orientation is of major importance for stable function of the foot. Reconstruction of fractures of this bone ideally requires the direct vision of the involved joint.

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

5.3.2.1 Peripheral Fractures

In peripheral fractures, there is a joint problem due to an external force such as a dislocation or quasi-dislocation in one of the four joints which link the talus to the upper ankle joint, the calcaneus and the navicular bone. The centre of the talus remains intact while the fracture causes a joint incongruence which impedes smooth articular function. Untreated, those fractures lead to joint stiffness and arthrosis. The most common peripheral fracture of the talus is the fracture of the lateral process, commonly called "***snowboarder's fracture***" ***(E110)*** which occurs at a forced pronation about the talo-calcaneo-cuboidal joint (coxa pedis) (right foot).



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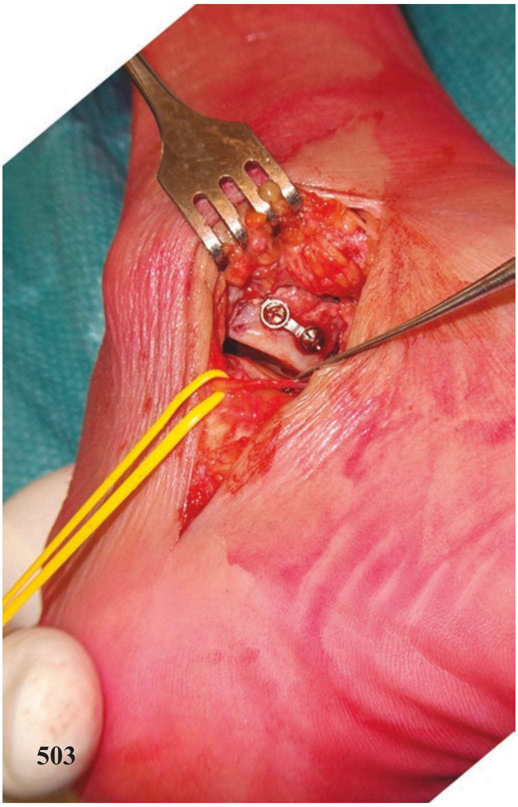
Evaluation of this lesion is not easy because there are two options for re-establishing smooth and pain-free articular function: anatomic reduction and stable internal fixation or debridement and resection of occasional small fragments. The first option is taken when the fracture produces a large and monolithic fragment, easy to handle for ***fixation***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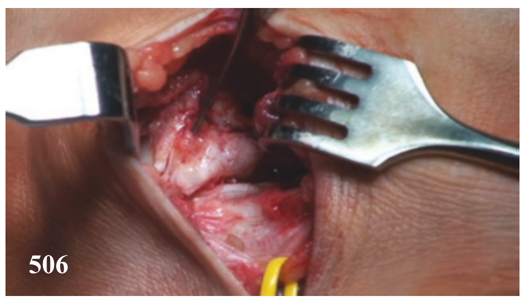
The second option is taken when the fracture produces multiple fragments where the articular portion cannot be recognized and, furthermore, is not re-fixable.


505

The fracture is ***directly inspected*** (right foot)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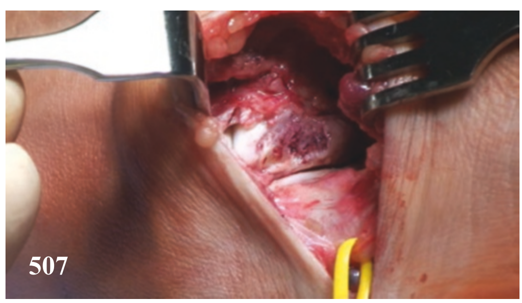
and ***judged to be resected***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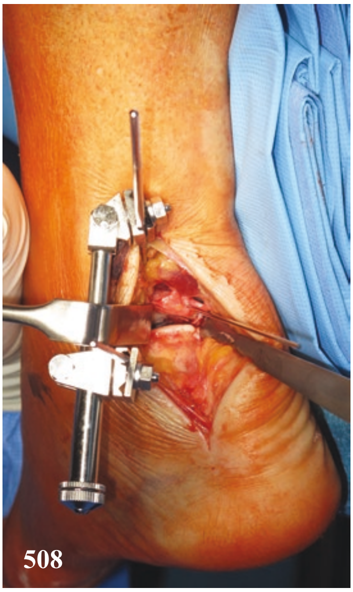
thus leading to excellent functional and pain-free results.

Natural healing of a fragmented lateral process of the talus may lead to painful impingement ***(E110)(O244)*** about the crucial angle of Gissane and secondary arthrosis of the subtalar joint.

A similar condition may occur in maximal flexion of the upper ankle joint. Abutment of the posterior process of the talus may produce its fracture. Here too, ***either removal or refixation*** of the fragment is indicated ***(O215-216)***.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5.3.2.2 Central Fractures

Central fractures including neck fractures of the talus occur particularly in a locked, plantigrade hindfoot. Those fractures can be produced "in vitro" by applying violent stress along the lower leg axis [84,85]. Forced hyperextension of the foot is known to produce fractures of the tibia, in particular, malleolar and pilon fractures without harming the talus [86].

In ***central fractures,***


509

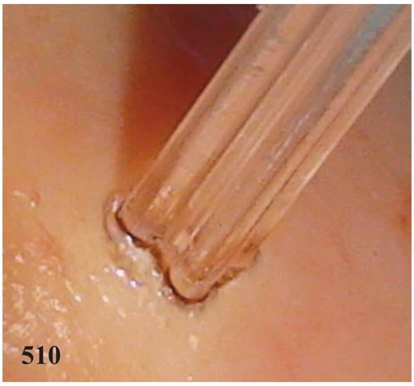
the general shape and external dimension of the foot is jeopardized. This fracture separates the upper ankle joint from one or both other joints. Under this aspect, the fracture type can be compared to the so-called "two-column fractures" of the acetabulum or to the more complex distal articular fractures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

Untreated, those fractures lead to misalignment of the whole foot with consecutive dysfunction and disability.

5.3.2.3 Approaches

Both peripheral and central lesions can, of course, run together.

Peripheral fractures may be approached directly through one single approach, wherever they occur, and the complexity of the talar joints is such that the fracture fragments in selected cases may be better removed rather than reduced and fixed. The function of the local joint needs to be assessed case by case to achieve a rationally sound treatment, taking into account the eventual risk of post-traumatic bony impingements. Some fractures involve essential aspects of the bone and due to their small dimensions, fixation means may include fibrin glue and/or ***rotational stable (bone guiding) resorbable pins***.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Central fractures of the talus


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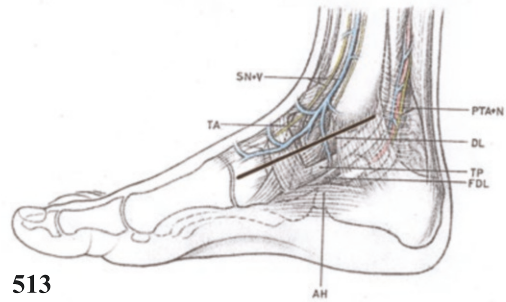
should be reduced and fixed from at least two (sometimes three) approaches ***(T614)(T622)*** because both joints, above and below the talus, are involved and the medial and lateral side must be checked for reduction. Involving the shape of the whole bone which guides four major joints about the hindfoot, 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** ***(T615)*** from the tibialis posterior tendon insertion passing above the sustentaculum tali, **the antero-lateral oblique approach** ***(T620)*** (modified Ducroquet approach [87]) and the **postero-lateral vertical approach** ***(T600)***, parallel to the heel cord [88]. All three approaches can be performed simultaneously in a normal vascular environment.

Medial Approach

The ***medial approach***



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is meant to visualize the subtalar joint congruency between the talar head, the navicular and the sustentaculum tali as well as the continuity of the medial wall of the talus. In selected 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 downwards and towards posterior allows an improvement in the visualization of the fracture while keeping the postero-medial blood supply, which comes from the posterior tibial artery, protected. A ***distracting device fixed between the tibia and the calcaneus***


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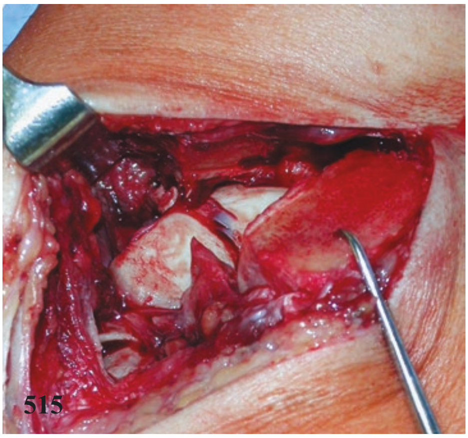
allows for simultaneous ***visual control of the medial tibio-talar and subtalar joint surfaces***.



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Antero-Lateral Approach

The ***antero-lateral approach (T620)***

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is used to visualize the lateral subtalar joint and the bony wall between neck and processus lateralis tali [87].

This approach is optimal for visualizing the ***processus lateralis tali, and includes eventual static distraction between the lateral aspect of the talar neck and the tuber calcanei.***

517

The entire 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, it covers well the bony situs and 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.

Postero-Lateral Approach

The postero-lateral approach ***(T600)*** is performed in one precise, single plane, running parallel to the heel cord and medial to the nervus suralis [44,88]. This approach naturally gives the ***optimal axis for screws fixing talus neck fractures***.

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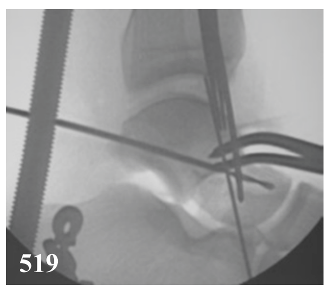

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The distal belly of the musculus flexor hallucis longus is kept medially, protecting the neuro-vascular bundle. The entire posterior articular aspect of the subtalar joint is visualized, together with the posterior aspect of the upper ankle joint.

5.3.3 Calcaneus Fractures

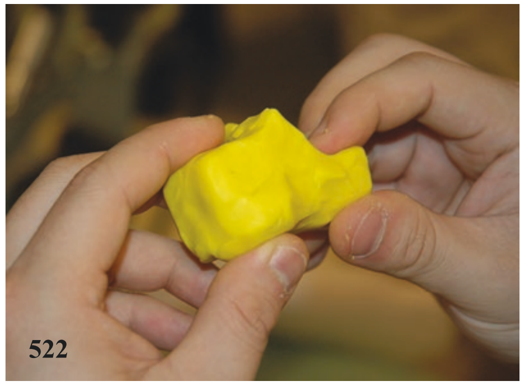
Calcaneus fractures follow a similar fate to the central talus fractures. A particular aspect of calcaneus fractures is the high risk of bleeding within the deep compartment of the foot, increasing the intra-compartmental hydraulic pressure and compartment ***syndrome*** [31]. This occurs more often in simple, but dislocated fractures where the inter-compartmental walls are intact. Thus, the diagnosis must be done at once to avoid the irreversible consequences. The latter include shortening of the quadratus plantae muscle and the shortening of the flexors of the toes. In the long run, the forefoot presents ***multiple distal hammer toes***.


520


521

Avoiding compartment syndrome of the foot necessitates, after recognition of pathological intra-compartmental pressure, the urgent release of the inter-compartmental walls (septae or aponeuroses) [80].

Reduction and internal fixation are indicated for all fractures which include intra-articular courses. Even non-displaced intra-articular fractures of the calcaneus are known to show a high likelihood of secondary displacement which can 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. For this reason, learning and teaching open reduction and internal fixation of calcaneus and talus fractures may be made easier by using soft malleable materials (plastiline) [89].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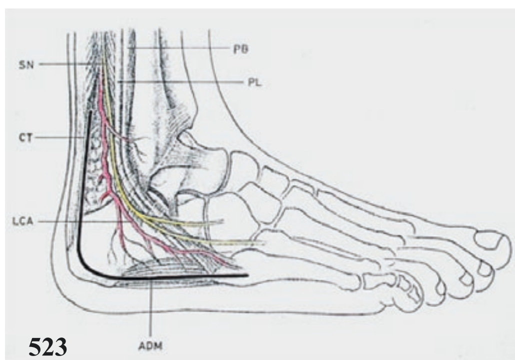
The aim is thus to restore the shape and orientation of the whole bone. A vascular-safe approach [33] is made ***respecting the vascularity of the lateral submalleolar aspect of the foot***.



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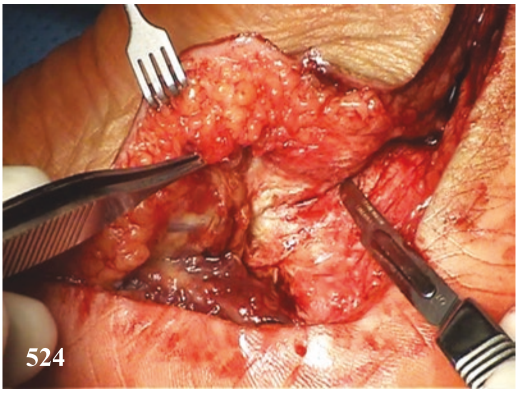
The vascularity of the soft tissue about the hindfoot is "centrifugal". By centrifugal vascularity, we mean a main source of blood supply from the deep layers at the centre of a joint and vascularity which spreads out centrifugally from this centre. The main weight-bearing function of the calcaneus occurs 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 postero-lateral aspect of the foot like a soft tissue flap. The ***postero-lateral periosteo-fascio-cutaneous flap*** [90]



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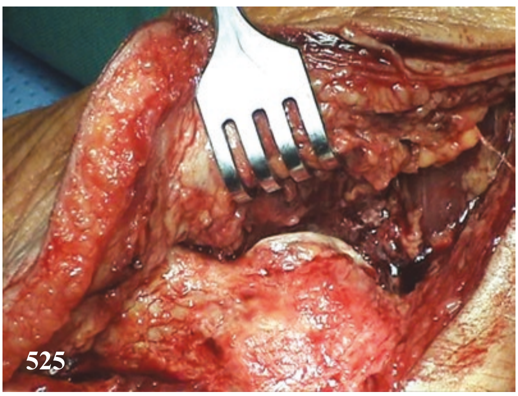
is reclined upwards allowing for visualization of ***the subtalar***



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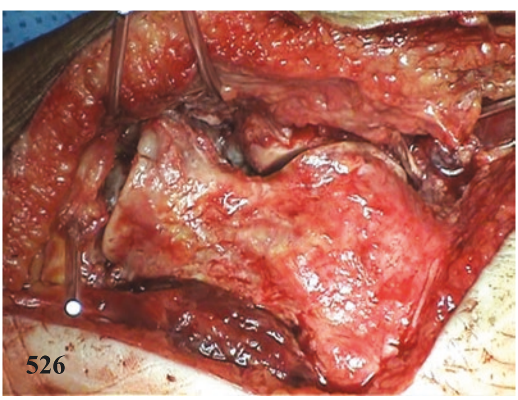
and **calcaneo-cuboidal joints** [91].



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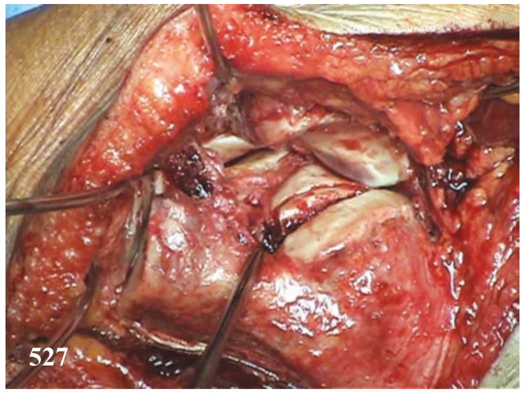
The medial aspect of the subtalar joint (***sustentaculum tali***) may also be visualized and checked with this approach.



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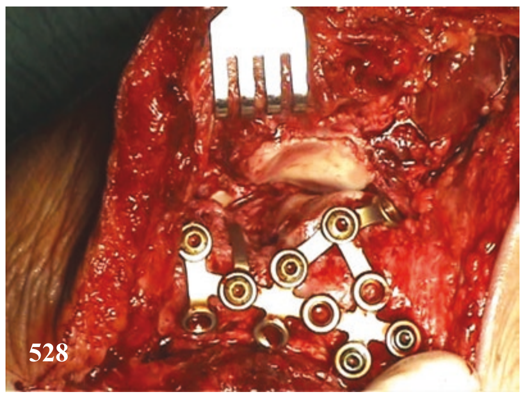
Congruency of the articular surfaces after fixation of the fragments is perfectly visualized



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and the approach is safe for ***rapid consolidation of the soft tissues.***

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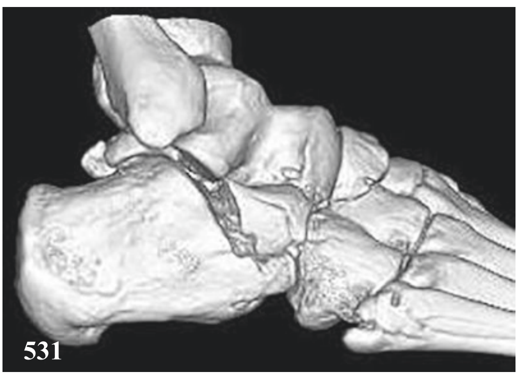
Such anatomical reconstruction allows for a good, ***long-lasting result (11 years follow-up).***


530

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 antero-lateral approach of the hindfoot [87]. Those fractures occur through the yield of the midtarsal joints. The navicular bone dislocates towards medial together with the cuboid and in some cases with a part of the anterior process of the calcaneus (swivel lesion) [92]. So-called ***Chopart fracture-dislocations***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also produce these kinds of lesions. For this reason, those fractures are often linked to a fracture of the talus which is addressed through the same approach.

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

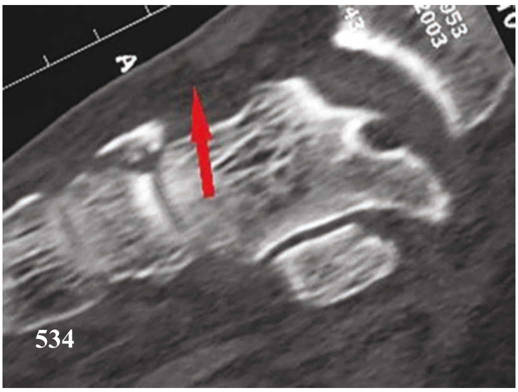

532

These fractures are severe lesions because the sustentaculum tali holds the talus at its physiological height. This fracture also corresponds to a protrusion of the talus within the acetabulum pedis by breaking its posterior wall. A minimal dislocation of this fracture should be reduced and fixed anatomically for proper articular function. The sustentaculum tali, like the medial malleolus of the upper ankle joint, is the fixed reference spot for the whole joint ***(E107).*** The best approach is performed directly on the sustentaculum tali between the tendons of the flexor digitorum longus and the flexor hallucis longus (***E119)***. The local bone offers a good hold ***for screws which cross the whole calcaneus***.


533

5.3.4 Fractures of the Navicular Bone

The acetabular cup of the coxa pedis represents an essential factor for a functional pro/supination of the hindfoot. The anterior wall of the acetabulum pedis ***(E114)*** is represented by the proximal articular facet of the navicular bone. Similar to the acetabulum in which the most frequent fracture is the posterior wall fracture due to posterior subluxation of the femoral head, dorso-lateral subluxation of the talar head causes a ***dorso-lateral fracture of the navicular bone.***



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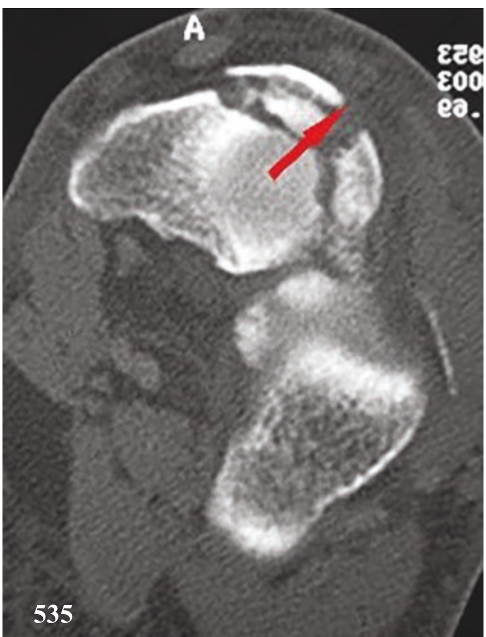

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When compared to the acetabulum coxae and its fractures [93], these lesions must be reduced perfectly, aiming at anatomical reduction of the joint surface. In this case, a ***single antero-lateral approach can be sufficient for the treatment.***

536

In more central fractures, due to protrusion of the coxa pedis, ***both extremities of the navicular bone may diverge.***

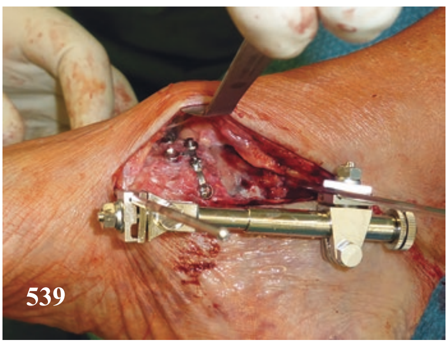
537

Similar to central fractures of the talus, it is logical to approach those fractures from medial and lateral to check for anatomical reduction. This allows for the checking of joint congruency at both extremities of the bone. Insight to the joint surfaces, such as for pilon and talus fractures, is best provided by

static bone distraction between the adjacent bones, the talus and the cuneiforms.

538

The "bipolar" medial and lateral view allows for limiting occasional devascularization of the bone. The plantar aspect of the navicular remains attached to the strong spring ligament or plantar calcaneo-navicular ligament. This part may represent the reference fragment in multifragmented fractures [94]. Multifragmentary fractures may thus be secured for functional after-treatment with the ***help of a dorsal plate***



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and occasional locking ***screws to be fixed to the plantar reference fragment***.

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The naviculo-cuneiform joint facets can be considered non-essential joints and may help in finding a reference grip to the occasional screw fixations which cross those joints.

The aforementioned "Chopart fracture-dislocations" ***(F531)*** involve the "crossroads" of the hindfoot by means of the space between talus, calcaneus, navicular and cuboid. The ***combination of navicular and talus fractures***

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belong to those lesions and should not be missed. Any suspicion of traumatic lesions in this region should be followed up by a detailed CT examination.

5.3.5 Tarso-Metatarsal Fractures

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

The freshly traumatized foot should first be evaluated clinically though the severity of fractures and eventual dislocations about the tarsometatarsal joints are ***not always suggestive clinically***.

543

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

544

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

545

546

Assessing the comprehensive lesion is essential to ***set out the strategy*** by means of the chronology of the treatment.

These fractures occur through a strong sprain in plantar flexion and rotation of the foot and are common in motorcycle accidents or in pedestrians who have been knocked down. The likelihood of compartment syndrome [80] should be evaluated in all these cases. In those fracture-dislocations, immediate open reduction allows for recognizing 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 neuro-vascular bundle*** allows for good visualization and handling.


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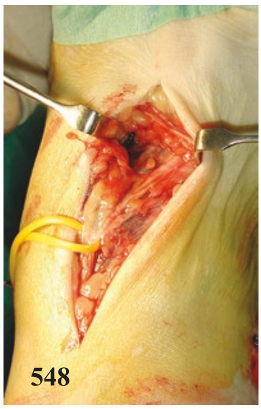
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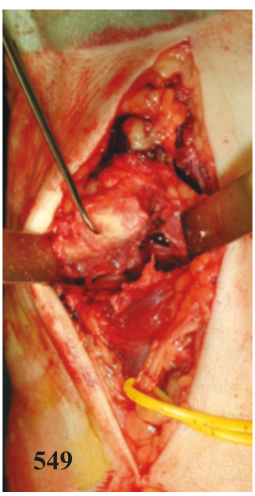
It is essential to recognize ***soft tissue entrapments*** and the reduction of ***locked dislocated fragments.***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Treatment relies on the recognition of the stability of the foot through the central (second and third) rays which can be fused at their respective TMT joints without any relevant loss of function. Temporary alignment with percutaneous wires is followed by ***percutaneous interfragmentary and transarticular fixation by screws***.


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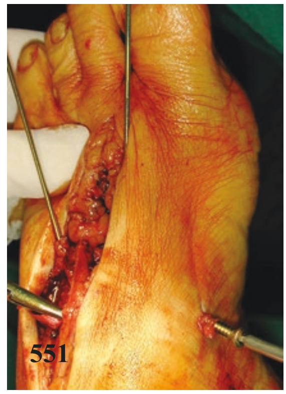
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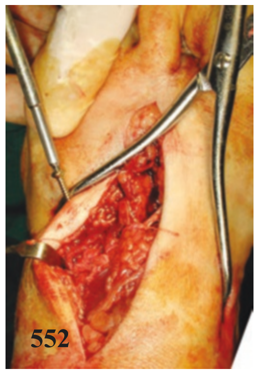
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553

The first ray holds a kind of intermediate position in the need for anatomical joint reconstruction or fusion.

It is also important to remember the ***need for mobility at the lateral (fourth and fifth) rays***


554

which should not be fused in order to achieve good function [95].

Symmetry to the other foot, if asymptomatic, should be respected.

555

556

In **non-evident dislocations**, diagnosis is much more difficult and as a result, is often missed. As an example, a short run on uneven ground in poor visibility and wearing high heels has a high exposure to such trauma.

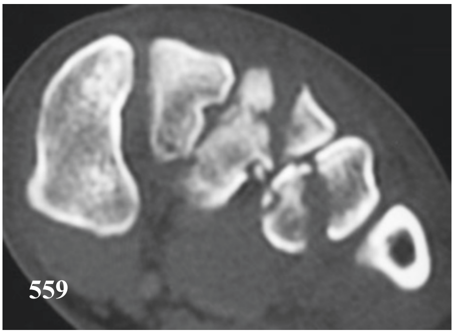
Localization of pain and ***painful examination of the single joints*** raises the suspicion of the lesion.

557

The complexity of the ***juxta-articular tarso-metatarsal fractures***

558

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



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The key lesion, focussing attention to the roof of the forefoot which is the second ray ***(A6)***, the torn or insufficient ***Lisfranc's ligament between the first cuneiform and the second metatarsal***, must be recognized.

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The question which arises most is in which cases should the joint be fused or in which cases should it be reconstructed [96]. The central axis (second tarsometatarsal joint) is the joint which best ***supports an occasional fusion***.

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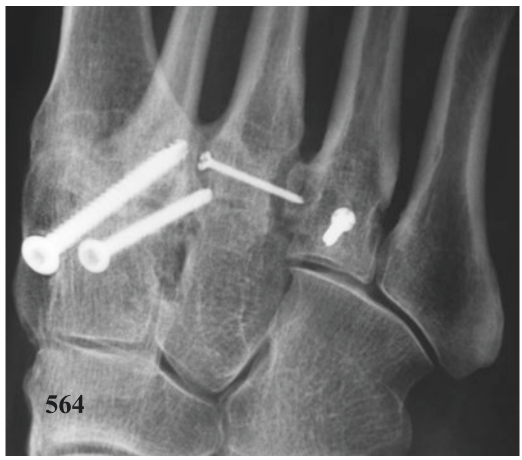

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Lateral TMT (4 and 5) joints do not allow for an occasional fusion after intra-articular fractures ***(A8)***.

5.3.6 Metatarsal Fractures

Diaphyseal fractures of the central metatarsi should be grossly aligned to respect the alignment of the anterior heel [34]. In most cases, a central medullary nailing is sufficient due to the combined stabilizing action of the intrinsic musculature (interossei). The

distal metaphyseal fractures which escape from the stabilizing intermetatarsal ligament

565

must be stabilized precisely to ***avoid*** secondary extension and in particular ***rotational mal- or non-union***

566

and to secure the anatomical parabolic alignment of the metatarsal heads or anterior ***heel and the rotational alignment of the toes.***

567

Fifth metatarsus fractures [97] are quite common. Twisting the foot in supination causes a proximal fifth metatarsus fracture, either within the joint, the proximal metaphysis or the diaphysis. Intra-articular fractures produce a relatively small proximal fragment in relation to the wide insertion surface covered by the fibularis brevis tendon. Those frequent fractures are thus generally stable and allow for immediate weight-bearing and walking within a FAO including a convex sole (cam walker). More seldom, the fracture does not allow for this kind of functional treatment and may not heal.

These cases require open reduction and internal fixation to become asymptomatic.


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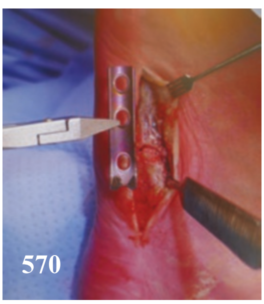
Two months post-trauma the fracture is still not consolidated and is painful. Treatment includes tension band fixation using a ***plate with prongs*** [98, p. 81] ***which are impacted from proximal***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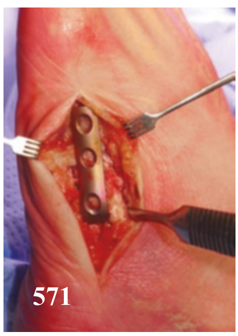
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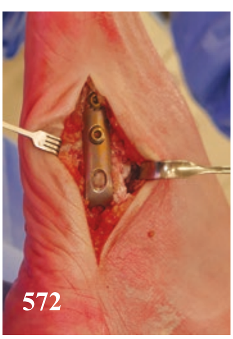
and fixed by ***tensioning the plate onto the bone*** using screws.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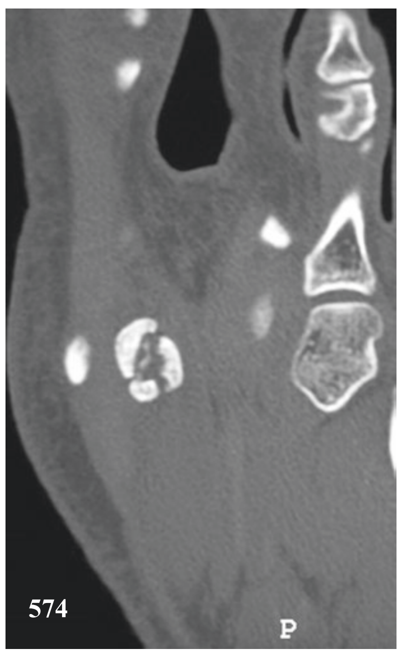
If the fracture dissociates the fifth metatarsus within the proximal metaphysis, the fracture is fundamentally unstable because the proximal fragment is firmly held by the fibularis brevis muscle while the distal fragment is tributary to the fibularis tertius muscle. Stable bone fixation is required to allow for healing [99].

Diaphyseal fractures can consolidate without problems, especially if they are long-shaped and present a low interfragmentary strain. The problem consists of the level and critical position of the fifth metatarsal head after consolidation. It might be too high (extension), too proximal (shortening) or twisted, which positions the corresponding toe in an unfavourable way ***(E54).*** In those cases, operative restoration of normal anatomy seems evident. In cases of non-relevant dislocation, non-operative treatment should include multiple radiological checks of the stability of the fracture.

5.3.7 Fractures of the Sesamoid Bones

Multipartite sesamoids are mostly due to an acute or fatigue fracture ***(E64)***. Assessment is done by CT for ***evaluation of the number, shape and dimension of the fragments as well as the density of bone***.



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An eventual bone graft is indicated [100]. The medial sesamoid fracture is approached from the medial utility line ***(T618)*** and the metatarso-phalangeal arthrotomy. The ***lateral sesamoid is approached from plantar***, the patient lying prone.

575

The articular layer is inspected and the ***quality of the cartilage*** evaluated.

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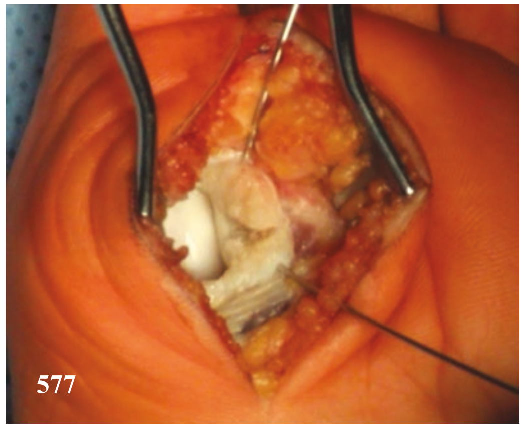
Eventual necrotic bone is extracted after lifting the cartilaginous layer and replaced by cancellous bone harvested at the metatarsal head. Reduction is eased by using ***joysticks*** (K-wires).



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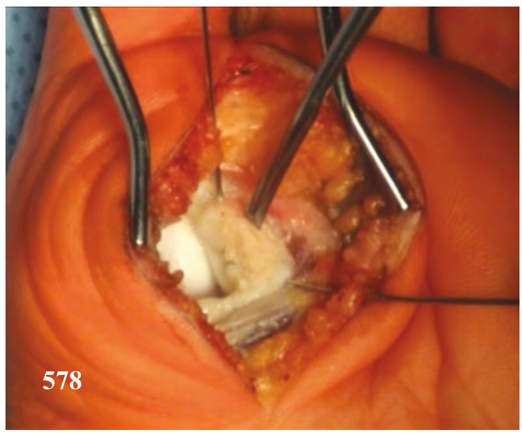

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The fragments are definitively ***fixed using 1.5 mm screws***.

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The skin is closed with ***anatomically adapting single stitches which remain for 3 weeks.***

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582

This technique avoids any step between the edges of the scar. Such a scar would remodel badly and remain painful.

Operative Techniques

Contents

K. Klaue, *The Foot*, https://doi.org/10.1007/978-3-662-64001-2_6

6.1 Positioning of the Patient

Anatomical structures about the foot and ankle are of relatively small dimensions. Handling nerves (e.g. neuromas), fascio-cutaneous flaps and small articular fracture fragments require that the surgeon is comfortable. It seems that a seated position allows for optimal relaxation during this kind of surgery. Magnifying glasses are mandatory in selected cases. Anterior, medial (medial utility) and antero-lateral approaches can be performed easily in ***supine positioning*** of the patient. The ***contra-lateral lower leg*** is secured with a belt (green arrow) and slightly extended and a contra-lateral buttress centred at the ***greater trochanter*** (red arrow) allows for occasional relevant tilting of the table.

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An inflatable tourniquet is applied to the thigh for minimal risk of venous thrombosis and a sealing tape avoids disinfectant liquid being trapped beneath the tourniquet to avoid skin lesions. When prepped, ***the knee must be included*** in the operative field for articular orientation.

585

Lateral positioning is optimal for postero-lateral approaches to the heel, subtalar and upper ankle joints. ***The non-operated leg is protected by a rigid U-formed cushion which is secured by two belts*** on the table.

586

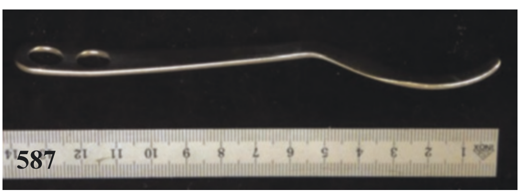
Care should be given to avoid compression of the lateral aspect of the opposite lower leg (fibular nerve).

6.2 Skin and Subcutaneous Handling

The osteo-articular structures about the foot and ankle are very close to the skin. This allows a direct approach to the structures which have to be addressed for surgical correction. On the other hand, there seems to be a critical distance between the skin incisions to avoid necrosis. In fact, the perfusion of the soft tissue hull about the foot and ankle follows a centrifugal pattern, centred 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, central fixation means are safe to preserve the soft tissues. Screws and nails can be easily introduced through small skin incisions and might be optimal in many cases to fulfil the required mechanical stability.

6.2.1 Instruments

In order to avoid deleterious local compression lesions at the surgical wound edges, ***adequate levers***



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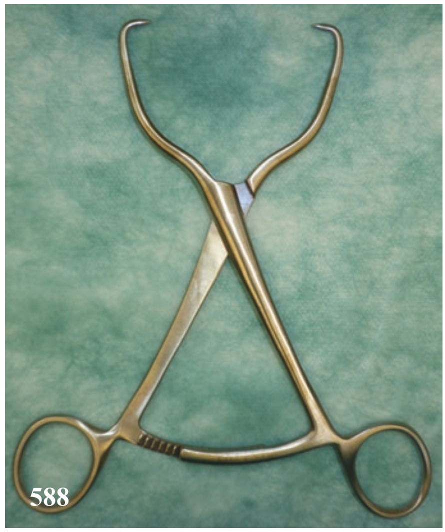
are used to optimize vision and reduce the risk of skin necrosis ***(T679)***.

Also, for reducing fractures, adapting subluxing joints and aligning metatarsals and the ankle, a percutaneous ***compression clamp***



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helps to secure the stability of the reduction. At the ***"closed" position of the clamp the compressing points should be aligned***.

6.2.2 Skin Plasty

6.2.2.1 Unidirectional Lengthening

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***.

589

The skin must be redirected. ***Taking the skin from lateral and medial***

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allows for an ***increase in its length along the long dorsal axis of the foot.***

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If the vascularity allows for undermining the skin, the ***transposition of the skin edges***

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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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6.2.2.2 Local Flaps

The soft tissue layers about the foot and ankle excluding the weight-bearing skin are thin and thus the osteo-articular structures are particularly exposed to trauma. Local pedicled flaps can basically be raised around any major joint due to the general centrifugal perfusion pattern of the soft tissue coverage [101]. The extension of the mobility of the local flaps goes from a shift of a few centimetres to a complete reversal of the blood flow. The soft tissue layer about the lateral aspect of the hindfoot corresponds to one of the multiple applications of small but essential shifts. The soft tissue layer can be moved within the sagittal plane to cover critical areas, for example after an osteosynthesis of the os calcis ***(T623)***.

The medial aspect of the ankle joint belongs to the most jeopardized soft tissue layer [102]. A ***chronic wound*** after ORIF of a pilon fracture ***must first be debrided***


596


597

More vascularized soft tissue layers are located on the lateral aspect of the ankle which allows raising interesting fascio-cutaneous flaps to cover the defect [103]. The anterior sopramalleolar skin allows the raising of a reverse flow (low arterial flux) fascio-cutaneous flap ***which can be raised and mobilized to cover the medial aspect of the ankle*** [104].


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6.3 Surgical Approaches

Surgical approaches to the osteo-articular structures of the foot and ankle appear simple because most of the surgical targets are very close to the skin. However, expert knowledge of the local anatomy is of primary importance in this kind of surgery. In fact, the occasionally very thin soft tissue layers include essential structures such as vessels, nerves and tendons which must be protected. The exact localization of skin incisions is thus critical because it often determines the vitality of the edges of the wound. Soft tissue flaps may, however, be produced on many occasions [105] as demonstrated above in just a few examples. The approaches do not harm by their dimension per se. The length of any scar does not inform about potential damage to the integrity of the body. The exposure must allow enough visibility and easy handling following the "minimax" rule popularized by Bernhard (Hardi) Weber [106]. So-called "less invasive" approaches often lack in rationale and conceal occasional harm while rendering on-site assessment and handling difficult. There is a lack of evidence that "less-invasive" approaches are safer or advantageous over a well-performed "minimax" approach.

6.3.1 Upper Ankle Joint

The approaches to this joint are required in malleolar and pilon fractures and in osteotomies and fusions.

6.3.1.1 Postero-Lateral

The vertical line, ***lateral to the heel cord and medial to the sural nerve***

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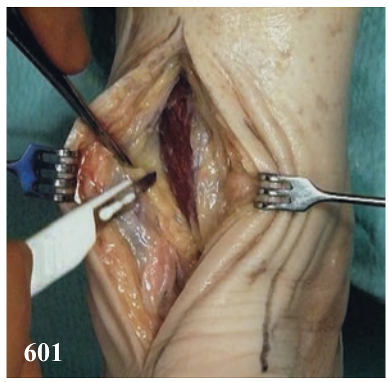
can be used to expose the deep structures in ***between the musculus. flexor hallucis longus and the fibular muscles*** [88].



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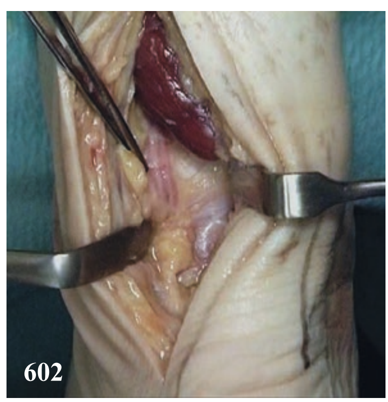
The flexor hallucis longus muscle is ***pulled towards medial, thus demonstrating the fibular vessels and the posterior capsule of the upper ankle joint.***



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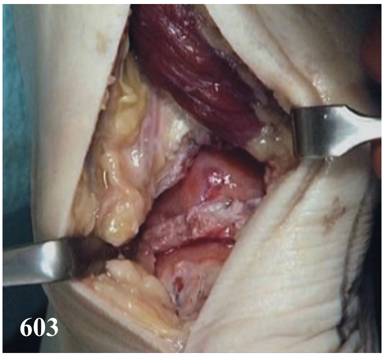
An ***optimal view on the whole posterior aspect of the upper and lower ankle joints is thus provided***.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6.3.1.2 Anterior

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

The medial aspect of the anterior upper ankle joint is best seen through the space between anterior tibial tendon and the extensor hallucis longus tendon. The anterior tibial artery and the N. fibularis profundus is thus protected laterally together with the M. extensor hallucis longus.

6.3.1.3 Antero-Lateral

The lateral aspect of the upper ankle joint is of special interest in the ***antero-lateral tubercle of Chaput*** such as in pilon tibial fractures ***(F496)*** and the revision and check of the distal tibio-fibular stability (syndesmosis).


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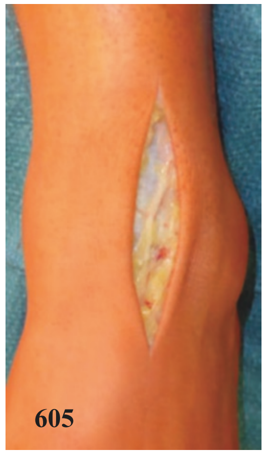
The pathway goes between the long extensor tendons of the toes and the anterior fibular artery. Above the retinaculum, however, the ***superficial fibular nerve must be protected and held towards medially.***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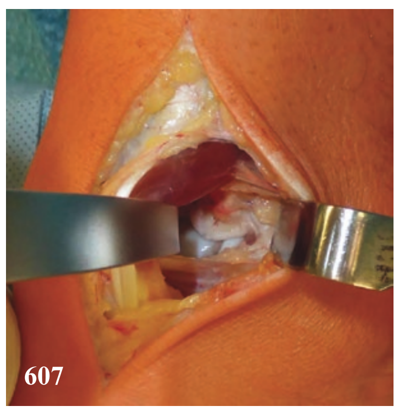
The easiest way below the retinaculum is to stick to the lateral edge of the most lateral tendon and carefully handle towards lateral all the soft tissue located above the anterior tibio-fibular ligament (syndesmosis). This approach, which can be extended towards proximally, allows perfect handling of the ***anterolateral lesions of the tibia, including the anterior tibio-fibular ligament.***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6.3.1.4 Postero-Medial

The ***postero-medial approach of the ankle*** is more critical than the others ***(F500)***. The skin incision is slightly curved ***between the medial malleolus and the heel cord***

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609

The pathway goes ***behind the tibial nerve***, observing and protecting its ***ramus calcaneus.*** (red arrow)

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

611

This aspect is often interesting in specific fractures of the pilon tibiale [107] and the control of the postero-medial reduction. It can be very useful to visualize complex pilon fractures using a joint distraction device ***(F499)***. The two other approaches to be used simultaneously with the postero-medial approach are the antero-lateral approach to the tibia and the postero-lateral approach to the fibula.

6.3.2 Fibula

The distal fibula is covered on its lateral aspect by just a few millimetres of skin and subcutaneous tissue. In order to avoid a scar on this critical spot, the cutaneous access to the fracture should be performed either anteriorly or ***posteriorly (F480)*** to the lateral crest of the fibula.

612

The postero-lateral aspect of the fibula is optimal for ***internal fixation by plate*** [82] of eventual fractures ***(F479).***

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6.3.3 Medial Utility

The medial aspect of the foot is easily exposed in distal continuation of the postero-medial approach. It allows for visualization of the dorsal and plantar aspect of the local anatomy thus avoiding any iatrogenic lesion of the cutaneous nerves. In fact, it follows the medial lower edge of the bony structures ***from the aforementioned approach to the end phalanx of the big toe (F513)***.

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It considers the upper edge of the m.abductor hallucis and allows presentation of ***the posterior tibial tendon***.

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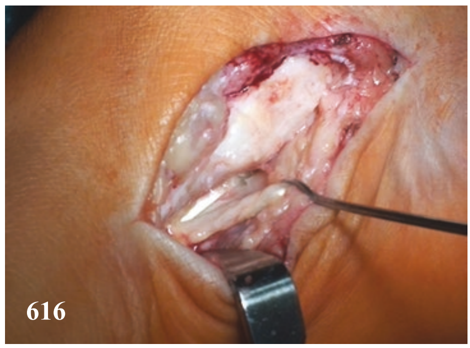
With this incision, the cutaneous nerves are safe and having moved the muscle belly of the abductor hallucis plantarward and following the plantar roof, the osteo-articular structures the "Master knot of Henry" [108] can be incised to discover both ***long flexors of the toes.***



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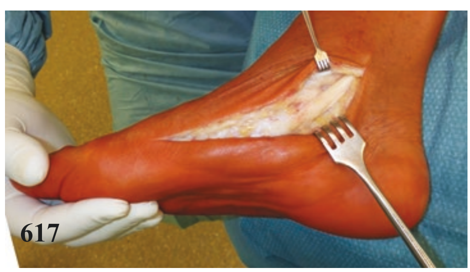
The tendons at this point cross each other and we can talk about the "chiasma of the long flexors". Through this approach the different tendon transfer procedures can be performed with optimal visualization and without any danger to the plantar nerves.

The ***medial aspects of the subtalar, the talo-navicular, naviculo-cuneiform and eventually the first tarsometatarsal joint,***



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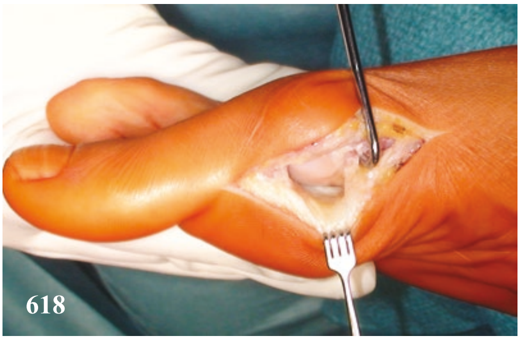
which is covered on this aspect by the anterior tibial tendon, are then visualized. Here again, the dorsal and especially the plantar aspect of the bone and joints are presented for osteotomies and fusions allowing for stable plantar plate tension band fixation [109]. Further distal, still between the dorso-medial and the plantar medial cutaneus nerves, the ***metatarso-phalangeo-sesamoidal joint***

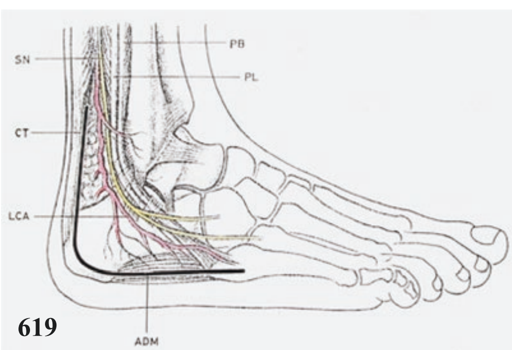


618

is approached including the arthrotomy. The metatarsal head can be presented on its dorsal aspect or at its metatarso-sesamoid joint aspect with one single incision.

6.3.4 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*** [91,110] ***(F524)*** which is reclined towards dorsal and distal allowing for safe visualization of the whole lateral calcaneus with the subtalar and calcaneo-cuboidal joints. Together with the vascular pedicle, the blood supply of the local skin and the sural nerve are safe within the flap. Any other skin incisions on the lateral aspect of the calcaneus jeopardize the blood perfusion.

6.3.5 Lateral Midfoot

The apex of the acetabulum pedis is located about the lateral midfoot. Here, the four bones: calcaneus (anterior process), cuboid, navicular (lateral part) and talus (lateral head) can be presented through one single approach ***(T737)***. Described in a more extended version by Ducroquet and Launay [87] it allows for all bony and ligamentous reconstructions, osteotomies and fusions about the lateral midfoot.

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

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It can be performed ***together with the postero-lateral approach*** because the local vascularity of the postero-lateral soft tissue flap is conducted by the sural neurovascular axis [105].

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622

In certain conditions, including soft tissue coverage by local flaps, both incisions can be linked ***to move the postero-lateral fascio-cutaneous flap*** [90].


623

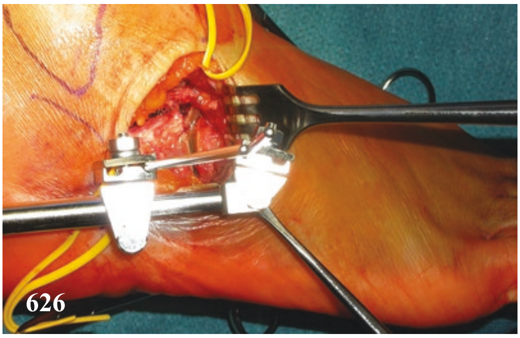
Dissection after the incision of the skin differs from the aforementioned approach to the calcaneus. The subcutaneous tissue is carefully dissected to find the ***sural nerve,***


624

which can have more than one branch at this level. The ***extensor digitorum brevis is reclined distally*** and allows safe, well-vascularized coverage. Both fibular tendons lie on the plantar aspect of the incision and may be undermined towards plantar if the calcaneus is approached for osteotomy ***(T731)***.


625

A ***local distraction device*** allows for eventual articular revision during surgery.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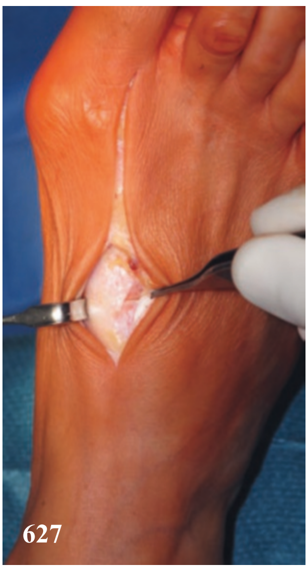
6.3.6 Medial Tarso-Metatarsus

The tarsometatarsal region medial of the anterior neurovascular bundle is best visualized ***between the long and the short extensor tendon 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 inter-metatarsal space is interesting in order to achieve post-traumatic reduction and eventual fusion between the first two medial metatarsals. In cases of chronic subluxation of the first metatarso-phalangeo-sesamoidal joint, the distal part of the incision is used for longitudinal arthrotomy. After skin incision, attention should be given to the dorso-lateral cutaneous nerve of the hallux which runs lateral to the short extensor tendon. A lateral joint arthrolysis allowing for reduction of the metatarsal head onto both sesamoid bones can then be safely performed, with eventual osteophytectomy of the lateral metatarsal head. The approach permits the surgeon to ***visualize the lateral aspect of the first metatarsal head*** and the first phalanx of the big toe ***(T763)***.


628

6.3.7 Central Tarso-Metatarsus

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 to ***visualize the second and third tarso-metatarsal joints (T674)***


629

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

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6.3.8 Lateral Tarso-Metatarsus

The fourth and fifth tarsometatarsal joints belong to the "cuboid foot" and can be ***exposed together*** for eventual osteosynthesis or arthroplasty ***(T782)***.

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

6.3.9 Central Metatarsus

Both second and third metatarsi belong together anatomically. In order to visualize the corresponding diaphysis for osteosynthesis or osteotomies ***(T794)***, a longitudinal incision is made exactly between both 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.

632

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

6.3.10 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, e.g. osteotomy.

Both incisions to ***expose the central and the fourth metatarsi can be performed simultaneously (T804).***

633

At the mid-level of the incision, the long extensor muscle tendon of the fifth toe crosses the field and must be protected.

6.3.11 Fifth Metatarsus

The fifth metatarsus must be approached laterally for osteotomy ***(T819)*** which reorients the bone in adduction or for fracture reduction and internal fixation. The approach is logically performed passing on the lateral aspect of the bone, ***above the abductor digiti quinti muscle***.

634

6.3.12 Lesser Toes

Toes 2 to 5 have to be approached for dorsal metatarso-phalangeal arthrolysis and extensor tenotomies, proximal interphalangeal fusion ***(T830)*** and flexor tendon transfers onto the first phalanx for active stabilization of the toes. The ***logical approach is thus dorsal***.

635

The flexor tendons can be harvested passing close to the bone towards plantar, at the level of the proximal interphalangeal joint ***(O433)***.

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

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6.4 Post-operative 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% [72]. Best healing, however, is obtained logically by reducing the strain of the soft tissues after surgical trauma. Sir Robert Jones introduced this concept in foot and ankle surgery at the beginning of the twentieth century [25]. Today, sterile, packed, soft padding of the whole foot and ankle when covered by plaster of Paris ***(F466-467)*** reduces 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 take about ***2 weeks*** to consolidate to allow motion.

637

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

6.5 Bone and Joint Reconstruction and Alignment

6.5.1 Supramalleolar Osteotomy

The aim is to redirect the upper ankle joint in a congruent tibio-fibular malleolar mortise to achieve perfect horizontality of the talar dome within the frontal plane. Consequently, both tibia and fibula are always osteotomized ***(O222)***. Due to the use of the oscillating saw, the anterior approach to the tibia is favourable. The tibia is exposed medial to the anterior tibial muscle and lateral to its tendon (more distal), thus protecting the anterior tibial artery and the deep fibular nerve. The fibula is best approached from lateral as for malleolar fractures ***(F476)***. 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 postero-lateral ***(T600)***. The fibular vessels are then visualized and protected while addressing the tibia and the fibula through the same approach ***(O224)***.

Plane cut osteotomies

638

allow for not only angular correction but also 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. Tibia and fibula are fixed by plates and screws. The osteotomy of the tibia is thus situated about three 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 non-desired 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 at varus, the ***fibula will be cut obliquely***

639

and the osteotomy surfaces will glide upon each other. ***The tibia is fixed first*** with a L-shaped plate allowing for at least 2 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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and does not require anatomic adaptation of the bone ends. The soft tissue layers about 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 for valgus, the ***fibula will undergo a resection*** about a centimetre or two above the tibial osteotomy by performing two ***parallel cuts***.

642

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

643

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 4 screws ***(O222)(O229).***

6.5.2 Lateral Malleolus Osteotomy

This kind of osteotomy is indicated in malunions of malleolar fractures ***(O230)***, in which the articular congruency of the malleolar fork is lost. The distal fibula should regain functional congruency with the upper ankle joint which had been lost through the previous trauma.

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

644

together with the whole underlying foot.

The contralateral radiograph is used as template for the correction

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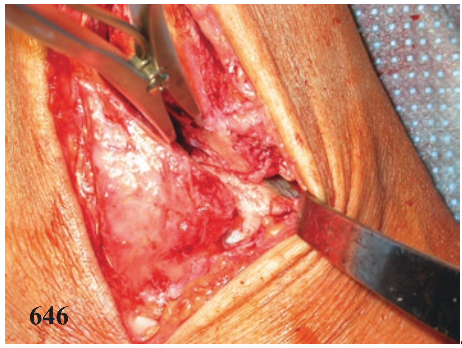
The aim is thus to regain length, internal rotation and adduction of the distal articular fragment which will reduce the talus beneath the tibia and correct the abnormally increased joint space about the medial malleolus.

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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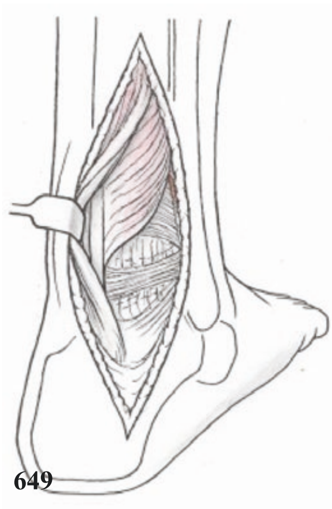
6.5.3 Upper Ankle Fusion

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 ***(O262)***. The logical pathway to correct the position is thus the postero-lateral approach [44] ***(T600)*** to "open" the posterior space, pulling the talus backwards for fusion to the tibial plafond. The postero-lateral 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 which is induced by the arthrodesis and occasional valgus correction, thus avoiding fibula-calcaneal impingement. The joint is opened and distracted. A ***distractor*** helps occasionally when placed medially between the tibia and the calcaneus thus ***avoiding the feared varus malunion***.


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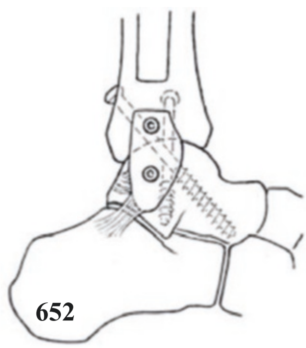
The entire joint can be seen and debridement is performed. The talus is placed judiciously beneath the tibial plafond with a discrete shift posterior to its normal position. A ***strong screw helps to pull it backwards*** when placed in the same oblique vertical plane as the surgical approach. This plane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


651

A second screw is placed percutaneously from medial and above the malleolus to the postero-lateral aspect of the talus. The ***syndesmosis can be used together with the fibulo-talar joint as fusion surfaces*** which 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 ***(O264)***.

6.5.4 Osteochondroplasty of the Talus

In long-lasting, symptomatic adult osteochondritis dissecans of the talus ***(O208-209)***, autologous osteo-cartilaginous transplants from the ipsilateral femoral condyle give very good results [40]. After either antero-medial, antero-lateral 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. Using the antero-medial approach, the ***distal Schanz screw is placed horizontally in oblique from medial to lateral***


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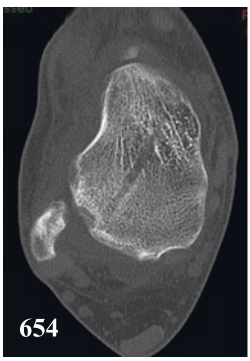
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Applying the antero-lateral approach, the Schanz screw is placed ***horizontally within the talus in oblique from antero-lateral to postero-medial.***


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Static distraction allows for ***full visualization of the talus and the tibial plafond***


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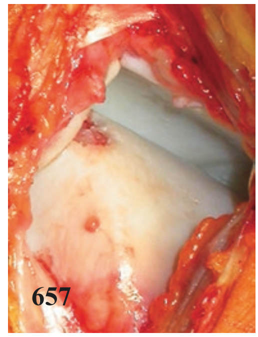
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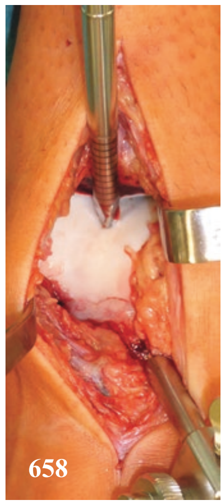
the ***avascular fragment is enucleated or drilled out***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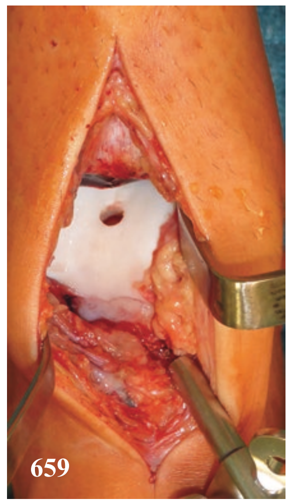
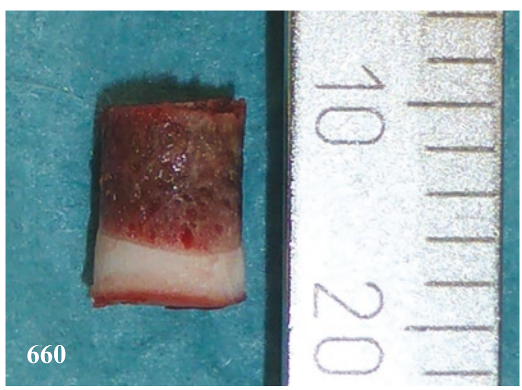

659

and the needed transplant evaluated. The ipsilateral medial femoral condyle is exposed and the ***transplant taken from the medial edge***,



660

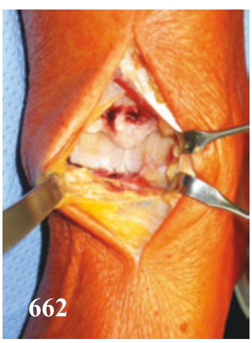
following the required shape of the recipient.

The specific tubular osteotomes and shanks are indispensable to achieve a ***stable transplant (O210).***

661.

6.5.5 Cheilectomy of the Upper Ankle Joint

In 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 which 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 (O214)***



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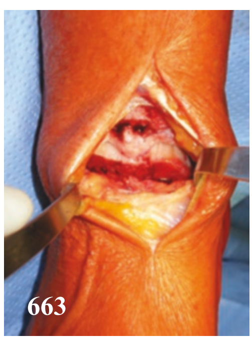


663

Soft tissue impingements about 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 and remains medial to the neurovascular bundle.

Postero-medial and lateral impingements (e.g. free talus fragments) ***(O215)(R189)*** are removed through the ***posterior medial approach*** [81]***, leaving the neurovascular bundle anterior to avoid any vascular disturbance to the talus.***

664

The calcaneal branch of the tibial nerve is also protected.

665

The ***fascia of the flexor hallucis longus is opened*** to mobilize the muscle towards posterior


666

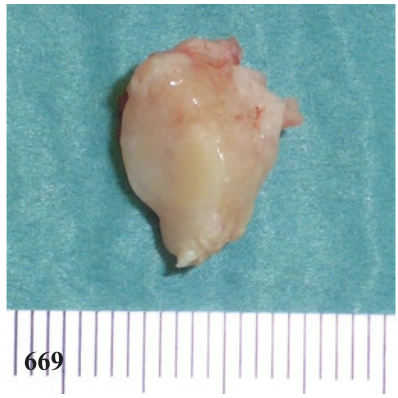
The pathway is located in ***between the tibial nerve and the flexor hallucis longus*** tendon

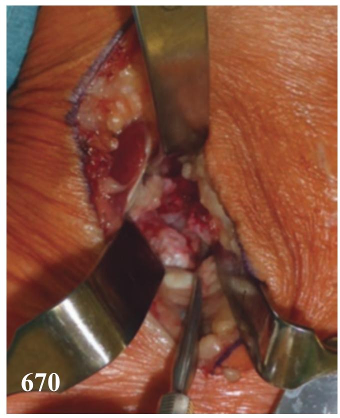

667

Both ***tibio-talar and talo-calcaneal joints*** are opened


668

and the free-moving ***fragment is enucleated (R189)***


669


670

A pointing ***postero-medial process also undergoes resection***


671

Postero-lateral impingements are removed in selected cases through the postero-lateral approach [44] ***(T603)***.

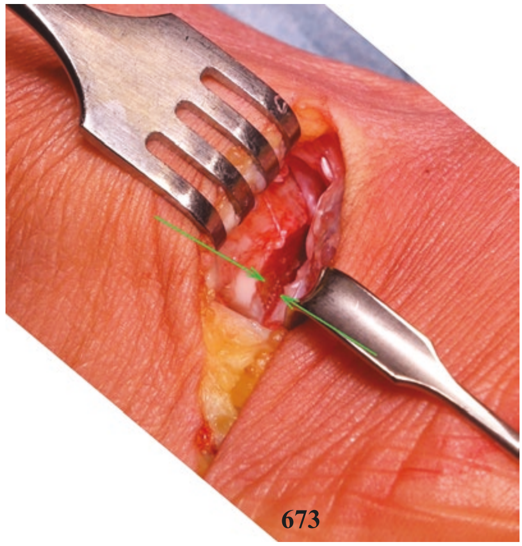
6

6.5.6 Cheilectomy of the Lower Ankle Joint

Peripheral fractures of the talus often impede articular function of the subtalar joint and provoke joint degeneration. Multi-fragmentary fractures of the lateral process of the talus which are obviously avascular are best removed, taking care to not jeopardize joint stability ***(F507)***. If not treated, those fractures often result in chronic pain due to the malunited impinging bone. Impingement may also occur after any surgical procedure about the sinus tarsi, e.g. central calcaneus osteotomy ***(O294)***, to repair pes planus abductus. Such impingement must also be recognized without previous trauma or surgery

(E110)(O244)(O354)(O316). Resection helps in restoring normal motion of the coxa pedis ***(O249-250)***. ***Cheilectomy on both talar (processus lateralis tali) and calcaneal side (critical angle of Gissane) avoids bony abutment in maximal pronation***


672


673

Comparative lateral radiographs under weight-bearing conditions demonstrate the ***pre- and post-operative conditions.***

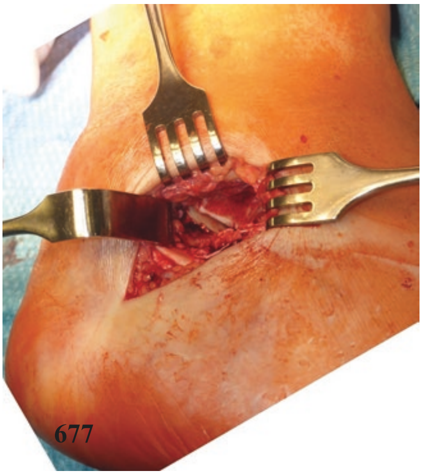

674


675

Lateral talo-calcaneal impingement may also occur after central calcaneus lengthening osteotomy. The intercalated bone graft may grow over the confines of normal calcaneus and represent an **obstacle to the lateral process of the talus in pronation.**


676

The optimal approach is the ***oblique antero-lateral approach*** due to the local vascularity of the soft tissues [87]. The short extensor muscle of the toes is detached and reclined towards distal.



677

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 centred on the sustentaculum between the flexor digitorum longus and the flexor hallucis longus ***(E119).***

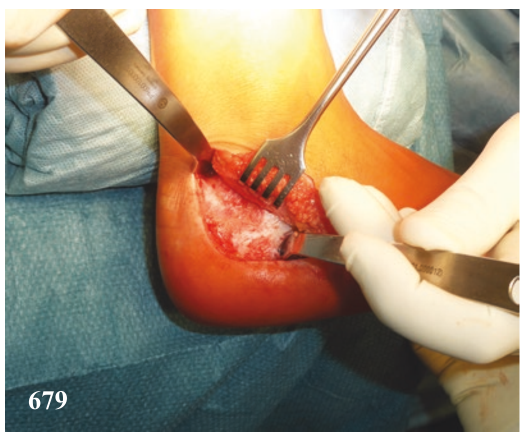
6.5.7 Reorientation Osteotomy of the Tuber Calcanei

In pes cavus varus adductus, and in morphologic instability of the hindfoot in general, the varus and adductus components are corrected by lateralizing the tuber calcanei ***(O235)***. For anatomical reasons including the trajectory of the lateral plantar nerve on one side and to avoid shortening of the calcaneus and consequently the lever of the heel cord, the osteotomy is directed on the ***perpendicular to the long axis of the calcaneus at the insertion of the plantar fascia*** [111]**.**

678

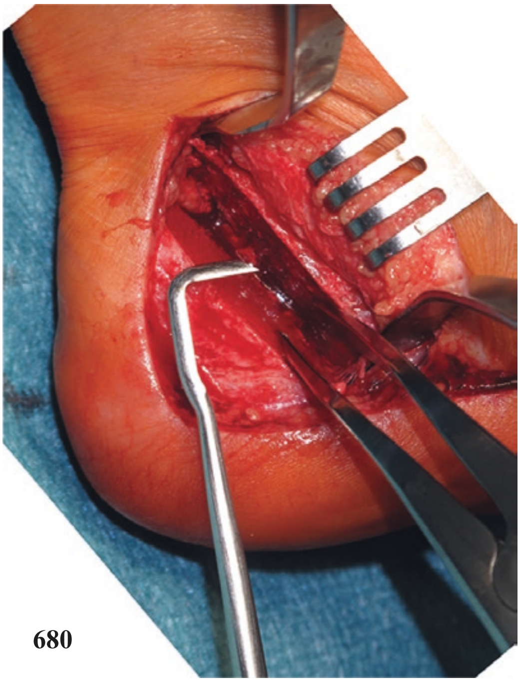
The course of the osteotomy avoids jeopardizing the neurological pedicle on the medial aspect of the hindfoot.

The approach is postero-lateral [91] and ***the periosteo-cutaneous flap is reclined upwards.***



679

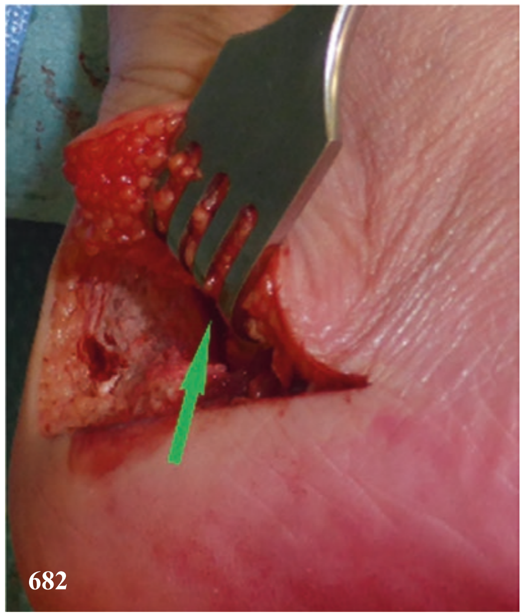
The exposition of the bone is smaller than for calcaneus fractures ***(F523)*** because only the tuber calcanei are approached. This approach avoids harming the integrity of the soft tissue and the sural nerve in particular. A direct approach (open or "mini-invasive") at the level of the osteotomy jeopardizes the anatomical perfusion of this flap [90]. Indirect release of the soft tissues on the medial aspect using an ***angulated periosteal elevator*** across the osteotomy site is performed


680

and distraction is then possible using a lamina spreader.


681

The tuber is ***shifted laterally*** (green arrow) about 1 to maximum 1.5 cm for optimal correction [112].


682

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

In the rare indications requiring a shift of the mechanical axis towards medial beneath the upper ankle joint [111] ***(O240)***, the tuber calcanei is moved towards medial through the same oblique tuber calcanei osteotomy. This correction allows for ***moving the weight-bearing axis of the upper ankle joint towards medial***. The procedure is similar to the lateral shift of the tuber ***(O236-237).***


683

6.5.8 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 the alignment of the axis of the talus to the axis of the first metatarsus within the sagittal plane ***(R176)***. The approach is clearly best performed ***from posterior-lateral*** because the largest mobilization of all tissues (bone and soft) is located behind the joint **(*T603*)**.

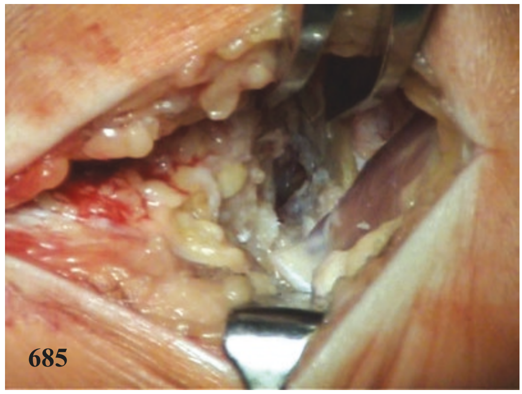
Additionally, the frontal alignment must be controlled at all times and this is only possible from behind using a distracting device in selected cases. The patient is lying on the contralateral side with a tourniquet on the thigh. This allows for a very convenient radiological control using vertical fluoroscopy and by bending of the knee joint [5 p.296, 113].

Skin incision is lateral and parallel to the heel cord.

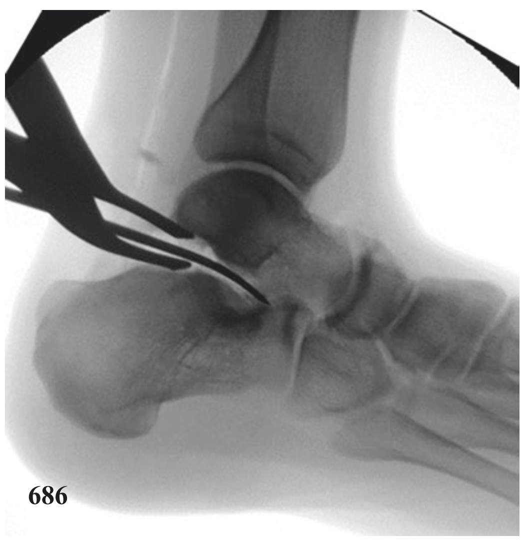

684

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.

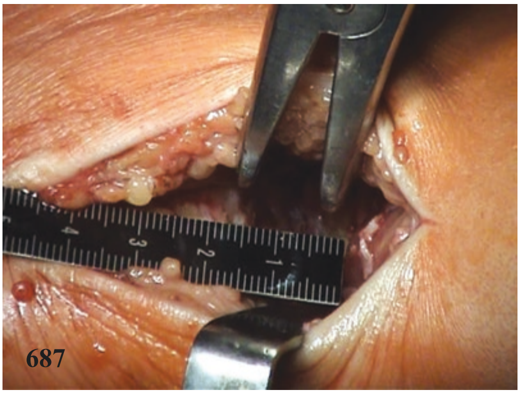
Its muscle belly, protecting the neurovascular bundle, is held towards medial with a ***smooth rectangular retractor (Langenbeck)***.


685

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 Schanz screw is fixed in the tuber calcanei and another one in the tibia, and a distraction device (distractor) is installed parallel to the lower leg ***(T650)***. Most often, the joint is more difficult to mobilize medially and in order 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 distraction forceps (laminar spreader) while the remnants of cartilage and the subchondral bone are removed using a ***curved Lambotte osteotome.***


686

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 physiological valgus of the heel is checked clinically and the divergence of talus and calcaneus is verified on a lateral fluoroscopy. The ***height and depth of the space*** between the talus and the calcaneus are evaluated and measured.

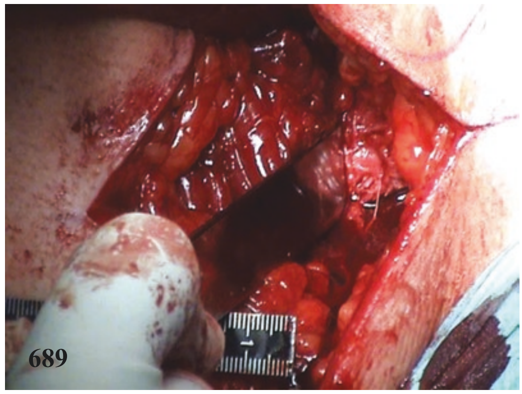


687

The ipsilateral ***posterior pelvic bone*** is considered for harvesting a tricortical bone block, which may measure up to 5 cm in height and provide about 2.5 cm natural width of dense cancellous bone.

688

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

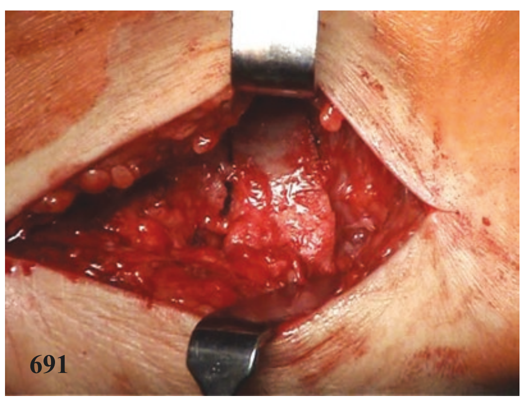


689

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

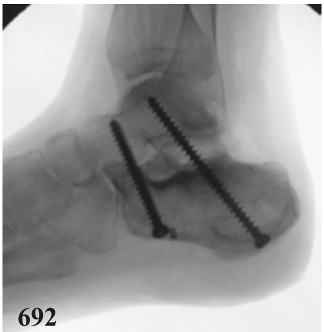
690

which includes most often a higher medial wall of the transplant than lateral and it is ***wedged in the posterior subtalar space (O266) (O270).***



691

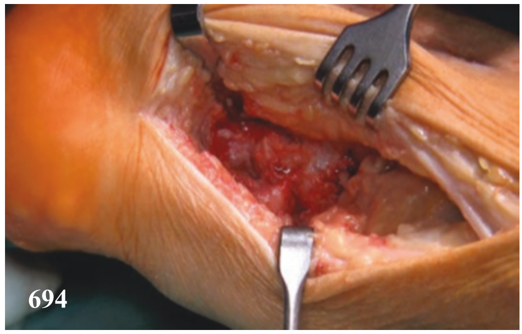
Spontaneous stability should be achieved while fixation by 2 screws protects the montage against eventual medial-lateral stresses within the frontal plane. The axes of those screws preferably ***cross the natural axis of the subtalar motion*** for optimal counteracting any eventual destabilizing stresses.


692

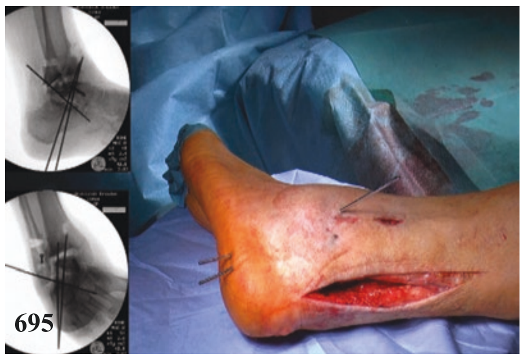
6.5.9 Tibio-Talo-Calcaneal Arthrodesis

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 ***(E51-52)***. Both joints must be mobilized to allow for free angulation and shift in any plane. To achieve good function, the aim is a slight, augmented external rotation of the foot in relation to the knee axis. Resecting the remaining cartilage and the occasional bone, the ***postero-lateral approach*** is probably the most accurate pathway in most cases **(*T600*).**


693


694

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


695

The frontal alignment of the lower leg and the axis of the foot to the knee axis are controlled clinically and radiologically. Attention must be paid to the physiological valgus of the heel. Within the sagittal plane, a perfect orthogonal position at right angles of the plantar surface to the lower leg must be checked. The optimal fixation of the tibia, the talus and the calcaneus is performed by a central load carrier by means of a rigid nail which bridges both joint surfaces at their approximate centre [114] ***(O274)***. The point of entrance of the nail is safe on the lateral aspect of the heel by means of the tuber calcanei. This approach avoids the known complications which concern the neurovascular bundle [115]. Furthermore, the implant is well centred, providing a corresponding lever on both calcaneus and distal tibia.

The **circular curve** crossing the tuber calcanei, the posterior subtalar joint facet, the centre of the distal tibial joint surface and the distal tibial metaphysis is found ***(O276)*** virtually using an ***external frame under radioscopy***.

696

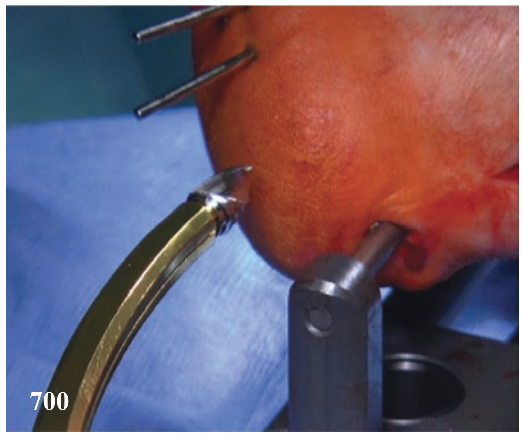
697

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

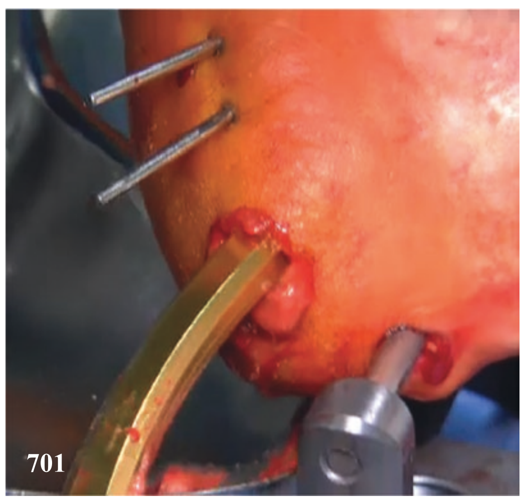
698

699

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



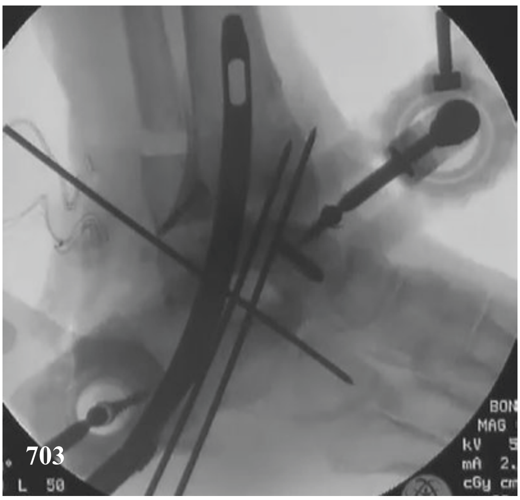
700



701

A corresponding ***curved nail is smoothly impacted*** in the opening following precisely the pre-drilled hole thus achieving immediate optimal stability.

702



703

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

704

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

705

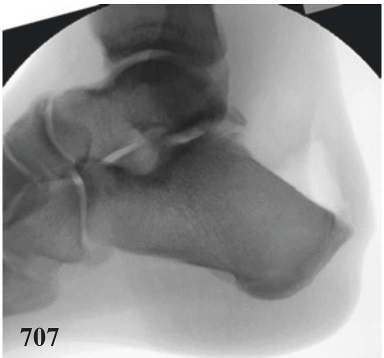
The construct thus defines a central load transmitter which contacts closely the cancellous bone of the 3 bones of the hindfoot ***(O245)***.

6.5.10 Posterior Calcaneal Ostectomy

Repetitive hammering of the postero-superior apophysis of the calcaneus on the distal Achilles tendon triggers a chronic pre-Achillean bursitis [18] ***(E86)***. A tendinitis component may also occur. The aim of the treatment is to remove the causal osteophyte ***(E95)***. The most efficient resection is the removal of all bone at the dorsum of the calcaneus ***(O204-205) which might interfere with the active flexion and extension***.

706

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***.



707

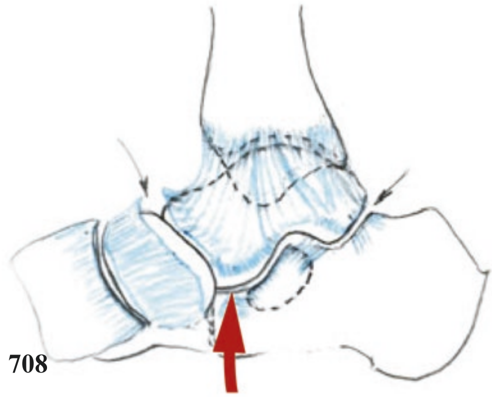
The lateral vertical approach at the lateral edge of the heel cord at about 6 cm is optimal because of the lateral position of the tuber calcanei.

6.5.11 Arthrolysis of the Talo-Calcaneo-Navicular Joint

Arthrolysis aims to open contracted, closed and often rigid joints in, for example, congenital club feet. The lower ankle joint is essentially made up of the talo-calcaneo-navicular joint. A closed talo-calcaneo-navicular 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 dorso-lateral aspect of the foot. It is the dysplastic coxa pedis ***(C969)***.

The first move to correct such a deformity is the opening of the calcaneo-navicular space or acetabulum pedis ***(O317)***. The approach is thus longitudinal medial ***(T614)*** to avoid problems in soft tissue healing.

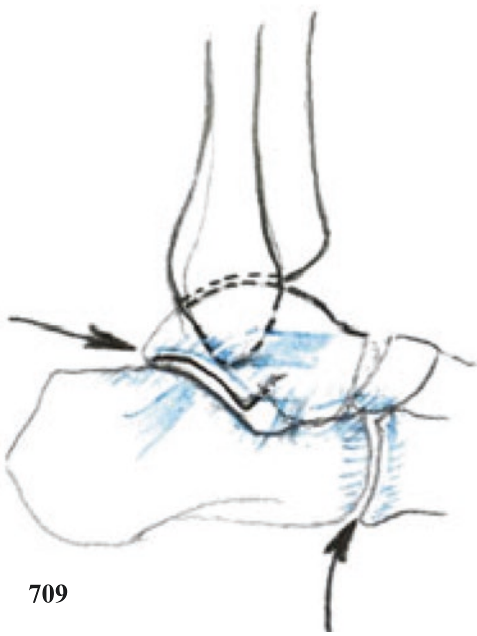
In addition to ***dividing the spring ligament*** (red arrow):



708

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 calcaneo-cuboidal joint is visualized and opened.

In selected cases, on the lateral aspect of the foot, the ***calcaneo-cuboidal joint will also be opened***

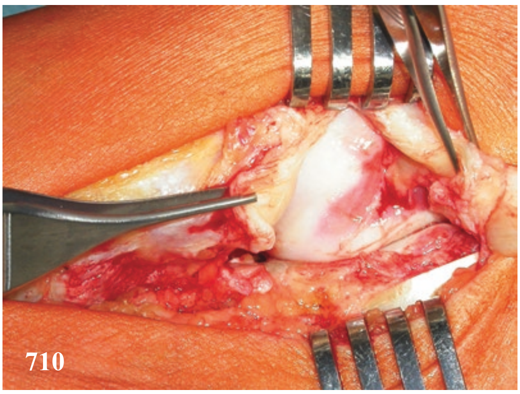


709

to allow for aligning the lateral wall of the calcaneus with the fifth metatarsus within the horizontal plane [116].

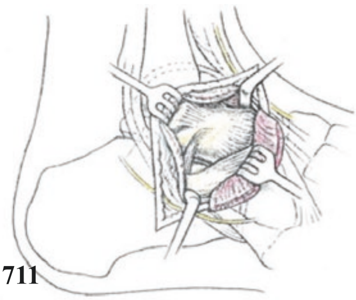
6.5.12 Central Talus Osteotomy

In mobile, flexible pes cavus varus adductus ***(O312)*** 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 towards morphological correction ***(O313)***. The procedure should be reserved for children over 10 years of age and young adults [117]. 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.***



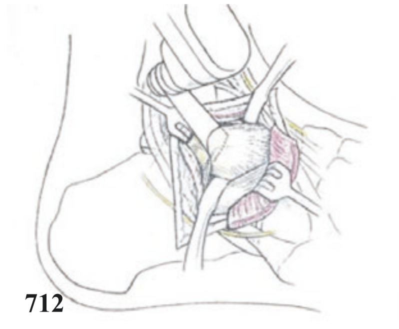
710

In addition to the medial longitudinal approach, a small ***antero-lateral approach (T620)***



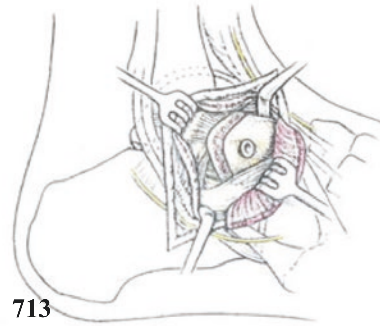
711

allows for optimal positioning of the talar neck osteotomy at the level of the canalis tarsi ***in front of the processus lateralis*** tali and directed medially, in front of the medial malleolus.



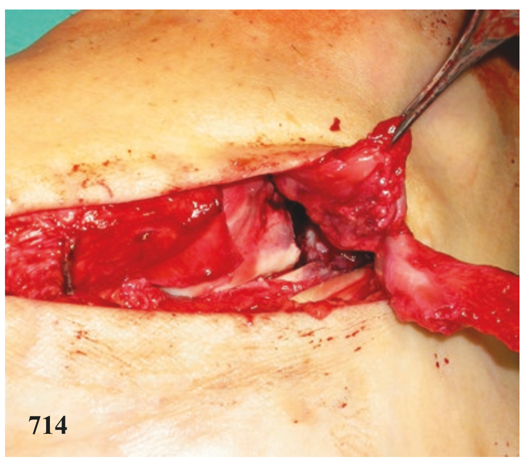
712

The talar head thus gets ***pushed towards medial*** onto the sustentaculum tali ***(O310-311)***,



713

pushing the navicular bone towards distal and lateral and thus the talo-navicular alignment improves. Seen from the medial side, the talar head occupies ***the space between navicular and sustentaculum tali,***



714

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

In severe cases, this effect is increased by interposing an autologous tricortical bone graft within the osteotomy [59].

6.5.13 Central Calcaneus Osteotomy

Symptomatic pronated feet with or without abductus may be corrected by the central calcaneal osteotomy ***(O282-284)*** [48]. The approach is antero-lateral, oblique and ***centring the crucial angle of Gissane***.

715

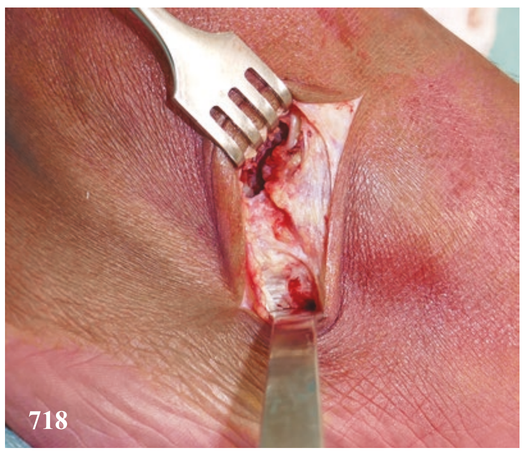
The ***sural nerve*** is presented and protected on a vessel loop

716

The short extensor muscle of the toes is detached from the calcaneus and reclined towards distal. The ***anterior aspect of the posterior facet of the calcaneus is shown while opening the joint***.

717

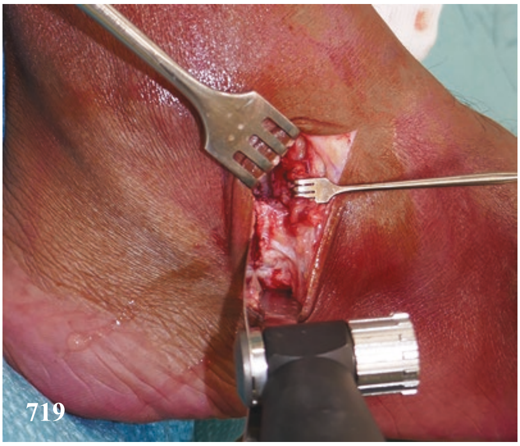
The lateral wall of the calcaneus is uncovered at the crucial angle of Gissane ***retracting the fibular tendons plantarwards***.



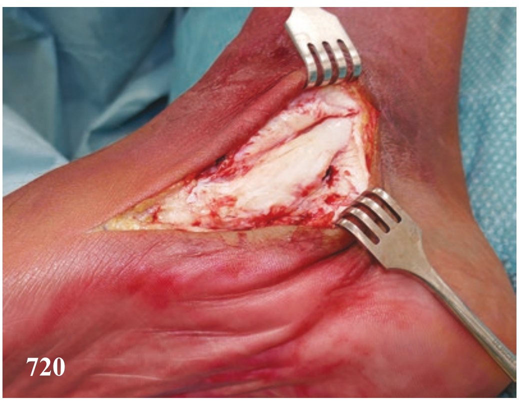
718

The osteotomy from lateral is partial and straight and does not cross the whole calcaneus body ***(O282)***, starting at the angle of Gissane.

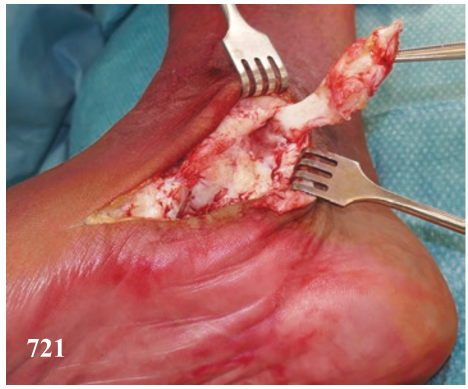
The osteotomy is made ***using a narrow oscillating saw ending its course precisely at the medial edge of the posterior facet***.


719

At this stage, the medial utility approach is performed ***longitudinally between the first cuneiform and follows the course of the posterior tibial tendon.***


720

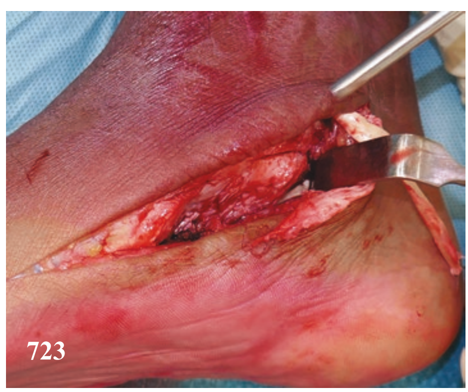
The tendon is inspected as far as the lesion expands, up the retro-malleolar region. ***Decision-making is performed regarding the resection of the tendon which depends on its shape, consistency, scarring and diameter***.


721

More distal, the tendon of the long flexor of the toes (FDL) which lies along the posterior tibial tendon, is exposed ***releasing the "Master knot" [108] (T908)***.


722

The long flexor of the hallux joins the FDL at this point which reveals the fibrous connections between both tendons [53]. After having sectioned the FDL for later transfer, the anterior subtalar joint is determined by ***exposing the sustentaculum tali.***


723

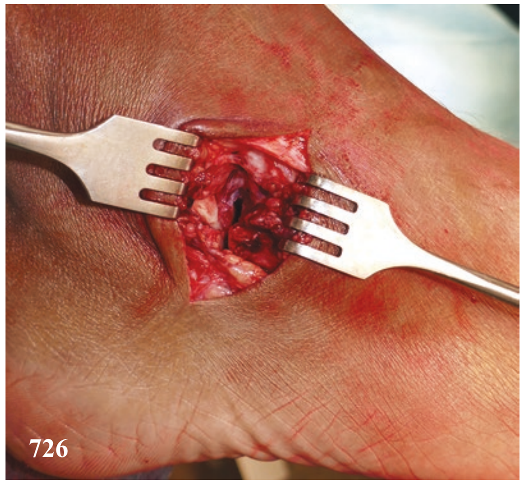
At this point, the medial wall of the calcaneus beneath the sustentaculum is exposed in a vertical fashion to localize the optimal position of the osteotomy. ***The soft tissue including abductor hallucis and neurovascular bundle is carefully held apart with the adequate lever (T587)***

724

Using a curved osteotome in a vertical fashion, the medial part of the osteotomy ***starts from behind the sustentaculum tali***

725

and joins the osteotomy previously performed from the lateral aspect in an oblique fashion ***(O282)***. The joining of both osteotomies allows the mobilization of both parts and is seen by a ***spontaneous opening of the osteotomy at the lateral aspect of the calcaneus.***



726

A lengthening of the calcaneus and angulation of the heel is then made by ***distracting both bony edges of the osteotomy using a lamina spreader*** laterally

727

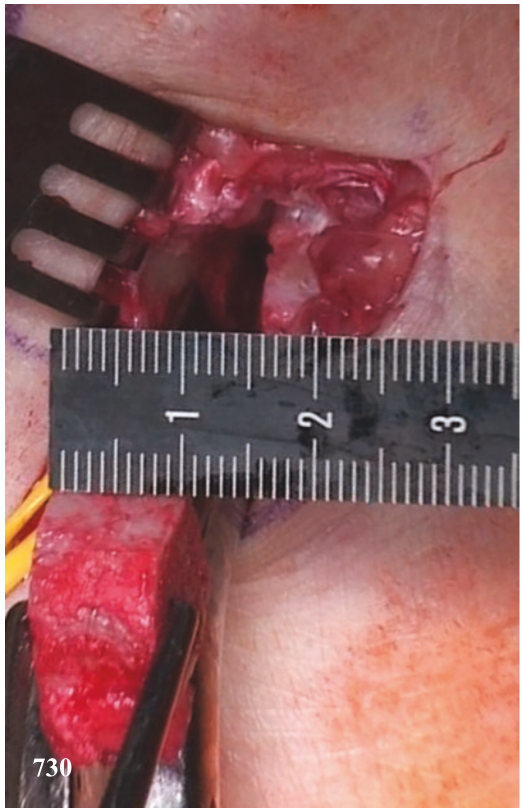
and in selected cases also behind the sustentaculum tali ***on the medial aspect of the calcaneus*** where the osteotomy opens spontaneously.


728

The talus undergoes a reorientation within the sagittal and horizontal planes until reaching anatomical alignment with the first metatarsus. This alignment is checked within the horizontal and the sagittal planes by fluoroscope in dorsoplantar and lateral projection and 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***


729

addressed in order to harvest the desired tricortical blocs on the level of the gluteus medius tubercle. After returning to the foot, the soft tissues are trimmed away from the grafts which are inserted to ***replace the distraction clamps on the lateral wall***



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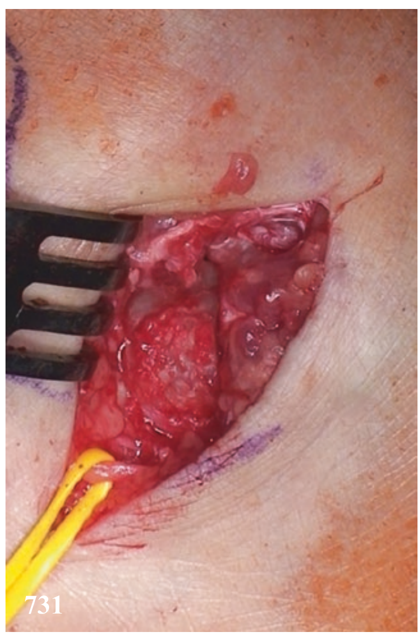
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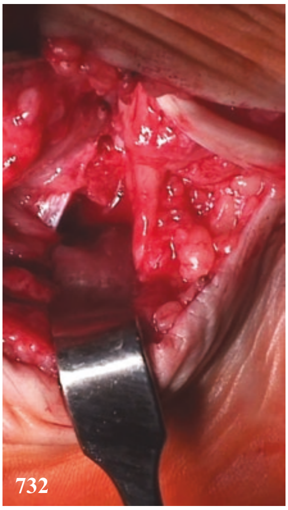
and at the ***medial aspect of the calcaneus***.



732

At this point, the montage is ***mechanically stable spontaneously*** allowing for free manual motion of the talo-calcaneo-navicular joint.

733

Fixation may be secured by one or two small inter-fragmentary screws crossing the graft ***(O289)***.

6.5.14 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 ***(O324)***. Two approaches are mandatory for safe control of the correction: the longitudinal medial approach from the medial cuneiform to the sustentaculum tali ***(T615)*** and the antero-lateral approach ***(T624)***. For ease, the patient is secured with contralateral buttresses allowing the table to be inclined up to about 40 degrees [5, p. 300].

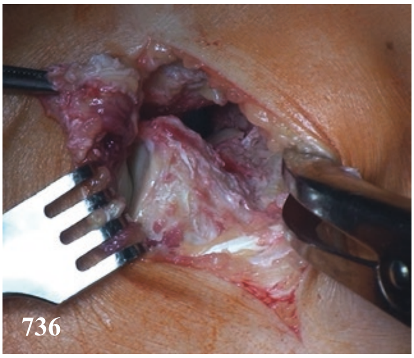
From the medial approach, the posterior tibial tendon is exposed and the talo-navicular joint is opened. For re-orienting a cavus-adductus deformed foot, the tendon will be divided for lengthening in order to avoid recurrence and to allow for a correction of the length of the medial column. The talar head is exposed by opening the subtalar joint. The plantar calcaneo-navicular 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 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.

734

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.

735

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



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and the lateral aspect of the talo-navicular joint. All those joints are progressively mobilized while removing the articular cartilage using the curved osteotome. To ease the access to the subtalar joint, a bone spreader is used in different positions. This allows for visualization 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 towards medially, only the flexor digitorum longus tendon crosses the view through the foot. For reorienting the four bones about the hindfoot, special attention is given to the ***full free view through the subtalar space*** between the two surgical approaches.

737

Full, free motion is also needed between the talar head and the navicular bone. If the main reorientation is performed within the horizontal plane, the 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 ***trans-articular Kirschner-wire***.

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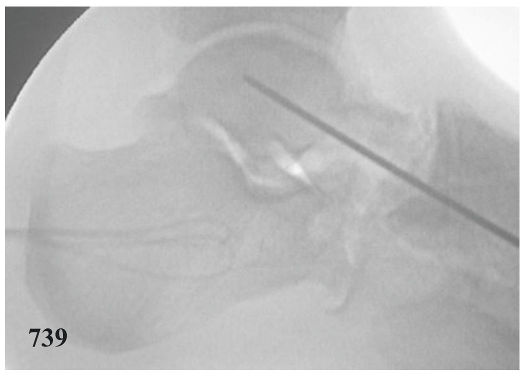


739

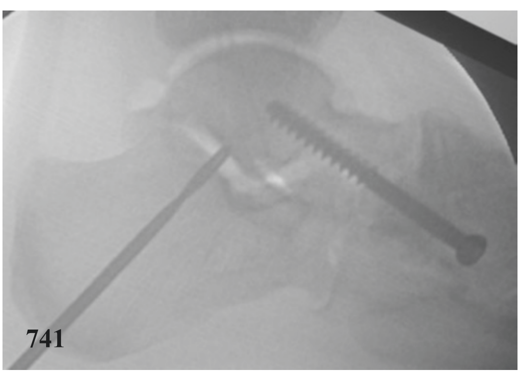
If the main reorientation is performed within the sagittal plane, the talus is “lifted” up along the posterior facet of the subtalar joint until the optimal position is reached. The lamina spreader is placed between the anterior process of the calcaneus and the lateral process of the talus for optimal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

Holding the foot in an orthogonal position, the desired valgus between the heel and the axis of the lower leg is controlled. At this stage, the calcaneo-cuboidal joint should, in

6

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 calcaneo-cuboidal joint is optimal for correcting the position of the foot within the frontal plane as the joint is located within this plane, and gliding the cuboid on the calcaneus rotates the foot around the talo-metatarsal axis. At this point, it may be wise to check the orientation of the four bones by fluoroscopy in dorso-plantar and lateral incidences. Definitive fixation of the medial column by means of the talo-navicular fusion is performed using one screw from distal to proximal centring the talus body. Through a ***small skin incision on the heel***, the ***calcaneo-talar fixation*** is performed using one screw which is driven through the centre of the subtalar facet into the talar dome.


740


741

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 calcaneo-cuboidal joint. The drill enters the cuboid from the top and ***centres the anterior process of the calcaneus***.


742

This ***3 screw-montage***


743


744

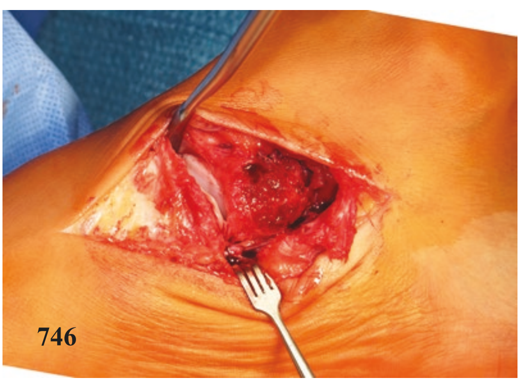
does not need additional bone graft because it forms a mechanical chain which is closed anteriorly by the cuneo-cuboid anatomical fixation ***(O325)***.

6.5.15 Naviculo-Cuneiform Arthrodesis

The naviculo-cuneiform joint can be considered a non-essential joint. The morphology and position of the naviculo-cuneiform joint participate in the fine adaptation of the foot during gait and running. In pes planus and/or abductus, in which the deformity or sag is located at the naviculo-cuneiform joint ***(O331)***, correcting fusion is indicated ***(O334)***[60]. The ***approach is longitudinal*** medial behind the anterior tibial tendon.

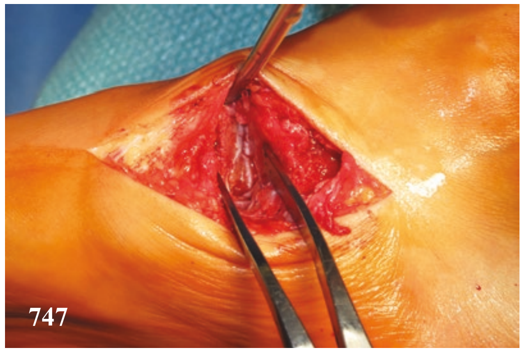
745

After arthrotomy, an ***occasional associated os acessorius naviculare (O331) is resected***



746

The cartilage and subchondral bone are removed on the first and second joints, keeping in mind the "conical" or cuneiform type of resection which directs the desired correction (plantar resection to correct pes planus, ***medial resection to correct pes abductus***).



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Temporarily hold the ***corrected position.***

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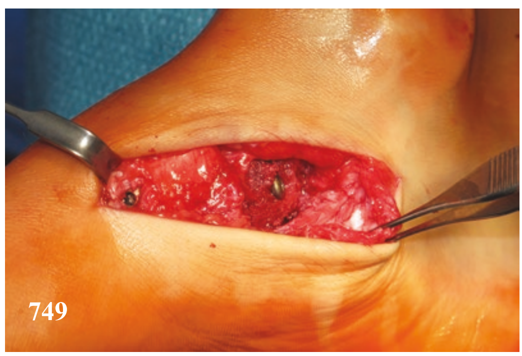
Fixation ensues with ***two obliquely inserted screws***.



749

More mechanically demanding fixations in, e.g., heavy, non-compliant patients with flat feet are stabilized with a plantar plate joining the navicular bone to the first cuneiform. This plate can be very thin as it acts as a plantar tension band. In more extensive instability distally, the fusion is extended through the same approach to the first metatarsus ***(O344-345)*** [61].

6

6.5.16 Talo-Metatarsal Arthrodesis

This procedure is the most stabilizing operation of the medial column of the foot. It corrects uncontrollable instability of the talo-navicular and distal joints ***(O352-353)***. The ***approach goes through the medial utility***


750

and additional ***percutaneous limited incisions to insert the implants, either on the dorsal aspect of the metatarso-phalangeal joint***


751

or on the ***postero-lateral aspect of the talus (F518)***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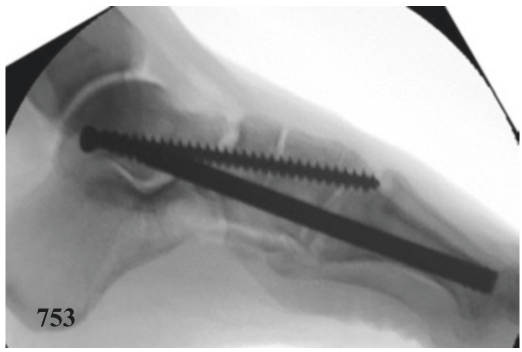
The implant(s) bridge four bones on a long lever and thus must be particularly resistant. A ***second axis of fixation*** is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therefore essential to ***catch the torque*** around the medial column of the foot.


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


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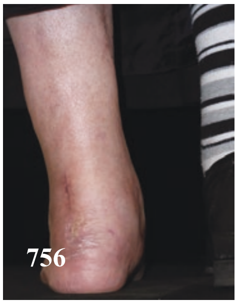
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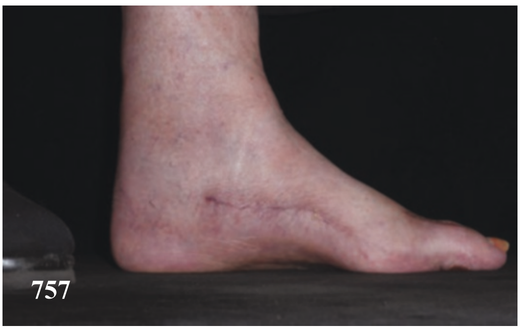
The reconstructed longitudinal arch resists weight-bearing through the ***internal beam.***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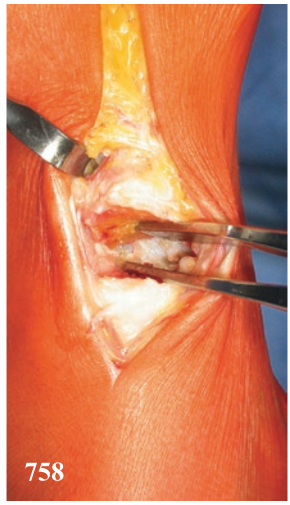
6.5.17 Fusion of the First Tarsometatarsal Joint and First Intermetatarsal Space *(E137-138)(O385)*

The approach is dorsal to the first ray, lateral to the extensor hallucis longus tendon ***(T627).*** The first cuneo-metatarsal joint and the space between the first metatarsus and the second cuneiform are visualized. The neuro-vascular 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 be able to ***visualize the long peroneus tendon fibres at the bottom of the joint***.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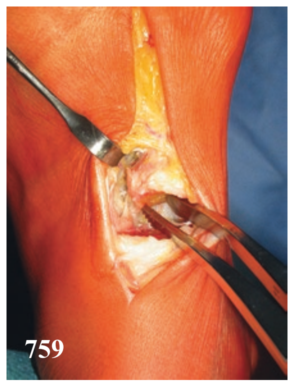
By twisting the spreader, ***the first metatarsus is moved medially***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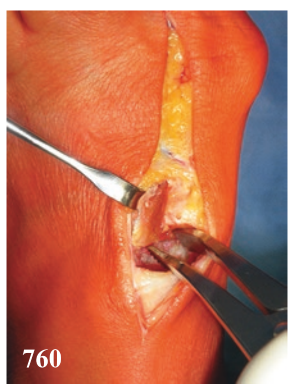
and the ***lateral condyle of the bone can be removed*** precisely with a straight and thin osteotome.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Continuing to hold the neuro-vascular bundle laterally, the periosteum of the medial basis of the ***second metatarsus*** is scraped and chiselled down and the ***first layer of the cortical bone is removed*** using the thin osteotome on about 1 cm^2

761

The horizontal correction of the first metatarsus depends on the resection of the corresponding bone on both first cuneiform and first metatarsus.

In case of a relevant horizontal malorientation (subluxation) of the metatarso-sesamoidal joint, the skin incision is prolonged towards distal to the dorso-lateral aspect of the first metatarsal head. The small dorso-lateral nerve is held laterally to expose the joint capsule. By stretching the first metatarsus towards medial, the arthrotomy is performed horizontally from the first phalanx to the posterior part of the metatarsal head until the lateral sesamoid bone is visualized. In some cases, ***an occasional lateral osteophyte*** is ***removed from the metatarsal head***.

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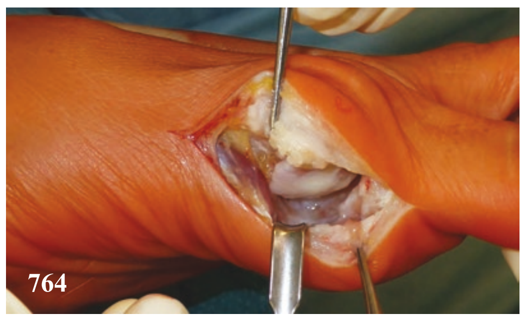
The medial aspect of the metatarso-phalangeal joint is approached through a second incision of about 5 cm ***(T618)***, avoiding the dorsal and plantar nerve of the hallux. ***The medial capsule is divided and mobilized*** from the metatarsus.



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An occasional pseudo exostosis is removed and the synovialis removed if irritated.

Under visual control through both approaches, a blunt elevator can be moved horizontally from distal to proximal on about 3 cm between 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 rotational adjustment is best achieved using a transverse Kirschner wire within the metatarsus and ***used as a joystick,***

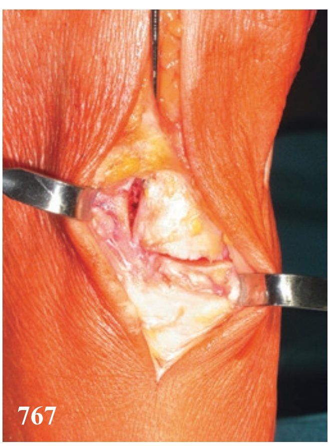

765


766

which allows for correction of an eventual pronation of the first metatarsus.

The first metatarsus head can now be positioned on the top of both sesamoids and at the correct height and rotation.

Following the metatarso-phalangeal release, orientation of the first ray is performed and fixed by ***impacting the base of the metatarsus within the angle metatarsus2 – cuneiform1***.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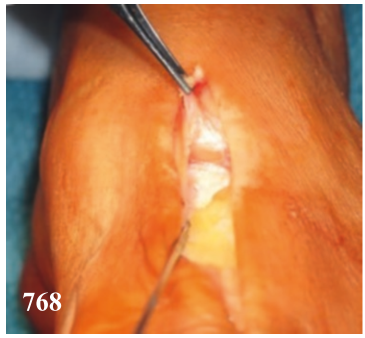
At this point, the vertical adjustment is best achieved by ***sliding up or down the first metatarsus on its cuneiform*** counterpart.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Provisory 1.6 mm Kirschner wires hold the position assisted by an occasional ***reduction clamp which helps when positioned between the metatarsal neck and percutaneously lateral to the second or third metatarsus***.


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Final 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. Three bones are fixed: first metatarsus-second metatarsus-first cuneiform. The antero-medial angle of the foot is thus stabilized providing for a new articulation with less amplitude: ***the joint between the three mutually fixed bones and the second cuneiform (O390)*** [29].

772

In large feet and if the patient is heavy and/or not reliable, the fixation will be increased (3–4 screws). Attention should always be drawn to the plantar buttress of the anterior heel. At the push-off phase of gait, the sagittal alignment of the metatarsal heads become essential. The fairly invasive liberation and reduction of the subluxation of the metatarsal head above the sesamoid bones implies a new mobility pattern between both articular structures. If scarring occurs after arthrolysis, secondary anchylosis ensues. Free plantar flexion of the metatarso-phalangeal joint is essential for functional push-off (***E144)***. The patient should therefore exercise early passive flexion in the post-operative period.

In revision cases, eventual ***length discrepancy between the metatarsals (E61) (O464)***

773

must be corrected by lengthening the first ray and ***shortening the lesser metatarsi (O465)***. In selected cases, the axial tension of the first ray is efficiently reduced by ***shortening the first phalanx (O414).***

774

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Autologous bone blocks from the pelvic crest and/or the osteotomized metatarsi are properly placed between the first cuneiform and the first and second metatarsus.


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6.5.18 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 ***(O371)***. The surgical approach is dorsal between the two corresponding rays ***(T632)***. A little branch of the fibularis superficialis nerve may cross the field and must be recognized and protected. The triangular space ***between the short extensor of the hallux and the long extensor tendon of the second toe*** is easily recognized and those structures are gently ***held apart to find the second and third TMT joints.***


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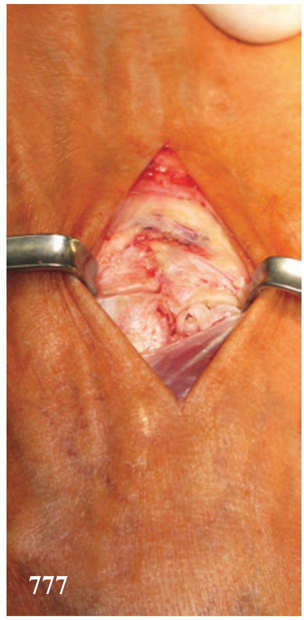
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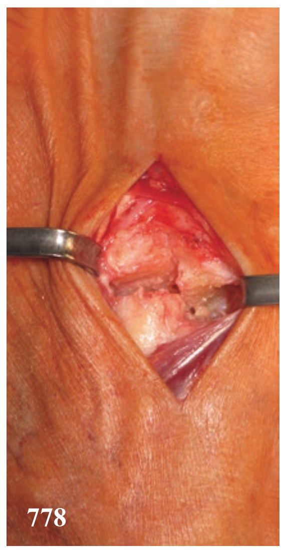
The joints are debrided and the ***residual cartilage with subchondral bone removed.***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The bone surfaces are approximated with the desired angulation, especially in the sagittal plane, and the corresponding level of the metatarsal heads is checked. The space between the third and the fourth metatarsi is better released to allow for length adaptation during this fusion. This is especially true in relevant shortening. ***Temporary fixation allows for definitive position control***.

779

Fixation occurs with screws, preferentially from proximal to distal.

In order to complete the fusion of the second ray, the medial side of the second metatarsus base is also approached, removing the cartilage and the corresponding lateral side of the first cuneiform for fusion. This takes place while continually protecting the neurovascular bundle by holding it gently towards medial. The approach remains proximal to the intermetatarsal perforating branch of the dorsalis pedis artery. Fixation occurs from medial, applying a screw through a stab incision on the proximal medial aspect of the first cuneiform. Its course follows the Lisfranc ligament: oblique from medial towards distal lateral, catching the basis of the second metatarsus ***(T371)***.

In cases of inflammatory or degenerative articular degeneration, ***all three medial tarsometatarsal joints are fused,*** including an eventual relevant reorientation.

780

In those cases, a second longitudinal approach to the first tarsometatarsal is performed to complete the fusion. Fixation means involve a number of 3.5 mm ***screws placed percutaneously from medial.*** Those screws join the first metatarsal to the third cuneiform and the first cuneiform to the third metatarsus in addition to the selected fixation of the two central rays. This fixation may e***ventually include plates***.

781

These approaches allow the dorsalis pedis neurovascular bundle to be protected and leave the insertion of the anterior tibial tendon untouched.

6.5.19 Fourth and Fifth Tarsometatarsal Arthroplasty

(O377)

The skin incision lies exactly between the proximal metaphysis of the fourth and fifth metatarsi ***(T631)***. The bones are covered here by the fibularis tertius tendon which is mobilized to reach the underlying joints. 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 corresponding long ***extensor tendons are then harvested***


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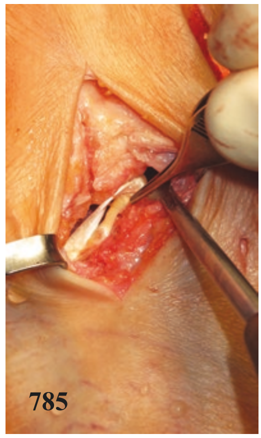
and the distal limb is adapted to the short fourth extensor tendon. The ***tendinous material is laid together smoothly in the groove***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separating the cuboid bone from the metatarsi.

The fibularis tertius tendon, the ***short extensor muscle and subcutaneous layer*** is adapted onto the plasty followed by the skin closure.


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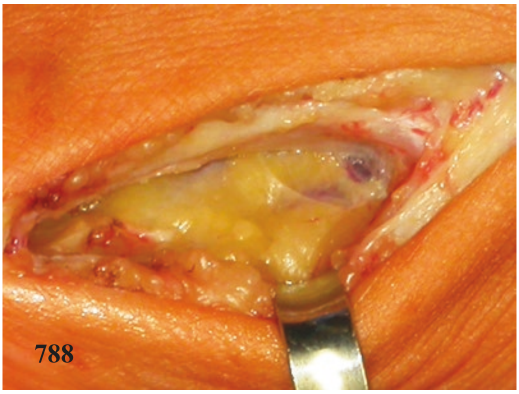
This montage allows for immediate, full weight-bearing using a rigid sole shoe.

6.5.20 Diaphyseal Osteotomy of the First Metatarsus

(O414)

The incision is made on the medial side of the metatarsus along the "medial utility line". The abductor hallucis is pushed towards plantar and the ***plantar aspect of the first metatarsus is expos*****ed** epiperiostally.



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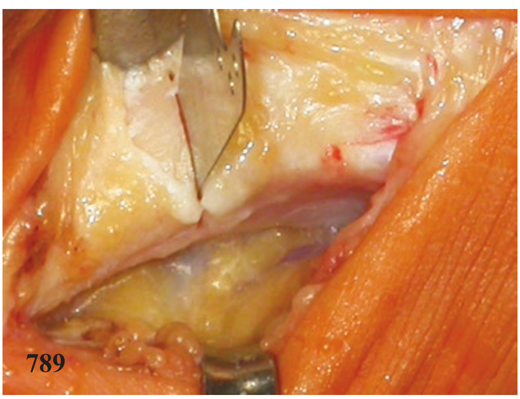
The distal metaphysis of the bone is not exposed to avoid harming the major nutrient vessel entering the bone which lies about 1 cm proximal to the posterior edge of the articular cartilage. If only shortening is the aim, the plate is adapted to the concave shape of the bone. If extension is desired, 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 ***proximal osteotomy is performed incomplete and a blade is inserted*** for orientation.



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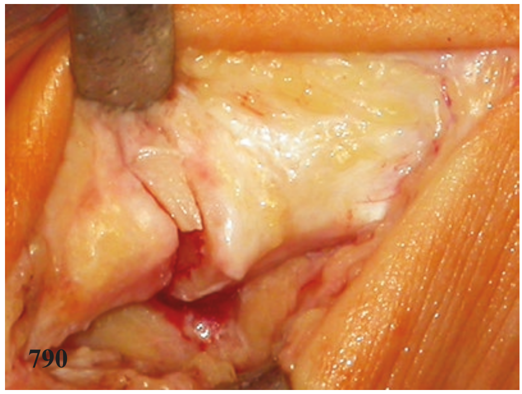
The second, distal osteotomy is performed either completely parallel for shortening or as a ***dorsal substraction wedge*** for dorsal extension.



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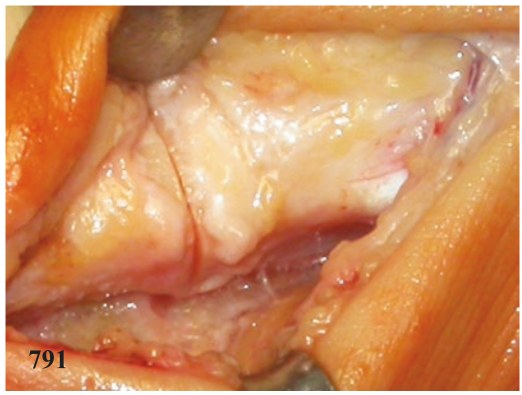
The wedge is removed and ***both fragments adapted***.



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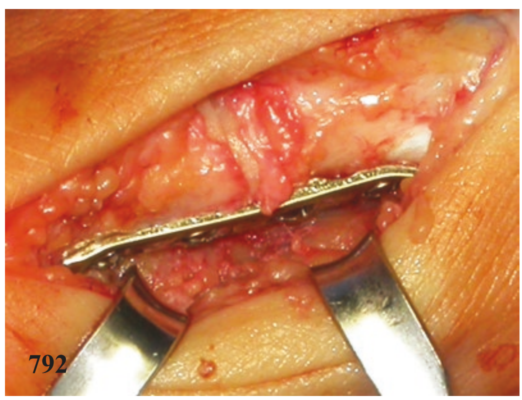
The plate is applied using the previously drilled borehole and a screw. The ***other three screws*** are put in place.



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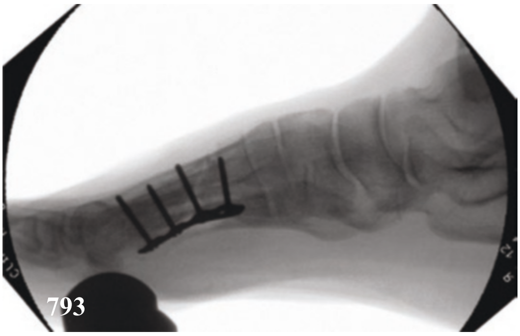
The plate is in a tension band position and ***stable for full weight-bearing***.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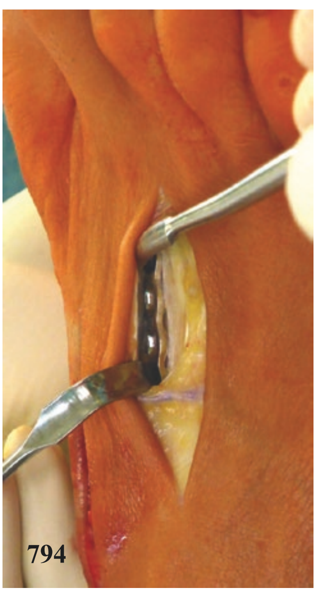
6.5.21 Diaphyseal Osteotomy of the Second and Third Metatarsus

(O465)

The approach is dorsal in between the second and the third metatarsus. This incision is perfectly compatible with a concomitant stabilization of the first ray. Beneath the skin the dissection is directed individually to both metatarsi, sparing a thin branch of the nervus fibularis superficialis. 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 4 holes*** is applied and adapted anatomically using pliers.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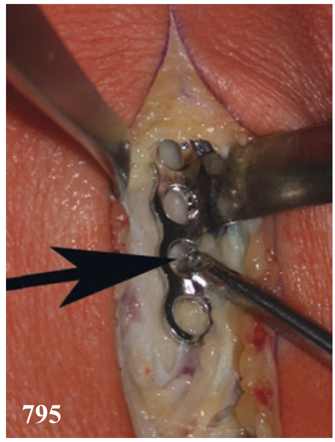
The ***second screw hole, numbered from proximal***, is drilled and the screw length determined.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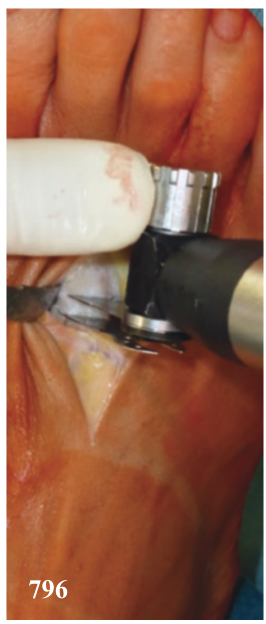
This allows rapid and safe application of the plate after the osteotomy.

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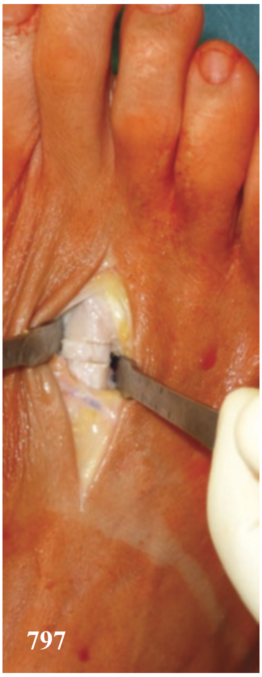
The proximal cut is then completed under stable conditions. ***Shortening of up to 10 mm is not a problem***.



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

798

The aid then holds and directs 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*** [118]

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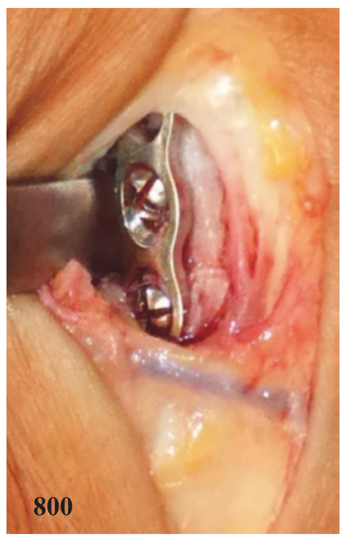


800

thus approximating the osteotomy planes and applying interfragmentary compression by tensioning 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.

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

completes the fixation.

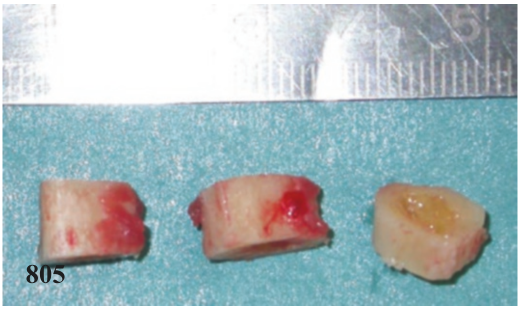
Such a montage ***allows full weight-bearing*** after surgery.

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

6.5.22 Diaphyseal Osteotomy of the Fourth Metatarsus

In selected cases of metatarsalgia 2-3-4, correction osteotomies aiming at shortening and/or extension are performed ***through 2 separate incisions (T633)***.

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


805

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


806


807

Thanks to the strong intermetatarsal soft tissue connections, i.e. the intermetatarsal ligament and the interosseous musculature, multiple osteotomies fixed by dorsal plates **allow for immediate full weight-bearing** in the post-operative phase.

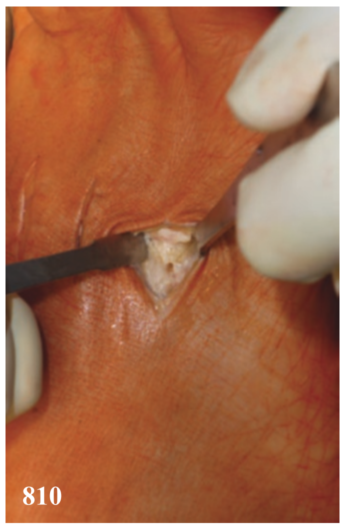
808


809

6.5.23 Proximal Metaphyseal Osteotomy of the Second, Third and Fourth Metatarsus

(O409)

The skin incision is about 2.5 cm in length, right over the proximal metaphysis of each metatarsus. The bone is exposed subperiosteally with a narrow periosteal elevator in an oblique fashion on each side of the bone directing from dorsal towards distal plantarwards. A 2 mm drill hole is performed at the same angle in the middle of the bone, close to the joint. Using a very small saw blade and obliquely positioned narrow retractors, an inclined vertical chevron-shaped osteotomy is performed [63] following the defined inclination and ***confluent proximally with the central borehole***.


810

Using a clamp and/or a thin, small osteotome, ***the distal part of the metatarsus is mobilized,***

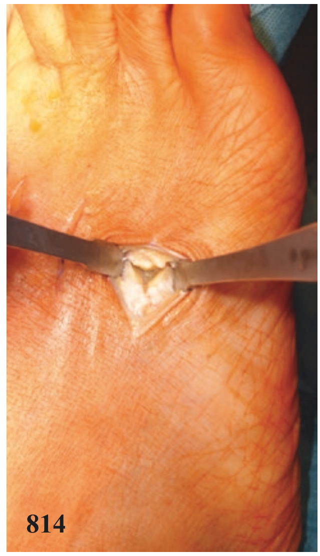

811

from the adherent soft tissues ***to allow guided gliding of the osteotomy planes*** on each other, towards dorsal and proximal.


812


813

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


814

The procedure is the same for all 3 metatarsi and does not entail any fixation means. Postoperatively however, the patient bears his whole weight immediately on a plantar orthosis including a retro-capital elevation pad and a shoe with a rigid sole ***(O365)***. The position of the osteotomy allows for a suspended hold through the interosseous musculature throughout weight-bearing conditions. The metatarsi thus remain attached to each other by the soft tissues including the intermetatarsal ligament, and the central anterior heel remains aligned.

6.5.24 Diaphyseal Adduction Osteotomy of the Fifth Metatarsus

(O407)

The incision is lateral to the fifth metatarsus ***(T634)*** and the muscle belly of the abductor digiti quinti is ***retracted plantarwards***.


815

The osteotomy is horizontal, dividing the naturally oblique metatarsus by a large osteotomy plane. The distal fragment is ***rotated in adduction*** on this large bony surface and fixed by two 2.0 mm screws ***(O408)***.

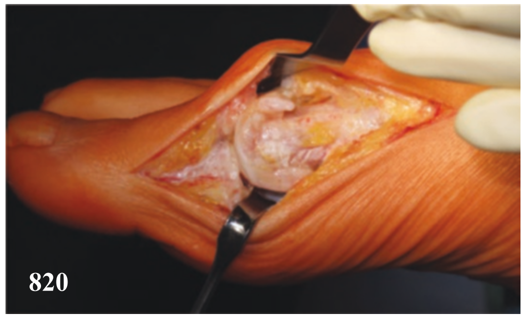
Cortical bone edges are removed using a rongeur

to avoid painful spots beneath the skin.

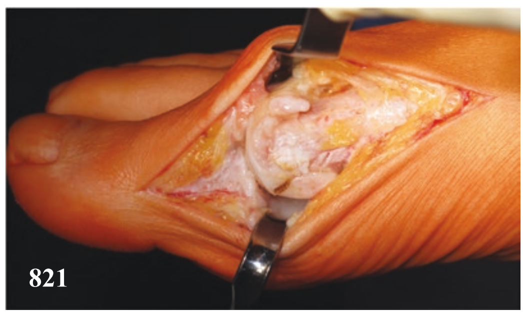
6.5.25 Intracapital Extension Osteotomy of the First Metatarsus (Watermann) [119]

(O416)

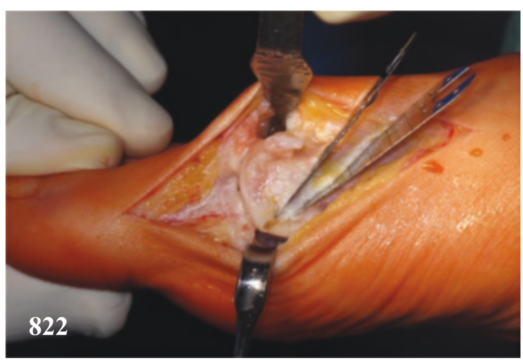
The ***approach is medial*** to the first metatarso-phalangeal joint, between the dorsomedial and the plantar medial nerve.



The arthrotomy demonstrates the metatarsal head. The slight change in curvature of the cartilaginous layer which separates the metatarso-phalangeal from the ***metatarso-sesmoidal joint is marked***.



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



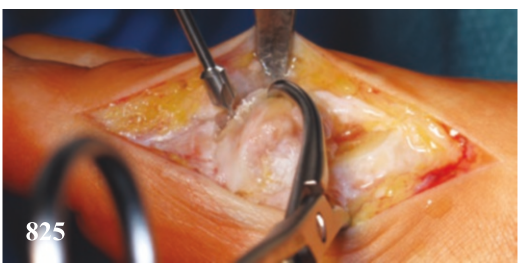
The cartilaginous layer is not cut. After removal of the intercalary bone, the distal fragment is carefully ***reclined towards posterior***,

823

hinging at the cartilage using a small reduction forceps.

824

Fixation is performed with a 2 mm screw from dorsal which is ***countersunk deep into the cartilaginous layer***.



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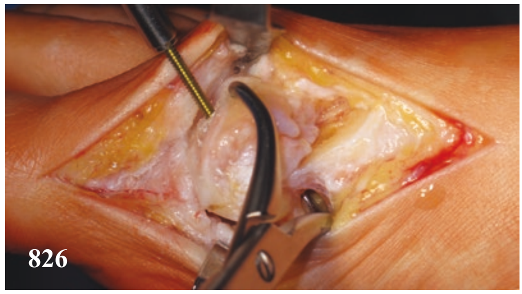

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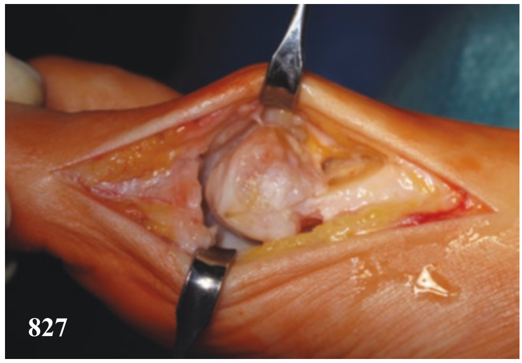

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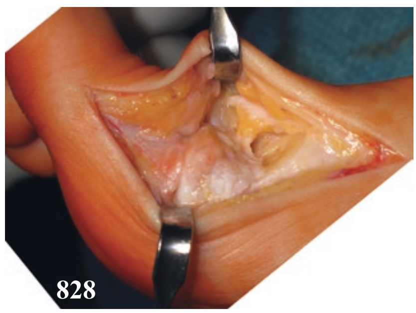
Sagittal ***mobility is increased*** due to the reduced dimension of the metatarsal head



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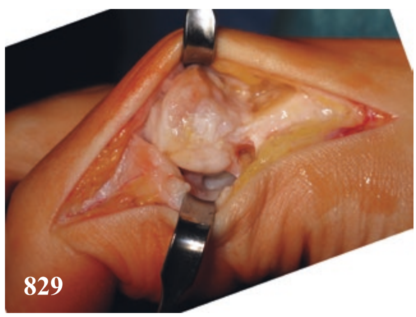

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6

6.5.26 Intracapital Extension Osteotomy of the Second and Third Metatarsus (Gauthier) [69] *(O426)*

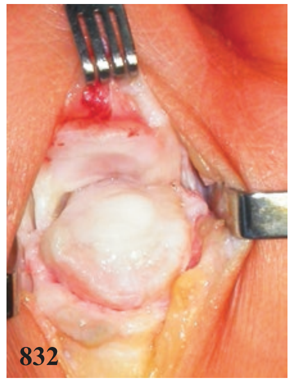
The incision is located above the metatarsal head. Best access is ***between the long and the short extensor tendon*** to avoid shortening through scarring.

830

After arthrotomy, which spares the plantar plate, the ***arthritis and joint destruction is evaluated***.

831

Manual distraction reveals the articular damage and demonstrates ***the intact plantar part*** of the head.

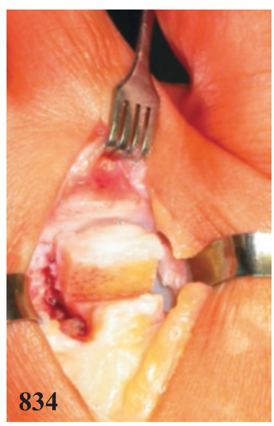


832

The ***lateral and medial osteophytes of the metatarsal head are carefully removed***.

833

An oblique osteotomy from distal dorsal towards the neck of the metatarsus is performed incompletely in order to evaluate and perform a ***vertical osteotomy which converges*** with the first cut.



834

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 which are countersunk*** into the cartilaginous layer.

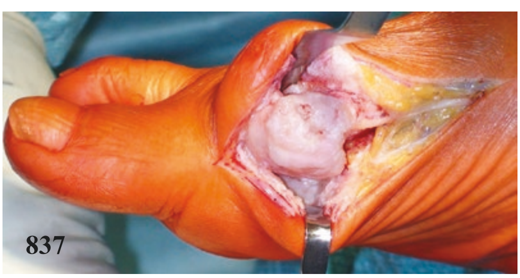
835

836

6.5.27 First Metatarso-Sesamoido-Phalangeal Joint Fusion

(O421)

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. ***The joint is opened***



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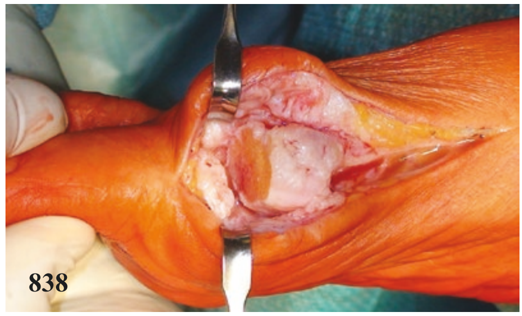
and the adductor hallucis is held towards plantar. The ***joint surfaces undergo resection using an oscillating saw*** avoiding heat necrosis.



838

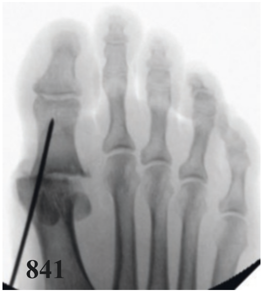
Any significant shortening should be achieved at the phalangeal side because the metatarsal head is essential for antero-medial weight-bearing and the metatarso-sesamoid fusion surface. The orientation of the first phalanx is crucial for smooth function. The aim is to achieve an ***exact horizontal***

839

840

and slight valgus position of the phalanx for optimal push-off. Shifting the phalanx onto 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.



841

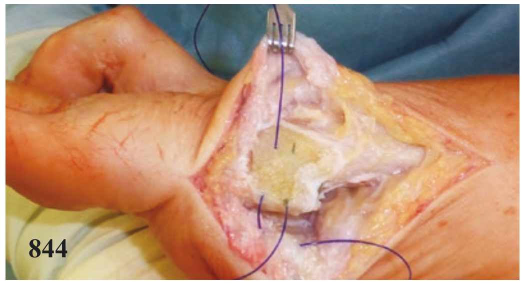
The horizontal orientation is verified with a vertical beam of a fluoroscope. Definitive fixation is secured using a 3.5 or 4.0 mm screw driven through the head of the metatarsus towards distal in the exact axis of the first phalanx. The condyles of the metatarsus act as an ***optimal countersink for the head of the screw***.

842

A second parallel screw, smaller in diameter if required, replaces the K-wire and secures the ***rotational stability*** of the montage.

843

The medial and dorsal overreaching bone is removed. The cartilaginous layer on both sides of the metatarso-sesamoid joint is then removed. A ***strong osteosuture***



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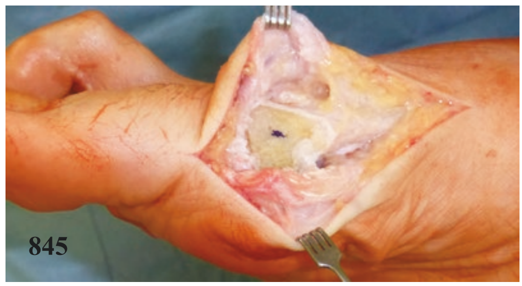
crossing the metatarsal head ***holds the sesamoid girdle*** for safe consolidation.



845

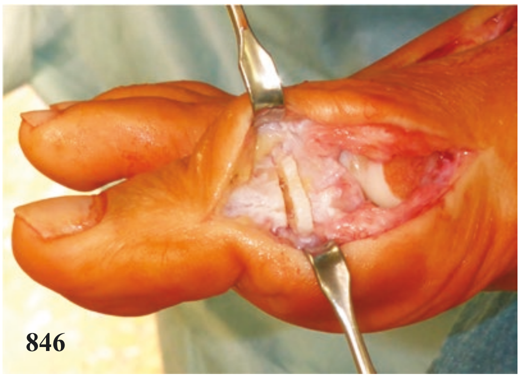
This fixation is ready for full weight-bearing using a rocker bottom walker [66].

6.5.28 Osteotomy of the First Phalanx of the Big Toe

(O414)

The skin incision lies on the medial utility line between the dorsal and the plantar medial nerves of the hallux ***(T534)***. The first metatarso-phalangeal joint is opened plantarwards. 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 evident 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.



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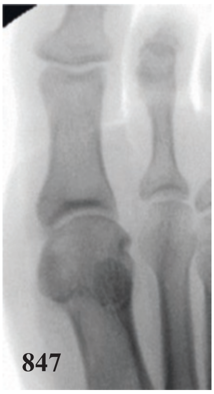
Approximation of the fragments is held with a ***temporary oblique K-wire***.



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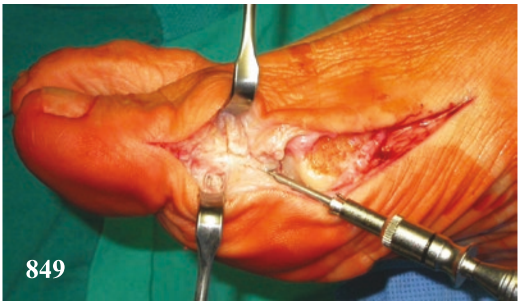
848

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.



849

This fixation is stable for ***full weight-bearing*** using a protecting shoe.

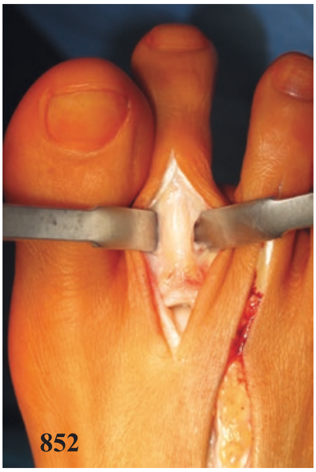
850

851

6.5.29 Shortening Osteotomy of the First Phalanx of the Lesser Rays

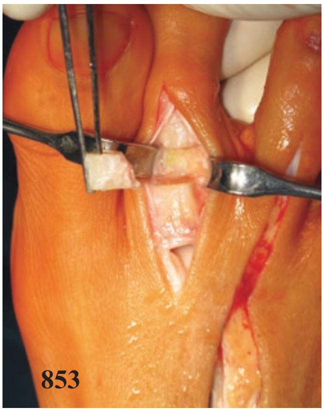
(O465)

The skin incision lies ***dorsal to the toe***.



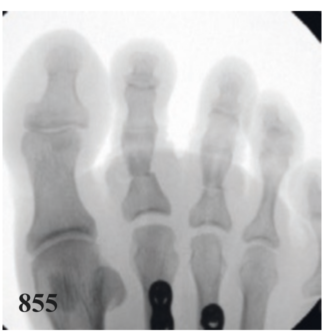
852

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. The mid-diaphyseal bone is divided using a micro-oscillating saw. The ***shortening length is determined by the proximal osteotomy.***


853

Fixation is secured using a ***straight profiled resorbable pin*** driven through both approximated fragments ***(F510)***.


854


855

6.5.30 Proximal Interphalangeal Fusion

(O439)

The skin incision lies on the top of the toe ***between the intermediate phalanx and the head of the metatarsus***.


856

The metatarso-phalangeal ***joint is opened wide*** just leaving the plantar plate of the joint capsule.


857

The ***proximal interphalangeal joint***


858

undergoes resection aiming at a slightly ***physiological angle in flexion*** of the fusion.

859

A 2.0 mm drill hole is made within the intermediate phalanx and through the first phalanx ***from the joint surface towards distal***.

860

A curved and profiled resorbable pin ***(F510)*** is driven by gentle hammering through a guiding sleeve from the joint through the first phalanx and ends ***within the intermediate phalanx*** [120].

861

The proximal ***overhanging extremity of the pin is resected flush*** to the cartilage surface of the joint

862

This montage achieves an immediate ***rotational functional stability*** in an anatomical orientation.

863

6.5.31 Distal Interphalangeal Fusion

(O453)

The skin 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***

864

and driven to the middle phalanx in a slightly functional flexion.

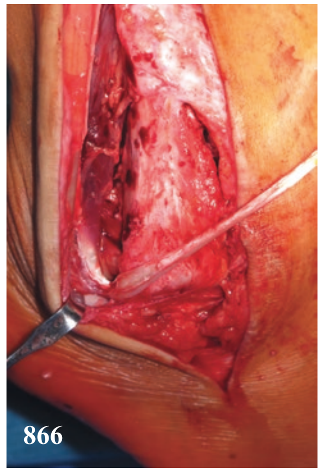
865

6.6 Ligamentous Reconstruction of the Ligaments About the Ankle Joints

6.6.1 Syndesmosis

The aim is to restore the mobility and stability between the distal tibia and fibula. The most logical approach is to reconstruct all three ligament components of the syndesmosis by means of the posterior, the intermediate and the anterior tibio-fibular ligaments ***(O253)*** [42]. As most cases are at the chronic stage and the local ligament structures are absent ***(O251)*** 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.

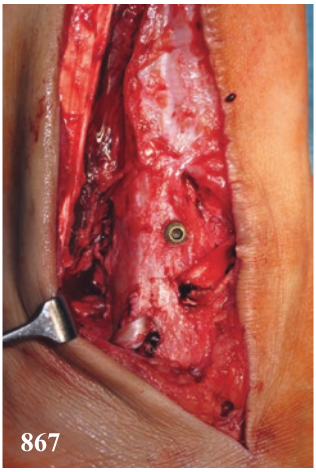
The graft is the anterior third of the tendon. The incision along the tendon runs up to 12 cm proximally and the graft is cut to obtain a ***distally pediculated graft beginning 10 mm below the tip of the fibula***.



866

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 postero-medial edge of the bone. Another hole is drilled through the fibula about 1.5 cm above the first hole, running slightly towards posterior, entering the postero-lateral extremity of the tibia. Another short hole is drilled from the posterior aspect of the tibia, converging the first borehole. 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 to adjust the fibula within the syndesmotic gutter ***(T588)***. It is placed horizontally between the tip of the fibula and the medial malleolus ***(F492)***. The graft is then pulled tight, directed towards 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.



867

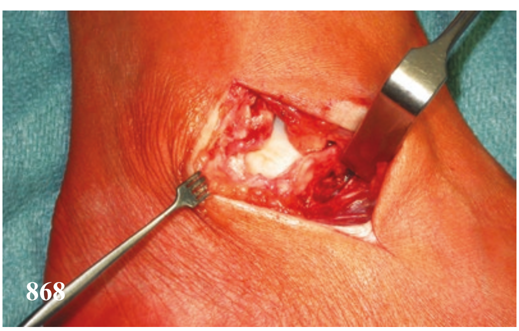
A screw or a cable ***(F493)*** replaces the clamp and secures the position of the fibula in its tibial concavity ***(F494)***.

6.6.2 Anterior Fibulo-Talar Ligament

6.6.2.1 Repair

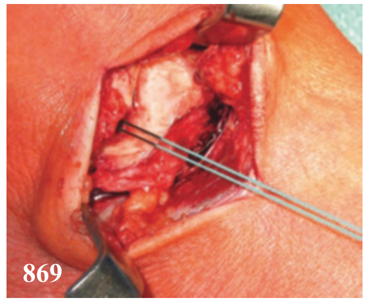
(E100)

The reconstruction of the antero-lateral ligament of the upper ankle joint, e.g. the ligamentum fibulo-talare anterius, is a keystone for rotatory (internal rotation of the talus) and sagittal (anterior shift for the talus) ***(E104)*** stability. The approach is either longitudinal or oblique (antero-lateral approach) with neither having an advantage over the other. The traumatized ligament is always ***stripped off its fibular origin.***



868

In some cases, the torn ligament is attached to a bony avulsion of the fibula. This occasional fragment is obviously avascular and is advantageously removed. Attaching non-resorbable sutures to the fibular side of the ligament preferably ***through an anchor***,



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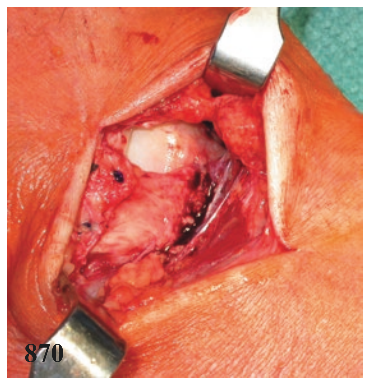
the ligament is taken and ***sutured in external rotation*** of the talus to the fibula [43].



870

Augmentation of this suture is performed taking the proximal edge of the frondiform ligament (retinaculum) and attaching it with the same sutures [121].

6.6.2.2 Plasty

In the absence of the ligament, a rationale choice should be made for a biological autologous transplant. There are two reasonable choices: If the calibre of the transplant is relevant, the ***anterior part of the short fibular tendon*** is a good choice.

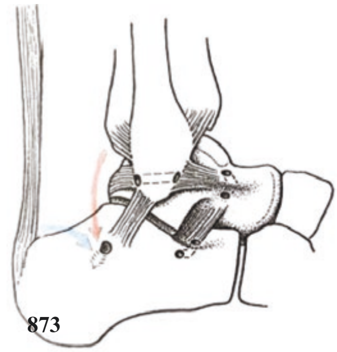
It runs close to the posterior aspect of the fibula exactly ***at the insertion of the fibulo-calcaneal ligament***.

871

In cases where the dimension of the transplant is not essential, the plantaris longus may be 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.***

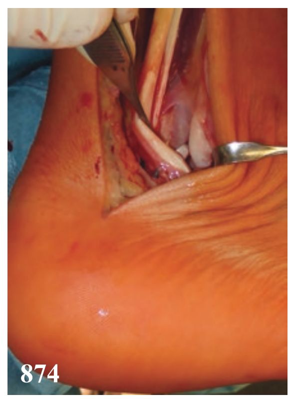
872

An oblique borehole through the calcaneus brings the transplant exactly ***at the insertion of the fibulo-calcaneal ligament***.



873

For both choices, the transplant is secured at the insertion of the fibula-calcaneal ligament onto the calcaneus using a bony anchor. A horizontal borehole is drilled from the origin of the fibulo-calcaneal ligament on the fibula through the bone within the sagittal plane, aiming at the origin of the anterior fibulo-talar ligament. Tightened between the bone anchor and the fibular hole, the transplant ***reconstructs anatomically the calcaneofibular ligament.***



874

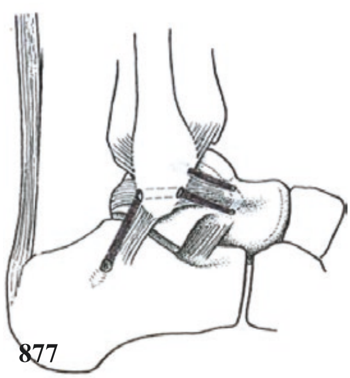
The sagittal borehole is aimed at the origin of the anterior fibulo-talar ligament. From there, the ***transplant is directed to the talus***


875

at the insertion of the anterior-fibulo-talar ligament (latero-dorsal 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 antero-lateral ligament with two limbs***.


876

Back to the fibula, the transplant is ***secured with a bone anchor*** or conducted into a second horizontal tunnel within the fibula.

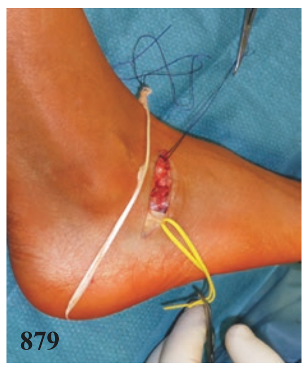

877

Healing of this approach is generally very safe. ***(T871)***


878

6.6.3 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.


879

The transplant is pulled across the sinus tarsi, crossing two 90-degree-angulated boreholes at the ***anterior aspect of Gissane's angle***


880

and through two similar 90-degree-angulated holes at the ***lateral neck of the talus***

881

882

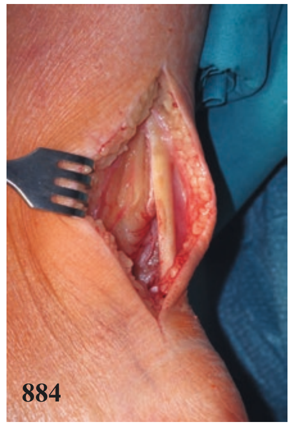
The upper and lower ankle joint ***stabilization can also be combined***

883

6.7 Tendinous Balance Reconstruction

6.7.1 Heel Cord Lengthening

The patient is supine, the contra-lateral 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 horizontally positioned nutrient vessels to the subcutaneous tissues. The ***incision measures about 8 cm along the medial edge of the heel cord***, and the peritenon is incised within the same plane ***(O193)***.



884

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 equally sized anterior and posterior limbs. The ***distal part of the cut ends anteriorly.***

885

The posterior limb is distal and the anterior limb is proximal, thus achieving the best conditions of vascularity and the contact surface between both limbs is maximized. This allows for an untouched postero-distal aspect of the tendon and avoids the healing callus being in a critical area.

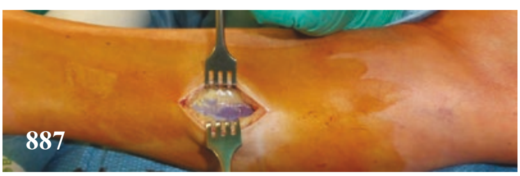
The ***final length of the heel cord is carefully adapted*** by playing with the upper ankle joint.

886

Three adaptive isolated sutures are placed with slow resorbing material closing the knots anteriorly. The peritenon is adapted with fine suture material and there are continuous sutures at the skin.

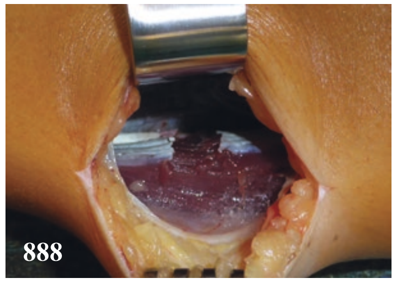
6.7.2 Gastrocnemius Fasciotomy

The patient is supine and the heel placed on a solid cushion. The shape of the musculus gastrocnemius is evaluated as its extension is very variable. The ***skin incision is longitudinal, measuring about 4 cm at the distal portion of the medial musculus gastrocnemius.***



887

An incision is made to the fascia cruris at the same level. Applying digital dissection, the separation of the musculi soleus and gastrocnemius medialis is found and visualized to their merging point distally. At about four centimetres from its insertion, the ***ventral fascia of the gastrocnemii is incised transversally*** along the whole width of the muscle ***(O194).***

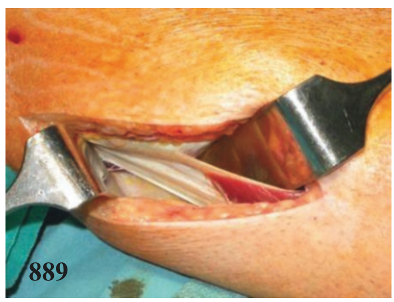


888

Care is taken not to cut any muscle fibres. The foot is extended forcefully towards dorsal to achieve about 3-4 cm structural elongation.

6.7.3 Gastrocnemius Tenotomy

The patient is positioned and the calf is approached as before. After visualization of the gastrocnemius insertion, 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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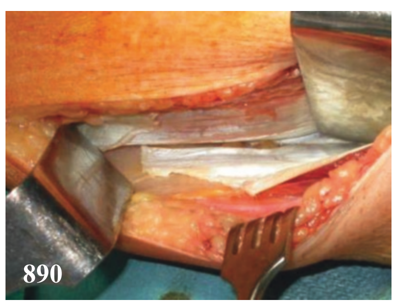
The gastrocnemius tendon is cut by scissors along its whole width ***(O195)*** [56]. Extending the foot fully, the ***muscle bellies retract automatically***.



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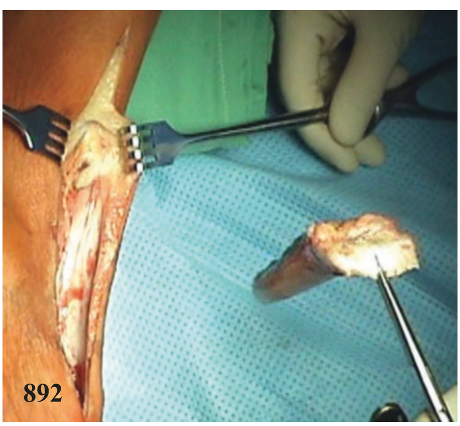
6.7.4 Heel Cord Plasty

In poorly perfused soft tissue ***(E17) (R186)***, including the tendon itself, it may be wise to look for a good vascular supply which 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 a 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 [122].

6

The patient is lying supine. The approach to the heel cord is performed longitudinally, medial to the tendon. After open inspection of the Achilles tendon, definitive indication for muscular flap transposition to the heel cord is decided. The ***tendon is debrided*** of all pathological and necrotic tissue and ***sometimes excised entirely***.

891



892

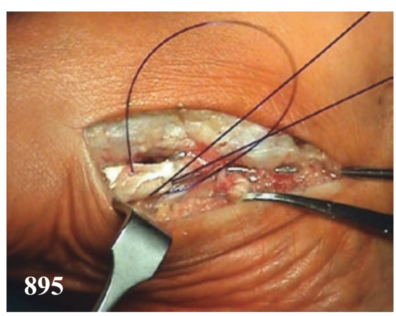
Lateral to the neuro-vascular bundle, the strong fascia of the musculus flexor hallucis longus is incised.

At this stage, the midfoot is approached from medial (medial utility) ***(T616)***, keeping close to the bone and remaining above the adductor hallucis longus, the "Master Knot" described by Henry [108] is incised and ***the flexor hallucis longus tendon is identified***.

893

The flexor hallucis longus tendon is tenotomized proximal to its expansions to the flexor digitorum longus tendon. The distal limb of the tenotomized tendon is pulled towards proximal provoking flexion of the hallux and is ***sutured through a buttonhole which is cut through the flexor digitorum longus tendon***.

894



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Returning to the first approach, the tenotomized ***tendon is pulled out*** of its pulley at the posterior aspect of the talus.


896

The tendon and its muscle are then detached progressively towards proximal. Attention is given to protect the fibular vessels located on the posterior aspect of the interosseous membrane. The muscle is ***mobilized towards proximal detaching it from the fibula,***


897

until its transposition to the posterior aspect of the calcaneus does ***not cause a relevant angulation (kinking)***


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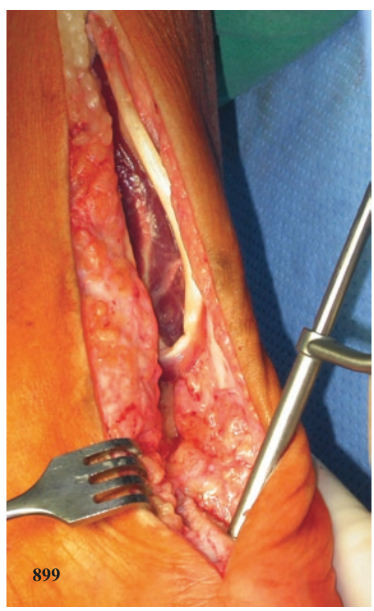
and its tensionless adaptation to the soleus muscle is possible. An ***8 mm hole*** is made from the top to mid-substance of the calcaneus at the ***most posterior aspect of the bone***.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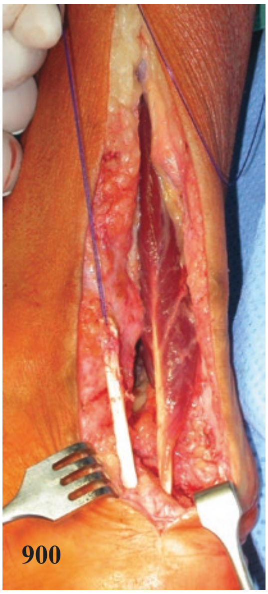
A horizontal joining hole is made from the medial aspect. The ***tendon is pulled through*** and pulled towards proximal



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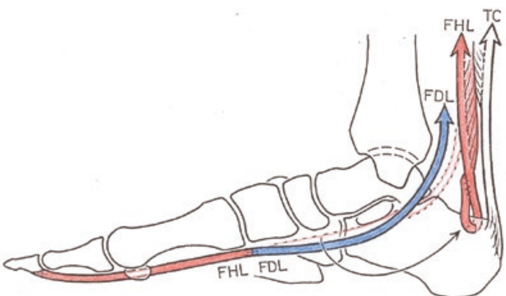
to be ***attached to the musculo-tendinous junction or more proximally if possible***.



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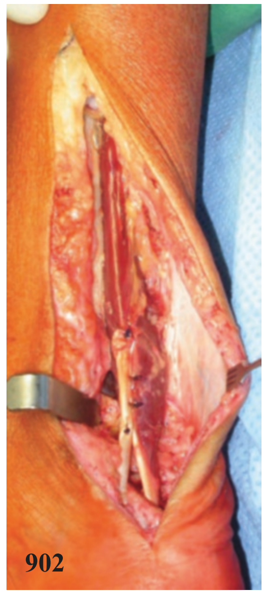
Attention is given to the ***tension of this attachment***: it should be done in a slight equinus of the foot

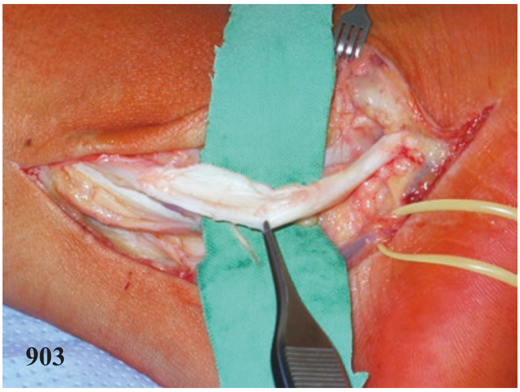


902

such as to allow a 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 [39].

6.7.5 Reconstruction of Fibular Tendons

These tendons rarely rupture acutely without prodromal symptoms or morphological abnormality. They are logically 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 which provokes irreversible lesions. These lesions are very different than those encountered at the posterior tibial tendon. Here, the tendon does not undergo hyperplasia but presents ***longitudinal splits and flattens,***



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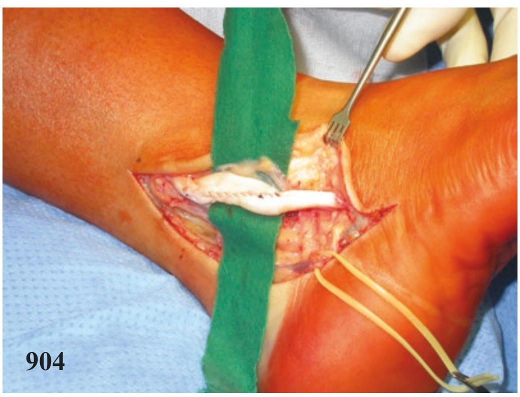
which may occur all along its course along the lateral aspect of the hindfoot. It also may separate into different parts without augmenting its diameter. The repair of the tendons includes a longitudinal suture (continuous) to ***restore their original tubular shape***.



904

The underlying cause of the chronic overload must always be evaluated before surgical treatment. It may include the morphological stabilization of the hindfoot by, e.g. lateralizing the heel and 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 neurological disease, pronation is powered by transferring the flexor hallucis longus tendon to the insertion of the fibularis brevis tendon ***(O320)*** [38].

6.7.6 Posterior Tibial Tendon Repair

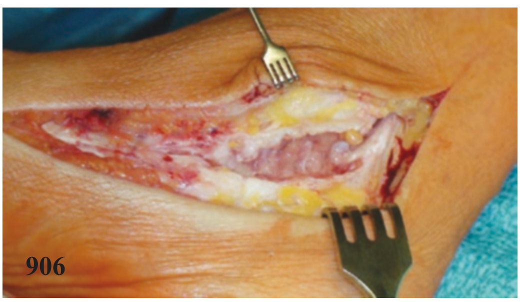
Similar to the heel cord, this tendon rarely ruptures without any underlying pathology. Experience shows however that purely traumatic ruptures occur at its insertion site and degenerative ruptures occur more proximally, about the retro-malleolar region. The acute, traumatic ruptures may respond well to a direct suture and careful after-treatment. The degenerative ruptures are due to a lack of blood supply [22] and a chronic inflammatory status which cause micro-ruptures and result in a ***larger tendon by hypertrophic scarring***.

905

The volume of such a tendon can thus increase 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 ***(E18)(E59)***: the mid-tarsal lever is no-longer efficient to transmit push-off. The distal part, especially the medial aspect of the foot extends, abduct and invert 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 the lateral process of the talus abuts onto the calcaneus about the critical angle of Gissane or floor of the sinus tarsi. Conventional radiographs demonstrate a disturbed alignment of both talus and first metatarsus axes ***(R169)***.

At this stage, a re-establishment of normal mutual osteo-articular orientation is clearly indicated to avoid degenerative diseases of the joint surfaces ***(O290)(O307)***. If this has already occurred, fusion of the four main bones of the hindfoot is necessary in order to re-establish the needed orientation of the foot beneath the upper ankle joint ***(O325-328)***.

In all stages of this degenerative disease, it is logically wise to re-establish the normal equilibrium of the extrinsic musculature and tendons. The tendon which runs closest to the posterior tibial tendon is the flexor digitorum longus ***(T615)***. It has the advantage of not being essential in its function of flexing the tip of the toes. The anatomy demonstrates the tendinous link originating from the flexor hallucis longus tendon and connecting more distal to the flexor digitorum longus about 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 talo-navicular joint ***(T617)***. In cases where the posterior tibial tendon must be replaced, the approach is ***extended proximally to the retro-malleolar region***.



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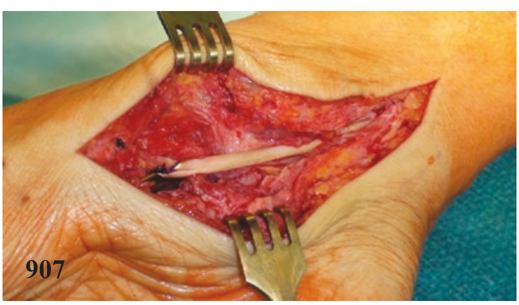
The transferred tendon then ***substitutes entirely the absent or resected posterior tibial tendon***



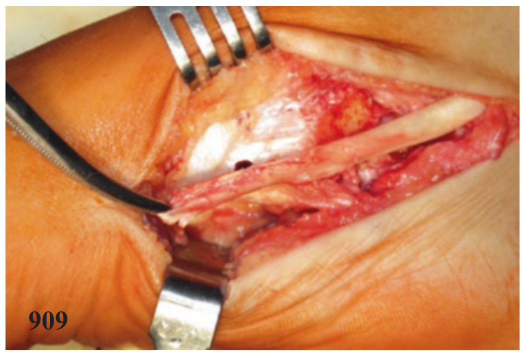
907

and is attached proximally with its muscle.

Leaving the adductor hallucis plantarwards, the roof of the medial arch allows the "Master knot" to be opened [21], disclosing ***the chiasma of the long flexors*** of the toes.

908

The flexor hallucis longus sends strong fibrous extensions to the distal part of the long flexors of the toes [53] and, therefore, ***harvesting the flexor digitorum longus***



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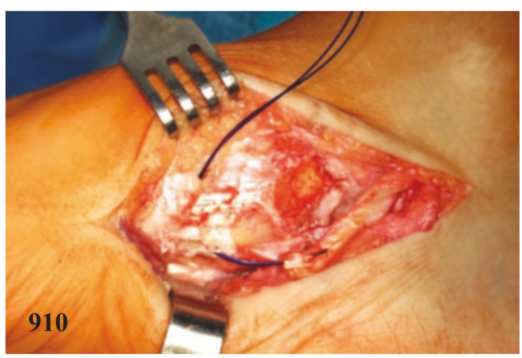
does not involve any relevant functional limitations.

A 4.5 mm borehole is made from plantar to mid-substance 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 [54] ***(O298)***.



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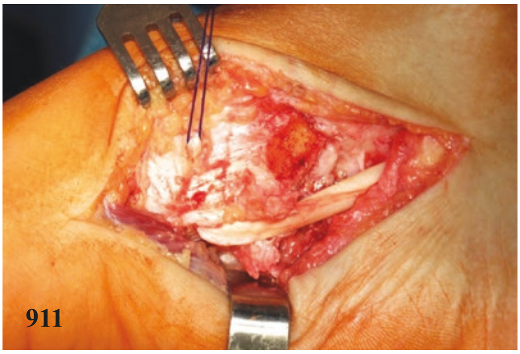
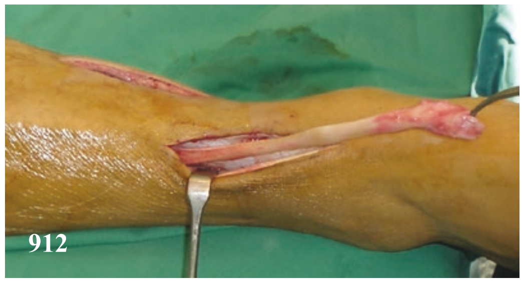

911

The length of the harvested tendon allows for this transfer and it secures the naviculo-cuneiform joint in addition to the sagging talo-navicular joint [55].

6.7.7 Posterior Tibial Tendon transfer onto the Dorsum of the Foot

(O196)

This transfer is very common in paralytic drop feet due to fibular paresis of all origins. As in all functional tendon transfers, a thorough neurological status (mapping) of all extrinsic muscles of the foot is helpful before surgery. Balancing these extrinsic muscle forces is challenging. Any slight imbalance is known to produce clubfoot, cavus foot and some flatfeet [38]. Completely removing the muscle power which holds the medial arch of the foot may create such imbalance. As a safety and contemporaneous measure, a "benign" transfer such as moving the tendon of the long flexor of the toes to the medial arch can logically avoid such iatrogenic pitfalls [54]. The patient is lying supine having the contralateral leg slightly lowered. Four incisions to the skin are required. The tendon is harvested through a medial utility incision centred on the medial navicular bone including a small extension towards distal. After tenotomy of the posterior tibial tendon and without harming the plantar extensions, the Master knot of Henry 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 about the postero-medial crest of the tibia at about two-thirds of its length. The posterior tibial tendon and muscle is 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 performed about half-way 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 pulled through towards anterior*** [123].


912

At this stage, it must be verified that the muscle and tendon do not present any angulation or kinking at this re-routing. From this point towards distal, the tendon will be driven through the subcutaneous tissue for optimal force transmission and gliding. A fourth incision is performed 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 borehole of about 8 to 10 mm diameter is drilled from the top of the foot to the medial plantar aspect of the foot***,


913

corresponding to the first cuneiform.

The flexor digitorum longus tendon is pulled through the borehole 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.

6.7.8 Long Toe Extensors Transfer on the Dorsum of the Foot

(O199)

In cases in which the posterior tibial tendon is not competent for reanimating the dorsal extension of the foot, relevant help can be found in the long extensors of the toes [38]. Equilibrium of the toes can be found by connecting the distal tendons of the harvested extensors to the short extensor of the neighbouring toes. Just as in transfer of the posterior tibial tendon on the dorsum of the foot, the point of action on the foot is critical. Dividing the extensor action on two distant spots seems valid at first sight but ends logically in a functional ankylosis of the underlying coxa pedis.

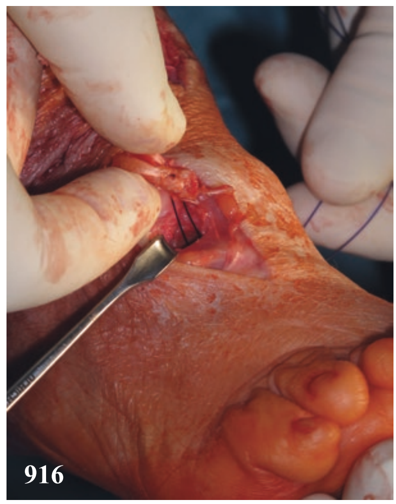
The appropriate approach to the dorsum of the foot is located at about the cuneiform level allowing the identification of the five tendons. At about the neck of each metatarsus, the long extensors are tenotomized and the distal limb is fixed without tension onto the respective extensor digitorum brevis tendon. The long ***extensor is then pulled out*** proximally.

914

A second incision is performed on the plantar medial aspect of the midfoot. A ***borehole is drilled*** from the desired and optimal insertion spot of the transfer to the plantar medial aspect of the first cuneiform.

915

All the tendons are then ***pulled through***



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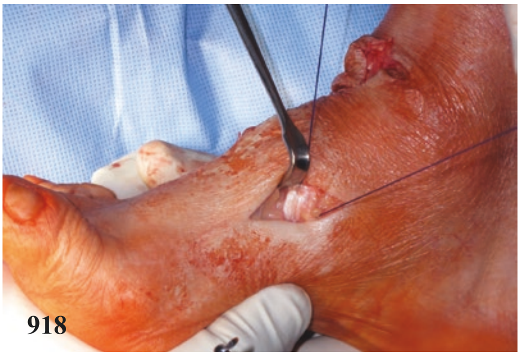
917

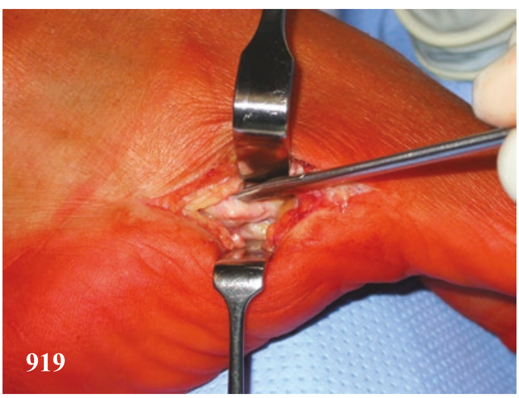
and ***fixed at the plantar side*** of the cuneiform, or to the extensions of the anterior tibial tendon ***while holding the foot in orthogonal position***.


918

6.7.9 Fibularis Longus Tendon Transfer onto Fibularis Brevis

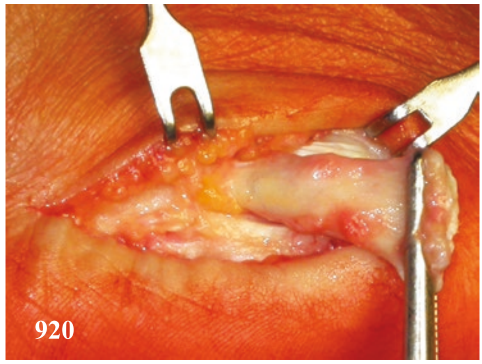
(O238)

Such a transfer is quite simple, requiring only one skin incision. The approach is thus lateral to the foot on about 5 cm proximal to the base of the fifth metatarsus. The fibularis brevis tendon is identified and a central hole is performed. Beneath this tendon and beneath the cuboid bone more proximal, the fibularis longus ***tendon is identified while turning in its plantar tunnel***.


919

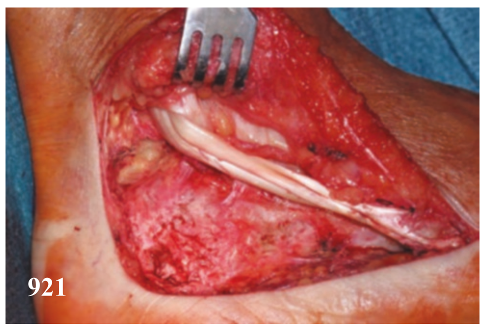
An eventual os peronealis is removed by enucleation.

The tendon is cut at this level and ***rerouted through the fibularis brevis tendon*** at its insertion.


920

The fibularis longus participates actively in the stability of the first metatarsal by powering flexion and abduction. In case of a congenital or other acquired instability of the first ray ***(E138) (R171-172),*** such transfer has the inherent risk of accelerating secondary imbalance of the forefoot requiring eventual stabilization ***(O387).***

Fibularis tendon repair **may need** the transfer of the neighbouring tendon. Such an approach needs a ***wider exposure,***


921

which heals uneventfully when the ***posterolateral flap is respected***

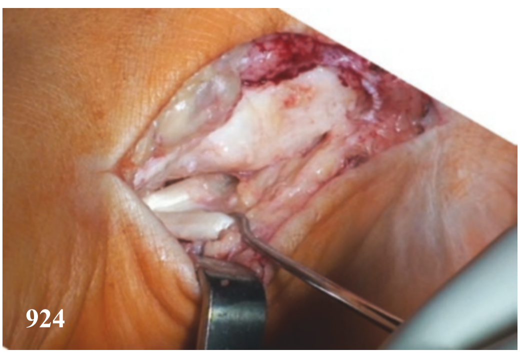

922


923

6.7.10 Flexor Hallucis Longus Tendon Transfer onto Fibularis Brevis

(O239)

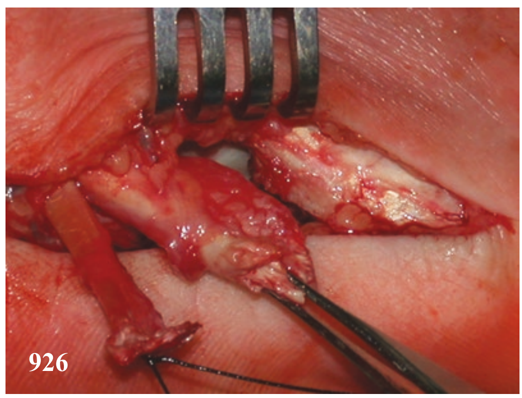
The rerouting of the flexor hallucis longus tendon to the lateral aspect of the foot requires three incisions. The first approach is along the medial utility line at the cuneiform level. The Master knot of Henry [108] is divided and ***the tendon is identified distal to its crossing with the flexor digitorum longus tendon.***


924

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 postero-medial approach is performed medially to the heel cord. ***The tendon is pulled out posteriorly***.


925

The fibular tendons are identified and the retinaculae opened widely from the postero-medial approach. On the lateral aspect of the foot, a third incision is performed about the insertion of the fibularis brevis tendon. To maximize active pronation, ***both flexor hallucis longus and fibularis longus tendons are transferred***.


926

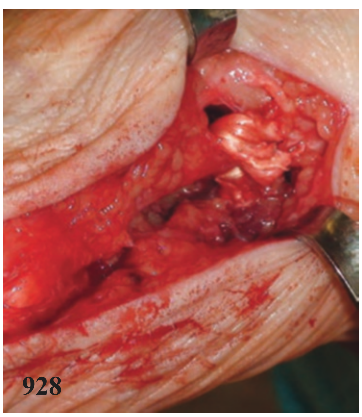
Here too, the retinaculae are opened towards proximally and the transplant pulled through to the fibularis brevis tendon where it gets anchored under slight pronation of the foot, allowing for a certain pretension of the tendon.

6.7.11 Flexor Hallucis Longus Tendon Transfer onto the Basis of the First Metatarsus

(O380)
This is indicated particularly in neurological and muscular diseases including metatarsus primus elevatus. The approach is longitudinal medial between the first metatarsus and the first cuneiform. Leaving the adductor hallucis plantarwards, the flexor hallucis longus tendon is followed distal from the chiasma of the long flexors of the toes. The ***tendon is then cut***


927

to be transferred to the base of the first metatarsus. The limb is pulled through a 4.5 mm borehole drilled within the sagittal plane through the base of the first metatarsus. The ***tendon is then attached to itself and to the insertion of the anterior tibial tendon***.


928

The TMT joint surface is more or less even and the function of the muscle is to hold the first metatarsal down, thus limiting shear motion towards the dorsum of the foot. Care must be given to the metatarso-phalangeal 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.

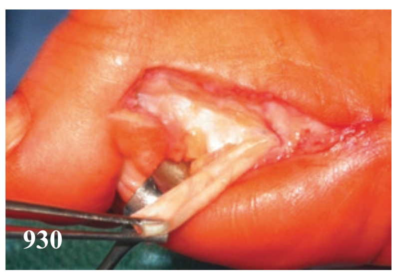
6.7.12 Flexor Hallucis Longus Tendon Transfer on the First Phalanx

Moving the flexor of the distal phalanx of the toe to the proximal phalanx is a good functional repair of painful and disabling hammer toes ***(O435-438)***. This is also true for the big toe despite the absence of the middle phalanx. The principle of the correction is however similar ***(O434)***.

The approach is along the ***medial utility line*** in between the dorsal and plantar medial nerve branches.


929

The concavity of the plantar aspect of the first phalanx is visualized. ***The underlying tendon is dissected about 1.5 cm towards distal and cut***.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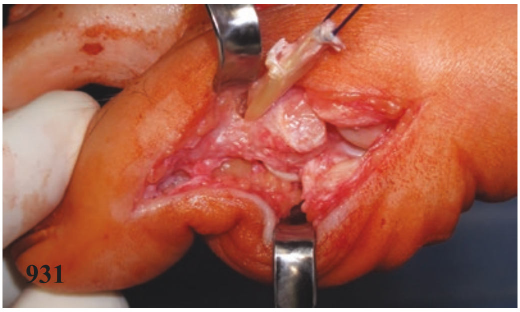
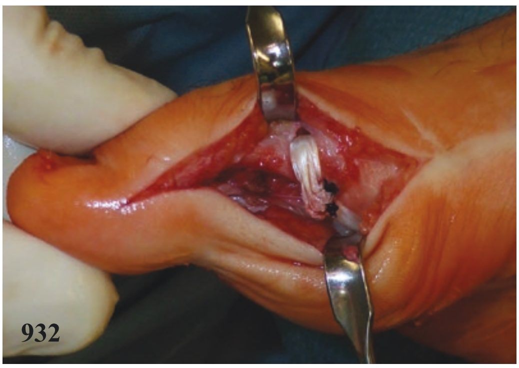
A 4.5 mm hole is drilled from medial through the first corticalis. The second hole is drilled from the plantar aspect of the base of the phalanx. The ***tendon is pulled***



931

through this angulated channel and ***sutured on itself.***



932

The transferred tendon must allow ***immediate stretching of the toe***.

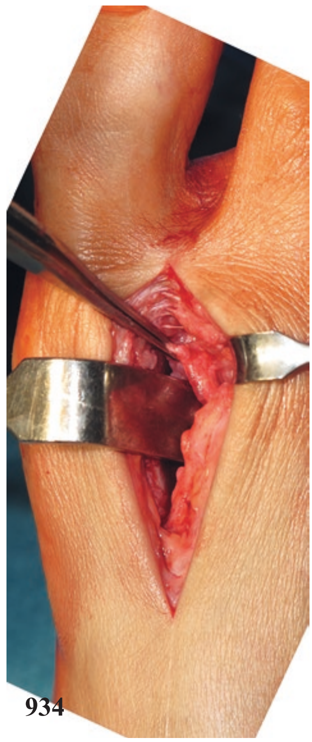
933

The dorsum of the toe thus remains untouched with its extensor tendons.

6.7.13 First Dorsal Interosseus Transfer on the First Phalanx of the Hallux

(E70) (O456)

The skin incision lies dorso-lateral to the distal aspect of the first metatarsus. The dorso-lateral 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 fibres are all protected and followed distal to the tendon which is ***cut at the level of the second metatarsal head***.



934

The muscle is carefully mobilized and directed towards the lateral aspect of the first phalanx of the big toe. The joint has been mobilized previously by arthrotomy. The tendon of the first interosseus muscle is then attached to the first phalanx of the big toe by transosseous sutures.

6.7.14 Flexor Digitorum Longus Tendon Transfer on the First Phalanx

(O434)

Transferring the long flexor of the lesser toes to the first phalanx can be proposed if the distal interphalangeal joint cannot be extended passively beyond the straight axis [15]. As mentioned above, transferring a tendon must be evaluated in terms of the physiological cost or consequences. In this case, transferring the tendon alone in hypermobile joints may end in a painful so-called "swan-neck deformity" ***(E83-84)***.

The ***approach is dorsal*** from the intermediate phalanx to the neck of the metatarsus ***(T635)***.

935

The extensors of the toe are divided for elongation and the joint is opened leaving only the plantar plate of the capsule intact. Choosing one side of the toe, and leaning against the bone and the first interphalangeal joint capsule, ***the flexor tendons are identified***

936

and caught on a smooth hook. The long flexor (which perforates the short flexor tendon) is cut and pulled back to the mid-length of the first phalanx. At this stage, the tendon, which has a double string shape is ***divided to obtain two limbs***.

937

One limb is caught beneath the phalanx using a mosquito clamp which is introduced ***from the opposite side of the phalanx***.

938

The result is 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 plantar wards*** and the occasional subluxed or dislocated toe is reduced at the metatarso-phalangeal joint.

939

The two limbs are then ***sutured together*** on the dorsum of the phalanx. This procedure is done ***on all lesser toes*** due to the common pull of the long flexor.

940

It is therefore indicated to adapt all the toes at the similar flexion while suturing the flexor tendon. The aim is the ***firm contact of all tips of the toes with the floor***.

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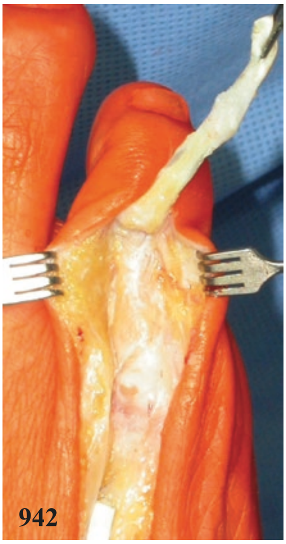
6.7.15 Extensor Digitorum Minimi Transfer on the Abductor Digiti Quinti

(O459)

The tendon is ***divided at the level of the metatarsal***



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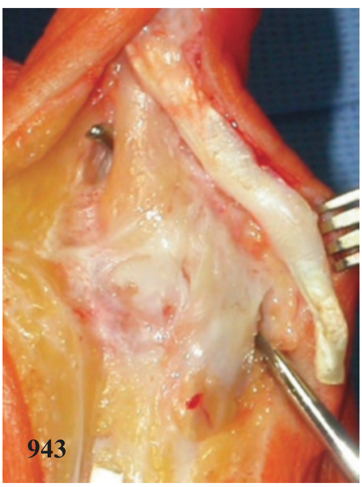
and an ***oblique plantar tunnel*** is prepared at the level of the metatarso-phalangeal joint.



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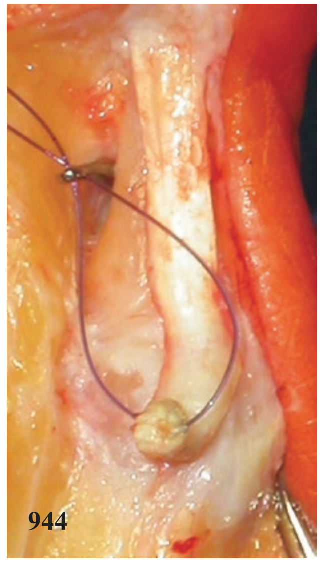
The distal limb of the ***tendon is taken***



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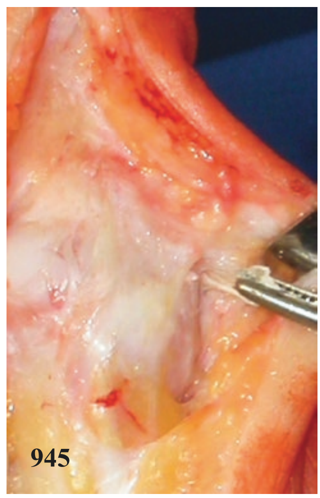
and passed within the oblique path, arriving at the basis of the ***lateral aspect of the metatarsal head***.



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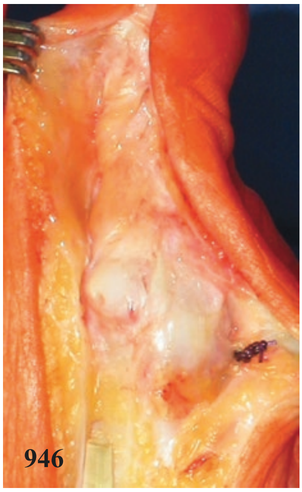
The tendon is sutured to the lateral ***tendino-capsular hood*** of the fifth metatarsal head and the abductor digiti quinti [71].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6.8 Intermetatarsal Neurectomy *(E143 R191)*

The approach is performed to reduce the collateral damage to a minimum. The involved nerves are located plantar to all osteo-articular 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 fibres of the plantar fascia longitudinally, the nerve is identified just beneath this layer. Magnifying glasses and instruments for micro-dissection help to free the nerve and to present the ***pseudoneuroma*** which is located at the level of the metatarsal heads ***(R191)*** [29].


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Dissecting distal to the tumour, both plantar digital nerves are presented a few millimetres and cut sharply. The removal of the nerve and the neuroma is then eased going towards proximal as all collateral nerve fibres situated plantar to the intermetatarsal ligament are also lifted and removed. The ligament is an important structure and does not get incised. The nerve is dissected and ***removed towards proximal together with the accompanying vessel*** which is cauterized while perforating the intermetatarsal ligament. The nerve is then cut proximally, at the level of the intrinsic musculature.

948

The stump neuroma [124] 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 cases of two pseudo-neuromae located in adjacent intermetatarsal spaces, the cut is ***centred on the corresponding metatarsus***

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and the dissection diverges beneath the dermis to allow ***uneventful healing of the plantar skin***.

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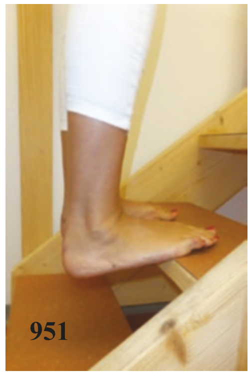
6.9 Stretching

In cases of calcaneodynia or heel cord tendinitis ***(E17)***, the concept of stretching the plantar fascia and the Achilles tendon is a keystone of non-operative treatment [124]. The inflammatory process affects vessels and increases local perfusion. By stretching the aforementioned structures, the vessels are tensioned and their calliper 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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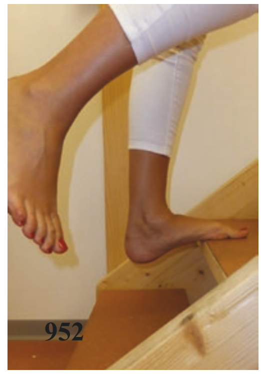

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Efficient stretching of the plantar fascia can be performed on the sitting patient who lies with one foot on the contralateral knee and, with his hands, pulls all ***toes in maximal dorsal extension***

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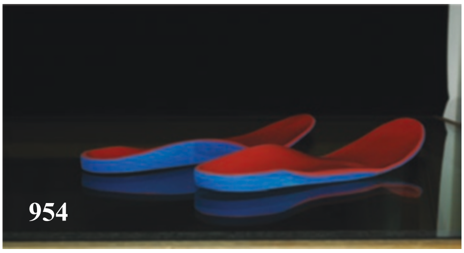
while the hindfoot is locked in pronation.

6.10 Orthoses

The weight-bearing area of the foot is very variable. In cavus feet, it is reduced and consequently, the local pressure on the plantar skin is high which triggers the formation of calluses which may jeopardize the vitality of the older skin and that affected by, e.g. diabetes. Simple overloading pain may also occur at the upper key of the arch. This is particularly valid for anterior pes cavus morphologies ***(R180)***. The consequences of pes cavus can be overcome by using a plantar support which increases the area and reproduces the anatomical shape of the sole of the foot. Diabetic feet suffer from a fragility of the skin to local overload after dislocation of, e.g. joints about 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 a reliable and constant corrective support, the orthosis should have a ***stable plane surface facing the shoe sole***.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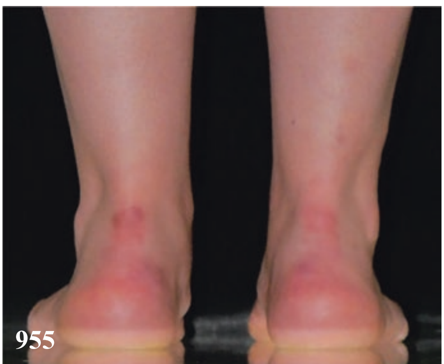
In order to relieve overload from the central metatarsal heads causing metatarsalgia, load sharing to the metatarsal shafts can be introduced by so-called “retro-capital supports”.

Hindfoot instability occurs logically ***in varus malalignment*** (right foot).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Provided a free mobility within the frontal plane through the coxa pedis ***(E106)***, modifying the buttressing plane of the hindfoot has a limited but efficient effect on apprehension and giving way. ***An orthosis including an upload on the lateral edge up to 8 mm provides such functional correction.***


957

Complex Reconstructions

Contents

K. Klaue, *The Foot*, https://doi.org/10.1007/978-3-662-64001-2_7

By complex reconstructions, we mean reconstructions which involve reorienting/fusing of more than one articular segment or interventions involving both structural (bone and joints) and multiple functional components (muscle tendons) about the foot and ankle. Additive soft tissue reconstructions by means of re-establishing a skin and subcutaneous hull after, e.g., trauma or repeated surgery also belong to this chapter. Foot deformities associated with metabolic diseases such as diabetes mellitus also represent a treatment challenge and include multiple aspects requiring complex reconstructions. Many revision cases also belong to this group of surgical treatment because their morphological and functional status does not correspond to the natural path of pathology which is familiar to the experienced orthopaedic surgeon. Revision cases are unique and thus represent a challenge to treat. Functional stability is the main aim in foot and ankle reconstructions and therefore most chronic dysfunctions require both a morphological and a functional intervention. In the following chapter, we align a series of typical clinical examples in which a number of separate procedures were performed simultaneously to achieve physiological orientation of the foot and balanced musculature. The rationale of the correction is outlined explaining why every step of the correction is performed. The planning of comprehensive corrections of foot deformities includes multiple factors such as: age, vascular and neurological status, functional expectations and compliance.

The major clinical factors to be re-established minimally are: painless static stability assessed by barefoot unipedal full weight-bearing ***(E54)*** and painless dynamic stability by spontaneous adequate proprioception. The latter is assessed by objective and subjective gait pattern. Otherwise healthy children and adults should be able to demonstrate the ability to stand tiptoe on one single leg rise. The major radiological factors on conventional bipedal standing radiographs are the horizontality of the talar dome within the frontal plane ***(R162)*** and the straight alignment of both talus and first metatarsal axes within the sagittal and the horizontal planes ***(R176) (R168)***. Considering the dynamic factor by walking (running), the parabolic alignment of all metatarsal heads [34] within the horizontal plane should be included in the normal alignment of the foot.

If there is a causal link between cavus or flat feet with disability, operative measures will probably include osteotomies, joint fusions, reorientation and redirecting muscle tendons. Diabetes mellitus is linked to the occurrence of diabetic arthropathies, collapsing arches and plantar malum perforans. The resulting disability can be improved by redirecting joint fusions and surgery on the tendons. Balancing muscle forces is also the logical and essential factor in salving procedures such as amputations. In the following chapter, a rational approach to those comprehensive pathologies is demonstrated.

7.1 Pes Cavus

Pes cavus is basically defined by the “cavity” seen in such feet at their plantar aspect along the long axis of the foot or sagittal plane. As a consequence, the weight-bearing surface or footprint is reduced in proportion to the importance of the “cavus” ***(E45)***. Reduction of the weight-bearing surface results in the proportional increase of the pressure applied onto the plantar skin which can be critical for the vitality of the corresponding soft tissues [6, 12]. Pes cavus, although belonging to a certain degree to the range of normality, may be due to an imbalance of the extrinsic musculature. In cases of imbalance, the alignment of the foot within the frontal plane is also affected. It thus implies that the supinators overcome the pronators. A so-called pes cavus varus ensues. The aetiology is always neurological or neuro-muscular such as poliomyelitis, CMT diseases, Friedreich’s ataxia, hemiplegia, cerebral palsy. Congenital club foot (pes cavus varus adductus) ***(E113)*** also belongs to those pathologies, as the origin of at least some types are linked to dysfunctional lumbar nerve roots due to viral infections during pregnancy [125] and seasonal appearance [126, 127].

In the adult foot, in addition to occasional pressure peaks, the plantar load is shifted towards lateral and functional stability is jeopardized causing recurrent sprains about the hindfoot. We may refer herein to pes cavus varus which are compensated and pes cavus varus which are decompensated.

7.1.1 Compensated Pes Cavus Varus

We refer to the pes cavus varus as compensated when the stability reported by the patient (subjective) is affected in normal function of walking, running or playing sport. These patients present a cavus varus deformity of the foot in which the weight-bearing pattern assessed on the footprint is moderately out of the range of normality. Surgical evaluation and single treatment principles are presented in the “basic surgical orthopaedic treatment” chapter above. However, some cases need a complex reconstruction located at different points within the foot and ankle (e.g. at the hindfoot and the forefoot). Such combined corrections are the result of a meticulous consideration of the deformities. There is a ***missing weight-bearing pattern of the lateral column of the foot together with a missing antero-medial buttress of the foot.***

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Lateralizing the heel through a tuber calcanei osteotomy only might be insufficient to achieve functional stability.

In those cases, ***extending dorsally the first ray (T362-365)***

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

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In more severe deformities, pronation of the foot can only be achieved properly by adding ***extension osteotomies of the central (II and III) metatarsi.***

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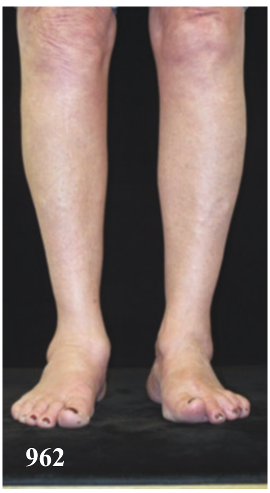
As outlined above, the imbalance of the extrinsic musculature must be added to the morphological indications. If the imbalance persists, recurrence of the deformity is logically programmed. In cavus varus, the pronators must be reinforced. In light cases, transferring the fibularis longus tendon to the insertion of the fibularis brevis tendon onto the fifth metatarsal base redirects muscle power which holds the longitudinal arch of the foot and potentializes pure pronation ***(O238).*** Further empowerment of pronation includes transferring the flexor hallucis longus on the lateral aspect of the foot ***(O320)***, lateralizing transfer of the long extensors of the toes ***(O199)*** and eventually the anterior tibialis tendon.

There are conditions which involve deformities ***both above and below the upper ankle joint***.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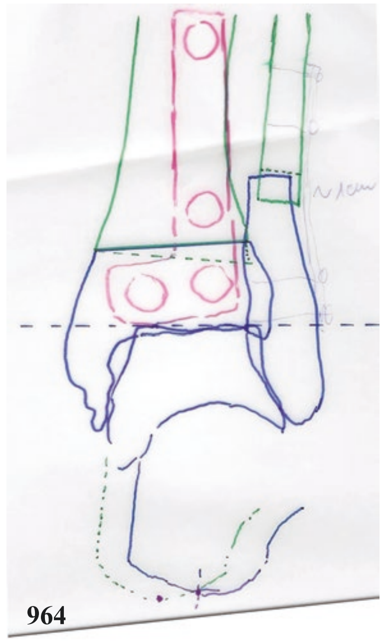
The statics are then considered by a comprehensive analysis of the radiographs taken under weight-bearing conditions. The sopramalleolar correction, i.e., ***bringing the talus perfectly horizontal***, is planned first ***(O222) (T643),***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while the position of the heel is considered afterwards. If the heel is still malaligned, surgical correction is then also ***performed on the heel level (O235) (T682).***


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7.1.2 Decompensated Pes Cavus Varus

Those patients (adult feet) have ***overloaded spots on the plantar sole and corresponding pain (E78-79)***.

The decompensation of the deformity is characterized by the non-reducibility of the physiological axes of the lower leg and foot. Therefore, stability is no longer provided and the walking perimeter is significantly reduced. Skin lesions may jeopardize the vitality of all soft tissues. The weight-bearing pattern is thus abnormal with plantar calluses. Functional instability with multiple ankle sprains completes the patient history. Non-treated club feet or incomplete corrections of pes equinus varus belong to this clinical picture. Treatment must be adapted to the individual case. Being aware of the core of the pathology which resides within the coxa pedis (talo-calcaneo-navicular joint), treatment must be focused on the reorientation of the four bones of the hindfoot. Surgical indications may differ in relation to the manual correctability of the whole deformity which signifies sufficient passive mobility of the joints. In cases of sufficient mobility, the joints may be reoriented by osteotomies with or without correcting fusions of non-essential joints. In cases that include stiff joints, reorienting fusions (triple arthrodesis) are indicated. The strategy to achieve this aim is two-fold. Decision-making depends on the vitality of the soft tissues in relation to the extent of the deformity. Either the correction can be performed in one *single step* or *progressive correction* is indicated.

7.1.2.1 Single Step Correction

Pes cavus varus presents a convexity dorso-lateral to the foot. This deformity also leads to hindfoot instability with recurrent sprains. By rotating the foot around an oblique axis which 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. This is the case in, e.g. neuropathic feet, myopathies and cerebral palsy. A dorso-lateral bone wedge is taken from both the navicular and cuneiform bones (dorso-lateral tarsectomy [128]. The calcaneo-cuboidal joint may also be fused in particular cases ***(O319)***. Instead of purely shortening the lateral column within the calcaneo-cuboidal joint, the cuboid can be translated upwards 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 post-traumatic ankylosis which 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 dorso-lateral extension of the foot because they are not involved in the surgical correction.

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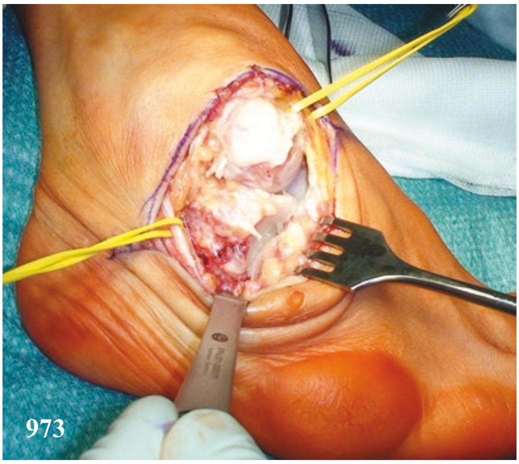
The motor counterpart consists in powering the pronators of the foot. Correction of imbalanced pes supinatus is performed in a quantitative rational way by transferring one or more muscle tendons of the supinators to the lateral dorsal aspect of the midfoot. It is wise to quantify the power of those 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 ***(O196)(T912)***. 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 ***(T915)***. This has the advantage of helping to correct the claw or hammertoes which often occur is this kind of pathology. However, the power of the long flexor tendons must be evaluated during the preoperative planning. While removing the power of the long extensor of the toes, the metatarso-phalangeal joints relax in flexion as desired. On the other hand, the long flexors of the toes may provoke an 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 ***(T920)***. 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 antero-medial 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 ***(T926)***.

The approach goes through ***an extended oblique antero-lateral incision (T624) to achieve the dorso-lateral tarsectomy.***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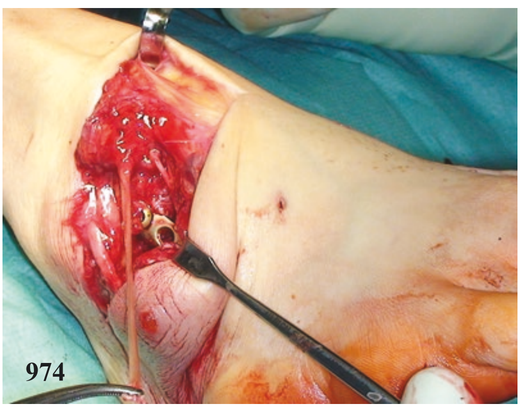
An essential part of the intervention is the ***correction of the muscle balance***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aiming at empowering the pronators (tibialis anterior) with a possible fibularis longus and flexor hallucis longus tendon transfer onto the lateral aspect of the foot. In cases which need more correction due to a severe deformity, the vitality of the soft tissue is jeopardized at the tension side which is medial. In those cases, a progressive correction is indicated.

7.1.2.2 Progressive Correction

These feet do not allow morphological correction without jeopardizing the soft tissue envelope of the whole foot. Here, the technique must be progressive to allow for the soft tissue to adapt progressively to the new orientation of the whole foot. The indication for progressive correction seems to be linked to the ***amount of malrotation within the frontal plane of the foot*** [129].


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Corresponding calluses are testimony to the pathological buttress on the dorsum of the foot


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A ***preserved radiological joint space of the upper ankle joint***

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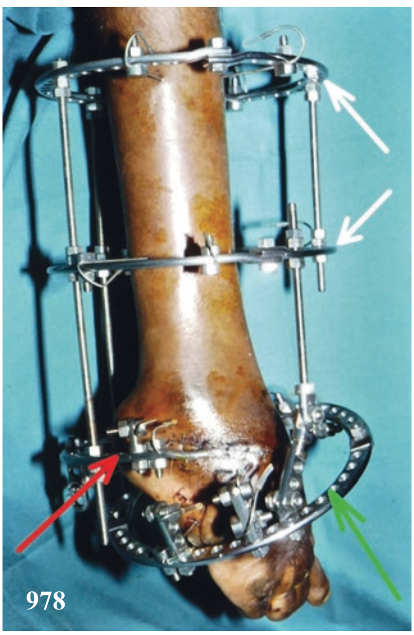
is also a good prognostic factor for progressive correction.

The first surgical step includes the initiation of the correction through a dorso-lateral tarsectomy. A versatile ***external fixator*** is then applied which allows for contemporaneous three-dimensional alteration of the foot and ankle. In addition to safely correcting the deformity, the global dimension of the foot is preserved.

The following montage includes a ***reference frame*** (2 circular rings) (white arrows) at the lower leg.

A ***hindfoot frame*** (semi-circular, red arrow) is linked to the reference frame for mostly shifting the heel towards distal within the frontal plane.

A midfoot frame (circular, green arrow) is linked ***independently*** to the reference frame for mostly rotating the foot distal of the midtarsal joints within a transverse/frontal plane.



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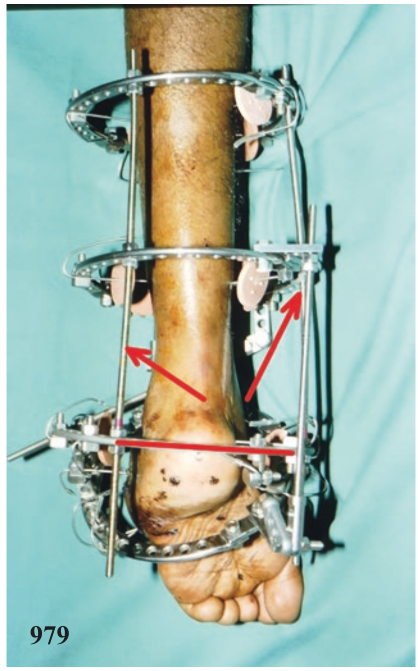
A ***push-pull mechanism using 2 vertical bars correct the heel within the frontal plane*** (red arrows and line)



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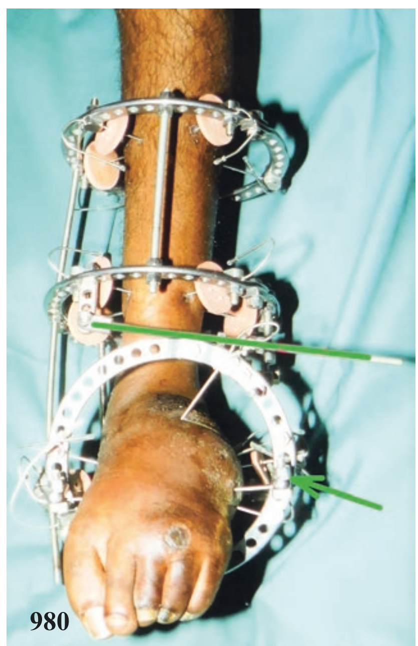
Followed later by a horizontal traction bar (green) to pronate the foot (rotating the forefoot ***like a steering wheel)*** (green arrow) ***together with a shift in extension and abduction.***



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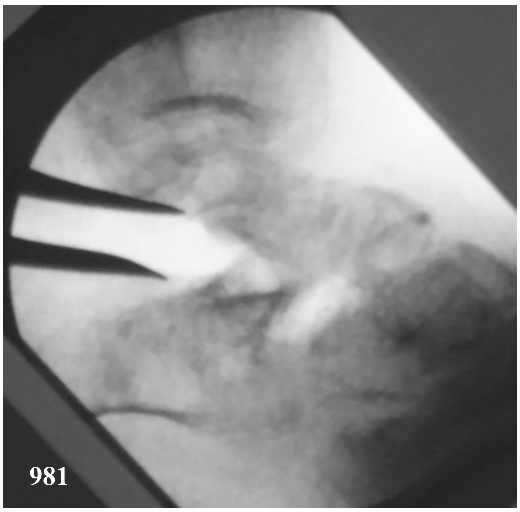
At the ***end of the correction*** path which lasts about 6–8 weeks, a 1–2 week pause within the fixator is taken to set the soft tissues.

The second step includes the final correction and stabilization/fusion of the coxa pedis. It is essential to observe at all times that the talo-metatarsal axis is aligned within the horizontal as well as the sagittal plane. ***Talo-calcaneo-navicular or triple arthrodesis*** by open means using occasionally autologous bone blocks harvested at the pelvic bone stabilizes the structural correction ***(O270)***.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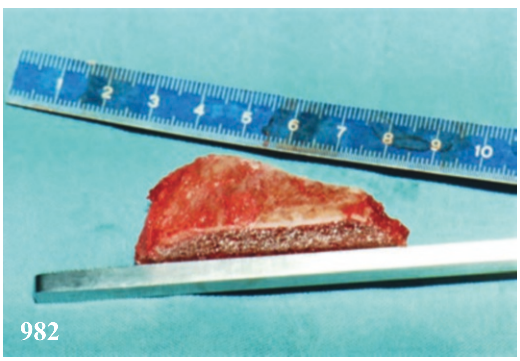
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The next surgical step includes the motor correction. The upper ankle joint functions within a residual arc of motion. The motor for flexion-extension within this arc of motion is performed by re-animation of the extensors thus avoiding relapse of the deformity. ***Transferring the tendons*** of the mm. tibialis anterior, fibularis as well as the long flexors of the toes onto the dorso-lateral aspect of the foot helps for ***long-lasting function.***


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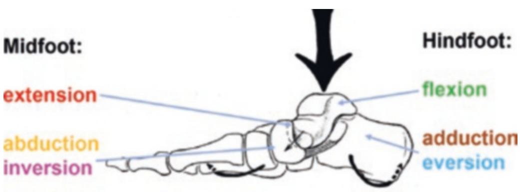
7.2 Pes Planus

So-called "flat feet" enclose a wide spectrum of different morphological and functional disabilities. In previous chapters, we proposed the evaluation and treatment of single aspects of relevant deformities which all may belong to the concept of "pronated foot". We now propose the evaluation and comprehensive treatment of the whole pathological flat foot. A flat foot in itself is not a pathological entity unless relevant pain and/or disability due to the deformity occurs. The common denominator of the mentioned "wide spectrum" is a break within the talo-metatarsal axis under weight-bearing conditions. This break in selected cases is located within the coxa pedis. In this configuration, the malorientation follows the protrusion of the talar head within the calcaneo-navicular joint cup (acetabulum pedis). Within the three planes of space, ***the calcaneus is adducted and everted and the foot distal to the navicular bone is abducted and inverted***.



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Those articular malorientations are each considered in relation to their proximally located bony structure. Considering the forefoot deformity within flat feet, by means of extension, abduction and inversion in relation to the talus, a wider classification can be proposed following the precise location of the deformity. Having in mind the spatial three-dimensional orientation, the axial "break" can thus be observed more or less at the:

- Talo-navicular joint
  - Sagittal break
  - Transverse break
- Naviculo-cuneiform joints
  - Sagittal break
  - Transverse break
- Tarso-metatarsal joints

From a therapeutic viewpoint, evaluating the mobility of the involved joints separately is essential. Functional "reorientation" procedures by osteotomies are generally indicated around mobile joints [47]. Reorientations that include fusing joints are indicated in ankylosed or in so-called "non-essential" joints. In the flat foot, both surgical procedures, osteotomies and fusions, may be applied simultaneously confirming the "complex" aspect of this kind of surgery discussed in this chapter.

7.2.1 Flexible Flat Foot

Those feet can be positioned manually from their planus valgus abductus to a normal alignment of the hindfoot. Reducing manually the exaggerated valgus of the hindfoot discloses the inversion of the forefoot. The inversion of the forefoot can be reduced manually by passive eversion. Shortened gastrocnemii is a rule in those feet because of the break within the midfoot and the hindfoot which is in equinus ***(O302)***. Surgery aims to relieve functional pain. Surgical treatment which addresses those complaints are usually fourfold:

1. Three-dimensional re-orientation of the talus and calcaneus
2. Reorientation of the medial column
3. Motor support for the "elevated longitudinal arch"
4. Length adaptation of the triceps surae

Those measures act in a synergetic way in re-establishing painless function of the foot. Care should be taken not to overcorrect the osteo-articular axes. Overcorrection by creating a "cavus-like" morphotype is usually not at all well supported. In summary, the general aim resides in the straight alignment of the talus-navicular-cuneiform1- metatarsus1 axis in the two horizontal (transverse) and sagittal planes.

As mentioned above, complex flat feet have complex clinical findings which all contribute to the functional limitations and pain.

The typical history, morphotype and findings are presented below with an example:

Active women between 20 and 30 years old, overweight. History of numerous sprains about the hindfoot. General augmented joint laxity. Slight genua valga. Both shoes are worn out at the *medial heel. Weight-bearing pain at the medial knee compartment with a tendency to hyperextension. Functional pes equinus. Augmented valgus of the hindfoot with a lowered longitudinal arch and* ***pain at the sinus tarsi****. Both heads of second and third metatarsi are painful on plantar palpation.*

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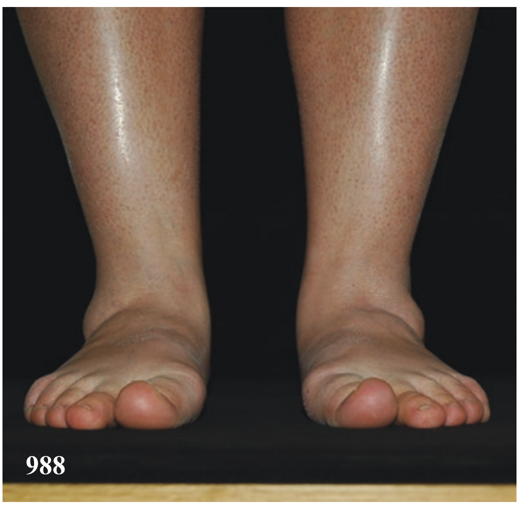

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The longitudinal arch ***is absent under weight-bearing conditions*** *but can be restored manually without resistance. The medial aspect of the first TMT joint is tender at palpation and the joint is hypermobile.*

989

In conventional radiographs under bilateral weight-bearing conditions, a slight degeneration of the first naviculo-cuneiform joint, an ***abduction angle of 20 degrees between first and second metatarsi and a slight reduced coverage of the talar head****.*

990

There is a sagittal angle of 20 degrees in extension between talus and first metatarsus and *the* ***apex of the angulation is located at the naviculo-cuneiform joint.***

991

The complexity of this case resides in the multiple locations of pathology which together cause the disability. Reduced general mobility increases body weight and worsens the condition of the patient.

It is essential to recognize the synergy of the different pathologies. The treatment plan should therefore present a corresponding synergy with its different steps. Overcorrection of the morphology should be avoided.

1. Sagittal reconstruction of the talo-metatarsal axis by re-orientation/fusion of the naviculo-cuneiform joint ***(O334)***
2. Horizontal talo-metatarsal re-alignment by reorientation/fusion of the cuneo-metatarsal and intermetatarsal 1-2 joints ***(O387)***
3. Posterior tibialis muscle/tendon augmentation by transferring the long flexor of the toes on the first cuneiform ***(O298)***
4. Distal gastrocnemius tenotomy ***(O195)***

Instability of the toes requires occasional ***secondary interventions***

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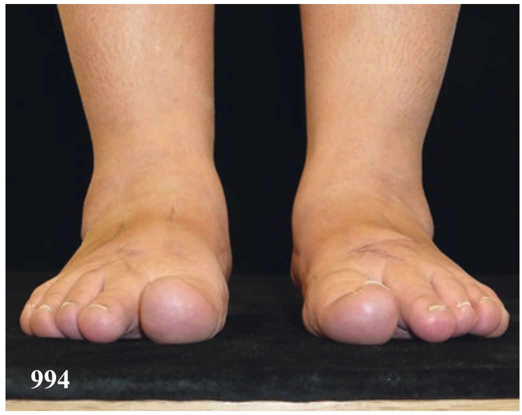
to achieve an ***active buttress of all tips of the toes.***



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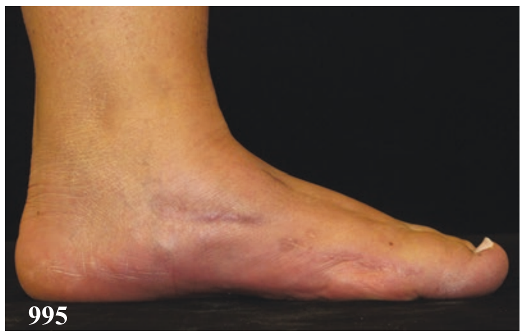
After the stabilization of the medial arch achieving a straight talo-metatarsal axis, ***the longitudinal arch is present under weight-bearing conditions*** which remains in the long term.



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The ligamentous stabilization of the ankle (Broström/Gould) is not typical for the correction of the complex flat foot but comes into play in the context of instability originating from the general articular hyperlaxity of the patient (anchor within the fibula).

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The location of the deformity must be analysed very carefully before planning surgical reorientation.

Another typical history, morphotype and findings are described below in the case of a 73-year-old woman.

This case demonstrates that each different aspect of the deformity must be recognized separately and quantitatively evaluated. The clinical assessment of the statics (weight-bearing conditions) with both knee joints symmetrical, allows for the comparison with the other asymptomatic foot. In this case, ***the assessment of the abductus (horizontal plane) is predominant***

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together with the ***valgus of the hindfoot (cavus valgus (E47))***

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according to a ***chronic degeneration of her posterior tibial tendon***

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In this case, including a degenerative condition of the posterior tibial tendon in an elderly patient, the following are the optimal strategies:

1. Horizontal correction of the abductus by distraction/fusion of the calcaneo-cuboidal joint [113] ***(O307)***
2. Sagittal talo-metatarsal re-alignment by flexion/fusion of the TMT joint [11] ***(O387)*** which corrects the hypervalgus of the hindfoot by reducing the inversion of the forefoot
3. Posterior tibialis muscle/tendon excision and substitution by transferring the long flexor of the toes on the first cuneiform [54] ***(T907)***
4. Distal gastrocnemius tenotomy to correct the sagittal functional pes equinus [56] ***(T890)***.

Beginning with the powerful ***calcaneo-cuboidal lengthening arthrodesis,*** the plantar fascia is tensioned ***(E29)***


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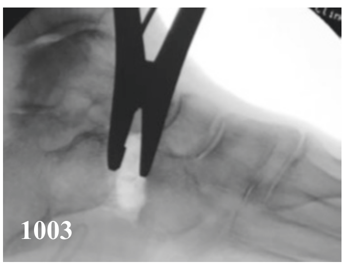
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Both calcaneal pitch and dorso-plantar talo-calcaneal angulation are corrected. The ***flexing arthrodesis at the medial column***


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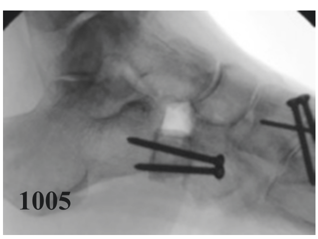
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corrects the residual strong inversion ***(C986)*** of the forefoot.

On the motor side, the substitution of the posterior tibial tendon by the ***flexor digitorum longus tendon*** removes the pain and stabilizes the perennity of the reconstruction.


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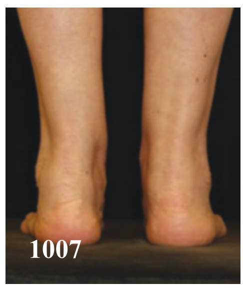
Perennity of the reconstruction is checked here at 1-year post-op.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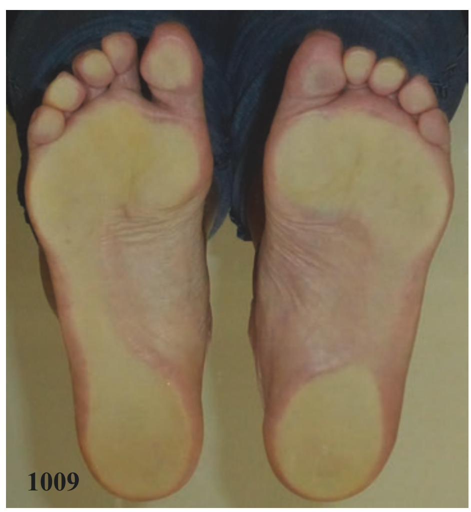
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Correcting symptomatic flexible pes planus abductus should thus preserve the essential mobility of the foot including the coxa pedis and the "calcaneopedal unit" [23]. Radiologically, the correction thus includes a ***straight talo-metatarsal axis*** within the ***horizontal***

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and the ***sagittal planes***.

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7.2.2 Rigid Flat Foot

Rigidity together with a flat foot morphotype is due to a lack of articular mobility of the hindfoot joints. The deformity cannot be corrected manually and symptoms are pain and disability. The lack of mobility is usually caused by congenital articular coalitions. Coalitions about the 4 hindfoot bones are well studied [6] and quite frequent. These deformities are generally discovered when patients are under the age of 20. The basic therapeutic questions reside in asking if the excision of the coalition results in improving functional motion in the long run. The decision-making is always very individual and is based on the exact knowledge of the extension of the coalition, the age of the patient and his/her functional expectations.

The calcaneo-navicular coalitions are the most frequent. Both bones ***belong to the acetabulum pedis and thus do not limit significantly the mobility of the coxa pedis***.

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It is thus not infrequent that morphological coalitions remain symptomatically quiet. The calcaneo-navicular coalitions may vary from a tiny cartilaginous "liaison" to a large bony bar. Functional pain (running and jumping) indicates ***surgical resection***

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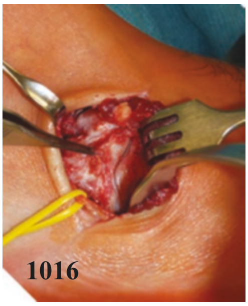
and eventual interposition of the musculus extensorum brevis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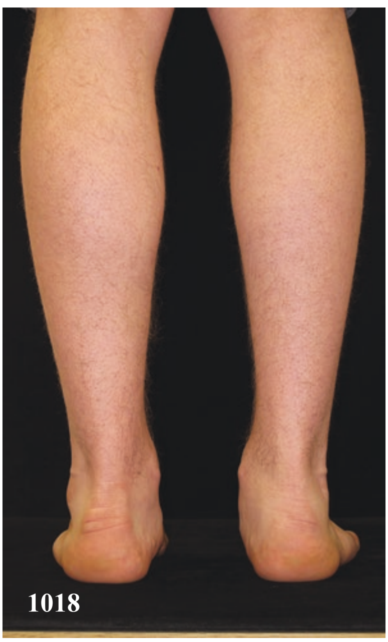
in patients in their second decade to avoid recurrent stiffness. Patients in their 20s, however, are examined by CT to evaluate the extension of the coalition for optimal choice of treatment, resection or fusion.

Talo-calcaneal coalitions may present difficulties in choosing the therapeutic approach. The clinical findings are a locked subtalar joint in valgus with functional pain. ***The calf muscle is weak*** (right side affected), and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the ***functional mobility***


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and the active mobility are ***considerably reduced.***


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Radiological findings are not always clear in conventional x-rays which do however demonstrate signs of the adjacent chronic hypermobility of the talo-navicular joint ***(talar beak) (O292).*** A radiological ***"sagging rope" of bone at the sustentaculum tali***

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signals the presence of the coalition.

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A CT examination is needed ***(R185)*** to know the extension of the bony bar.

In most adult cases, the chronic lack of motion is irreversible considering the complex mechanics of the subtalar joint. Treating the pain and the deformity implies ***reorientation fusion of the subtalar joint using the autologous tricortical bone block*** taken at the ipsilateral pelvis ***(T692)***.

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The amount of correction may be very small but has a relevant impact on the comprehensive aspect and orientation of the foot and ankle, which should be ***similar to the contralateral normal foot (C1018-1020 same case).***

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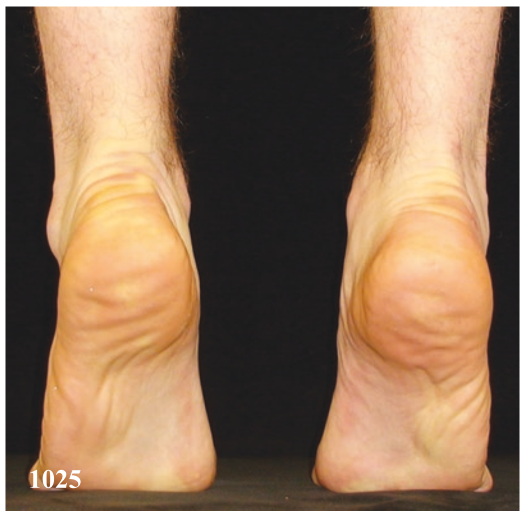

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The correction should affect the orientation within the horizontal plane (abduction) too. ***The orientation must be similar to the other foot.***


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Talo-navicular coalitions are less frequent and may be associated with other dysmelias [130]. They cannot be successfully removed to achieve improved functional motion. Mobility of the talo-calcaneo-navicular joint or coxa pedis is thus excluded. Some motion within the frontal plane is still possible between the lateral foot [23] and the talus. This kind of deformity is usually well supported by compensating the lack of talo-navicular mobility by morphological adaptation of the neighboring joints. The ***naviculo-cuneiform joints***


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and the ***upper ankle joint*** are more solicited and juvenile morphological adaptation ensues. In fact, in infancy, feet with a talo-navicular coalition may develop a so-***called "ball-and-socket" joint between the tibialfibula and the talus.***


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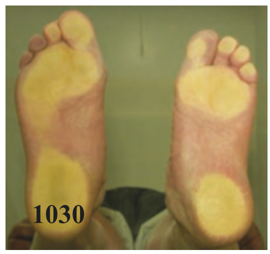
If the alignment of the foot allows for functional stability, ***ball-and-socket joints*** may be ***symptom-free for life,***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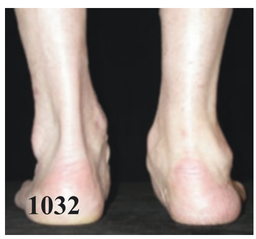
demonstrating functional adaptive ***motion within the frontal plane***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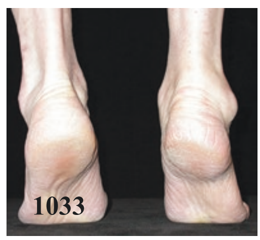
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Calcaneo-cuboidal coalitions are rare and do not impede basic function of the foot and ankle while belonging to the calcaneopedal unit [28]. They are thus widely asymptomatic if they do not cause a relevant misalignment of the lateral column of the foot.

7.3 Surgical Reconstructions of Diabetic Arthropathies

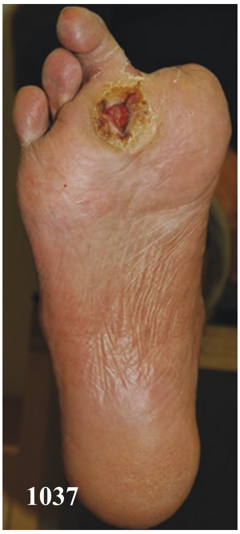
7.3.1 The Pathology

Diabetes mellitus is associated with an occasional severe osteo-arthropathy [131]. The joints collapse and the subchondral bone is not able to sustain physiological load. This pathology concerns particularly the foot and ankle. Within the foot and ankle, the normal axes of the joints are thus disturbed and the whole foot loses physiological contact to the ground. Deep sensitivity on the plantar aspect of the foot is lost and thus self-protection to local overload is not cognitive. At this point prophylactic treatment appears. The diabetic foot is potentially in danger and should be protected. The best protection is to make the patient aware of the specific problem of the vitality of the feet in the presence of diabetes. Structural protection is then provided by adapting the weight-bearing surface through ***anatomic orthopaedic orthoses*** which cushion the maximum of plantar surface thus reducing local pressure.

Local overload exceeding physiological limits of the plantar skin (ca. 10 kg/cm^2 [132]) results in its break down and produce the so-called malum perforans. Very little is known about its pathology and pathogeny. Currently, microscopic investigations cannot help to assess the specific histopathology of the bone tissue [133]. Astonishingly enough, it seems that even minor trauma to the foot in diabetic patients triggers the degenerative process [134]. Fractures about the ankle in diabetic patients present a real challenge in the process of bone healing [135, 136]. Healing of traumatized cartilage also seems to be impeded in a diabetic environment [137]. Diabetes is often linked to atherosclerosis which may cause major complications in treating diabetic osteo-arthropathy.

Clinical assessment of the diabetic patient often occurs late in the course of the pathology due to the lack of attention given to the pathology, despite the patient occasionally experiencing symptoms over a long period. Optimal assessment includes orthopaedic, neurological and vascular conditions. Verifying peripheral blood supply is often confounded by the warm and reddish appearance of the skin due to the spontaneous sacral diabetic sympathectomy which is linked to the basic pathology. At this stage, one has to recall the influence of the heel cord in forefoot buttress. Shortened triceps surae, and especially the gastrocnemii cause forefoot overload and jeopardize the corresponding plantar skin. The phases of clinically relevant pathology often begin with a plantar breakdown of the soft tissues about the forefoot. Additional shortcomings such as lacking antero-medial buttress due to previous surgery including localized amputations complete the disbalance thus concentrating the local overload. Consequently, the ultimate pressure of about 10 kg/cm^2 is easily reached in such conditions

and causes a malum perforans beneath the second metatarsal head.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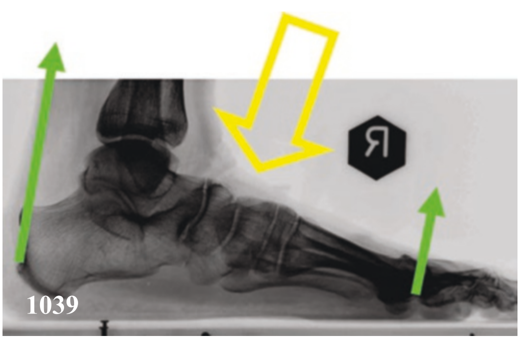
The phases of the osteoarthropathy are specific: the foot becomes swollen, reddish and hot, simulating bacterial infection. The foot then may alter its axes in relation to the localization of the affected joint.

7.3.2 Midfoot Diabetic Arthropathy

The most frequent and spectacular location of the collapsing process is located about the midfoot. Mechanics of push-off during walking demonstrates a dorsal (extension) bending stress to the part of the foot located in front of the upper ankle joint. Due to the remaining lever-arm, the still-short triceps surae and its correlating pes equinus, the midfoot joints undergo chronic overload. ***This force applies through a relatively long lever arm.***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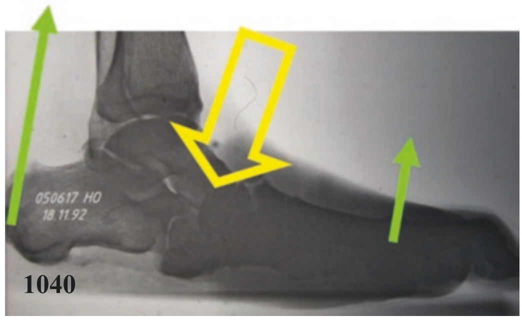
The mechanical challenge is that this lever arm is articulated by multiple joints: talo-navicular, naviculo-cuneiform and TMT. If one (or more) of those joints can no longer resist stress because of destruction triggered by diabetes, comminuted fractures of the corresponding bones likely occur. The ***talo-metatarsal axis deforms in extension and abduction,***



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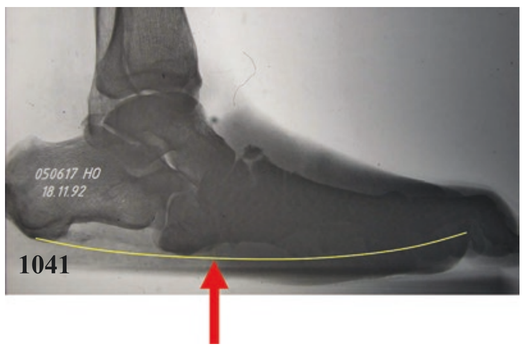
and the ***longitudinal arch of the foot becomes convex***.



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Most often, diabetic foot destruction is slowly progressive, with the different stages of the deformity appearing on both of the patient's feet.

It begins with the most loaded joint, ***the second metatarsal which undergoes hyperplasia,***

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followed by the ***destruction of the corresponding TMT joint.***

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The other foot of the same patient is already one step further.

Due to the structural asymmetry of the normal foot, the deformity preferentially goes through ***shortening, extension and abduction.***

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Midfoot break eliminates the longitudinal arch of the foot which collapses.

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The bony structures about the navicular, the cuneiforms and the cuboid thus press onto the plantar skin.

Weight-bearing under this condition helps to cause a local ***malum perforans beneath the corresponding bone.***

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Such a collapse leaves a modified footprint and bony spurs at the plantar aspect of the foot which causes localized overpressure under weight-bearing conditions. Lacking sensation to this local overload bypasses natural protective means and breakdown of the skin and subcutis ensues.

Logical bacterial contamination of this spontaneous wound does not, however, imply bone infection. In the presence of sufficient blood supply, granulation tissue grows to repair the wound without success.

This ever-spontaneous attempt to close the wound suggests the treatment. Removing the newly appeared bony spur by ***re-orienting arthrodesis of the destroyed joints***

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allows most often for rapid consolidation of the soft tissue mantle. At two weeks, and a further 6 weeks post-operative, relevant skin and subcutis defects consolidate with bone fusion. As explained above, muscle balance must be assessed and adjusted by tendon transfers or lengthening. Collapse of the midfoot increases naturally the equinus of the hindfoot and shortening of the calf musculature. Consequently, restoring the longitudinal arch of the foot most often implies the need for lengthening either the gastrocnemii or the whole heel cord ***(O193-195)***. Surgical correction, together with patient's compliance may ***preserve the results for years***.


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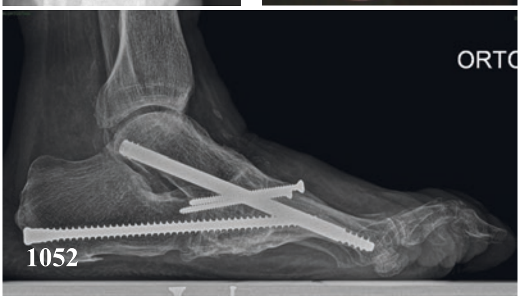

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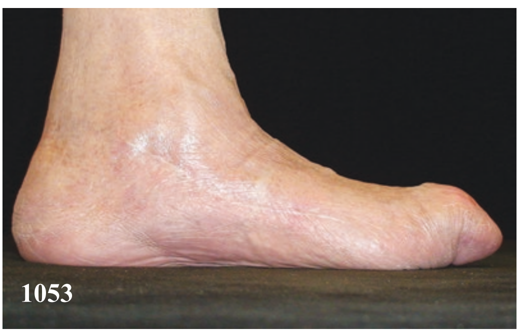
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The posterior lever arm which is constituted by the calcaneus is located behind the upper ankle joint. This lever undergoes a similar load in dorsal extension but much less because it is far shorter. One can observe a progressive pronation within the subtalar joint together with the dorsal extension of the calcaneus.

7.3.3 Hindfoot Diabetic Arthropathy

Diabetic destruction of the root of the foot by means of the hindfoot is a surgical challenge. If there is an additional relevant occluding arthropathy, treatment which leads to preserving the original length of the limb can be considered to be a success. If additional deep ***infection can be demonstrated***,


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the goal is to prevent a life-threatening sepsis while retaining a maximal ability for autonomous weight-bearing.

The assessment thus is preferentially multidisciplinary, including angiology and endocrinology. Conventional radiographs allow for ***assessing the bony destruction and dislocations.***


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Deep infection limits considerably the choice of treatment. Immediate stability is required to allow for ambulation under full weight-bearing conditions. Bone necrectomy is the condition for healing under stable conditions. It is essential in the mechanics of fixation to ***prevent the implants from backing down*** and jeopardizing the already delicate plantar skin.


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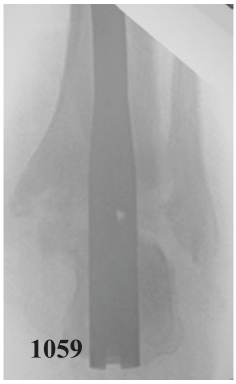
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At this point, the orthopaedic technician should allow for rapid ambulation ***using adequate orthoses.***


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Lasting weight-bearing on a physiological length of the limb [138, 139] will only be achieved with good compliance and therapeutic coordination.


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7.4 Revisions After Failed Surgical Treatment

7.4.1 Revisions After Failed Arthroplasty

7.4.1.1 After Total Ankle Replacement

Prosthetic replacements of the upper ankle joint have been initiated with the introduction of hip arthroplasties. Preserving mobility of the hip together with the ability for weight-bearing allows for much better function than hip fusion. The same is not true for the upper ankle joint. Fusion of the upper ankle joint may allow for good and long-lasting function and may improve gait pattern [140]. Complications followed by short-term operative revisions after upper ankle arthroplasty occur in more than 10% of cases [141–143]. A meta-analysis of six studies counting each at least 200 cases clearly demonstrate a higher rate of complications and reoperation rate for total ankle arthroplasty when compared to upper ankle arthrodesis [144]. In selected cases, particularly loss of bone stock, tibio-talo-calcaneal fusion ***(O276) (T705)*** in anatomical alignment is a safe salvage procedure for long-lasting function [44]. Height of the hindfoot in anatomic alignment and safe consolidation is best achieved using an ***autologous tricortical bone block from the posterior pelvic crest.***


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In the particular situation of ***non-controllable pain after total ankle arthroplasty***,


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tibio-talo-calcaneal fusion in anatomical shape and alignment

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is indicated. Due to the combined fusion of both hindfoot joints, the central stabilization ***(O276-277)*** in ***anatomical valgus and posterior offset of the tuber calcanei***


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is a prerequisite for ***stability and painless function.***

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Taking as a model the contralateral foot, which may have a particular morphotype, ***helps avoid eventual overcorrection***.

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7.4.1.2 After MTP1 Arthroplasty

Unstable arthroplasties with or without loosened prosthetic components about the first metatarso-phalangeal joint have to be removed due to dysfunction and pain. Removal of the prosthetic components may result in a ***relevant bone loss.***

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Fusion of the joint is compatible with a perfect function of walking and running. The prerequisites are length and orientation of the big toe. The missing bone substance is best replaced by an ***autologous bone block harvested at the anterior pelvic crest (T729)***

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This restores ***physiological length and may often allow for saving the interphalangeal joint***

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to restore ***physiological push-off.***


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7.4.2 Malunited Osteo-Articular Reconstructions

7.4.2.1 Post-traumatic Malunions

Revisions of post-traumatic conditions and revisions after ORIF are frequent. In cases of ***complex TMT 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 which are ***linked to bone length***,


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


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Those conditions demonstrate the interdependence between post-traumatic deformities or limitations and the original anatomical particularities. Here, the destruction of the central and medial (second and first) tarsometatarsal joints required ***fusion (F554)***, the fourth and fifth tarsometatarsal joints required an interposition ***arthroplasty (T785)***, the anterior heel needed a ***horizontal as well as a sagittal alignment***, the mobility of the first metatarsophalangeal joint had to be improved by arthrolysis, and a ***decompressing shortening osteotomy of the first phalanx (O414)*** while the fifth toe underwent a pronating tendon transfer ***(T943)***


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


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7.4.2.2 Malunited Arhrodeses

If joints have to be fused about the foot and ankle, the neighbouring joints have to take up the loss of function and thus are likely to decompensate and degenerate. If the fused joints are not in physiological alignment, functional and painful instability ensues. Most severe and relevant malunited fusions are located at the root of the foot by means of the upper ankle and lower ankle joints. ***Misalignment of the talo-metatarsal axis***

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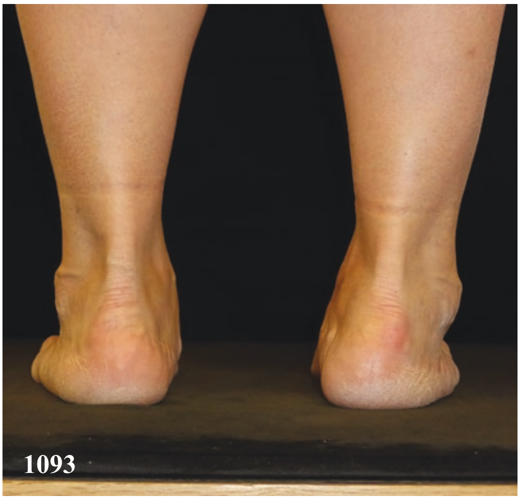
results in ***evident instability of the whole hindfoot.***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Salvage goes through osteotomizing the fusion and reorienting the four bones of the hindfoot, in this case by ***abduction and pronation of the forefoot***


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Ankle fusions are very sensitive concerning alignment and ***do not tolerate misalignment*** within the ***sagittal***


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and the ***frontal planes*** (red arc around the tuber calcanei).

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The arthrodesis should demonstrate a vertical axis of the tibia and a slight valgus of the heel ***(E16)***.

Treatment goes logically through the ***double osteotomy and reorientation at the anatomical sites of the fused joints.***

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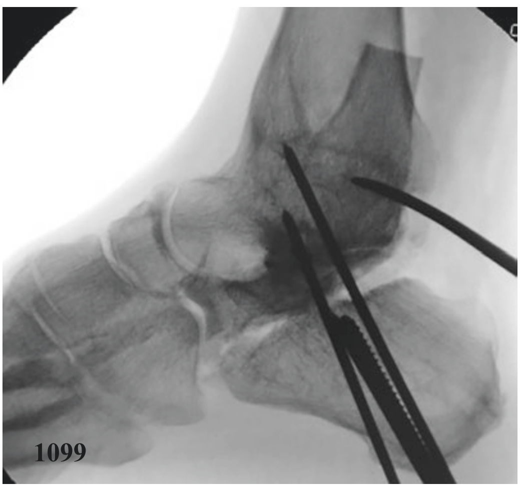

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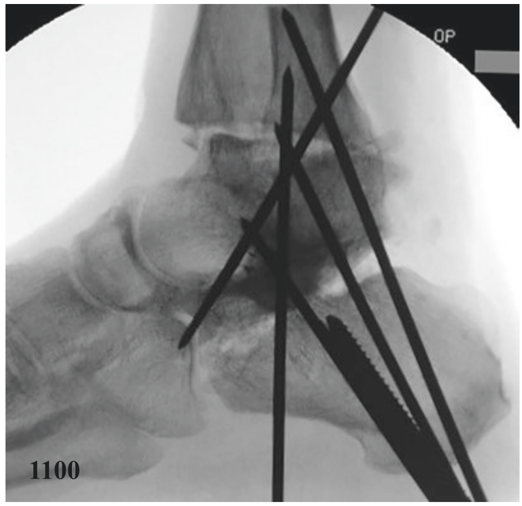
The reorientation must consider the rotation within the horizontal plane (**rotation in relation to the knee axis**), and an eventual slide within the sagittal plane (***shifting the foot more posteriorly)***.



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The length of the fibula often plays a major role in these corrections (reflecting pulley of the fibular tendons) and thus must be adapted precisely by a ***reorienting osteotomy,***

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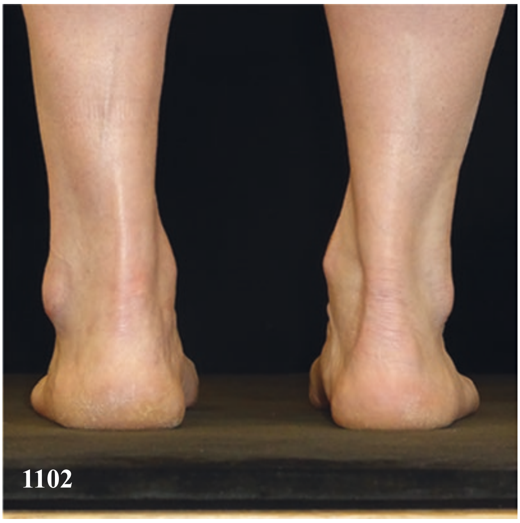
providing a ***stable valgus position of the hindfoot (left foot)***.



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7.5 Amputations

Amputations about the foot are probably one of the first surgical procedures performed by mankind. There are a manifold of amputation levels and techniques. While indicated after trauma or infections or vascular diseases, attention is still focussed mainly on soft tissue coverage. Amputations on any level often include peripheral nerve sections which likely cause phantom pain. True neuroma which grows at the extremity of the sectioned or injured nerve may be painful at any slight mechanical stress and demonstrate a positive Tinel test [145]. These neuromas can be avoided by immediate intra-operative application of fibrine glue on the fresh nerve stump [146]. Sustainable function after amputation should, however, be the first target of the orthopaedic surgeon. In the following section, different categories of amputations will be described together with, as throughout the manual, an explanation of the "why" of the steps proposed. In fact, it appears that these techniques belong to "complex reconstructions" and not to simple ablative surgery.

7.5.1 Transphalangeal Amputation

Partial amputation of the toes should preserve their protective function of unloading the metatarsal heads. This protection is provided by the windlass mechanism applied onto the first phalanx in plantar flexion [8]. The plantar fascia is connected to the base of the first phalanx of each toe through the plantar plate. Bearing weight on the longitudinal arch or the foot thus applies the first phalanx onto the ground. Consequently, amputation of the toes allows a normal function of the foot if the windlass mechanism is safe. In doubtful conditions, transfer and fixation of the short/long flexor tendon of the toe onto the first phalanx ***(O387)*** consolidates the function of the plantar plate.

7.5.2 Transmetatarsal Amputation

Amputation of the distal part of the foot including the metatarsal heads may lead to a fully normal gait pattern using a rigid forefoot orthosis in normal shoes. Preserving the metatarsal heads does not provide functional advantages. The windlass mechanism provided by the plantar fascia is lost with the absence of the toes. The "normality" of running and walking relies on the integrity of the two tendinous "staples" by means of both muscular antagonist couples: fibularis longus/ tibialis anterior and fibularis brevis/tibialis posterior ***(E26)*** and sufficient functional dorsal extension of the foot. The posterior tibial tendon expands spider-wise onto the proximal aspect of all lateral metatarsi and thus allows for functional integrity of the foot after transverse amputation on the metatarsal level. Severe soft tissue destruction about the forefoot is often ***treated by multiple and often successive peripheral amputation means***

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without muscular balancing. Weak dorsal extension of the foot and consequently overpowered foot flexion and an irregular amputation site ensues. Overload of the remaining forefoot structures and ***repeated trauma results in unstable scars.***

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The key to a functional ***transmetatarsal amputation***

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is a transfer of ***all long extensors of the toes onto the dorsum of the foot.***

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Most often, a radical lengthening of the triceps surae or ***heel cord lengthening***


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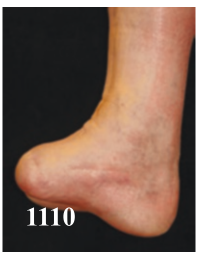
must be associated to equilibrate the forces [10] within the sagittal plane and thus avoid equinus of the foot.

This allows for a good, ***long-lasting functional result of the procedure.***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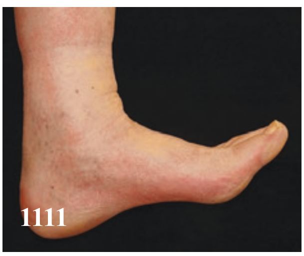
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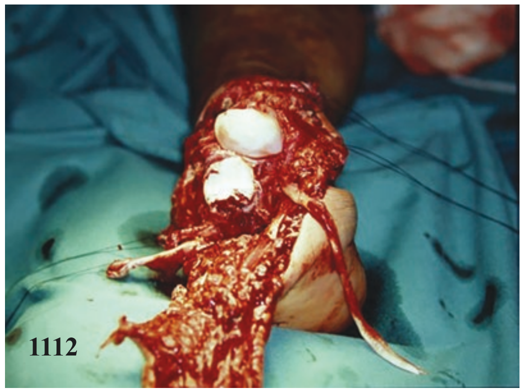
7.5.3 Tarso-Metatarsal Amputation (Lisfranc)

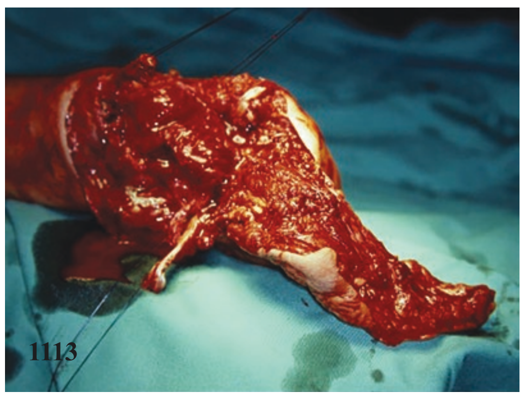
Forefoot amputation through the TMT joints [147] does not provide for a smooth function such as for the transmetatarsal level. The aim, though, is similar, insuring a strong functional dorsal extension of the foot which mainly includes balancing the forces within the sagittal plane.

7.5.4 Midfoot Amputation (Chopart)

Midfoot amputation at the level of the talonavicular and calcaneo-cuboidal joints allows for a safe buttress at the heel. In exceptional cases, the function of an intact subtalar joint may be preserved. The biological conditions though must be optimal, such as in fresh trauma and ***intact perfusion of the hindfoot soft tissues after thorough necrectomy.***


1112

In such situations, future secure post-traumatic function depends on the ***vitality of the plantar skin.***


1113

Those cases thus belong to the complex reconstructions which are preferably performed in steps. In the first step, the ***coverage and stabil-***

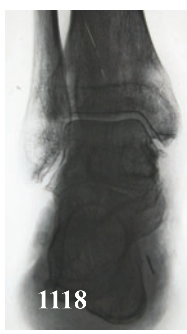
ity of all remaining bony and nervous structures must be secured.

After consolidation of such coverage, and applying temporary transarticular immobilization (KW), the previously saved tendons can be reinserted to stabilize the function of both upper and subtalar joints. Prerequisite is a judicious application of an equilibrated transfer of tendons.

In this case, the still available flexor hallucis longus together with the flexor digitorum longus tendons are harvested and ***driven through the interosseous membrane***

and ***transferred to the lateral aspect of the calcaneus***

in plantigrade position of the heel after tenotomy of the Achilles tendon. The extensor tendons, available but shorter, are fixed onto the lateral aspect of the talus providing a ***good orientation of the heel***



and a ***physiological hindfoot mobility.***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All cases in this field must be checked individually to achieve the desired and expected function, but the principles of morphological (osteo-articular structures) and functional (musculo-tendinous balance) reconstructions remain constant.

As another example of mid-tarsal amputation in which the stability of the joints could not be taken for granted, a ***fusion of both upper ankle and subtalar joints*** may be required.


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7.5.5 Hindfoot Amputations

Preserving leg length is a valuable argument in order to allow for convenient weight-bearing without prosthetic assistance. If the heel pad is the only remaining vital part of the non-infected foot, enucleation of the talus and hyperextension of the calcaneus and fusion to the tibial pilon (Pirogov's osteoplastic amputation) allows for a weight bearable lower limb. The required stability is achieved by fusing the processus anterior calcanei to the tibial plafond [138].

7.5.6 Single Ray Amputation

Vital impairment of the metatarsus may occur locally due to acute trauma (shot wound), chronic infection, post-traumatic necrosis of bone and/or soft tissues. In cases localizing the pathological spot about the central forefoot, vascular supply lateral and medial of the lesion should be granted by the vascular arch localized on the dorsal and plantar aspect of the forefoot. Such a condition allows for eventual ***axial resections of digital rays***.


1124

The plantar rays are articulated at the level of the cuneiforms. Functional ***resections of plantar rays are thus logically achieved on the cuneiform level***

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to respect and preserve the ***overall aspect of the foot***.

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Ray resections require reorientation at the root of the remaining rays to fill the gap. This implies in this case a ***reorienting arthrodesis of the medial TMT joints (T780-781)***.

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7

Supplementary Information

K. Klaue, *The Foot*, https://doi.org/10.1007/978-3-662-64001-2

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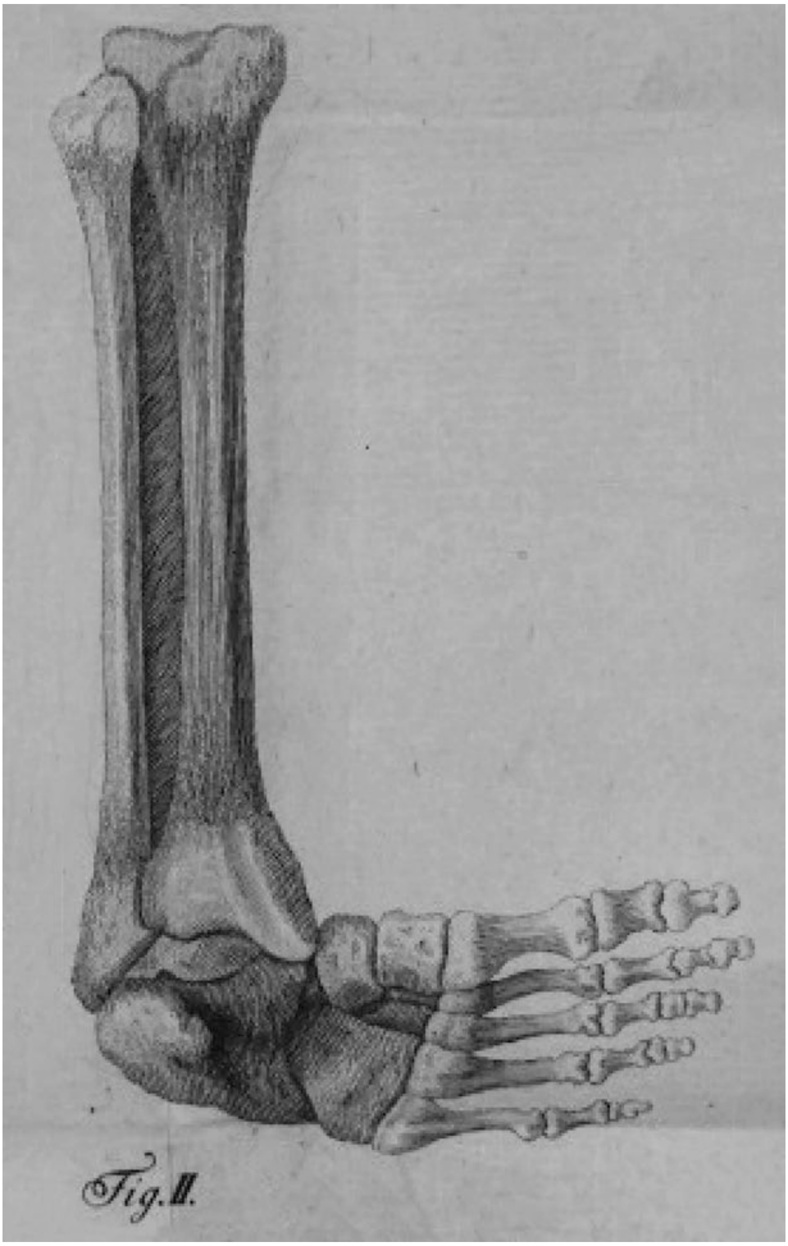
Learning, doing and teaching in medicine implies a continual interaction between physician and patient in a context that is constantly evolving. Through travelling around the globe, I have noted that health expectations, desires and aspirations are very similar for all populations, in all religions and convictions. I am only a witness for the field of the locomotor system but we have to admit that there is a striving for life and happiness, movement and freedom common to all humans.

However, population growth in a limited environment which includes limited resources leads to a progressive restriction in individual freedom. We should therefore only invest in sustainable technology, leading humanity towards a circular economy and consumption. Growth is a short-sighted view and belongs to the past. Research should respond to the inevitable need for global recycling using energy sources which exclude waste. The exponential alteration in our environment because of changing climate conditions, a shortage of non-renewable resources and worldwide spread of waste is neither compatible with our biology or with our common striving for life, motion and freedom.

The answer lies in education, global thinking and global handling. Efficient research, learning and creation not only strives for cutting-edge knowledge within a specific and therefore limited domain but cultivates a close interest in the apparently unrelated fields of art and science. We should remind any newcomer to research of the maxim: “If all you do is follow the herd, you’ll just be stepping in poop all day” (W.W.Dyer).

Recognizing the likelihood of interconnection between unrelated fields is what is called “horizontal learning”. This attitude is not only the most rationale and efficient but also provides surprises and great fun.



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