Posttraumatic ankle osteoarthritis: How initial cartilage lesions, the deltoid ligament and hindfoot alignment affect the outcome of operatively treated ankle fractures

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CHAPTER 9

GENERAL DISCUSSION AND CONCLUSIONS
Ankle osteoarthritis

Reports on the short-time outcome of ankle fracture treatment focus mainly on non-union rate and complications.\textsuperscript{1,2} Reports on the long-term outcome address primarily the development of posttraumatic osteoarthritis.\textsuperscript{3-4} Ankle osteoarthritis does not always seem to be the result of the normal ageing processes, since the vast majority (70-78\%) is of posttraumatic origin.\textsuperscript{5-7} In posttraumatic cases the initiator of the joint degeneration is a mechanical stress in the joint, and the inflammatory component is a subsequent reaction that follows later from the local damage.\textsuperscript{8} The process of joint degeneration is accompanied by attempted repair of cartilage tissue and remodeling, sclerosis of subchondral bone, and formation of osteophytes and subchondral bone cysts.\textsuperscript{9,10} However, since articular cartilage has no nerve endings and a vascular system is absent, injury to the cartilage without an inflammatory response of the synovium or damage to the underlying bone will often go unrecognized.\textsuperscript{11} From a clinical point of view, pain may be an alarm bell that is set off too late; since pain is probably not only caused by synovial irritation but also by the stimulation of the nerve endings in the subchondral bone underneath the cartilage defect, hypothetically induced by repetitive high fluid pressure during loading.\textsuperscript{12} Radiographic signs of osteoarthritis may exist in the absence of clinical findings. Although cartilage has a limited capability to repair, by means of cell division and proteoglycan synthesis,\textsuperscript{13} in general osteoarthritis is known for its ‘irreversibility’ because of the permanent nature of damage to the collagen matrix.

Osteoarthritis can be graded by visual inspection of cartilage through arthroscopy, histological inspection, analysis of radiographical imaging, and by the clinical symptoms. Since roentgen imaging is less invasive than surgery, a combination of clinical and radiological classifications are clinically used.\textsuperscript{14-22} Marginal osteophytes were first described as an early sign of osteoarthritis of the knee joint by Kellgren and Lawrence in 1957.\textsuperscript{9} This appears to be the most sensitive radiographic sign of articular cartilage degeneration within the knee joint.\textsuperscript{23} Many radiographical classifications have been developed over the past decades. For the ankle, for example, the Kannus\textsuperscript{24} the Takakura\textsuperscript{25-27} and the van Dijk\textsuperscript{28} classifications are used. They take cysts, subchondral sclerosis, osteophytes and joint space narrowing into account. However, correct
application of classification systems can be difficult due to inexact wording of the descriptors. For example the Kellgren and Lawrence scale, which is widely used to quantify the level of osteoarthritis into four grades with 0 being normal and 4 severe osteoarthritis, has been found to exist in five different versions. Next to conventional roentgen imaging, bone scintigraphy and single positron emission computed tomography combined with conventional computed tomography (SPECT/CT) is used. Currently the usefulness of these new techniques becomes more clear in early stages of osteoarthritis.\(^{29-31}\)

In order to measure the impairment for the patient, which results from ankle osteoarthritis, several clinical instruments have been developed. One of the commonly used clinical instruments is the American Orthopaedic Foot and Ankle Society (AOFAS) clinical rating scales which comprises both subjective, or patient reported items, and objective, or physician-assessed items.\(^{32}\) The Foot Function Index (FFI) is an instrument to measure the impact of foot pathology on function. It consists of a series of 23 visual analogue scales, nine related to pain, nine related to difficulties of performing tasks, and five related to patient limitations.\(^{33}\) The Ankle Osteoarthritis Scale (AOS) was derived from the Foot Function Index. It maintains the visual analogue scale structure but dispenses with the five questions on limitations, and modifies anatomic descriptors for the difficulty and pain subscales.\(^{34}\) The AOFAS, AOS and FFI\(^ {35}\) show acceptable responsiveness, and when using the validated short form 36, an instrument to measure general health and functioning, as the standard, the three region or disease specific scores all showed similar criterion validity.\(^ {36}\)

The validity of outcome measures is of utmost importance. The definition of osteoarthritis, whether this is based on clinical or on radiographical findings is variable. This is mainly due to lack of knowledge about what osteoarthritis exactly is, the lack of knowledge about how pain is influenced by function and the lack of knowledge about how pain and function are influenced by ones psychic health. The definition of osteoarthritis has become more clear in modern times, but is still subject to debate.
Known factors to influence the development of posttraumatic ankle osteoarthritis

Probably restoration of mortise congruity is the most important factor to influence the outcome after ankle fracture treatment. Joy and colleagues found that 84% of anatomically reduced fractures have good clinical results, whereas 64% of the patients with a poor reduction have poor clinical results, after an average of 2.8 years. There is clinical evidence that conservative treatment of 2mm displaced fibular fractures can give excellent long-term outcomes, if there is medial integrity. It is controversial that intra-articular fractures do not need an anatomic reduction to have good outcomes. Van den Bekerom and van Dijk, but also earlier studies show that some fibular fracture displacement may be tolerated if the mortise congruity is maintained. In these cases the proximal part of the fibula rotates and medializes, whereas the distal part remains in its anatomical position. (Figure 1)

Figure 1: A schematic representation of a Weber B type ankle fracture in which there is an anatomical configuration of the fibula on the left. On the right there is a congruent mortise despite of some fracture displacement. The expected outcome of a “non-anatomical” configuration of the fibula is in this case as good as an anatomical configuration, because the mortise remains intact.
This category of supination external rotation fractures is unique, since other variations of displacement may not be tolerated well: shortening or external rotation of the distal fibula compromise the mortise congruity. Only two biomechanical studies address distal fibula fractures without additional sectioning of the deltoid ligament. Both found significant changes up to 33% increase of peak pressure and 8% reduction of contact area with a shortened fibula and 73% peak pressure increase and 9% contact area reduction with externally rotated distal fibula fragments.\textsuperscript{44,45} The weight bearing function of the fibula was investigated by Lambert, which changed the view that the fibula does not act as a lateral strut or buttress, but actually participates in weight bearing. Dependent on the position of the foot 7-15% of the bodily weight is transferred through the fibula.\textsuperscript{46,47} Therefore shortening of the fibula leads to lateral tibiotalar overload. (Figure 2)

Figure 2: A schematic representation of a Weber B type ankle fracture in which there occurs shortening of the fibula. On the left the unloaded initial situation is given. The right drawing illustrates a loaded situation in which over time lateral tibiotalar peak pressures may increase and lead to asymmetrical (valgus) osteoarthritis.
Mortise incongruity as caused by a residual lateral talar displacement (Figure 3) is especially poorly tolerated and biomechanical evidence shows that this leads to an abnormal stress distribution on the articular cartilage. One millimeter of talar displacement leads to 40-50% reduction of contact area. It must be noted that in this frequently quoted study, the investigators placed metal plates as spacers between the medial malleolus and the talus, in order to maintain the lateral talar displacement. Approximately 80% of the taluses have a saddle shape, hence in normal weightbearing conditions they should have the tendency to stay underneath the tibia, because of the bony congruency. However clinical studies confirm that 1-2 mm of lateral talar displacement does occur and may predispose to ankle osteoarthritis. In a biomechanical study 2 millimeters lateral displacement of the fibula (with the talus following accordingly) has been shown to lead to increased tibiotalar contact stress. Only 55% good results were found after conservative treatment of ankle fractures in which the fibula was fractured and the deltoid ligament

Figure 3: A schematic representation of a Weber B type ankle fracture in which the deltoid ligament is disrupted. On the left the initial unloaded situation without talar displacement is given. The right drawing illustrates the loaded situation as it may develop over time, in which a lateral talus displacement may lead to tibiotalar osteoarthritis.
ruptured as well. So it can be stated that in cases of a combination of a distal fibula fracture and a deltoid ligament rupture, there is a need for anatomical reduction of the fibula, to restore tibiotalar congruity and reduce the talar displacement. There is evidence that these fractures in some cases have been mis-diagnosed as stable, and that conservative treatment in these cases was a poor option. A recent randomized study shows that conservative treatment of supination external rotation fractures with a deltoid ligament rupture leads to outcomes comparable to operative intervention. However 20% of patients treated non-operatively develop medial joint space widening within 1 year. At longer follow up, these patients may develop clinical symptoms. Reduction of the talar displacement by reconstrucion of the fibula may even lead to good results if performed when there is already onset of osteoarthritic changes in the ankle joint. Many authors have performed a lengthening osteotomy years after ankle fractures in cases of malunited fibulae.

Fracture reduction is a surgeon related factor on the outcome. Important for the outcome of ankle fracture treatment are also patient related factors. Comorbidities influence the outcome of ankle fracture treatment regardless of fracture severity or successful anatomical reduction. Patients with diabetes have an increased rate of complications following both operative and nonoperative ankle fracture treatment. Egol et al found in their series of operatively treated ankle fractures that 92% of the patients without diabetes recovered more than 90% of function, whereas only 71% of the patients with diabetes did. The presence of complicated diabetes is a strong predictor (OR 2.30) for short-term complications, as is peripheral vascular disease (OR 1.65). Complicated diabetes increases the likelihood 5 times of needing revision surgery or arthrodesis after ankle fracture, compared to patients with uncomplicated diabetes. A recent study found that patients with complicated diabetes were 7.63 times more likely to experience a wound complication, in comparison to uncomplicated diabetes. Especially Charcot neuroarthropathy leads to high rates of complications. An increased body mass index (BMI) may predispose to more severe or displaced fractures. Loss of reduction or failure of fracture fixation may be related to a higher BMI. A recent report assessing risk factors for radiographic osteoarthritis of the ankle by multivariate regression models found a substantially increasing risk with rising BMI (OR 1.17).
Other reported risk factors are age over 40,\(^{53}\) persisting ligamentous instability,\(^ {73}\) the development of arthrofibrosis\(^ {74}\) and open fractures.\(^ {75}\)

**Unknown factors that might influence the development of posttraumatic ankle osteoarthritis**

A factor thought to play a role in the development of posttraumatic ankle osteoarthritis is the presence of intra-articular cartilage lesions that result from ankle fractures. This factor is not surgeon related, nor patient related. It is inherent to the trauma mechanism; a side-effect of the ankle fracture. Chondral lesions are seen with chronic instability and after ankle trauma, being ligament rupture, bone fracture or combined lesions.\(^ {76-78}\) Studies on articular surface lesions after trauma by CT and MRI suggest that superficial lesions frequently occur without any significant impact on the functional outcome.\(^ {79;80}\) May this be the case, in 48% of the patients with deeper, osteochondral lesions after ankle trauma, radiologic signs of osteoarthritis were noted.\(^ {81}\) Osteochondral lesions, either avascular or traumatic in origin, eventually progress into ankle osteoarthritis.\(^ {82;83}\) In co-existence with the quality of fracture reduction, the extent of the initial cartilage injury might be a major determinant of joint degeneration after trauma.\(^ {84;85}\)

Furthermore the alignment of the hindfoot in the coronal plane is known to play a role in knee fractures.\(^ {86}\) In ankle osteoarthritis more than half of the patients have varus or valgus malalignment.\(^ {87}\) Is this the result of asymmetric wear, or could malalignment in the coronal plane induce osteoarthritis? Biomechanical studies have shown pressure changes in the ankle joint as a result of fibular malunion.\(^ {55}\) Also the influence of medializing and lateralizing calcaneus osteotomies has been studied in vitro.\(^ {88}\) But the exact role of supramalleolar deformities on pressure changes in the ankle joint has not been established yet.

The deltoid ligament is known to play a role in peritalar instability.\(^ {77;89;90}\) It is unknown if the deltoid ligament rupture as part of a supination external rotation ankle fracture predisposes to insufficiency, influencing the development of osteoarthritis. As stated earlier, mortise incongruity because of a residual talar displacement is not well tolerated as this leads to abnormal
loads on the articular cartilage. \(^{48,49}\) The role of the deltoid ligament in the development of posttraumatic osteoarthritis has not been investigated yet.

In order to answer some of the remaining questions, a narrative review (Chapter 4) and a systematic review of the literature (Chapter 2) were undertaken. Additionally a clinical follow-up study (Chapters 3 and 5), a radiographic study (Chapter 6) and a biomechanical study (Chapters 7 and 8) were performed in order to clarify the role of the deltoid ligament, cartilage lesions and hindfoot alignment in the coronal plane as factors influencing the mechanics of the ankle and the clinical and radiographical outcome after ankle fracture treatment.

**Systematic review of the literature**

A lack of quality studies was found with follow-up times of more than 5 years on predicting factors for the development of posttraumatic ankle osteoarthritis (Chapter 2). Several factors could not be identified. For example no study addressed the role of hindfoot alignment. Interestingly only 80% of surgically reduced fractures of the ankle showed good to excellent long-term outcomes. Several studies have labeled the adequacy of fracture reduction. Optimally reduced fractures had an odds ratio of 11.2 \((p<0.05)\) on having a good to excellent outcome with respect to poorly reduced fractures. The Weber A type fractures do not show a better long-term outcome when compared to Weber B type fractures. Weber B type fractures had an odds ratio of 1.08 \((\text{not significant})\) of having a good to excellent outcome with respect to Weber A type fractures. Unlike often taught, the Weber A type fractures are not ‘benign’ fractures. Vertical fractures of the medial malleolus in supination-adduction trauma should be reduced anatomically because of the weightbearing area on the distal tibia involved. In these type of fractures there may be impaction of the medial tibial plafond, \(^{95}\) which is probably often overlooked and untreated. Restoration of the zone of impaction and anatomic reduction is essential to the prevention of posttraumatic osteoarthritis in plafond injuries. \(^{96}\)

Two studies reported on the posterior fragment as a risk factor for the development of osteoarthritis, with 58.1% good or excellent long-term outcomes. \(^{3,97}\) Macko et al found 88%, 80% and 65% remaining tibiotalar contact
areas after posterior malleolus osteotomies of a quarter, a third and a half of the lateral joint-line distance respectively. There is consensus that posterior malleolar fractures should be addressed and anatomically reduced when the fragment constitutes more than 25-33% of the tibiotalar joint surface. However the fragment size is measured on standard lateral radiographs, which are unreliable because of the oblique fracture pattern (Figure 4). One study compared plain radiographs with CT images and found a good correlation for the measurement of fragment size. However, the fragment size was measured on a single sagittal CT slice as well. A study that quantifies the articular surface of the fracture fragment with respect to the entire tibial plafond in 3D, could provide the true size. Currently such a study is in progress in our collaborative.

In one of the identified studies the initial cartilage lesions had been recorded. In patients in whom these lesions were seen during the open reduction of the fracture, only 33.3% had good outcomes. However there may have been more lesions gone undetected. The OR of having a good to excellent outcome was 5.0 (not significant) in favour of the fractures without cartilage lesions.

Figure 4: on lateral radiographs the size of the posterior fragment is usually overestimated. The schematic drawing on the left represents measurement on a lateral plain radiograph. The fragment size is approximately 40% of the joint surface. On the right is the same fragment depicted. However it can be appreciated that because of the oblique fracture line, the actual fragment size is approximately only 25% of the joint surface.
Cartilage lesions

A study was performed in which patients were followed, who underwent arthroscopy at the time of fracture reduction to describe the intra-articular (osteo-)chondral lesions, to reveal the specific influence of these lesions on the development of posttraumatic osteoarthritis (Chapter 3). We found that open anatomical reduction and internal fixation of unstable ankle fractures can lead to high mean overall clinical (AOFAS score 88.9) and radiographic outcome scores (Kannus score 89.8) at a mean of 13 years after ankle fracture. When cartilage damage was present anywhere in the joint, the odds of the patient having a suboptimal long-term outcome (AOFAS score lower than 90) was 5 to 1, whereas the chance of showing radiographic signs of joint degeneration (Kannus score lower than 90) was 3.5 to 1. We found no correlation between the amount of lesions and clinical outcome. However, we found specific locations in the joint to be important. Lesions on the anterolateral aspect of the talus and those on the medial malleolus increased the risk of developing posttraumatic osteoarthritis. In addition we found a correlation between the depth of the lesions and the long-term AOFAS and Kannus scores, the deeper lesions had worse outcomes.

When discussing cartilage injury, three main problems deserve attention: die-punch injury, large defects and the inferior quality of repair tissue (fibrocartilage). The osteoarthritic changes induced by trauma, may be due to chondrocyte apoptosis, which has been simulated in a blunt articular impact model. Under normal physiologic conditions, activities like stair climbing can result in peak mechanical stresses on the cartilage of 15 to 20 MPa, which is well tolerated and lead to compressive strains of about 1% to 3%. It has been shown in the knee joint that fractures cause impact loads of over 25 Mpa, thus exceeding the threshold human articular cartilage can withstand. The regenerating capability of chondrocytes is age-dependent, which may explain why age is a risk factor for the development of posttraumatic osteoarthritis. In a large series of 345 ankle fractures treated operatively, Lindsjö found that the rate of excellent or good results was 81% for the displaced fractures but only 38% for the impacted fractures. Some optimally treated fractures still develop osteoarthritis: the remodeling capacity may be eliminated due to impaction apoptosis. However when a remodeling capa-
lity exists in the majority of circumstances, it may need the ideal environment - stability, congruency, even load distribution - to develop its potential. This may be the true rationale behind optimal restoration of mortise congruity and anatomical fracture reduction in ankle fracture treatment. Two other problems exist: large defects and the insufficient repair tissue. There are cases in which the cartilage defect is large enough (>7.5x15mm), it can alter the joint mechanics. Because of edge loading, there is limited healing potential. When the injury has been able to heal, it could be only temporarily. Over time, the fibrocartilage that fills a deep defect usually disintegrates. This means that the largest and deepest defects reoccur over a long period of time. This may be one of the reasons why it sometimes takes several decades for posttraumatic osteoarthritis to develop in the ankle joint.

Osteochondral lesions have poor outcomes when left untreated: good in 16%, fair in 9%, and poor in 75%. A systematic review of treatment strategies for osteochondral defects on the talus by Verhagen et al in 2003 demonstrated only a 45% success rate for nonoperative treatment. Patients who underwent excision, curettage, and microfracture reached an 88% rate of successful outcomes. Excision and curettage alone produced a 78% success rate, and excision alone produced a 38% success rate. Microfracturing is the gold standard treatment of osteochondral defects. The inability of this treatment to restore hyaline articular cartilage has stimulated researchers to find newer treatment options that attempt to achieve a more durable repair. Hyaluronic acid visco-supplements are used to treat osteoarthritis in hip, knee and ankle joint. Some authors state that in the ankle joint it does not seem to have the same effect. However recently it has been shown to be effective for up to 6 months in the treatment of symptomatic ankle osteoarthritis. Intra-articular injection of hyaluronan acid derivatives may be beneficial because of restoration of visco-elastic properties, anti-inflammatory and anti-nociceptive effects, hyaluronan synthesis normalisation and and inhibition of degradation. In cases of residual biomechanical problems, these must be firstly treated, followed by rheological restoration of the joint homeostasis.

In the literature review was found that intra-articular cartilage lesions seen after ankle fractures play a role in the development of posttraumatic osteoarthritis. Maybe some minor injuries can go without any disturbance of the synovial joint homeostasis, but there is a degree of damage in which the car-
tilage is incapable of a sufficient repair response. There is a point of no return, although it is not completely understood why and when this exactly occurs. This irreversibility has made osteoarthritis difficult to treat, and continues to stimulate researchers to develop preventive strategies, possibly already at the time of fracture treatment.

The deltoid ligament

In the diagnostic process following an ankle fracture, the gravity stress radiograph has provided the best results in detection of deltoid ligament rupture in patients with supination external rotation ankle fractures. In a literature review it was found that a medial clear space of over 4 mm, as seen on plain radiographic mortise views, to be suspect for a ruptured deep deltoid ligament. Pain over the deltoid ligament, swelling, ecchymosis, or combinations thereof, do not have sufficient sensitivity and specificity to rule out medial injury. Theoretically, ultrasound examination of the deltoid region has potential. In many cases, the reconstruction of the deltoid ligament is not necessary. When the fibula fracture is adequately reduced and the talus is no longer laterally displaced, there is no indication to perform a surgical exploration. In cases of doubt, arthroscopy could be of assistance to determine interposition when the medial clear space remains wide after proper reduction (Chapter 4).

Additionally in a long-term follow up study (Chapter 5), it was observed that after supination external rotation fractures, a fractured medial malleolus has a worse prognosis than a partial or complete rupture of the deltoid ligament. The remaining deltoid ligament insufficiency does not appear to play a role in these fractures. Radiologically, there were no significant differences detectable between the groups. Some biomechanical studies addressed this issue, such as Clarke et al. who found a decrease of the contact area of the tibiotalar joint by 15-20% only after additional sectioning of the deltoid ligament in ankles with a lateral malleolus osteotomy. Joy considered having a tear of the deltoid ligament to be a risk factor for worse clinical outcome when compared to a medial malleolus fractures. In the series described, the deltoid ligaments were sutured. In the clinical series (Chapter 5) it is shown that the deltoid ligament version of the supination external rotation
type 4 fractures in fact has better outcomes, if compared to the medial mal-
leolus fracture version. Posttraumatic osteoarthritis as a result of chronic
medial instability that may develop from a deltoid ligament rupture as part of
an ankle fracture is not yet well understood, although osteoarthritis resulting
from ligamentous instability is a recognized long-term effect. In the current
clinical series (Chapter 5) deltoid insufficiency after traumatic rupture as a
factor was not identified to play a role.

In cases of a non-displaced fibula fracture at the level of the syndesmo-
sis without medial injury conservative treatment is a valid option. Pre-exis-
ting deltoid insufficiency has not been taken into account in decision making
about ankle fracture stability. Theoretically a lax deltoid ligament is mechani-
cally similar to a deltoid ligament rupture. In combination with a distal fibula
fracture this may result in lateral talar displacement. Such a fracture would
require operative fixation of the fibula regardless of fracture displacement. In
such cases a seemingly stable fracture, treated conservatively, may lead to an
unfavorable outcome. Clinically there is some evidence that a chronic deltoid
insufficiency in combination with valgus of the hindfoot predisposes the ankle
to early osteoarthritis. Interestingly in gravity stress testing after an ankle
fracture a false positive stress test can be seen in 88.5% of the cases when a
cut-off medial clear space is chosen of 3mm, but also in 7.7% of the cases in
which a medial clear space of larger than 6mm is seen. Maybe in the latter
cases the intact, but insufficient, deltoid ligament allows a lateral talar dis-
placement of more than 1-2 mm in the presence of a distal fibula fracture and
can be best treated operatively. Perhaps all distal fibula fractures should recei-
ve a (gravity) stress view at presentation, not only to rule out deltoid ligament
rupture, but also pre-existing dysfunction.

Hindfoot varus and valgus

Supramalleolar osteotomies have been used to correct distal tibial malalign-
ment and asymmetrical osteoarthritis of the ankle joint. For pre-opera-
tive planning, reliable radiographic images are required. A radiographic study
was performed to describe the normal range of the medial distal tibial angle
(MDTA) and inter- and intra-observer variability of measuring the MDTA on
radiographs (Chapter 6). The normal range of the MDTA is 87 - 97.5 degrees. It was observed that the MDTA measured on partial and entire lower leg images can be as much as 5° in difference. An excellent interobserver reliability can be achieved for measuring angles of the distal tibia: the mean measurement difference between observers was less than 1°. In measuring the MDTA the tibial plafond line appears to be the key determinant for the accuracy. The standard method should be the acquisition of two images of the lower leg: one focused on the knee joint, the other focused on the ankle joint, maintaining parallel X-rays with regard to the joint surfaces. This could make the evaluation of the alignment more accurate and consistent.

In the biomechanical study it was concluded that varus and valgus deformity of the distal tibia cause significant changes in the contact area of the tibiotalar joint of up to 36% and a mean reduction in tibiotalar force transmission of up to 30% (Chapter 7). A paradoxical pressure distribution was seen after supramalleolar tibial osteotomy if the fibula was left intact. After creating a distal tibial varus, a counter-intuitive lateral pressure overload occurred (Figure 5). Only after the fibula was divided did the hindfoot adopt a varus position and a medial shift of the pressure distribution (Figure 6). An identical phenomenon was seen with supramalleolar valgus (Figures 7 and 8). The effect of the fibula on the characteristics of the tibiotalar joint is more marked with valgus deformity than with varus. Furthermore, the biomechanical findings support the justification of supramalleolar osteotomies in cases of malalignment, since it was possible to achieve significant tibiotalar pressure changes (Chapter 7).

Load distribution in the ankle joint is not only affected by the orientation of the MDTA, but also by joint congruency. Therefore supramalleolar deformities, or asymmetric osteoarthritis, cannot be compared to knee joint deformities for example, since in the knee joint only correction of the alignment of two bones must be accomplished. When planning a supramalleolar osteotomy both alignment and congruency have to be addressed. From a biomechanical perspective two essentially different groups of varus and valgus deformities of the ankle joint should be distinguished. In the first group an isolated frontal plane deformity is found. The second group presents a combined alteration in both the bony alignment and the congruency of the ankle joint. Secondly, in the majority of cases, asymmetric osteoarthritis is not a sin-
Figure 5: A schematic representation of a distal closing-wedge varus osteotomy of the tibia; without a fibula osteotomy this leads to lateral tibiotalar overload. Note that the talus does not follow the distal tibial articular surface.

Figure 6: A schematic representation of a distal closing-wedge varus osteotomy of the tibia; if the fibula is allowed to lengthen, the tibiotalar pressure shifts in the expected direction, in this case towards the medial side.
Figure 7: A schematic representation of a distal opening-wedge valgus osteotomy of the tibia; without a fibula osteotomy this leads to a medial tibiotalar overload.

Figure 8: A schematic representation of a distal opening-wedge valgus osteotomy of the tibia; if the fibula is allowed to shorten, the tibiotalar pressure shifts in the expected direction in this case towards the lateral side.
gle frontal plane deformity. The changes of load distribution and force transfer across the ankle joint occur in a biplanar pattern and not only in a medio-lateral direction (Chapter 8).

There is a correlation between chronic lateral ankle instability, varus malalignment and varus osteoarthritis. Valderrabano found that the average tibiotalar alignment was varus in their patient population with ankle osteoarthritis from several etiologies. In case of varus malalignment there is still containment of the talus because of the medial malleolus. Stress fractures of the medial malleolus may occur. This predisposition still is more favorable than a valgus hindfoot. In general, a tibiotalar varus can lead to asymmetric osteoarthritis without a great amount of pain. Patients with a tibiotalar varus may even have a better general function than their counterparts with neutral or valgus hindfeet. Since the normal MDTA is in slight valgus, shortening of the fibula may lead to more lateral overload in patients who are at the valgus end of the normal range, than in a patient with a slight varus in the distal tibia - where there is more load through the medial malleolus. Speculatively a varus-normal hindfoot may be protective against osteoarthritis in suboptimally treated lateral malleolus fractures. There is no clinical evidence yet to confirm this hypothesis.

There is some evidence that valgus malalignment in combination with deltoid insufficiency leads to valgus osteoarthritis. In case of valgus malalignment, the syndesmotic complex and the deltoid ligament may not be able to constrain a displacement. In such cases it is not uncommon that the talus tilts within the mortise and drives into the anterolateral tibial plafond. Longstanding valgus malalignment without ankle fractures are also known to lead to ankle problems. However, the subtalar joint has more inversion than eversion capacity. Therefore a tibiotalar valgus can be corrected more easily in the subtalar joint, whereas a tibiotalar varus is more difficult to compensate for in the subtalar joint.

The subtalar joint is crucial for the stress concentration in the tibiotalar joint. There may be a threshold regarding the subtalar joint varus or valgus compensation capability. The valgus inclination of the subtalar joint can compensate the varus tilting in the tibiotalar joint until a certain point, after which it gives into a varus tilting of the entire hindfoot. When the subtalar joint can no longer compensate against tibiotalar varus or valgus stress in
cases of asymmetrical wear, the osteoarthritis in the tibiotalar joint swiftly reaches its final stadium with joint obliteration. \textsuperscript{25,27,130,131} This forms the basis for the Takakura classification, as his group classified varus osteoarthritis of the tibiotalar joint in stages \textsuperscript{1-4,25} recently modified by Tanaka, who divided Stage 3 into ‘a’ and ‘b’. \textsuperscript{131} Stage 3b and stage 4 are regarded as end-stages and have been reported to respond poorly to a supramalleolar osteotomy because most of the ankles with Stage-3b osteoarthritis did not improve to Stage 1 after surgery. \textsuperscript{131} A recent report does not support this conclusion, because some ankles with Stage-3B osteoarthritis improved to Stage 2 after surgery and improvements to lower stages should also be regarded as satisfactory results. \textsuperscript{140} In general, correction osteotomies should preferably be performed while there are sufficient layers of cartilage left. \textsuperscript{127-129,135}

\textbf{General conclusions}

Only 80\% of all surgically reduced ankle fractures have a good to excellent long-term outcome. The remainder may have suboptimal outcomes because of accompanying intra-articular cartilage lesions. These lesions may eventually play a role in the development of posttraumatic osteoarthritis.

The Weber A type fractures do not have a better long-term outcome than type B fractures. A vertical fracture of the medial malleolus in the weightbearing area and medial malleolus cartilage lesions can result from the supination adduction (Weber A type) ankle fracture.

Cartilage damage that is present anywhere in the ankle joint after ankle fracture is correlated to inferior long term clinical and radiographical outcomes.

No correlation is found between the number of cartilage lesions in the ankle joint and the long-term clinical outcome.

There is a correlation between the location and depth of the lesions and the clinical outcome: lesions on the anterior and lateral aspects of the talus and those on the medial malleolus increase the risk of posttraumatic osteoarthri-
tis. Deeper lesions have worse long-term clinical outcomes.

A fractured medial malleolus in supination external rotation ankle fractures, has a worse prognosis than a partial or complete rupture of the deltoid ligament.

The medial distal tibial angle (MDTA) measured on partial and entire lower leg images can be as much as 5° in difference.

An excellent interobserver reliability can be achieved for measuring the MDTA of the distal tibia: the mean measurement difference between observers was less than 1°.

Varus and valgus deformity of the distal tibia cause significant changes in the contact area of the tibiotalar joint of up to 36% and a mean reduction in tibiotalar force transmission of up to 30%.

A paradoxical pressure distribution is seen after supramalleolar tibial osteotomy when the fibula is left intact: supramalleolar varus leads to posterolateral tibiotalar overload, supramalleolar valgus leads to anteromedial tibiotalar overload.

Load distribution in the ankle joint is not only affected by the orientation of the MDTA, but also by joint congruency. When planning a supramalleolar osteotomy, alignment has to be corrected and mortise congruency maintained by addressing the fibula.

The changes of load distribution and force transfer across the ankle joint occur in a biplanar pattern and not only in a medio-lateral direction.
References


