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

Citation for published version (APA):
Stufkens, S. A. S. (2014). 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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S.A.S. STUFKENS

POSTTRAUMATIC ANKLE OSTEOARTHRITIS
Only 80% of all surgically reduced ankle fractures have a good to excellent long-term outcome. (This thesis)

The Weber A type fractures do not have a better long-term outcome than type B fractures. (This thesis)

Cartilage damage that is present anywhere in the ankle joint after ankle fracture is correlated to inferior long-term outcomes. (This thesis)

There can be as much as 5° in difference of the medial distal tibial angle when measured on ankle images compared to entire lower leg images. (This thesis)

Varus and valgus deformity of the distal tibia cause significant changes in the pressure distribution and contact area of the tibiotalar joint. (This thesis)

A paradoxical pressure distribution is seen after supramalleolar tibial osteotomy when the fibula is left intact. (This thesis)

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. (This thesis)

“The patient does not care about your science; what he wants to know is, can you cure him?” (Martin H. Fischer)

“Some days you catch the bear. Some days the bear catches you. Some days you can not even find the forest.” (Cherokee saying)

“It is nice to be important, but it is more important to be nice.” (Scooter)
POSTTRAUMATIC ANKLE OSTEOARTHRITIS

HOW INITIAL CARTILAGE LESIONS, THE DELTOID LIGAMENT AND HINDFOOT ALIGNMENT AFFECT THE OUTCOME OF OPERATIVELY TREATED ANKLE FRACTURES
This thesis was prepared at the Orthopaedic Department of the Kantonsspital Baselland, Liestal, Switzerland and at the Orthotrauma Research Center Amsterdam, Academic Medical Center, University of Amsterdam, The Netherlands. Biomechanical investigations have been performed at the Experimental Laboratory of the VUmc, Amsterdam, The Netherlands.

Research support was provided by the AO Research Fund Grant S-08-34H (Davos, Switzerland) and grants from the SUVA insurance company (Lucerne, Switzerland) and Robert Mathys Foundation (Bettlach, Switzerland).

Publication and distribution of this thesis was kindly supported by Anna Fonds te Leiden, Nederlandse Orthopedische Vereniging, Graduate School AMC, Stichting Klinisch Wetenschappelijk Onderzoek Slotervaartziekenhuis, Reumafonds, Implantcast, DePuy Synthes, Integra Life Sciences, ChipSoft, Mathys Orthopaedics, and Leuk Orthopedie.

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Lay-out: D. Volman & S.A.S. Stufkens
Printed by: GVO drukkers & vormgevers B.V. | Ponsen & Looijen
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HOW INITIAL CARTILAGE LESIONS, THE DELTOID LIGAMENT AND HINDFOOT ALIGNMENT AFFECT THE OUTCOME OF OPERATIVELY TREATED ANKLE FRACTURES

ACADEMISCH PROEFSCHRIFT

Ter verkrijging van de graad van doctor

aan de Universiteit van Amsterdam

op gezag van de Rector Magnificus

prof. dr. D.C. van den Boom

ten overstaan van een door het college voor promoties ingestelde commissie, in het openbaar te verdedigen in de Agnietenkapel

op vrijdag 28 februari 2014, te 12:00 uur

door

Sjoerd Antoine Sebastiaan Stufkens

egeboren te de Bilt
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Faculteit der Geneeskunde
voor Mariken, Hugo en Thomas
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PART I
INTRODUCTION
CHAPTER 1

GENERAL INTRODUCTION
Problem statement and aim of this thesis

The quality of the reduction of intra-articular fractures is of paramount importance for a satisfactory outcome in all joints. Accordingly, the most important aspect of conservative or surgical treatment of ankle fractures, is achieving anatomical reduction, thereby restoring the congruity of the mortise. Malunion increases the chance of development of early degenerative joint disease. Other factors that have been recognized to play a role are: ligamentous instability, age, fracture luxation or fracture dislocations, the size of the posterior malleolar fragment and systemic factors that affect bone healing. Not yet fully recognized is the possibly adverse effect of intra-articular cartilage lesions that are often seen after ankle fractures. The vast majority (70-78%) of ankle osteoarthritis is of posttraumatic origin. Among other questions, it remains to be answered, why a significant part of the operatively - anatomically - reduced ankle fractures still result in posttraumatic osteoarthritis. In this thesis we address the role of the intra-articular cartilage lesions, the role of the deltoid ligament and the role of the alignment of the hindfoot.

Ankle anatomy

The osteology of the ankle joint comprises three bones and three articulations. The tibia and fibula both articulate at their distal ends with the talus. This is the true ankle articulation (Figure 1). The fibula is in contact with the tibia only at a tiny surface extending from the articular surface of the lateral malleolus, and includes a synovial recess of 1cm. This tibio-fibular connection is known as the syndesmosis. The distal part of the fibula is known as the lateral malleolus and extents 1cm more distal than the medial malleolus. The medial malleolus is an apophysis of the distal tibia and consists of two colliculi separated by a groove. The ventral colliculus extents 0,5cm farther than the posterior colliculus. A prominence of the distal tibia on the dorsal aspect is known as the posterior malleolus. The tibia and fibula are tightly bound together thus constituting a ‘fork’: the medial malleolus, tibial plafond and lateral malleolus cover the talus on three sides. The term ankle ‘mortise’
CHAPTER 1 - GENERAL INTRODUCTION

Figure 1: the bones of the ankle joint seen from ventralateral (left) and posteromedial (right). Images modified from www.anatomy.tv (Primal Pictures Ltd 2013).

Figure 2: the ligamentous structures around the ankle seen from lateral on the left and from medial on the right. In the left image the ligaments are numbered 1) anterior syndesmotic ligament, 2) anterior talofibular ligament, 3) calcaneofibular ligament, 4) lateral talocalcaneal ligament. In the right image the ligaments are numbered 1) anterior tibiotalar ligament, 2) tibionavicular ligament, 3) spring ligament, 4) tibiocalcaneal ligament, 5) posterior tibiotalar ligament. Images modified from www.anatomy.tv (Primal Pictures Ltd 2013)
or ‘mortice’ is therefore not exactly correct. In woodworking terminology, ‘bridle’ joint would be more synonymous. The talus is an intercalated bone with no tendons attached, but firmly bound by ligaments to the tibia, fibula and calcaneus (Figure 2). The talar dome is cylindrical with the convexity in the antero-posterior direction. More accurately, the trochlea is the frustum of a cone with the apex on the medial side. The movement of the talus within the malleoli is hinge-like, permitting rotatory movements in the sagittal plane with, on average 20° of dorsiflexion and 50° of plantarflexion. The talar trochlea is wider anteriorly than posteriorly, giving it a wedge shaped appearance in the transverse plane. 19

On the medial side the deltoid ligament connects the tibia firmly to the posteromedial talus with deep fibres. With superficial fibers the tibia is connected to the navicular bone, the spring ligament and to the calcaneus. 20 The strongest portion of the deltoid ligament are the deep fibers, strictly holding the tibia on top of the talus, allowing a minimum of relative movement. 21 The tibia and fibula are bound together by three structures, from ventral to dorsal: the anterior tibiofibular ligament, the interosseous membrane, and the posterior tibiofibular ligament, together the syndesmotic complex. The posterior syndesmotic ligament consists of two layers, the superior band and the deep band, also named transverse ligament. This component is very strong and thick, acting as a posterior labrum. 18 On the lateral side, the fibula is attached to the talus by the anterior and posterior talofibular ligaments and to the calcaneus by the calcaneofibular ligament.

**Ankle fractures**

Sir Percivall Pott (Figure 3) wrote in 1768: “... the fibula breaks in the weak part already mentioned, that is within two or three inches of its lower extremity. When this happens, the inferior fractured end of the fibula falls inward toward the tibia, that extremity of the bone which forms the outer ankle is turned somewhat outward and upward, and the tibia having lost its proper support, and not being of itself capable of steadily preserving its true perpendicular bearing, is forced off from the astralagus 18 inwards, by which means

*Astragalus is the old anatomic name for the talus*
the weak bursal, or common ligament of the joint is violently stretched, if not torn, and the strong ones, which fasten the tibia to the astralagus and os calcis, are always lacerated, thus producing at the same time a perfect fracture and a partial dislocation, to which is sometimes added a wound in the integuments, made by the bone at the inner ankle." This is one of the first injury pattern descriptions of the ankle in Western literature. It is this early description that preserves the eponym of Pott’s fracture for ankle fractures. The French usually prefer their own eponyms, and in this case it is quite justified. In France, ankle fractures are referred to as “Dupuytren” and “Maisonneuve” fractures, the former is located distally, the latter is located in the proximal fibula. Guillaume Dupuytren (Figure 3) was among the first to use cadaver experiments to produce ankle fractures by outward movement of the foot. Jules Germain Maisonneuve (Figure 3) was the first to recognize the importance of external rotation as common fracture mechanism. He also recognized the ligamentous lesions that accompany ankle fractures and described the

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* Os calcis is the old anatomic name for the calcaneus

† Integuments are the soft layers covering the joint, i.e. the capsule and skin
high fibular fracture that bears his name. Dupuytren was the greater surgeon, but Maisonneuve truly understood the pathogenesis of ankle fractures. Many different fractures around the ankle exist, but only a specific sort of fractures is called ankle fracture. Tibial plafond fractures caused by a hammering (“pilon” in French) of the talus by axial force, are not ankle fractures. Talus fractures are also not considered ankle fractures. Ankle fractures are fractures of either the lateral, the medial or the posterior malleolus, or combinations thereof, caused by rotation, abduction or adduction of the talus. As Maisonneuve described, next to interruption of bony continuity, ruptured ligaments around the ankle contribute to instability of the joint and need to be recognized. On the medial side, a ruptured deltoid ligament is the equivalent of a medial malleolus fracture. A lateral malleolus fracture is commonly an oblique fracture, between the anterior and posterior tibiofibular ligaments. However, together with a lateral malleolus fracture, the syndesmotic ligaments may also rupture. Most often the anterior tibiofibular ligament yields first in case of external rotation. If the posterior tibiofibular ligament ruptures, there is a marked instability, allowing diastasis between the tibia and fibula. However, the posterior ligament is strong, resulting in avulsion of the posterior malleolus in most cases.

Ankle fracture classifications

Among some residual archaic eponymic designations for ankle fractures, today two classification systems are commonly used: the Lauge-Hansen system (Fig 4), commonly perceived as difficult, and the Weber system (Fig 5), perceived as easy. The Weber system has been incorporated in the AO nomenclature (Fig 6). The Belgian surgeon Robert Danis (1949) and subsequently the Swiss surgeon Bernhard Georg Weber (1972) classified ankle fractures by the radiographic anatomical features. More specifically, they described the level of the fracture from the distal tip in its relationship to the syndesmosis. Weber type A fractures are below the syndesmosis. They correspond to the Lauge-Hansen supination-adduction fractures. Type B fractures are at the level of the syndesmosis. They correspond to the Lauge-Hansen supi-
Figure 4: The Lauge-Hansen ankle classification consists of two terms, one to describe the position of the foot - in supination or in pronation - and another to describe the movement of the talus in the mortise - abduction, adduction or external rotation - plus stages 1 to 4 to indicate the different structures that fracture or rupture. Images modified from www.radiologyassistant.nl (original by Robin Smithuis).

Figure 6: The Weber classification consists of three types of ankle fractures. Weber A is an infrasyndesmotic fibular fracture. Weber B is an transsyndesmotic fibula fracture. Weber C is a suprasyndesmotic fibula fracture. The medial and posterior injuries have to be separately mentioned. Images modified from www.radiologyassistant.nl (original by Robin Smithuis).
nation-external rotation fractures and pronation-abduction fractures. Type C fractures are above the syndesmosis. They include Lauge-Hansen pronation-external rotation and pronation-abduction fractures. The AO group used the Weber system as the basis of a comprehensive fracture classification, consisting of groups and subgroups to include 27 fracture types. An alternative is to describe ankle fractures on the basis of the number of malleoli fractured. Although this excludes useful information, it has been shown to be of prognostic value. The Lauge-Hansen system has been reported to have a poor interobserver reliability, because of its limitation as a predictor of soft-tissue damage associated with ankle fractures, and leaving too many fractures unclassifiable.
Ankle fracture treatment

The most important Dutch contribution to fracture treatment, around 1850, has probably been the invention of the plaster cast on a roll. Operative treatment only matured at the turn of the 19th century thanks to radiography, antiseptic wound treatment and the development of anesthesia. In the first half of the 20th century, many complications frequently associated with peri-articular fractures could still not be prevented. It was the Arbeitsgemeinschaft für Osteosynthesefragen, founded in 1958, that have changed the entire approach of fracture treatment. Uniform fracture registration and teaching of principles like anatomical reduction, stable internal fixation and early mobilization of joints, have had a great influence on treatment regimens worldwide.

In the early years of ankle fracture surgery, the medial malleolus was considered the main column of the ankle mortise. Hence, displaced bimalleolar fractures were treated by open reduction and fixation of the medial malleous in conjunction with closed reduction of the fibular fracture. In 1977 Yablon published a widely quoted paper in which was stated that the talus ‘follows’ the fibula in ankle fractures, pointing towards the lateral malleolus as the key to ankle stability. Recently the tide has turned again, as the medial malleolus has regained its popularity as the most important structure to assure mortise congruity and stability after anatomical reduction and fixation.

The conservative treatment of closed, stable, non-displaced ankle fractures, and of some minimally displaced fractures has proven to be successful. The current indications for operative treatment of ankle fractures are: open fractures, fracture displacement of more than 2mm, lateral malleolar shortening by more than 2mm or rotation by over 5 degrees, any lateral talar shift, bimalleolar and trimalleolar fractures, syndesmotic disruption, and instability based on stress views. Open anatomical reduction and internal fixation with lag screws and a plate on the fibula and screws on the medial side, is generally considered the treatment of choice for most fractures. In some cases additional reduction and fixation of a posterior malleolus fragment is necessary, as is the placement of a syndesmotic screw.
CHAPTER 1 - GENERAL INTRODUCTION

Results of ankle fracture treatment

Conservative treatment of apparently stable ankle fractures leads to good clinical and radiological results in 95% of the cases. The failures may have been caused by missed unstable fractures. This is not fully understood. Alternatively, the cartilage lesions occurring together with ankle fractures may cause these failures. Open treatment, leading to better results for unstable fractures, comes with the price of surgical complications. However the reported complication rates are relatively low: 0.34% pulmonary embolisms, 1.44% wound infections, 0.82% revision surgery and 0.96% need for fusion or prosthesis within five years. Approximately 80-90% of the operatively treated patients have excellent short-term results. However at 10 years follow-up or longer, some report only 52% good-to-excellent results. Because of the widely held assumption - that the quality of the fracture reduction is of paramount importance for a satisfactory long-term outcome - the question remains, why a significant part of the operatively anatomically reduced fractures still result in posttraumatic osteoarthritis. Radiographic changes are common after 10 years in about 70-75% of the cases. In general, posttraumatic arthritis is reported to occur in 14% to 50% of all operatively treated ankle fractures. In ankle fracture treatment, the role of the intra-articular cartilage lesions that are often seen after ankle fractures, the role of the deltoid ligament, and the role of coronal plane alignment of the hindfoot are unknown.

Outline of this thesis

In order to quantify the existing knowledge about the influence of cartilage lesions, the deltoid ligament ruptures and hindfoot alignment on the long-term outcome after operatively treated ankle fractures, a systematic literature review was undertaken, of which the results are presented in chapter 2. Because of the lack of information on the role of accompanying initial cartilage lesions after ankle fractures, a cross-sectional long-term follow up study of operatively treated ankle fractures, in which the cartilage lesions have been described at the time of fracture management, was performed. The results are presented in chapter 3. Unknown is the exact role deltoid ligament ruptures
play in ankle fractures. Instability of the mortise occurs when the deltoid ruptures together with a lateral malleolus fracture. How to best diagnose a deltoid ligament rupture and whether to address the ligament with open suturing is not established yet. Chapter 4 consists of a narrative review of the diagnosis and treatment of deltoid ligament lesions that accompany ankle fractures. How the ruptured deltoid ligament effects the long-term outcome of ankle fracture treatment has not been clarified yet. In chapter 5 we present the results of a long-term follow up study of ankle fractures with a deltoid ligament lesion. Chapter 6, 7 and 8 are devoted to malalignment of the ankle in the coronal plane. The measurements in the coronal plane are dependent on image properties and observer reliability. In the literature a wide variation of nomenclature, measurement methods and normal ranges can be found. In chapter 6 a radiologic study is presented in which we point to the importance of whole lower leg images when measuring the varus or valgus of the distal tibia. Additionally a standardized measurement method is described as are the inter- and intra observer reliabilities. The influence of alignment of the distal tibia in the coronal plane on the ankle joint and congruency has not been studied yet. Hypothetically the ankle joint is influenced by varus and valgus malunions after fracture. In chapter 7 and 8 the results are presented of a biomechanical study, in which the tibio-talar pressures are measured after creating varus and valgus malalignment in the distal tibia and fibula.

References


CHAPTER 2

LONG-TERM OUTCOME AFTER OPERATIVELY TREATED ANKLE FRACTURES

Published as:

CHAPTER 2 - LONG-TERM OUTCOME OF ANKLE FRACTURES

Introduction

Dislocated or unstable ankle fractures are generally treated with surgical anatomical reduction and internal fixation. The main rationale behind this treatment is the avoidance of secondary dislocation, leading to mal- and non-union. Mal-union is probably the most important factor in the development of posttraumatic osteoarthritis. The aim of this literature review was to clarify the role of fracture type, fracture mechanism, fracture severity, initial cartilage damage and hindfoot alignment on the development of posttraumatic osteoarthritis. Our objective was to systematically review the highest level of available evidence on the long-term outcome (more than 4 years of follow-up) after operatively treated ankle fractures in the English, German and Dutch literature.

Materials and methods

Data sources

A search term with Boolean operators (assessment OR evaluation OR follow-up OR long-term*) AND (surgery OR surgical* OR operativ*) AND (ankle fracture* OR malleol* fracture*) was constructed. The search was limited to humans and adults and the following databases were searched from 1966 to 2008 to identify studies relating to functional outcome, subjective (patient-centred) outcome and radiographic evaluation at least (a follow-up group mean of) 4 years after an operatively treated ankle fracture. The computerised databases were searched of:

1. Cochrane Database of Systematic Reviews and Cochrane Clinical Trial Register (3rd Quarter 2008): two results in ‘economic evaluations’. None of them relevant.
3. EMBASE (January 1974 to August 2008): 349 papers found of which 35 potentially relevant, these were identical to the papers found in MEDLINE.
4. Orthopaedic Trauma Association annual meetings’ abstracts archives website (January 1996 to August 2008): 0 papers found using our search term.

The search of the literature performed in this study was according to the Quor-rom \textsuperscript{12} statement and limited to published original clinical studies including operatively treated ankle fractures (AO/OTA type 44 A–C). Only studies with a minimum of eight patients were included. Stress fractures, paediatric fractures, pathologic fractures, open fractures, and distal tibia fractures (AO/OTA type 43 A–C) were excluded. Articles that reported mixed series of ankle fractures and pilon fractures were only included if the data of the ankle fractures could be extracted separately. Articles that reported conservative treatment of ankle fractures were excluded. Article reporting mixed series of conservative and operative treatment were included if the surgically treated fractures could be extracted separately.

Malunion is thought to be the most important factor determining the long-term outcome after ankle fracture; the definition of mal-union was documented for each article. The rate of mal-union according to the authors’ definition was extracted from each article. The lists of references of retrieved publications were manually checked for additional studies potentially meeting the inclusion criteria and not found by the electronic search. The search was restricted to articles written in the English, German and Dutch language. Case reports, descriptions of surgical techniques and abstracts from scientific meetings were excluded.

\textit{Study selection}

From the literature search the title and abstract of potentially relevant articles were assessed. The full article was retrieved when the title or abstract revealed insufficient information to determine appropriateness for inclusion. All identified studies were assessed independently by two authors (S.S. and M.B.) for inclusion using the mentioned criteria. Disagreement was resolved by group discussion with arbitration by a third author (G.K.) where differences remained. Of the 42 initially relevant papers, 18 met our inclusion criteria.
Data extraction

The data from the included studies were extracted by one author (S.S.), and were verified by a second author (M.B.). Disagreement was resolved in a consensus meeting or by third party adjudication (G.K.) when necessary. Studies were not blinded for author, affiliation and source. 9;12;14 No authors were contacted in order to complete the required data and for further information on methodology. Relevant information regarding the level of evidence, mean years of follow-up, number of patients included and number available for follow-up, fracture type, associated ligamentary injuries, and the previously mentioned outcome measures were extracted. Methodological quality of included studies was assessed by assigning Levels of Evidence as defined by the Centre for Evidence Based Medicine (https://ccywhq051ord469b1f9r.sec.amc.nl). In short, for studies on therapy or prognosis, Level I is attributed to well designed and performed randomised controlled trials, Level II are cohort studies, Level III are case–control studies, Level IV are case series and Level V are expert opinion articles.

Data synthesis

Based on the levels of evidence recommendations for future research were formulated. Conclusions of this review can be used to better inform patients about prognosis after ankle fracture. A grade was added based on the evidence supporting that recommendation. Grade A: treatment options or prognosis are supported by strong evidence (consistent with Level I or II studies), Grade B: treatment options or prognosis are supported by fair evidence (consistent with Level III or IV studies), Grade C: treatment options or prognosis are supported by either conflicting or poor quality evidence (Level IV studies), and Grade D: when insufficient evidence exists to make a recommendation.

Statistics

When pooling of the data was possible and clinically relevant, odd-ratios (ORs) were calculated to compare the influence of several prognostic factors (quality of the fracture reduction, different fracture types, and presence of car-
Results

There was only one Level I study, \(^3\) one Level II study, \(^8\) four Level III studies \(^1;10;20;21\) and 12 Level IV studies. \(^2;4-7;11;13;15-19\) Two studies mention to aim to report on the analysis of some prognostic factors. \(^4;16\) None of the studies was designed to prospectively address influential factors for the development of osteoarthritis.

Overall outcome

A total of 1822 fractures were identified. The mean sample-size weighted follow-up was 5.1 years. The initial number of patients that were included in the studies was 2724, which results in a long-term follow-up rate of 66.9%. The overall outcome is summarised in Table 1. Out of the 18 papers found, 7 reported both clinical and radiological outcomes. The remaining 9 reported on objective and subjective clinical findings only. Pooling of the overall outcome could not be performed because of the heterogeneity of the used questionnaires and outcome parameters.

Regarding the fracture reduction we found 4 papers reporting on 106 fractures (Table 2). In the study of Bauer, \(^3\) we interpreted the Magnussen scores ‘0’ and ‘(+)’ as good or excellent. In Fogel’s study \(^7\) the Performance index scores were transformed: a score of 78.8 in 17 patients is equal to ‘good to excellent’ outcome in \((78.8/100) \times 17 = 13\) patients. In the studies of Finnan \(^6\) and Specchiulli, \(^17\) having ‘no arthritis’ was regarded as ‘good to excellent’ outcome. Of the optimally reduced fractures, 79.3% showed good to excellent results at long-term follow-up. However of the fractures that were given the remark ‘Fair’ regarding the reduction, only 67.6% had good to excellent results. Poorly reduced fractures had inferior long-term results: only 25.5% good or excellent results were reported. The odd-ratios (ORs) of having a good to excellent outcome were calculated for the 3 reduction groups (Table
7). ‘Optimal’ fracture reduction had an OR of 11.17 (95% CI 3.65–34.15) for good to excellent outcome when compared to ‘Poor’ fracture reduction. ‘Fair’ reduction had an OR of 6.08 (95% CI 1.99–18.59) on good to excellent outcome when compared with ‘Poor’ reduction. The difference between ‘Optimal’ and ‘Fair’ reduction on a good to excellent outcome was not significant with an OR of 1.85 (95% CI 0.60–5.62).

Of the fractures which were classified according to Danis–Weber, 736 were eligible for correlation with the long-term outcome (Table 3). Weber type A fractures resulted in 82.7% of the cases in a good or excellent outcome. Better results were seen in the second category: 83.8% of the Weber B fractures had a good or excellent outcome. The most unfavourable outcome was seen in Weber C fractures: 70.4% of the fractures had good to excellent results. The Weber B type fractures consist of fibula pathology with or without medial involvement. In 442 fractures this division was possible by comparison of the Lauge-Hansen supination–exorotation (SER) stage 2 and 4. Fractures of the SER-2 type resulted in 92.2% of the cases in good or excellent outcomes, whereas surgically treated SER-4 types led to 81.7% good or excellent outcome (Table 4). Significant differences were seen between Weber A and C types, between Weber B and C types, and between Lauge-Hansen SER-2 and SER-4 fractures. ORs were calculated (Table 7). Weber type A revealed an OR of 2.01 (95% CI 1.13–3.57) on a good or excellent outcome when compared to Weber C type fractures. Weber B showed an OR of 2.17 (95% CI 1.22–3.86) on a good to excellent outcome when compared to Weber C. The difference between Weber A and Weber B was not significant with an OR of 1.08 (95% CI 0.61–1.92).

**Cartilage lesions**

The initial cartilage damage is a factor we hypothesised to be of influence. Only one study 7 reported on the influence of initial cartilage lesions on the outcome (Table 5). 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 5.00 (95% CI 0.82–30.46) in favour of the fractures without cartilage lesions (Table 7), although this was not significant.
### Table 1: Overall Outcome

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Level of Evidence</th>
<th>Included (n)</th>
<th>Type of Injury</th>
<th>Follow-Up (n)</th>
<th>FU (years)</th>
<th>Outcome Parameter</th>
<th>Score</th>
<th>Complications</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Svend-Hansen</td>
<td>1978</td>
<td>IV</td>
<td>33</td>
<td>Bi- or trimal-malleolar ankle fractures</td>
<td>29</td>
<td>4.8</td>
<td>Radiologic score: slight, moderate, severe arthritis</td>
<td>-</td>
<td>14 slight, 8 moderate, 7 severe</td>
<td>Exact reposition of the lateral malleolus is essential for good joint function and the prevention of development of posttraumatic arthrosis.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Questionnaire: excellent, satisfactory, unsatisfactory, failure</td>
<td>-</td>
<td>3 excellent, 10 satisfactory, 8 unsatisfactory, 8 failure</td>
<td></td>
</tr>
<tr>
<td>Schweiberer</td>
<td>1978</td>
<td>IV</td>
<td>203</td>
<td>All malleolar fractures</td>
<td>100</td>
<td>6.5</td>
<td>Weber's protocol (0-24); 0 excellent, 1-2 good, 3 poor</td>
<td>-</td>
<td>32 excellent, 40 good, 38 poor</td>
<td>Best treatment of ankle fractures is early reduction, fixation and rapid mobilisation.</td>
</tr>
<tr>
<td>Hughes</td>
<td>1979</td>
<td>II</td>
<td>448</td>
<td>All ankle fracture types</td>
<td>448</td>
<td>4-12</td>
<td>Weber's protocol (0-24); 0 excellent, 1-2 good, 3 poor</td>
<td>-</td>
<td>344 good to excellent, 104 poor</td>
<td>Supination-abduction and supination-eversion ankle fractures are best treated by open reduction, anatomical restoration and stabilization.</td>
</tr>
<tr>
<td>Yde (a)</td>
<td>1980</td>
<td>III</td>
<td>34</td>
<td>SE II ankle fractures</td>
<td>34</td>
<td>3-10</td>
<td>Subjective symptoms; good, medium, poor</td>
<td>-</td>
<td>30 good, 4 medium, 0 poor</td>
<td>SE II fractures are rightly considered a relatively benign injury which leaves few major permanent complaints.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Modified Cedell's classification</td>
<td>-</td>
<td>33 good, 1 medium, 0 poor</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Radiological changes according to Magnusson and Weber</td>
<td>-</td>
<td>Signs of arthrosis in 1; no signs in 33</td>
<td></td>
</tr>
<tr>
<td>Yde (b)</td>
<td>1980</td>
<td>III</td>
<td>79</td>
<td>SE IV ankle fractures</td>
<td>60</td>
<td>3-10</td>
<td>Cedell: Subjective symptoms; good, medium, poor</td>
<td>-</td>
<td>50 good, 8 medium, 2 poor</td>
<td>Operative treatment leads to significantly better results than conservative treatment in SE IV ankle fractures.</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Modified Cedell's classification; objective symptoms; good, medium, poor</td>
<td>-</td>
<td>52 good, 7 medium, 1 poor</td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Radiological changes according to Magnusson and Weber</td>
<td>-</td>
<td>Signs of arthrosis in 12; no signs in 48</td>
<td></td>
</tr>
</tbody>
</table>
Table 1: overall outcome (continued)

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Level of Evidence</th>
<th>Included (n)</th>
<th>Type of injury</th>
<th>Follow-up (n)</th>
<th>FU (years)</th>
<th>Outcome parameter</th>
<th>Score</th>
<th>Complications</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reuwer</td>
<td>1984</td>
<td>IV</td>
<td>260</td>
<td>Displaced ankle fractures</td>
<td>193</td>
<td>4</td>
<td>Weber's protocol (0-24); 0 excellent, 1-2 good, 3+ poor</td>
<td>-</td>
<td>97 excellent; 73 good; 23 poor</td>
<td>Best results are achieved by open reduction and rigid fixation. Absolute anatomic reduction is essential to prevent postraumatic arthritis.</td>
</tr>
<tr>
<td>Bauer</td>
<td>1985</td>
<td>I</td>
<td>111</td>
<td>All patients with malleolar fractures except for Weber type C</td>
<td>43</td>
<td>7</td>
<td>Questionnaire</td>
<td>-</td>
<td>11 significant symptoms</td>
<td>In about 3% of the patients in both groups symptoms of arthritis were present. Factors other than the treatment may play a role for the outcome.</td>
</tr>
<tr>
<td>Ali</td>
<td>1987</td>
<td>III</td>
<td>50</td>
<td>Displaced bi- or trimalleolar fractures</td>
<td>38</td>
<td>7</td>
<td>Questionnaire</td>
<td>-</td>
<td>36 satisfied, 2 not satisfied</td>
<td>Open reduction and internal fixation for unstable fractures in the elderly gives significantly better long term results when compared to nonoperative treatment.</td>
</tr>
<tr>
<td>Fogel</td>
<td>1987</td>
<td>IV</td>
<td>26</td>
<td>Consecutive ankle fractures with late treatment (14-31 days after injury)</td>
<td>25</td>
<td>6,6</td>
<td>Performance index (0-100); &gt;75 good, 50-74 fair, &lt;50 poor</td>
<td>68</td>
<td>13 good; 4 fair; 8 poor</td>
<td>Up to 70% of patients with delayed treatment will realize a satisfactory result.</td>
</tr>
<tr>
<td>Jaskulka</td>
<td>1989</td>
<td>III</td>
<td>280</td>
<td>Malleolar fractures</td>
<td>142</td>
<td>5,7</td>
<td>Modified Weber's protocol (including radiologic criteria)</td>
<td>-</td>
<td>57 excellent; 37 good; 29 fair; 39 poor</td>
<td>A definite rise in the incidence of osteoarthritis must be expected in cases of bimalleolar luxation fractures accompanied by a fracture of the posterior tibial margin.</td>
</tr>
<tr>
<td>Bagger</td>
<td>1993</td>
<td>IV</td>
<td>69</td>
<td>Bi- or trimalleolar ankle fractures</td>
<td>69</td>
<td>9,6</td>
<td>Questionnaire (A no complaints; B occasional complaints; C daily slight complaints; D daily disabling complaints)</td>
<td>-</td>
<td>19 A; 29 B; 15 C; 6 D</td>
<td>Patients with joint dislocation after ankle fracture have chronic complaints 4 times as often as patients without dislocation.</td>
</tr>
<tr>
<td>Laarhoven</td>
<td>1996</td>
<td>IV</td>
<td>580</td>
<td>All ankle fracture types</td>
<td>401</td>
<td>5</td>
<td>Olerud-Molander Ankle Score (0-100); &lt;91 excellent; 61-90 good; 31-60 fair; &lt;30 poor</td>
<td>-</td>
<td>no separation between operative and conservative possible</td>
<td>A broad indication for conservative, even functional treatment and restricted use of implants during osteosynthesis is appear justified considering the results obtained.</td>
</tr>
</tbody>
</table>

Clinical findings -
Table 1: overall outcome (continued)

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Level of Evidence</th>
<th>Included (n)</th>
<th>Type of injury</th>
<th>Follow-up (n)</th>
<th>FU (years)</th>
<th>Outcome parameter</th>
<th>Score</th>
<th>Complications</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day</td>
<td>2001</td>
<td>IV</td>
<td>153</td>
<td>Displaced bimalleolar ankle fractures</td>
<td>25</td>
<td>10-14</td>
<td>Phillips scoring system (0-115); &gt;110 excellent, 96-109 good, 70-95 fair, &lt;70 poor</td>
<td>-</td>
<td>10 excellent; 6 good; 3 fair; 6 poor; 13 asymptomatic patients underwent elective removal of the metal</td>
<td>36% of the patients had moderate or severe arthritis at a minimum of 10-year follow-up. This is in contrast with the excellent short-term results reported in the literature.</td>
</tr>
<tr>
<td>Specchiulli</td>
<td>2004</td>
<td>IV</td>
<td>75</td>
<td>Ankle fractures</td>
<td>75</td>
<td>5,6</td>
<td>Cedell criteria</td>
<td>-</td>
<td>6 excellent; 10 good; 7 fair; 2 poor</td>
<td></td>
</tr>
<tr>
<td>Finnan</td>
<td>2005</td>
<td>IV</td>
<td>156</td>
<td>Isolated closed SE IV fractures</td>
<td>26</td>
<td>5,1</td>
<td>SMFA (0-100)</td>
<td>Only Mobility index significantly worse score compared with normal population</td>
<td>none reported</td>
<td>Patients with less than optimal radiographic reduction after surgery or lack of radiographic evidence of arthritis at relatively early follow-up, they are more likely to have a negative effect on their quality of life.</td>
</tr>
<tr>
<td>Kellgren &amp; Moore</td>
<td>2005</td>
<td>IV</td>
<td>-</td>
<td>Ankle fractures</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>6 some arthritis; 20 no arthritis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shah</td>
<td>2007</td>
<td>IV</td>
<td>85</td>
<td>Isolated closed Weber B or C ankle fracture</td>
<td>69</td>
<td>5</td>
<td>Olerud-Molander Ankle Score (0-100); &gt;91 excellent; 61-90 good; 31-60 fair; &lt;30 poor</td>
<td>-</td>
<td>19 excellent; 33 good; 13 fair; 4 poor</td>
<td></td>
</tr>
<tr>
<td>Vries, de</td>
<td>2005</td>
<td>IV</td>
<td>82</td>
<td>Ankle fractures with a posterior malleolar fragment</td>
<td>45</td>
<td>13</td>
<td>AFSS (0-150)</td>
<td>124</td>
<td>none reported</td>
<td>Patients with posterior malleolar fractures showed good results after a mean of 13 years of follow-up. Outcome was not affected by size or fixation of the posterior tibial fragment.</td>
</tr>
</tbody>
</table>

Note: FU = follow-up; IV = internal validity; SMFA = score for mobility function assessment; AFSS = ankle foot surgery score; Olerud-Molander Ankle Score; AFSS = ankle foot surgery score; Kellgren & Moore = Kellgren & Moore radiographic score; Shah = Shah scoring system.
Table 2: fracture reduction and outcome

<table>
<thead>
<tr>
<th>Study</th>
<th>Reduction</th>
<th>Outcome parameter</th>
<th>n1</th>
<th>Subgroup</th>
<th>n2</th>
<th>n2/n1</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bauer 1985</td>
<td>Cedell reduction criteria</td>
<td>Magnussen</td>
<td>20</td>
<td>Anatomic</td>
<td>8</td>
<td>40,0%</td>
<td>8</td>
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<td></td>
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<td></td>
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<td></td>
<td>3</td>
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<td>(+)</td>
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<td>5,0%</td>
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<td></td>
<td>0</td>
<td>0,0%</td>
<td>+++</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>13</td>
<td>Good</td>
<td>3</td>
<td>23,1%</td>
<td>0</td>
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<td>6</td>
<td>46,2%</td>
<td>(+)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>30,8%</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0,0%</td>
<td>++</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0,0%</td>
<td>+++</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td>Poor</td>
<td>1</td>
<td>10,0%</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
<td>4</td>
<td>40,0%</td>
<td>(+)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>10,0%</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>20,0%</td>
<td>++</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>20,0%</td>
<td>+++</td>
</tr>
<tr>
<td>Fogel 1987</td>
<td>Grade I: anatomic, Grade II: &lt; 2 mm displacement, Grade III: &gt; 2 mm displacement</td>
<td>Performance index (0-100)</td>
<td>17</td>
<td>Grade I</td>
<td>17</td>
<td>-</td>
<td>78,8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>Grade II</td>
<td>5</td>
<td>-</td>
<td>57,8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>Grade III</td>
<td>3</td>
<td>-</td>
<td>46</td>
</tr>
<tr>
<td>Specchiulli 2004</td>
<td>Satisfactory/Unsatisfactory</td>
<td>Unknown arthritis score</td>
<td>12</td>
<td>Unsatisfactory</td>
<td>10</td>
<td>83.3% arthritis</td>
<td></td>
</tr>
<tr>
<td>Finnan 2005</td>
<td>Good/Fair</td>
<td>Kellgren and moore</td>
<td>19</td>
<td>Good</td>
<td>4</td>
<td>21,1% arthritis</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15</td>
<td>-</td>
<td>78,9% no arthritis</td>
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</tr>
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<td></td>
<td></td>
<td>2</td>
<td>Fair</td>
<td>28,6% arthritis</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>-</td>
<td>71,4% no arthritis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pooled data</td>
<td>Optimal reduction</td>
<td></td>
<td>56</td>
<td>Optimal reduction</td>
<td>31</td>
<td>55,4% Good to excellent</td>
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</tr>
<tr>
<td></td>
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<td></td>
<td>25</td>
<td>Fair reduction</td>
<td>56,0% Good to excellent</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>25</td>
<td>Poor reduction</td>
<td>20,0% Good to excellent</td>
<td></td>
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</tr>
</tbody>
</table>

**Posterior fragment**

Regarding the posterior fragment, two studies reported on the long-term outcome (Table 6). The scores of de Vries\(^5\) were transformed: of the 45 patients with a mean score of 124, \((124/150) \times 45 = 37\) were thought to have a good or excellent result. In a total of 107 fractures 58.1% of the results were good or excellent.

**Hindfoot alignment**

None of the studies addressed the influence of hindfoot varus or valgus on the long-term outcome after ankle fracture.
Table 3: fractures classified according to Danis-Weber

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Outcome parameter</th>
<th>n1</th>
<th>Subgroup</th>
<th>n2</th>
<th>n2/n1</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hughes</td>
<td>1979</td>
<td>Weber's protocol</td>
<td>70</td>
<td>Type A</td>
<td>57</td>
<td>81.4%</td>
<td>good to excellent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13</td>
<td>18.6%</td>
<td>poor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>206</td>
<td>79.1%</td>
<td>good to excellent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>43</td>
<td>20.9%</td>
<td>poor</td>
</tr>
<tr>
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<td></td>
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<td></td>
<td>Type C</td>
<td>124</td>
<td>72.1%</td>
<td>good to excellent</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>48</td>
<td>27.9%</td>
<td>poor</td>
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<tr>
<td>Schweiberer</td>
<td>1978</td>
<td>Weber's protocol</td>
<td>10</td>
<td>Type A</td>
<td>5</td>
<td>50.0%</td>
<td>excellent</td>
</tr>
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<td></td>
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<td></td>
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<td></td>
<td>3</td>
<td>30.0%</td>
<td>good</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>20.0%</td>
<td>poor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Type B syndes-</td>
<td>7</td>
<td>63.6%</td>
<td>excellent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>36.4%</td>
<td>good</td>
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<td></td>
<td></td>
<td></td>
<td>Type B syndes+</td>
<td>7</td>
<td>20.0%</td>
<td>excellent</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20</td>
<td>57.1%</td>
<td>good</td>
</tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>8</td>
<td>22.9%</td>
<td>poor</td>
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<td>Type C</td>
<td>10</td>
<td>25.6%</td>
<td>excellent</td>
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<td>12</td>
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<td>17</td>
<td>43.6%</td>
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<td></td>
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<td>Atypical</td>
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<td>60.0%</td>
<td>excellent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>20.0%</td>
<td>good</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>20.0%</td>
<td>poor</td>
</tr>
<tr>
<td>Reuwer</td>
<td>1984</td>
<td>Weber's protocol</td>
<td>24</td>
<td>Type A</td>
<td>16</td>
<td>66.7%</td>
<td>excellent</td>
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<td></td>
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<td>5</td>
<td>20.8%</td>
<td>good</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>12.5%</td>
<td>poor</td>
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<td></td>
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<td></td>
<td></td>
<td>Type B</td>
<td>63</td>
<td>48.5%</td>
<td>excellent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>56</td>
<td>43.1%</td>
<td>good</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11</td>
<td>8.5%</td>
<td>poor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Type C</td>
<td>17</td>
<td>43.6%</td>
<td>excellent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13</td>
<td>33.3%</td>
<td>good</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
<td>23.1%</td>
<td>poor</td>
</tr>
<tr>
<td>Pooled Data</td>
<td></td>
<td></td>
<td>104</td>
<td>Type A</td>
<td>86</td>
<td>82.7%</td>
<td>good to excellent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>382</td>
<td>83.8%</td>
<td>good to excellent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Type C</td>
<td>176</td>
<td>70.4%</td>
<td>good to excellent</td>
</tr>
</tbody>
</table>

syndes: without syndesmosis injury, syndes+: with syndesmosis injury.
Table 4: fractures classified according to Lauge-Hansen

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Outcome parameter</th>
<th>n1</th>
<th>subgroup</th>
<th>n2</th>
<th>n2/n1</th>
<th>Score</th>
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<tbody>
<tr>
<td>Yde (b)</td>
<td>1980</td>
<td>Cedell subjective+objective</td>
<td>120</td>
<td>SE IV</td>
<td>102</td>
<td>85,0%</td>
<td>good</td>
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<td></td>
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<td></td>
<td>3</td>
</tr>
<tr>
<td>Yde (a)</td>
<td>1980</td>
<td>Cedell subjective+objective</td>
<td>69</td>
<td>SE II</td>
<td>63</td>
<td>91,3%</td>
<td>good</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Bagger</td>
<td>1993</td>
<td>Questionnaire</td>
<td>28</td>
<td>SE II</td>
<td>13</td>
<td>46,4%</td>
<td>no complaints</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>69</td>
<td>SE IV</td>
<td>19</td>
<td>27,5%</td>
<td>no complaints</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>29</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Finnan</td>
<td>2005</td>
<td>Kellgren and Moore</td>
<td>26</td>
<td>SE IV</td>
<td>19</td>
<td>73,1%</td>
<td>good</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Reuwer</td>
<td>1984</td>
<td>Weber’s protocol</td>
<td>44</td>
<td>SE II</td>
<td>26</td>
<td>59,1%</td>
<td>excellent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16</td>
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<td></td>
<td>2</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>86</td>
<td>SE IV</td>
<td>37</td>
<td>43,0%</td>
<td>excellent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>40</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Pooled Data</td>
<td></td>
<td></td>
<td>141</td>
<td>SE II</td>
<td>131</td>
<td>92,9%</td>
<td>good to excellent</td>
</tr>
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**Discussion**

Despite of the lack of long-term follow-up studies that investigate several factors simultaneously, we found some studies that report on individual prognostic criteria. The natural evolution of posttraumatic osteoarthritis after ankle fracture is dependent on the fracture reduction and fracture mechanism, perhaps on the initial cartilage lesions, and unknown is the role of hindfoot alignment. Interestingly, only 79.3% of the optimally reduced fractures show good to excellent long-term outcome. The remainder suffers from joint degeneration apparently because of other factors. Because of the lack of evidence, our conclusions are only of Grade B and Grade C value.
The Weber A type fractures do not show a superior long-term outcome when compared to Weber B type fractures (Grade C). Two hypotheses were formulated to explain this finding: the Weber A fractures are the result of a supination–adduction trauma mechanism. The adduction force will lead to compression of the cartilage between the talus and medial malleolus/medial tibia plafond. In case of a fracture of the medial malleolus, the typical pattern is a vertical fracture line. This fracture of the medial tibia plafond can be regarded a pilon type of fracture including cartilage damage in the weight-bearing area. This can easily explain the negative influence on the end result. The second hypothesis is that ab- and adduction ankle fractures lead to more severe initial cartilage damage and hence to worse results. Especially when the Weber B category is divided in the Lauge-Hansen categories SER-2 and SER-4, it becomes apparent that the combination of lateral and medial pathology leads to an unfavourable outcome (Grade B). Therefore we recommend use of the Weber classification only when also mentioning the medial involvement or use of the Lauge-Hansen classification.

Concerning the other factors such as cartilage lesions, the posterior malleolus, and hindfoot alignment, no relevant conclusions can be drawn from the currently available literature. In order to answer the remaining questions, the following idealised study should be undertaken: a prospective follow-up series in which the initial cartilage lesions are assessed prior to fracture reduction through arthroscopy. During this examination the syndesmosis can be assessed as well. An extensive history should be taken to identify additional risk factors like smoking, diabetes, osteoporosis and obesity for example. The fracture reduction should be quantified with a postoperative CT-scan. In theory a spiral CT after fracture reduction could identify the intra-articular osteochondral lesions and loose bodies as well. On whole lower leg images the hindfoot alignment could be measured directly postoperatively. These data should then be used in a multiple regression analysis to determine each individual influence on the long-term outcome.

In conclusion we found that poor fracture reduction resulted in an inferior long-term outcome when compared to fair or good reduction. Weber A type fractures do not have a better long-term outcome when compared to Weber B type fractures. Lauge-Hansen SER-2 type fractures do have a superior long-term outcome when compared to SER-4 type fractures.
### Table 5: Initial cartilage lesions and outcome

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Outcome parameter</th>
<th>n1</th>
<th>Subgroup</th>
<th>n2</th>
<th>n2/n1</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fogel</td>
<td>1987</td>
<td>Performance index</td>
<td>9</td>
<td>with cartilage lesions</td>
<td>3</td>
<td>33.3%</td>
<td>good</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td>66.7%</td>
<td>fair or poor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14</td>
<td>33.3%</td>
<td>good</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>without cartilage lesions</td>
<td>10</td>
<td>71.4%</td>
<td>good</td>
</tr>
</tbody>
</table>

### Table 6: Posterior fragment and outcome

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Outcome parameter</th>
<th>n1</th>
<th>Subgroup</th>
<th>n2</th>
<th>n2/n1</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jaskulka</td>
<td>1989</td>
<td>Modified Weber’s protocol</td>
<td>32</td>
<td>avulsion fragment</td>
<td>7</td>
<td>21.9%</td>
<td>excellent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>15.6%</td>
<td>good</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
<td>28.1%</td>
<td>fair</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11</td>
<td>34.4%</td>
<td>poor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>fragment &gt; 5%</td>
<td>30</td>
<td>26.7%</td>
<td>excellent</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>16.7%</td>
<td>good</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td>26.7%</td>
<td>fair</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>9</td>
<td>30.0%</td>
<td>poor</td>
</tr>
<tr>
<td>de Vries</td>
<td>2005</td>
<td>Phillips clinical score (0-150)</td>
<td>45</td>
<td>all posterior</td>
<td>124</td>
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<tr>
<td>pooled data</td>
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<td>107</td>
<td>posterior fragment</td>
<td>25</td>
<td>23.4%</td>
<td>good to excellent</td>
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</table>

### Table 7: Odds-ratio on good to excellent outcome

<table>
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<th>Comparison</th>
<th>OR</th>
<th>95% CI</th>
<th>p</th>
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<td><strong>Reduction</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Optimal versus Poor</td>
<td>11.17</td>
<td>(3.65;34.15)</td>
<td>*</td>
</tr>
<tr>
<td>Fair versus Poor</td>
<td>6.08</td>
<td>(1.99;18.59)</td>
<td>*</td>
</tr>
<tr>
<td>Optimal versus Fair</td>
<td>1.84</td>
<td>(0.60;5.62)</td>
<td></td>
</tr>
<tr>
<td><strong>Fracture type Weber</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type A versus Type C</td>
<td>2.01</td>
<td>(1.13;3.57)</td>
<td>*</td>
</tr>
<tr>
<td>Type B versus Type C</td>
<td>2.17</td>
<td>(1.22;3.86)</td>
<td>*</td>
</tr>
<tr>
<td>Type B versus Type A</td>
<td>1.08</td>
<td>(0.61;1.92)</td>
<td></td>
</tr>
<tr>
<td><strong>Fracture type Lauge-Hansen</strong></td>
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<td></td>
</tr>
<tr>
<td>SER-2 versus SER-4</td>
<td>2.93</td>
<td>(1.4;5.9)</td>
<td>*</td>
</tr>
<tr>
<td><strong>Cartilage lesions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without versus with</td>
<td>5.00</td>
<td>(0.82;30.46)</td>
<td></td>
</tr>
</tbody>
</table>

*Significant at p < 0.05.
CHAPTER 2 - LONG-TERM OUTCOME OF ANKLE FRACTURES

References


PART II
CARTILAGE LESIONS
CHAPTER 3

THE ROLE OF ACCOMPANYING INITIAL CARTILAGE LESIONS AFTER ANKLE FRACTURES

Published as:

CHAPTER 3 - CARTILAGE LESIONS

Introduction

The ankle is a very congruent joint and highly resistant to primary degenerative disease. Unlike osteoarthritis in the hip or knee, osteoarthritis in the ankle joint is predominantly the result of a traumatic event. Posttraumatic osteoarthritis accounts for at least 12% of the combined prevalence of hip, knee, and ankle arthritis, whereas between 70% and 80% of the cases of ankle arthritis alone are of posttraumatic origin.

Malunion is probably the most important cause of osteoarthritis after an ankle fracture. Other factors that are considered to play a role are suboptimal alignment in the coronal or sagittal plane, ligament damage leading to ligamentous instability, and the development of arthrofibrosis. Relevant factors affecting the early outcome after ankle fracture are sex, age, body mass index, and diabetes, but the roles of these variables in the long-term outcome are unclear. Surprisingly little is known about the relationship between initial cartilage damage and the development of osteoarthritis of the ankle. Nevertheless, some authors consider these lesions to influence the development of posttraumatic osteoarthritis. Arthroscopy performed directly after an ankle fracture often shows more damage to the cartilage than was expected on the basis of plain radiographs. Cartilage lesions have been found in 79% to 90% of ankles examined arthroscopically after an ankle fracture. Although the role of arthroscopy in the acute treatment of ankle fractures has not been established, the modality has been shown to be valuable for obtaining detailed knowledge about the fractured ankle and in the treatment of symptomatic osteophytes after ankle fracture.

We hypothesized that the more extensive the initial cartilage damage, the higher the chance of osteoarthritis developing later. Although we know that the talus is the most common location of cartilage damage caused by an ankle fracture, we do not know whether the location of the cartilage injury influences the development of posttraumatic osteoarthritis. To the best of our knowledge, there have been no previous studies correlating the location and extent of cartilage lesions following ankle fractures with the long-term outcome. In this follow-up study of a consecutive series of patients, we examined the correlation between the initial cartilage damage seen at arthroscopy performed directly after a displaced ankle fracture and the clinical and radiographic long-term results associated with that fracture.
CHAPTER 3 - CARTILAGE LESIONS

Materials and Methods

Study Design and Patient Demographics

We performed a long-term follow-up study of 109 patients in whom an ankle fracture had been treated operatively according to the AO principles between June 1993 and November 1997 at the Kantonsspital Liestal and the Kantonsspital St. Gallen, both in Switzerland. These patients were recruited from a consecutive cohort of 288 patients for whom arthroscopy had been performed prior to the surgical management of the ankle fracture. Fifty-seven (19.8%) of these patients had died, and an attempt was made to contact the remaining 231 patients. Thirty-seven (16.0%) of the 231 patients had emigrated, seventy-one (30.7%) refused to participate in the study, fourteen (6.1%) could not be located, and 109 (47.2%) were recruited into the study. The two main reasons why patients declined our invitation to participate in the follow-up study were the requirement for additional radiographic evaluation and health and age-related problems that limited the patients’ ability to travel to our hospital. We identified no differences in terms of the demographic data or the original arthroscopic findings between the study subjects and those who did not participate.

The mean duration of follow-up of the 109 patients was 12.9 years (range, 11.3 to 14.8 years). Sixty-one patients (56%) were male, and forty-eight (44%) were female. The mean age at the time of injury was 37.4 years (range, sixteen to seventy-one years) for the male patients and 50.2 years (range, twenty to seventy-six years) for the female patients. The right ankle was involved in fifty-three (49%) of the cases. Most (40%) of the injuries had been the result of a sports accident. The other fractures were sustained in a traffic collision (18%), at home (17%), at work (8%), or for another reason (16%). Approval for this long-term outcome evaluation was provided by our institutional review board and the cantonal ethical committee. We included all patients who were available for follow-up and provided written informed consent. None of the patients who were available had a systemic inflammatory disease or were unable to complete questionnaires, both of which were exclusion criteria. We did exclude one patient who had had a substantial ankle injury before the index ankle fracture and two patients who had had a subop-
timal reduction of the fracture, defined as shortening of the fibula or lateral displacement of the fibula identified on reevaluation of the postoperative radiographs.

**Main Variables**

Arthroscopy had been carried out with the patient under general or regional anesthesia and had been followed by open reduction and internal fixation. The patients were placed supine on the table with the knee flexed in a knee-holder, which allowed the experienced arthroscopists to perform the arthroscopy without a distraction device. Before creation of the portals by blunt dissection, the joint was inflated with saline solution. A 4.5-mm, 30° arthroscope was used in a standard central anterior portal. After aspiration of the saline solution, the examination was performed in a CO2-filled joint. When necessary, additional anteromedial and anterolateral portals were created for the insertion of instruments. All intra-articular lesions were extensively documented. Inspection and probing were used to grade the cartilage lesions. Grade I represented intact cartilage; grade II represented superficial bruises, fissuring, or degeneration of <50% of the thickness of the cartilage; grade-III lesions involved deeper changes, involving >50% of the cartilage thickness; and grade IV indicated that subchondral bone was visible (Fig. 1). There were ten possible locations of the cartilage lesions: the medial malleolus; the lateral malleolus; the anterior, medial, lateral, and posterior aspects of the tibia; and the anterior, medial, lateral, and posterior aspects of the talus.

**Outcome Parameters**

The clinical results were evaluated by an independent orthopaedic foot and ankle surgeon without knowledge of the injury or the intra-articular lesions that had been identified arthroscopically. The American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot score was used to quantify the long-term clinical outcome. Anteroposterior and lateral radiographs of the ankle were evaluated by an experienced radiologist, without knowledge of the clinical results, who used a modification of the Kannus arthritis score to determine the severity of the osteoarthritis on a 100-point scale. This score is based on
several aspects of arthritis, such as the amount of sclerosis visible, formation of osteophytes, calcification of the ligaments, joint space narrowing, and cyst formation\textsuperscript{28,29}.

**Statistical Methods**

The main analysis focused on the correlation between the depth and location of cartilage damage and the development of clinical or radiographic signs of osteoarthritis. To detect the influence of various variables on the two main clinical and radiographic outcome parameters (the AOFAS hindfoot score and the modified Kannus arthritis score), variables were dichotomized at \(=90\) points (indicating signs of joint degeneration) and \(>90\) points (indicating an optimal long-term outcome). First, patients were divided into two groups: those with an initial cartilage lesion and those without such a lesion. Second, the damage levels were reduced to two categories in order to investigate the role of the depth of the lesions in several locations within the joint. The first category included intact cartilage and lesions up to 50% in depth. The second category consisted of lesions exceeding 50% in depth, up to the subchondral bone. Multiple logistic regression analysis was performed to detect the in-
fluence of each damage variable separately on the dichotomized AOFAS and Kannus scores. Results are presented as odds ratios with corresponding 95% confidence intervals and p values. An odds ratio of greater than one indicates that the odds of disease developing (clinical and radiographic scores of $\geq 90$ points) is greater in the exposed group (patients with an intra-articular lesion) than in the unexposed group (patients who do not have such a lesion). To adjust for sex, age, and body mass index, these variables were also included in the regression model. A p value of $<0.05$ was considered significant. Because this study was exploratory, there was no adjustment for multiple comparisons.

Table 1: Frequency of initial cartilage lesions seen in the ankle joint

<table>
<thead>
<tr>
<th>Lesions on the Talus</th>
<th>Anterior</th>
<th>Medial</th>
<th>Lateral</th>
<th>Posterior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intact</td>
<td>76.1%</td>
<td>66.1%</td>
<td>78.9%</td>
<td>100.0%</td>
</tr>
<tr>
<td>$&lt;50%$ depth</td>
<td>17.0%</td>
<td>20.2%</td>
<td>11.9%</td>
<td>0.0%</td>
</tr>
<tr>
<td>$&gt;50%$ depth</td>
<td>5.0%</td>
<td>11.9%</td>
<td>7.3%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Subchondral bone</td>
<td>3.0%</td>
<td>1.8%</td>
<td>1.8%</td>
<td>0.0%</td>
</tr>
<tr>
<td></td>
<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lesions on the Tibia</th>
<th>Anterior</th>
<th>Medial</th>
<th>Lateral</th>
<th>Posterior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intact</td>
<td>91.7%</td>
<td>92.7%</td>
<td>97.2%</td>
<td>83.5%</td>
</tr>
<tr>
<td>$&lt;50%$ depth</td>
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<td>3.7%</td>
<td>1.8%</td>
<td>4.6%</td>
</tr>
<tr>
<td>$&gt;50%$ depth</td>
<td>3.7%</td>
<td>3.7%</td>
<td>0.9%</td>
<td>9.2%</td>
</tr>
<tr>
<td>Subchondral bone</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>2.8%</td>
</tr>
<tr>
<td></td>
<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lesions on the Malleoli</th>
<th>Medial</th>
<th>Lateral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intact</td>
<td>61.5%</td>
<td>61.5%</td>
</tr>
<tr>
<td>$&lt;50%$ depth</td>
<td>16.5%</td>
<td>13.8%</td>
</tr>
<tr>
<td>$&gt;50%$ depth</td>
<td>12.8%</td>
<td>9.2%</td>
</tr>
<tr>
<td>Subchondral bone</td>
<td>9.2%</td>
<td>15.6%</td>
</tr>
<tr>
<td></td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>
Results

Descriptive Statistics

According to the Weber classification system\textsuperscript{30}, 15\% of the fractures were type A, 68\% were type B, and 17\% were type C. The AO 44-B1 fracture\textsuperscript{31} was the most common, accounting for 27\% of all fractures, followed by the 44-B3 type, accounting for 21\%. At arthroscopy, a cartilage lesion was found on the talus in 65\% of the patients, on the tibia in 50\%, and on the fibula in 39\%. No cartilage damage was seen in 19\% of the patients. Only the talus was involved in 17\% of the patients; only the tibia, in 8\%; and only the fibula, in 6\%. Both the talus and the tibia had damaged cartilage in 17\% of the patients; both the talus and the fibula, in 7\%; and both the tibia and the fibula, in 5\%. All three surfaces were affected in 21\% of the patients. In total, 81\% of the patients had some form of initial cartilage damage in the ankle joint directly after the ankle fracture (Table I, Figs. 2 and 3). At the time of long-term follow-up, clinical signs of osteoarthritis as defined by an AOFAS score of $\geq 90$ points were seen in 39\% (forty-three) of the 109 patients, whereas radiographic signs of osteoarthritis as defined by a modified Kannus score of $\geq 90$ points were seen in
43% (forty-seven). The mean AOFAS score was 88.9 points (range, 18 to 100 points), and the mean radiographic score was 89.8 points (range, 54 to 100 points). The data for both main outcome parameters were skewed toward the maximum score.

**Statistical Analysis**

As mentioned, we first divided the patients into two groups: those with an initial cartilage lesion and those without such a lesion. Cartilage damage in the ankle joint was associated with an AOFAS score of ≥90 points (odds ratio = 5.0 [95% confidence interval = 1.3 to 20.1]; p = 0.02) and with a radiographic score of ≥90 points (odds ratio = 3.4 [95% confidence interval = 1.0 to 11.2]; p = 0.04). Then we assessed the cartilage damage at each separate surface.

### Table 1: Frequency of initial cartilage lesions seen in the ankle joint

<table>
<thead>
<tr>
<th>Cartilage damage predictor of AOFAS hindfoot score of &lt;90 points when:</th>
<th>Odds Ratio</th>
<th>95% Confidence Interval</th>
<th>P Value</th>
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</thead>
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<tr>
<td>Present in ankle joint</td>
<td>5.0</td>
<td>1.25-20.12</td>
<td>0.02*</td>
</tr>
<tr>
<td>Present on tibia</td>
<td>2.7</td>
<td>1.14-6.44</td>
<td>0.02*</td>
</tr>
<tr>
<td>Present on fibula</td>
<td>1.8</td>
<td>0.78-4.14</td>
<td>0.17</td>
</tr>
<tr>
<td>Present on talus</td>
<td>3.7</td>
<td>1.39-9.97</td>
<td>&lt;0.01†</td>
</tr>
<tr>
<td>&gt;50% of depth on posterior aspect of tibial plafond</td>
<td>0.6</td>
<td>0.15-2.03</td>
<td>0.38</td>
</tr>
<tr>
<td>&gt;50% of depth on medial malleolus</td>
<td>5.2</td>
<td>1.85-14.57</td>
<td>&lt;0.01†</td>
</tr>
<tr>
<td>&gt;50% of depth on anterior aspect of talus</td>
<td>12.3</td>
<td>1.41-108.0</td>
<td>0.02*</td>
</tr>
<tr>
<td>&gt;50% of depth on lateral aspect of talus</td>
<td>5.4</td>
<td>1.24-23.48</td>
<td>0.02*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cartilage damage predictor of Kannus radiographic score of &lt;90 points when:</th>
<th>Odds Ratio</th>
<th>95% Confidence Interval</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present in ankle joint</td>
<td>3.4</td>
<td>1.04-11.17</td>
<td>0.04*</td>
</tr>
<tr>
<td>Present on tibia</td>
<td>3.3</td>
<td>1.42-7.61</td>
<td>&lt;0.01†</td>
</tr>
<tr>
<td>Present on fibula</td>
<td>0.8</td>
<td>0.34-1.76</td>
<td>0.54</td>
</tr>
<tr>
<td>Present on talus</td>
<td>2.4</td>
<td>0.99-5.78</td>
<td>0.05*</td>
</tr>
<tr>
<td>&gt;50% of depth on posterior aspect of tibial plafond</td>
<td>4.7</td>
<td>1.18-18.79</td>
<td>0.03*</td>
</tr>
<tr>
<td>&gt;50% of depth on medial malleolus</td>
<td>2.9</td>
<td>1.08-7.90</td>
<td>0.03*</td>
</tr>
<tr>
<td>&gt;50% of depth on anterior aspect of talus</td>
<td>4.7</td>
<td>0.88-25.63</td>
<td>0.07</td>
</tr>
<tr>
<td>&gt;50% of depth on lateral aspect of talus</td>
<td>1.6</td>
<td>0.42-6.30</td>
<td>0.48</td>
</tr>
</tbody>
</table>

*Significant at p < 0.05.
†Highly significant at p < 0.01.
Cartilage damage on the tibia, including the medial malleolus, was associated with an AOFAS score of $\geq 90$ points (odds ratio = 2.7 [95% confidence interval = 1.1 to 6.4]; $p = 0.02$) as well as with a radiographic score of $\geq 90$ points (odds ratio = 3.3 [95% confidence interval = 1.4 to 7.6]; $p < 0.01$). Cartilage damage on the talus was associated with an AOFAS score of $\geq 90$ points (odds ratio = 3.7 [95% confidence interval = 1.4 to 10.0]; $p < 0.01$) as well as with a radiographic score of $\geq 90$ points (odds ratio = 2.4 [95% confidence interval = 1.0 to 5.8]; $p = 0.05$). Lesions of the fibula were not found to be associated with a significant increase in the risk of the development of posttraumatic osteoarthritis.

When we assessed the depth of the lesions at different locations, we found significant relationships between the long-term clinical outcome and a lesion exceeding 50% of the cartilage depth on the anterior aspect of the talus (odds ratio = 12.3 [95% confidence interval = 1.4 to 108.0]; $p = 0.02$) and such a lesion on the lateral aspect of the talus (odds ratio = 5.4 [95% confidence interval = 1.0 to 5.8]; $p = 0.05$). When we assessed the depth of the lesions at different locations, we found significant relationships between the long-term clinical outcome and a lesion exceeding 50% of the cartilage depth on the anterior aspect of the talus (odds ratio = 12.3 [95% confidence interval = 1.4 to 108.0]; $p = 0.02$) and such a lesion on the lateral aspect of the talus (odds ratio = 5.4 [95% confidence interval = 1.0 to 5.8]; $p = 0.05$).
interval = 1.2 to 23.5]; p = 0.02). Damage exceeding 50% of the cartilage depth on the medial malleolus alone was associated with both clinical signs of osteoarthritis (odds ratio = 5.2 [95% confidence interval = 1.9 to 14.6]; p < 0.01) and with radiographic signs of osteoarthritis (odds ratio = 2.9 [95% confidence interval = 1.1 to 7.9]; p = 0.03). The deep lesions on the tibial plafond had little predictive value, with only the lesions on the posterior aspect of the tibial plafond having an association with a radiographic score of =90 points (odds ratio = 4.7 [95% confidence interval = 1.2 to 18.8]; p = 0.03) (Table II, Figs. 4 and 5).

Discussion

It is generally accepted that open reduction and internal fixation is the best treatment for unstable or displaced ankle fractures. This is reflected by our results, which showed high mean overall clinical and radiographic outcome scores at a mean of thirteen years after ankle fracture. In general, posttraumatic arthritis is reported to occur in 14% to 50% of all fractured ankles. Few authors have suggested that the need for a perfect reduction was not supported by their data. Bauer et al. studied 143 patients thirty years after the treatment of an ankle fracture with closed methods; 82% were free of arthritis, and 83% were free of symptoms. This finding is in contrast with that in the series reported by Beris et al., in which osteoarthritis developed in 78% of twenty-three patients who had had a poor reduction. Most authors have agreed that accurate reduction leads to the best results. While malunion is probably the most important cause of osteoarthritis after ankle fracture, other factors that may play a role are varus or valgus alignment of the distal part of the tibia, ligament damage leading to ligamentous instability, and the development of arthrofibrosis.

Recent studies have suggested that abnormal loading alone does not explain the increased prevalence of osteoarthritis in fractured ankles. 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. He suggested that articular cartilage damage at the time of the fracture could have an influence on the overall outcome. This
opinion was shared by Marsh et al., who considered the extent of the initial cartilage injury to be the primary determinant of joint degeneration after trauma\textsuperscript{22}. Also, Lantz et al. mentioned that unrecognized injuries to the cartilaginous surfaces of the tibiotalar joint could be the origin of osteoarthritis after anatomical reduction and stabilization of ankle fractures\textsuperscript{21}. In their series of sixty-three surgically treated patients, those authors found many talar dome chondral injuries, and the overall results were worse in patients with such lesions. Some studies do not support this hypothesis. Ono et al. reported cartilage damage in only 20\% of 105 patients who had undergone open reduction and internal fixation of a malleolar fracture with arthroscopic confirmation of an anatomical reduction\textsuperscript{42}. Those authors concluded that cartilage injury could not be of much importance. However, we found no studies in the literature in which a long-term evaluation of clinical and radiographic outcome parameters was performed in a group of patients who had had arthroscopy before fracture treatment. In our series, we correlated the outcome with the articular cartilage lesions that had been seen initially in order to determine the role of those lesions in the development of posttraumatic osteoarthritis.

Our hypothesis was that the more extensive the initial cartilage damage, the higher the chance that osteoarthritis would develop later. Regarding the location of the cartilage damage, we expected worse outcomes when lesions had been seen on the talus, as other authors had reported concern about these lesions\textsuperscript{21,43}. Our results showed that cartilage damage at the time of an ankle fracture does play an important role in the development of posttraumatic osteoarthritis. When cartilage damage is present in the joint, the odds of the patient having a suboptimal long-term clinical outcome (an AOFAS score of <90 points) is five to one, whereas the chance of showing radiographic signs of joint degeneration (a Kannus arthritis score of <90 points) is three and a half to one. We found no correlation between the number of lesions and the long-term outcome; however, we found specific locations in the joint to be important factors. The lesions on the anterior and lateral aspects of the talus (Fig. 2) and those on the medial malleolus (Fig. 3) were shown to significantly increase the risk of posttraumatic osteoarthritis. Lesions on the posterior aspect of the tibial plafond also led to an unfavorable radiographic score. In addition, there was a correlation between the depth of the lesions and the long-term outcome. Deep lesions extending into the subchondral bone are
thought to heal better than lesions that do not extend into the subchondral bone\textsuperscript{44,45}. The deep lesions cause hemorrhage and fibrin-clot formation and activate an inflammatory response. In this study, however, the deeper lesions correlated with worse long-term outcomes. This could be the result of the location of the lesions. The deepest lesions were found in the medial and lateral regions of the talus, where the cartilage is, on the average, thicker. Mean cartilage thickness ranges from 0.91 mm in the fibula, to 1.21 mm in the tibia, to 1.34 mm in the talus\textsuperscript{46}, and the thickest cartilage is found over the talar shoulders, where osteochondritis dissecans lesions commonly occur\textsuperscript{47-49}. Over time, the fibrocartilage that fills a deep defect often begins to show evidence of depletion of matrix proteoglycans, fragmentation, and fibrillation. The fibrocartilage then fragments and disintegrates\textsuperscript{22}. The defects that result from ankle fractures in locations where the cartilage is thickest may therefore be too deep to heal adequately and remain filled with fibrocartilage. This would mean that the largest and deepest defects would recur over a long period of time. This could also explain why it sometimes takes several decades for posttraumatic osteoarthritis to develop in the ankle joint. We did not perform arthroscopy at the time of follow-up, and hence we cannot confirm whether lesions recurred.

Other limitations of our study include the loss to follow-up. The data were gathered prospectively, but no protocol was installed to track patients at specific intervals. Therefore, the >80\% recruitment criterion for a well-documented follow-up study\textsuperscript{50} was not met. The initial population in which arthroscopy was performed consisted of 288 consecutive patients with an ankle fracture. We were able to contact and recruit only 109 of them. The two main reasons for patients not wanting to participate in the follow-up study were the requirement for additional radiographic studies and health-related problems that limited their ability to travel. No one mentioned an ankle-related problem as the reason for refusing to return for our long-term evaluation, and the demographics and arthroscopic findings of the study group were similar to those of the patients who were lost to follow-up. The mean follow-up time of nearly thirteen years could also be an explanation for the reduced number of patients who were available to us.

Our findings show that initial cartilage damage seen arthroscopically after an ankle fracture is an independent predictor of posttraumatic osteoarthritis. Lesions on the talus and tibia are associated with negative long-
term results, whereas lesions on the fibula do not correlate with a worse long-term outcome. Specifically, deep lesions on the anterior and lateral aspects of the talus and on the medial malleolus correlated with an unfavorable clinical outcome. Newer imaging techniques, such as diffraction-enhanced x-ray imaging\textsuperscript{51}, may make it possible to identify these articular cartilage lesions without resorting to arthroscopy. The location and severity of osteochondral lesions are important factors in the prognosis of ankle fractures, and it is important to identify these lesions. Additional biochemical and clinical research is needed to develop an effective treatment plan for these lesions in order to improve the long-term outcome after ankle fractures.

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PART III
THE DELTOID LIGAMENT
CHAPTER 4

THE DIAGNOSIS AND TREATMENT OF DELTOID LIGAMENT LESIONS

Published as:

Introduction

Supination–external rotation (SE) fractures, also known as Weber B type fractures, are the most common ankle fractures and account for as many as 80% of all ankle fractures. A decision for operative or nonoperative treatment is based on the stability of the ankle as operatively managed unstable fractures have a better outcome than those treated conservatively. Medial instability associated with a lateral malleolar fracture can result from a medial malleolar fracture, a deltoid ligament lesion or a combination of osseous and ligamentous lesions. The diagnosis of deltoid ligament lesions in SE fractures has limitations. Several authors have reported the possibility of unrecognized unstable fractures in their series of stable fractures (which are often treated conservatively), negatively influencing the outcome. Differentiation of unstable and stable types is therefore important. In this review of the deltoid ligament in SE ankle fractures, we provide an overview of present knowledge on this topic as reported in the literature and based on the experience of two experienced foot and ankle surgeons (BH and CNvD). We focus on the SE type of ankle fractures as they represent the main body of ankle fractures and present a diagnostic challenge. This review is to communicate the need for continued research for diagnostic methods and treatment strategies regarding the injury of this ligament. Levels of evidence were applied to the individual studies reviewed and grades were applied to the recommendations for clinical practice (Table 1).

Anatomy

The general bony anatomy of the ankle joint is well known. The medial malleolus has two colliculi divided by a groove. On the posterolateral side, the posterior tibial tendon (PTT) and the flexor digitorum longus (FDL) pass. The deltoid ligament is attached to both colliculi proximally and has several insertions distally on the navicular, talus and calcaneus and onto the spring ligament. The narrow proximal anchoring and multiple distal attachments give the ligament, its typical shape and its name. The first anatomical division is between superficial and deep layers of the ligament. The superficial fibres
CHAPTER 4 - DELTOID LIGAMENT DIAGNOSIS AND TREATMENT

Table 1: Level of evidence and grades of recommendation

<table>
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<tr>
<th>Level of Evidence</th>
<th>Description</th>
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</thead>
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<tr>
<td>Level I</td>
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</tr>
<tr>
<td>Level II</td>
<td>prospective comparative study</td>
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<tr>
<td>Level III</td>
<td>retrospective case control study</td>
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<tr>
<td>Level IV</td>
<td>case series</td>
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<td>Level V</td>
<td>expert opinion</td>
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Grades of Recommendation (given to various treatment options based on Level of Evidence supporting that treatment)

<table>
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<tr>
<th>Grade</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Grade A</td>
<td>treatment options are supported by strong evidence (consistent with Level I or II studies)</td>
</tr>
<tr>
<td>Grade B</td>
<td>treatment options are supported by fair evidence (consistent with Level III or IV studies)</td>
</tr>
<tr>
<td>Grade C</td>
<td>treatment options are supported by either conflicting or poor quality evidence (Level IV studies)</td>
</tr>
<tr>
<td>Grade I</td>
<td>when insufficient evidence exists to make a recommendation</td>
</tr>
</tbody>
</table>

originates on the anterior colliculus and cross two joints (tibiotalar and talocalcaneal), whereas the deep part, originating in the groove between and on the posterior colliculus, only bridges the tibiotalar joint. Historically, other authors have described from three to six differing anatomical divisions. In our opinion, the deltoid ligament is comprised of six different parts according to different functional properties (see Fig. 1). Superficial and anterior are the tibionavicular (TNL), the tibiospring (TSL) and the tibiocalcaneal (TCL) ligaments. The deep layer consists of the superficial posterior (sPTTL), deep posterior (dPTTL) and anterior tibiotalar (ATTL) ligaments. There can be individual differences; the TNL is considered by some to be a thickened fibrous part of the anterior ankle capsule, rather than a separate ligament. The dPTTL appears on magnetic resonance imaging (MRI) and in anatomical dissection as thickest and bridges the posterior colliculus and the medial tubercle of the talus. The TSL is the component of the deltoid ligament without two bony attachments. It originates from the anterior colliculus and fans out to the plantar calcaneonavicular or spring ligament thereby forming a functional unit with this ligament. It appears on MRI as the second largest component. In anatomical preparations, however, the TCL is recognized as being at least as thick as the dPTTL. When Mengiardi et al. evaluated the visibility and signal intensity characteristics of the deltoid ligament on MRI in asymptomatic volunteers, the dPTTL and TSL were always visible. The ATTL and TNL were only seen in about half of the subjects.
Biomechanics of the deltoid ligament

The deltoid ligament is thought to have a dual function; to provide medial stability to the tibiotalar joint and to transfer forces between tibia and tarsus. The primary function of the deltoid ligament is the firm fixation of the tibia above the talus and to restrict the tendency of the talus to shift into a valgus position, to translate anterolaterally or to externally rotate. The intact deltoid ligament prevents the talus shifting more than 2 mm laterally, even if the lateral structures are not in place. Normal movement of the talus in the mortise is possible in all three planes. The normal range of motion is described variously: plantar flexion is reported to exceed dorsiflexion by 4–5 times or by up to 80%, at maximum plantar flexion of the foot, internal rotation of 1.9° of the talus is seen, whereas at maximum dorsiflexion 7.2° of external rotation. Adduction and abduction with intact ligaments are
widely disputed and range from $5^\circ$ symmetrically to some extreme values $^{10, 66, 108, 112}$. Internal and external rotation have been reported to range from 14 to $24^\circ$ $^{56, 79, 108}$.

Cutting of the deltoid ligament has been performed by several authors in order to investigate its function $^{39, 93, 108}$. Severe instability is reported when cutting the entire ligament but a surprising degree of stability is found remaining when cutting only the superficial part of the deltoid ligament. With the deep part still intact, only 4–7° of external rotation of the talus was possible $^{79, 108}$. In the absence of a medial injury, a complete fibular osteotomy does not cause abnormal motion of the ankle $^{83, 111}$. The ATTL together with the anterior talofibular ligament on the lateral side is thought to restrict forward translation of the talus. However, some authors state that the ATTL has no independent function and that the lateral ligament mainly restricts plantar flexion $^{108}$. According to Dehne and Dias $^{27, 30}$, the posterior tibiotalar ligament restricts internal rotation of the talus solely by means of its deep fibres. However, these authors have not performed isolated sectioning of these fibres. In a study of injuries to the different ankle ligaments performed by Rasmussen, it was found that cutting of both the TCL and the ATTL hardly affected talar movement in any direction $^{108}$.

There is an agreement between radiological and anatomic studies over the strength of the different components of the deltoid ligament. The dPTTL appears to be the strongest followed by the TSL. The TCL and TNL are weaker than the latter $^{58, 97, 108, 119}$. In addition, there is interlacing of the TSL and the TNL. This spring ligament complex supports the talar head medially and stabilizes the entire talocalcaneonavicular joint. Hintermann also suggests a relationship between laxity of this ligament complex and medial ankle instability $^{51}$.

The weakness of in vitro studies is many authors have used nonstandardized forces to induce movements of the separate structures in the ankle joint. The results of these biomechanical studies are to be interpreted with caution as the cadaver does not bear weight and the ligaments may behave differently in vivo.
Mechanism of trauma

The main causes of deltoid ligament lesions are pronation or rotation movements of the hindfoot \(^4, 53, 61, 64, 69, 72, 131\). The first systematic investigation of ankle fracture patterns and the accompanying injury to ankle joint ligaments was done by Lauge-Hansen. Although several of the proposed injury mechanisms and the height of the fibular fracture in SE fractures have been disputed by some authors, many studies are based on his work and his terminology has become widely used \(^40, 54, 69, 85, 98, 127\). His system of fracture and ligament injury pattern is based on cadaver experiments. Lauge-Hansen simulated several rotational, abduction and adduction movements of the lower leg with regard to a fixed foot in pronation or in supination. SE rotation is the mechanism that causes approximately 80% of all ankle fractures. Lauge-Hansen found that in stage one, a rupture or avulsion of the anterior tibiofibular ligament occurs. The deltoid ligament is lax since the position of the foot is in supination. Further external rotation of the foot increases the pressure of the talus against the fibula results in a twisting motion of the fibula around its longitudinal axis, producing the typical spiral (Weber B) fracture at the level of the syndesmosis (see Fig. 2). In this second stage, the deltoid ligament is still lax since the foot is still supinated. The interosseous transverse ligament, interosseous membrane, posterior syndesmosis and deltoid ligament remain intact at this stage. When the external rotation is continued, the talus is subluxed and the hindfoot adopts a valgus position. The foot cannot maintain the supinated position which becomes neutral and now moves into a pronated position but still without rupture of the deltoid ligament. During this movement, the tip of the fractured fibula and the talus can collide with the posterior tibial tubercle, resulting in a splitting off of a triangular shaped piece also known as Volkmann’s fracture. The posterior tibiofibular ligaments are very strong and rupture is uncommon \(^72, 127\). In the original experiments, a posterior malleolar fracture or posterior talofibular ligament rupture was named stage three. When more external rotation was performed, a fracture of the medial malleolus resulted (see Fig. 3). In his first report, Lauge-Hansen did not describe deltoid ruptures from this (end-stage) grade four SE fracture. In later publications, he stated that medial malleolar fractures could be replaced by deltoid ligament injury which completed his system of injury patterns arising from
CHAPTER 4 - DELTOID LIGAMENT DIAGNOSIS AND TREATMENT

Figure 2: AP and lateral radiographic images of a SE-2 fracture, consisting of a spiral or oblique fibula fracture at the level of the syndesmosis.

Figure 3: AP and lateral radiographic images of a SE-4 fracture consisting of a spiral or oblique fracture laterally and a transverse medial malleolar (avulsion) fracture.
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Figure 4: AP and lateral radiographic images of a SE-4 fracture consisting of a spiral or oblique fracture laterally and a deep deltoid rupture, allowing a talar shift (resulting in widening of the medial clear space).

Figure 5: AP and lateral radiographic images of a SE-4 fracture consisting of a spiral or oblique fracture laterally with a combination of an avulsion fracture medially. There may also be a deep deltoid rupture. When in doubt, medial integrity could be tested by gravity stress radiography.
SE rotation forces (see Fig. 4)\textsuperscript{63, 64}. Other authors deduced from the described mechanism that in stage four avulsion fractures should occur at the same rate as deltoid ligament ruptures\textsuperscript{4, 20, 69, 123, 131}. Moreover, Rasmussen found that especially the deep portions of the deltoid ligament, which are thought to be the main stabilizers, could rupture in external rotation while the superficial components remain intact\textsuperscript{108}.

Approximately, a quarter of patients with stage four SE fractures are thought to suffer an avulsion fracture medially and a rupture of one of the components of the deltoid ligament (Fig. 5)\textsuperscript{117}. In bimalleolar fractures, the medial injury may appear to be this osseous avulsion only with the deltoid ligament left intact on the displaced fragment but this injury may also be a combination of ligamentous and osseous injury with disruption of the deep portion of the deltoid ligament. As reported by several authors, there should be awareness of the possibility of a deltoid rupture in combination with a medial fracture\textsuperscript{94, 117}. The superficial component of the deltoid ligament is thin and weaker than the deep part and is under tension during external rotation of the ankle when the foot is in plantar flexion. Therefore, fixation of small anterior fractures of the medial malleolus, to which only the superficial portion of the ligament attaches, may not be sufficient to restore medial stability\textsuperscript{40, 94, 125}. In 60–70\% of the avulsion fractures of the posterior colliculus, the strong posterior tibiotalar ligament remains intact and attached to the fractured fragment, while the other weaker components are torn\textsuperscript{58, 117, 119}.

The mechanism underlying SE and pronation–external rotation (PE) fractures is similar. The difference is the position of the foot at the moment of external rotation. With a foot in pronation, there is initial tension on the medial structures. A lateral fracture resulting from PE is unstable for there is always a medial fracture or deltoid rupture. This has been questioned by authors who report observing high fibular fractures without injury at the medial side\textsuperscript{40, 85}. The frequency of injury to the deltoid ligament in SE fractures is higher than previously expected and ranges from 20 to 50\%\textsuperscript{49, 69}. These figures may underestimate the true frequency due to lack of diagnostic reliability.
Diagnosis

The Lauge-Hansen classification has the additional advantage of taking ligamentous injuries into account. The comprehensiveness of the system does make it more difficult to use than the Weber classification. Thorough knowledge of ankle anatomy and subgroups of the Lauge-Hansen system are required for its application but, although precision can be improved by teaching, some studies have shown that the system cannot be applied consistently with only poor to fair inter-observer reliability. The problem of inconsistent application of the Lauge-Hansen scheme is compounded by fractures patterns that escape this classification system. Some fractures considered stable by the Lauge-Hansen classification may require careful examination to rule out deep deltoid injury. Therefore, the diagnostic value of the Lauge-Hansen classification for ligamentous injuries in SE fractures seems limited. Although the Lauge-Hansen system is not infallible, 91.6% of the fractures in the study of Schuberth et al. that were classifiable according to the scheme demonstrated the expected deltoid ligament findings. The problem in SE fractures is the ‘invisible medial injury’. The decision to treat a seemingly stable SE stage two fracture conservatively, without accurate assessment of deltoid ligament injury, may predispose a patient to early posttraumatic osteoarthritis. Rupture of the deep deltoid ligament combined with a displaced lateral malleolar fracture is the biomechanical equivalent of a bimalleolar fracture and is best treated with open reduction and internal fixation of the fibula to restore ankle mortise anatomy.

A recent systematic review of the modalities for evaluation of the integrity of the deltoid ligament in patients with SE ankle fractures was published by van den Bekerom et al. (level I evidence). Many orthopaedic surgeons rely on clinical signs such as ecchymosis, swelling and tenderness to evaluate integrity of the medial structures. Similarly, in lateral ligament injuries, clinical evaluation has been proven to be of great value; additional (imaging) investigation has shown little or no added contribution to accurately make the diagnosis. A review in a publication from the American Academy of Orthopaedic Surgeons supports the use of medial tenderness as a predictor of deep deltoid disruption in SE type ankle fractures. Despite this, the current literature cautions against clinical features of the injured ankle as
adequate predictors of medial stability of the ankle joint (based on level III and IV evidence) \(^{26, 36, 78}\). When these clinical symptoms are present, it may be likely that there is a soft-tissue injury. This injury could consist of only the superficial deltoid ligaments with intact deep structures. The superficial ligaments deliver little contribution to medial stability of the ankle and, like the stronger deep component, can also be injured by means of a rotational mechanism \(^{78, 84, 108}\).

As the initial radiographs of an ankle injury with an isolated distal fibular fracture at the level of the syndesmosis may be inconclusive, a stress radiograph has been recommended to determine the integrity of the medial clear space (based on level III and IV evidence) \(^{36, 62, 67, 78, 127}\). The medial clear space is measured from the superior-medial aspect of the talus to the superior-medial corner of the tibial plafond. External rotation stress radiographs, as described by Pankovich, are considered the gold standard but this test has its shortcomings and has never been validated (level IV evidence) \(^{44, 78, 97, 98}\). Tornetta stated that these tests are the gold standard for subluxation as an indirect measurement of deltoid injury or deltoid insufficiency \(^{125}\). The reported amount of widening of the medial clear space as indicative for a positive external rotation stress test or gravity stress test varies \(^{19, 25, 36, 41, 44, 46, 57, 75, 78, 86, 99, 102, 117}\). Normal values are reported to vary from 1 to 5 mm \(^{19, 25, 44, 46}\). A medial clear space of more than 4 mm, with that value being at least 1 mm greater than the superior tibiotalar space, is accepted to represent a deep deltoid ligament rupture (based on level III and IV evidence) \(^{3, 35, 36, 41, 45, 78, 87}\). In a cadaver study, transection of the superficial deltoid ligament alone did not cause medial clear space widening, even in the presence of a fibular fracture \(^{86}\). However, an intact superficial part, and a negative abduction stress test, does not guarantee an intact deep ligament \(^{108}\). The direction of rotational stress applied to the foot has a greater effect on medial clear space in predicting deep deltoid ligament status than does the amount of ankle flexion. Stress radiographs obtained with the foot in dorsiflexion with addition of external rotation were most predictive of deep deltoid ligament disruption after distal fibular fracture \(^{99}\). The amount of applied force necessary when performing an external rotation stress radiograph is not well defined. Xenos recommends 5 Newton metre, McConnell and Park recommend 8 pounds and Tornetta used 20 pounds \(^{25, 78, 99, 125}\). Patients may experience pain during an ankle stress test
which could then increase resistive muscle forces. This could limit the amount of rotation possible in the injured ankle; therefore, these tests are only well tolerated with the use of analgesics, narcotics or under general anaesthesia. To solve this problem Michelson proposed a gravity stress test. There was no significant difference between the gravity and manual stress radiograph with regard to mean medial clear space or talar shift measured in association with either fracture pattern. The visual analogue pain score indicated that patients perceived more discomfort while being examined with manual stress applied compared to gravity testing (level III evidence). The main limitation of the gravity stress radiograph is the inability to control dorsiflexion and plantar flexion. However, this technique involves less radiation exposure to the physician and can be performed by assistant radiographers. The use of weight bearing radiographs as proposed by Weber et al. is an easy, pain-free, safe and reliable method to exclude the need for operative treatment with excellent clinical outcome in the majority of the patients seen at latest follow-up. Further studies are required concerning this type of radiograph, because at last follow-up, the patients were only interviewed by phone only and no radiographs taken for final assessment. Asymptomatic ankle arthritis, ankle instability, or poor range of motion of the hindfoot joints might have been missed in this study.

Arthroscopy has been used to assess cartilage lesions and ligamentous damage in acute ankle trauma. Schuberth et al. compared deep deltoid ligament integrity as seen with arthroscopy with corresponding medial clear space measurements in a clinical setting. They concluded that displaced SE fractures in patients with medial ankle tenderness, but without overt widening of the medial clear space on injury radiographs require careful attention because the integrity cannot be reliably predicted by injury radiographs. Damage to the ligaments cannot always be identified by arthroscopy. Hintermann reported that only 84.4% of deltoid ligaments could be seen on arthroscopy directly after trauma and superficial components cannot be seen at all.

Magnetic resonance imaging (MRI) may help in determining deltoid ligament integrity after trauma and for individual cases in which doubt about joint stability and soft-tissue integrity exists. In a preliminary report, Koval et al. concluded that medial clear space measurements on manual
stress radiographic testing did not correlate with deep deltoid rupture on MRI (level IV evidence). These conclusions should be interpreted with caution because of the incomplete and short-term follow-up in their study. Clearly, there are limitations in its practicality because of cost and convenience.

Ultrasound imaging is often considered as a complementary modality to MRI. Modern ultrasound techniques like 3-D rendering have become competitive. The major advantages of ultrasound include dynamic evaluation of structures, low cost and wide availability. The main disadvantage is a high degree of operator dependency. In general, the cost-effectiveness of ultrasound could justify its use as a first-line examination technique. The deltoid ligaments are best visualized on sonograms when the hindfoot is turned laterally and the ankle is in dorsiflexion. This makes ultrasound investigation in ankle fractures difficult as when compared to investigating the ligaments in ankle sprain. In the acute setting of a ruptured deltoid, an anechoic zone crossing the ligament can be seen but also oedema, ecchymosis and avulsions of the bony insertion. On the lateral side of the ankle joint, sonography has been proven to correctly diagnose ligamentous lesions with accuracy as high as 87–100 % (level IV evidence). Sonography, while useful for depicting and studying the integrity of the medial collateral ankle ligaments, has yet to be proven for detecting deltoid ruptures sustained in ankle fractures. Several authors advocate further research in the different imaging modalities.

Treatment

In 1987, Baird and Jackson performed a review of the literature on the most appropriate treatment of ankle injuries in which the deltoid ligament is ruptured and the fibula is fractured at the level of the syndesmosis. Based on the premise that the ruptured ends of the deltoid ligament retract and are not apposed and that disrupted ligaments heal better when they are surgically approximated, they found twelve articles, which advocated surgical repair of the ligament in conjunction with reduction of the fibular fracture. However, nine other articles reported adequate results without surgical repair of the deltoid ligament. These depended...
<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Study Level</th>
<th>n</th>
<th>Type of injury</th>
<th>Number of patients available for follow-up</th>
<th>Mean follow-up</th>
<th>Sutured</th>
<th>Outcome</th>
<th>Not sutured</th>
<th>Outcome</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baird and Jackson</td>
<td>1987</td>
<td>IV</td>
<td>70</td>
<td>“Distal fibular fracture and disruption of the deltoid ligament”</td>
<td>24 (13 SE#, 11 PE#)</td>
<td>36 months</td>
<td>3</td>
<td>1 SE# excellent, 2 PE# poor</td>
<td>21</td>
<td>8 SE# excellent, 5 PE# excellent, 3 SE# good, 3 PE# good, 1 SE# fair, 1 PE# poor</td>
<td>90% of the non-repaired ligaments had a good or excellent result. Only if the medial clear space remains widened after fracture reduction does the medial side need to be explored.</td>
</tr>
<tr>
<td>Harper</td>
<td>1988</td>
<td>IV</td>
<td>42</td>
<td>“Fracture dislocations of the ankle”</td>
<td>36 (18 SE#, 15 PE#, 2 maissonneuve, 1 syndesmotic diastasis)</td>
<td>30 months</td>
<td>0</td>
<td>-</td>
<td>36</td>
<td>12 SE# good, 4 SE# fair, 2 SE# poor, 14 PE# good, 1 PE# poor, 1 maissonneuve good, 1 maissonneuve poor, 1 diastasis good</td>
<td>The deltoid ligament will heal sufficiently with nonoperative treatment, provided that the medial joint space is maintained in a reduced position.</td>
</tr>
<tr>
<td>Zeegers and van der Werken</td>
<td>1989</td>
<td>IV</td>
<td>28</td>
<td>“Ankle fracture associated with a ruptured deltoid ligament”</td>
<td>28 (12 SE#, 10 PE#, 6 PA#)</td>
<td>18 months</td>
<td>0</td>
<td>-</td>
<td>28</td>
<td>20 patients (very) good, 8 patients poor</td>
<td>After anatomical reconstruction of the lateral malleolus with perfect congruity of the ankle mortise there is no need to explore and suture the ruptured deltoid ligament.</td>
</tr>
<tr>
<td>Strömsöe et al.</td>
<td>1995</td>
<td>II</td>
<td>50</td>
<td>“Weber B and C types and a ruptured deltoid ligament”</td>
<td>50 (30 Weber B, 20 Weber C)</td>
<td>17 months</td>
<td>25</td>
<td>no differences between groups</td>
<td>25</td>
<td>no differences between groups</td>
<td>A ruptured deltoid can be left unexplored. Operating time is reduced and the skin over the medial malleolus is left untouched.</td>
</tr>
<tr>
<td>Maynou et al.</td>
<td>1997</td>
<td>III</td>
<td>44</td>
<td>“Ankle fractures with deltoid ligament rupture”</td>
<td>44 (7 OCD and 2 malreductions were evaluated separately)</td>
<td>56 months</td>
<td>18</td>
<td>2 medial instability</td>
<td>17</td>
<td>2 medial instability, more ossifications of the deltoid (p&lt;0.013), 1 posttraumatic osteoarthritis</td>
<td>Repair of the deltoid ligament is unnecessary if the internal fixation of the fibula achieves an anatomical reconstruction of the mortise.</td>
</tr>
<tr>
<td>Tourne et al.</td>
<td>1999</td>
<td>IV</td>
<td>48</td>
<td>“Weber A, B and C fractures with a ruptured medial collateral ligament”</td>
<td>33</td>
<td>27 months</td>
<td>0</td>
<td>-</td>
<td>33</td>
<td>82.5% excellent and good, 7.3% normal Rx, 15% anterior impingement, 12% deltoid calcifications</td>
<td>Suggestion to leave the ligament tears unexplored (medial, tibiofibular, and syndesmotic).</td>
</tr>
</tbody>
</table>
on restoration of the normal osteoligamentous anatomy of the lateral structures of the ankle joint to achieve stability of the ankle. As the primary objective of these studies was not to evaluate the need for deltoid reconstruction, these studies had a limited number of patients. Moreover, there were different objective and subjective outcome measurements and it was difficult to reconcile the validity of contradictory viewpoints. In their own results (level IV evidence) of three sutured deltoid ligaments, two had poor results but these two ruptures were the result of a PE fracture, while the repaired ligament after SE type fracture had an excellent outcome. A typical example of a brief mention in treatment of the deltoid ligament was reported by Lindsjö in an otherwise outstanding follow-up study of 327 ankle fractures: ‘The deltoid ligaments was sutured to similar extents in the two result groups “excellent to good” and “acceptable to poor”. Injuries to these ligaments do not appear to have been a discriminating factor of importance in this material’.

We found only six publications in which the need for exploration and suturing the deltoid ligament after ankle fractures was the primary question (Table 2). Although these studies are different in design and have different inclusion criteria, they have similar conclusions (based on level II–IV evidence). These studies show that in the event of an adequate reduction in the fractured fibula and normalization of the medial clear space, it is not necessary to explore the medial clear space and to reconstruct the deltoid ligament. Only if there is interposition on the medial side after adequate reduction in the fibular fracture is an exploration of the medial clear space required. However, in all six articles, there was not a single patient in which exploration was needed. Theoretically, soft tissue, scar tissue, ligament remnants, or chondral fragments may be interposed between the talus and the medial malleolus. If this is the case, they should be removed to enable an adequate reduction.

**Conclusion and recommendations**

There have been many studies examining the diagnosis and treatment of SE type ankle fractures. In spite of common agreement on treating unstable fractures with open reduction and internal fixation, there have been reports of unsatisfying results with conservative treatment of seemingly stable fractures.
The Weber classification does not take the status of ligaments into account whereas the Lauge-Hansen classification does. In SE type 2 fractures, the deltoid ligament is intact, but SE type 4 represents an unstable configuration. In case of tibiotalar displacement of more than four millimetres, there is no problem with making the diagnosis but in cases where the X-ray shows no displacement there still can be a deltoid ligament rupture. The question remains as to which diagnostic tools are the best at examining the integrity of deep portion of the deltoid ligament.

- The gravity stress radiograph has provided the best results in detection of deltoid ligament rupture in patients with SE ankle fractures.
- A medial clear space of over four millimetres seen after fibular fracture, with that value being at least one millimetre greater than the superior tibiotalar space, is a value that is accepted to represent a ruptured deep deltoid ligament.
- Other diagnostic criteria, such as pain over the deltoid ligament, swelling, ecchymosis, or combinations thereof have not shown sufficient sensitivity and specificity to rule out instability of the ankle joint, and further investigation is therefore warranted.
- Theoretically, ultrasound examination of the deltoid region has potential. Ultrasonography is, however, a dynamic investigation and requires experienced hands. Further studies comparing combinations of different diagnostic (imaging) modalities could improve inter- and intra-observer reliability.
- The treatment of deltoid ligament lesions (exploration and reconstruction of the deltoid ligament) is only necessary if there is interposition on the medial side after adequate reduction of the fibular fracture.
- When the fibula fracture is adequately reduced and the medial clear space has returned to its normal width there is no indication to perform an 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 - DELTOID LIGAMENT DIAGNOSIS AND TREATMENT

References


CHAPTER 5

THE ROLE OF DELTOID LIGAMENT LESIONS IN SUPINATION EXOROTATION TYPE 4 ANKLE FRACTURES

Published as:

CHAPTER 5 - DELTOID LIGAMENT IN SER-4 FRACTURES

Introduction

The fourth stage of the supination-external rotation (SER 4) type of ankle fracture consisting of a fibular fracture at the level of the syndesmosis and a medial malleolar fracture or a rupture of the deltoid ligament, is unstable. It is usually treated operatively.\(^2\)\(^-\)\(^6\) A fracture of the medial malleolus can be seen on a plain radiograph of the ankle whereas a ruptured deltoid ligament is difficult to diagnose. The gravity stress test is considered to be the best test for establishing disruption of the medial collateral ligament.\(^7\)\(^-\)\(^{11}\) Arthroscopy, although invasive, MRI and perhaps ultrasonography may be of value.\(^{11}\)\(^-\)\(^{13}\)

The aim of treatment of a fracture of the medial malleolus by open reduction and internal fixation is to restore the articular surface. Since the medial ligaments are still intact after anatomical reduction of the fracture the ankle is stable on the medial side. We were able to find only one report which compared the results of SER-4 fractures with either a medial malleolar fracture or rupture of the deltoid ligament.\(^{14}\) This study showed that the Short Musculoskeletal Function Assessment score\(^{15}\) was worse in patients with a bimalleolar fracture at a maximum of one year postoperatively. In order to clarify the role of the deltoid ligament in the long term in SER-4 fractures, we compared the radiological and clinical results of the bony type with those of the ligamentous type of fracture.

Patients and Methods

After approval of the study by the institutional and cantonal ethical review boards, we undertook a long-term follow-up of a consecutive series of 288 patients who had been treated surgically for a fracture of the ankle between 1993 and 1997 in the hospitals of Liestal and St. Gallen and prospectively evaluated the development of post-traumatic osteoarthritis. There were 66 SER-4 fractures of which 36 were available for follow-up at a mean of 13 years (11 to 14). There were 15 males and 21 females, with a mean age of 46.9 years (16 to 76). The right side was involved in 17 (47%) and the left in 19 (53%). Most (15) of the fractures were the result of a sports injury. Among other causes were road-traffic accidents (eight) and injuries at home (six).
Standard anteroposterior (AP) and lateral radiographs of the ankle had been taken in all patients (Fig. 1). These were independently reviewed to confirm the Lauge-Hansen classification by an expert foot and ankle surgeon (NvD). A medial clear space of 4 mm or more or of 1 mm more of the superior clear space was considered to indicate a rupture of the deltoid ligament. In addition to the assessment of the radiographs, arthroscopy had been performed in all patients before reduction and fixation of the fracture, to evaluate the integrity of the medial structures. Radiological assessment showed that there were 25 medial malleolar fractures and 17 ruptures of the deltoid ligament, all of which had been confirmed arthroscopically. In six patients there was a combination of a medial malleolar (avulsion) fracture and a partial rupture of the deltoid ligament. In order to make sound comparisons, we divided the series into two groups, those with an intact deltoid ligament (n = 19) and those with a partial or completely ruptured deltoid ligament (n = 17).

All the patients had been treated by a similar surgical protocol, which consisted of restoration of the fibular length and anatomical fixation of the fibular fracture with a tubular plate and screws. The syndesmotic complex had been assessed and found to be damaged in 18 of the 36 patients, but arthroscopic examination before surgery and per-operative hook-testing showed that there were no complete ruptures requiring stabilisation of the syndesmosis. There were no fragments of the posterior malleolus larger than 33% of the articular surface which required fixation.
If a fracture of the medial malleolus was present, it was reduced and stabilised by one or two screws. Post-operative treatment consisted of partial weight-bearing for six weeks in a plaster cast, followed by full weight-bearing with passive and active physiotherapy to the ankle in all patients.

At follow-up at a mean of 13 (11 to 14) years, the clinical results were assessed by an independent orthopaedic surgeon (MK) with no prior knowledge of the type of trauma, the type of fracture or the radiographs. The American Orthopedic Foot and Ankle Society (AOFAS) hind-foot score was used to quantify the clinical outcome. A validated visual analogue score (VAS) for pain and function was used to assess the subjective outcome. The short-form 36 quality of life score was recorded. Weight-bearing AP and lateral radiographs were evaluated by an orthopaedic foot and ankle surgeon (BH) with no knowledge of the initial type of fracture or the clinical result. We used a modified version of the score of Kannus, Jarvinen and Paakkala to determine the level of osteoarthritis on a 100-point scale. This score takes several aspects of arthritis into account, including the amount of sclerosis visible, the formation of osteophytes, calcification of the ligaments, narrowing of the joint space and the formation of cysts.

**Statistical analysis**

All data were analysed using the SPSS version 16.0 software (SPSS Inc., Chicago, Illinois). Continuous variables, such as the VAS pain score, the AOFAS hind-foot score, the SF-36 score and the Kannus arthritis score were analysed using the t-test or the Mann-Whitney U test in the case of skewed distributions, to assess differences between the groups. The odds ratio was calculated to assess the increase in risk of having cartilage lesions. A p-value < 0.05 was considered to be statistically significant.

**Results**

The mean total AOFAS score at follow-up was 86.6 (53 to 100) and the mean modified Kannus radiological score was 88.3 (74 to 100). There was a significant difference (p = 0.015) between the total AOFAS hind-foot score for intact
and damaged (partially or completely ruptured) deltoid ligaments and for the functional element of the score in favour of the damaged ligament group (41.8 (95% CI 38.7 to 45.0) versus 45.5 (95% CI 42.5 to 48.4), Table I). However, there was no significant difference between the two groups for the pain or alignment elements of the score (Table I). With regard to the SF-36 score the only significant difference (p = 0.050) between the two groups was in the bodily pain score (Fig. 2). The subjective VAS score showed no significant differences between the intact and damaged deltoid ligament groups although the intact group tended to score lower (Fig. 3).

The modified Kannus radiological score showed no significant differences between the two groups (87.1 (95% CI 84.2 to 89.9) for the intact group versus 89.8 (95% CI 86.3 to 93.0) for the group with a damaged deltoid). However, arthroscopically, there was a significant difference (p = 0.05) in the intra-articular loose bodies seen between the two groups, with an increased risk in the group with an intact deltoid ligament (Table II). There was no significant difference in lesions of the lateral (p = 0.58) or medial (p = 0.10) deep cartilage between the two groups.

Table 1: Mean (95% confidence interval (CI) details of the American orthopaedic foot and ankle society (AOFAS) hindfoot score in the groups with and without an initial deltoid ligament.

<table>
<thead>
<tr>
<th>AOFAS Score</th>
<th>Deltoid</th>
<th>Mean (95% CI)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain</td>
<td>Intact</td>
<td>34 (31 - 37)</td>
<td>.167</td>
</tr>
<tr>
<td></td>
<td>Damaged</td>
<td>36 (34 - 39)</td>
<td></td>
</tr>
<tr>
<td>Function</td>
<td>Intact</td>
<td>42 (39 - 45)</td>
<td>.047*</td>
</tr>
<tr>
<td></td>
<td>Damaged</td>
<td>45 (42 - 48)</td>
<td></td>
</tr>
<tr>
<td>Alignment</td>
<td>Intact</td>
<td>07 (06 - 09)</td>
<td>.191</td>
</tr>
<tr>
<td></td>
<td>Damaged</td>
<td>09 (07 - 10)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>Intact</td>
<td>83 (77 - 88)</td>
<td>.015*</td>
</tr>
<tr>
<td></td>
<td>Damaged</td>
<td>91 (86 - 96)</td>
<td></td>
</tr>
</tbody>
</table>

*Significant at p < 0.05.
Figure 2: Bar chart showing that the short-form (SF) 36 score for bodily pain was significantly lower in the group with an intact deltoid ligament than in that with a (partially) ruptured deltoid ligament (error bars indicate 95% confidence intervals).

Figure 3: Bar chart showing that the subjective visual analogue scale (VAS) did not show a significant difference between the two groups although the group with an intact deltoid ligament had a lower score (error bars indicate 95% confidence intervals).
Discussion

The results of our study suggest that at a mean follow-up of 13 years (11 to 14) an SER-4 fracture with a fracture of the medial malleolus has a worse prognosis than that with a partial or complete rupture of the deltoid ligament. Significant differences were seen in the total AOFAS hind-foot score and function score (Table I). The SF-36 subscore for bodily pain was significantly lower in the group with an intact deltoid ligament (Fig. 2). The subjective VAS score was also lower in the intact deltoid group, but this did not reach significance (Fig. 3). Radiologically, there were no significant differences detectable between the groups. Tejwani et al\textsuperscript{14} described a series of similar patients with a maximum follow-up of one year. They found that bimalleolar fractures had a worse prognosis than fibular fractures associated with a lesion of the deltoid ligament. They suggested that the difference between the two groups might even out with longer follow-up. However, the results of our study after 13 years suggest that this may not be the case. This does not mean that the combination of a lesion of the deltoid ligament and a lateral malleolar fracture should be underestimated. In order to obtain a good clinical result, the lateral malleolus must be anatomically reduced and open reduction and internal fixation are commonly used.\textsuperscript{2–5,10,22–24} The deltoid ligament should heal with no residual laxity when the ankle mortise is intact. Good results can be obtained by conservative treatment as shown by Wei et al\textsuperscript{25} if anatomical reduction can be obtained and maintained. They recorded a mean AOFAS score of 98 (87 to 100) after a mean follow-up of 20 years in bi- and trimalleolar fractures treated by closed reduction and with a non-weight-bearing long-leg cast for six weeks followed by a short-leg cast for six weeks.

There are other factors which could influence the development of post-traumatic osteoarthritis. The medial malleolar fracture could represent a more serious injury than its ligamentous equivalent because of the energy transferred into intra-articular lesions. Several authors point out the possibility of these cartilage lesions having a significant influence on the long-term outcome.\textsuperscript{26–31} In our study there was a significant difference (p < 0.05) between the two groups with regard to loose bodies seen at arthroscopy when the deltoid ligament was intact (Table II). The odds ratio of having loose bodies was 5.5. Of the 36 patients, ten were found to have a cartilage lesion of a depth
of > 50% on the medial side and nine on the lateral side. Analysis of the data showed a positive correlation between deep cartilage damage and an intact deltoid ligament, but this was not significant.

The limitations of our study include the lack of pre-operative functional data and the relatively small number of patients who could be followed up. Only 36 of the 66 SER-4 fractures were seen at a mean of 13 years after injury. Further limitations include the use of the Lauge-Hansen classification, since the reproducibility of this classification is quite modest according to Thomsen et al.\textsuperscript{32} The original fractures consisted of the AO/ASIF types\textsuperscript{33} 44-B2.1, 44-B2.2, 44-B3.1 and 44-B3.2. The AOFAS hind-foot score and the Kannus arthritis score have not yet been fully validated, although the subjective part of the AOFAS hind-foot score has shown some validity in a recent review\textsuperscript{34} and has been widely used in foot and ankle studies.\textsuperscript{35} The Kannus arthritis score is more sensitive than for example the Takakura\textsuperscript{36} osteoarthritis score or the Kellgren-Lawrence score.\textsuperscript{37} Since there was no severe end-stage arthritis in our patients at follow-up we chose a radiological scoring system which still has discriminating power in a patient group with little signs of osteoarthritis.

The results of our study suggest that 13 years after operative management of a SER-4 ankle fracture patients with a partial or complete rupture of the deltoid ligament tend to have better results than those with a fracture of the medial malleolus.

Table 2: Free bodies present in the joint as shown by arthroscopy, by number and percentage.

<table>
<thead>
<tr>
<th>Free bodies</th>
<th>Intact</th>
<th>(Partially) Ruptured</th>
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<td>19</td>
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<td>100%</td>
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</table>

*Significant at \( p < 0.05 \).
References


33. No authors listed. AO foundation. https://c5ezou06t8jye58i-gh8rmg.sec.amc.nl (date last accessed 5 October 2009).


PART IV
VARUS AND VALGUS
CHAPTER 6

MEASUREMENT OF THE MDTA

Published as:

CHAPTER 6 - MEASUREMENT OF THE MDTA

Introduction

Deformity of the distal tibia in the coronal plane may be congenital, dysplastic, developmental or traumatic in origin. Many authors have investigated the value of reconstructive procedures.\textsuperscript{5,12,14,15,19–22} Corrective surgery is usually planned based on upright, weight bearing, full lower limb radiographs. The ankle joint orientation is in slight valgus to the tibial shaft axis. During the midstance phase of gait, the tibia is thought to be in approximately 3 degrees of adduction, thereby allowing the tibial plateau to become horizontal.\textsuperscript{16} The slight valgus of the ankle joint makes the distal tibial plafond parallel to the knee joint and therefore, parallel to the ground during single leg stance. If a deformity above the ankle is suspected, it is generally accepted that radiographic evaluation should commence with weight-bearing bilateral mortise and lateral films on long cassettes. However, measurements are sometimes made on mortise images of the ankle only, which do not include the tibial plateau. It is not yet known if these mortise view measurements are reliable, reproducible and valid as compared to the anatomical and mechanical axes measured in whole leg images. We hypothesized that the medial distal tibial angle (MDTA)\textsuperscript{16} would not be the same when measured on whole lower leg images compared with mortise view ankle images.

Materials and methods

Population

A power analysis was performed before this institutional review board-approved study was begun. We calculated that a sample of 37 radiographs would be required to detect a difference of 2 degrees (own preliminary investigations) between the mortise radiographs and the lower leg radiographs with an alpha of 0.05, a power of 0.80, and a standard deviation of 3 degrees.\textsuperscript{7,9} Subsequently, 24 healthy volunteers without a history of ankle surgery or deformation of the lower limb were recruited. There were 12 men and 12 women included with a mean age of 32 ± 7.6 (range, 21 to 56) years.
Radiographic technique

The volunteers stood in an upright position, bearing weight on both legs without footwear. Plain radiographs were taken of both lower legs in exactly the same fashion. First a mortise-view radiograph was taken with the foot in 20 degrees internal rotation. The film focus distance (FFD) was 100 cm in all cases. The beam (6 mAs, 55 kV) was centered on the ankle joint. The second image taken was of the whole lower leg. The volunteers stood on both legs with a 10 cm foam block separating the ankles. The patient was positioned with the patellae facing forward. The FFD was 200 cm in all cases. The beam (8 mAs, 64 kV) was centered on the middle of the tibia halfway between the knee joint and ankle joint.

Measurement methods

The mechanical axis of the tibia passes through the center of the knee joint line to the center of the ankle plafond. The anatomical axis of the tibia is the mid-diaphyseal line. The mechanical axis was chosen for this study as it was considered easier to determine with reliability. Additionally, the tibia has a slight physiological s-shape and no study has yet reported on which two mid-diaphyseal points to choose.

The radiographic images were evaluated with Image Access® software. A randomized database was created with all lower leg and mortise views of the ankle mixed. The five observers, a fellowship trained orthopaedic foot and ankle surgeon (M.K.), three residents interested in foot and ankle surgery (S.S., A.B., and J.S.) and one biomechanical movement scientist experienced in foot and ankle imaging (L.B.), measured all images according to the protocol below.

To establish the center of the tibial plateau (Figure 1: “1”), a circle was drawn (Figure 1: “2”) and positioned to fit between the medial and lateral cortex at the widest location of the tibial plateau (Figure 1: “3”). The center of the circle was the most proximal point of the longitudinal mechanical axis of the tibia (Figure 1: “D”). The center of the ankle joint was less straightforward to determine. Each observer drew a circle over the distal tibia and adjusted its radius so it would fit inside three cortices: the medial, lateral and tibial pla-
fond (Figure 1: “A”). The center of the circle (Figure 1: “C”) was on the mechanical axis that passed through the center of the talus (Figure 1: “B”).

The joint orientation line in the frontal plane was drawn across the flat subchondral line of the tibial plafond.16 Three medial distal tibial angles were measured: one ‘high’ (the angle between the joint orientation line and the mechanical axis of the tibia measured on entire lower leg views), one ‘middle’ and one ‘low’ (the angle between the joint orientation line and the mechanical axis measured distally in the tibia). The ‘high’ MDTA (Figure 2: “a”) was measured by finding the center of the tibial plateau (Figure 2: “A”), the center of the ankle (Figure 2: “B”), connecting the points by the tibial mechanical axis (Figure 2: “C”), and the joint orientation line (Figure 2: “D”).

As many ankle mortise views do not show the entire tibial shaft, we wanted to evaluate how far distally the MDTA could be reliably measured. Figure 3 illustrates how the ‘middle’ MDTA was measured. The mechanical axis of the tibia cannot be drawn while the plateau is not visible. Therefore a most proximal mid-diaphyseal point was chosen (Figure 3: “A”) and connected with a point in the center of the distal tibial metaphysis, which we considered to be the center of the ankle joint (Figure 3: “B”) (see also Figure 5). The MDTA (Figure 3: “a”) was the angle between the provisional tibial axis (Figure 3: “C”) and the joint orientation line (Figure 3: “D”). Figure 4 shows the ‘low’ MDTA. To mimic situations in which only a small mortise view of the ankle was available, a circle was drawn on top of the distal circle to determine the joint center. The circles touched each other and the cortices. The centers of both circles (Figure 4: “A” and “B”) were connected indicating the longitudinal tibial axis (Figure 4: “C”). The MDTA (Figure 4: “a”) was the angle between the tibial axis (Figure 4: “C”) and the joint orientation line (Figure 4: “D”).

Statistical analysis

A Kolmogorov-Smirnov normality test was used to determine if the data were consistent with the Gaussian distribution, using the Kolmogorov-Smirnov distance. As all data were normally distributed, the Student t-test and ANOVA-test were used to compare data in two and in more than two groups, respectively. A p value less than 0.05 was considered to be statistically significant. The intraobserver and interobserver reliability were determined by cal-
Figure 1: The center of the tibial plateau (1) is determined by drawing a circle (2) within the medial and lateral cortex (3). A second circle fits inside the distal tibia between the medial and lateral cortex (A) and touches the plafond distally. The mechanical axis (D) goes through both the center of the distal tibia and the center of the talus (C). The method of determination of the center of the distal tibia is an alternative to determination of the width of the talus because the rounded edges of the talar shoulders (B) might negatively affect the accuracy of that measurement method.
Figure 2: Alpha is the medial distal tibial angle between the joint orientation line (D) and the mechanical axis of the tibia (C). The mechanical axis goes through the proximal (A) and distal (B) joint center points.

Figure 3: Point A indicates the most proximal mid-diaphyseal point visible on this mortise view. Point B indicates the joint center. The MDTA (α) is the angle between the joint orientation line (D) and the longitudinal tibial axis (C).
Figure 4: As in Figure 3, point A indicates the proximal point chosen to determine the tibial axis. Point B indicates the joint center. The MDTA (α) is the angle between the joint orientation line (D) and the longitudinal tibial axis (C).

calculating the kappa values on the basis of multi-rater kappa. Multi-rater kappa summarizes the strength of agreement for all possible comparisons between the observers including the same and mixed types of experience levels.\(^{18}\) The kappa statistic was used as the chance-corrected measurement of agreement and was interpreted as perfect in range 0.81 to 1.00; as good in range 0.61 to 0.80; as moderate in range 0.41 to 0.60; as fair in range 0.21 to 0.40; and as poor in range 0.00 to 0.20 according to the benchmark definitions of Landis and Koch.\(^{11}\) Data were analyzed using SPSS version 9.0 and SigmaPlot 2004 for Windows.
Results

In our population, we found three significantly different mean values for the 'high', 'middle', and 'low' MDTAs of the ankle joint. In the ‘high’ view, the long leg view, the mean angle was 94.6 degrees with a standard deviation of 2.6 degrees and a range of 88.5 to 101.4 degrees. In the ‘middle’ view, the mean angle was 89.0 degrees with a standard deviation of 2.3 degrees and a range of 83.9 to 94.1 degrees. In the ‘low’ view, the mean angle was 92.1 degrees with a standard deviation of 2.2 degrees, ranging from 87.0 to 97.5 degrees.

The three means were significantly (p < 0.01) different from each other (Table 1). There was no difference between the means measured by the different observers as tested by ANOVA analysis (Table 2). There was also no difference seen between the MDTAs of men and women in our population (Table 3). There was, however, a significant difference between the left and right legs measured, justifying the assessment of 48 legs in 24 individuals (Table 4).

The mean difference between the measurements of the five observers was very small. In the ‘high’ MDTA, the measurement error was 0.60 degrees with a 95% CI of 0.52 to 0.68 degrees. In mortise views of the ankle, the ‘middle’ MDTA achieved an accuracy of 0.50 degrees with a 95% CI of 0.43 to 0.57. In the ‘low’ MDTA, the five observers measured within a mean of 0.60 degrees of each other with a 95% CI of 0.52 to 0.68 degrees (Table 5). The kappa values for each angle measured by the five observers are displayed in Tables 6 to 8. The ‘high’ measurements have an average kappa value of 0.85, the ‘middle’ measurements a kappa value of 0.84 and the ‘low’ measurements a kappa value of 0.83, all within the highest association range.

Discussion

The MDTA was not the same on whole lower leg images and mortise views of the ankle. Foot and ankle surgeons should take this into account when planning coronal deformity correction of the distal tibia, assessing placement of total ankle replacement tibia components and monitoring varus or valgus tilting after fractures. There was an excellent interobserver reliability for the angles measured. Our results show that there was a significant difference
between the MDTA as measured on whole lower leg images compared with the angle measured on standard mortise view images. The mean measurement difference between observers was less than 1 degree. Reliability of the measurements was good with a high association (= 0.85) between observers for the angles measured on the whole lower leg images and also a high association (= 0.83) between the observers for the mortise image measurements. Our results show that the measurement methods for ‘high’, ‘middle’, and ‘low’ MDTAs can be regarded as highly reliable. Further, the MDTA cannot be regarded as a single entity on radiographs taken of either the lower leg or the mortise view. The MDTA measured on ‘middle’ view images and entire lower leg images can be as much as 5 degrees in difference, which we consider clinically relevant. In measuring the MDTA the tibial plafond line appears to be the key factor in accuracy as the ‘middle’ and ‘low’ views have the lowest kappa and measurement error values. Ideally in alignment measurement, entire lower leg images should be obtained in which the knee and ankle joint are separately captured.

The current measurement method has resulted from descriptions found in the literature regarding determination of the center of the ankle joint and the mechanical axis of the tibia.\textsuperscript{7,10,13,16,17} Moreland et al. stated that the center of the ankle can be found by determining three points: the centers of the talus, malleoli and soft tissue just proximal to the level of the joint space (Figure 5).\textsuperscript{13} The mid-talar point is the most important to detect where the mechanical axis intersects the ankle joint.\textsuperscript{16} We sought the method that would be maximally restrictive and therefore have the best repeatability.

One weakness of our study is the limited number of subjects. While the 24 individuals do not represent a true spread of a population, the power analysis showed it can be seen as a sufficient sample. As there were significant differences in MDTAs between the left and right legs, the 24 individuals provided 48 unique extremities. Another weakness is the use of plain radiographs instead of CT imaging with 3D reconstruction to retrieve anatomical or mechanical axes. We are well aware of the possibilities of techniques that are currently being developed, but as long as these techniques are not available to the average foot and ankle surgeon, measurements will be based on conventional methods. Thus, the most common imaging modality, plain film radiography, was used in this study.

Plain-films of the lower extremity are commonly used to evaluate ma-
Table 1a: Mean values of the MDTA in HIGH-MIDDLE-LOW measurements

<table>
<thead>
<tr>
<th>t-test</th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
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<td>94.6°</td>
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<td>101.4°</td>
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<td>89.0°</td>
<td>2.3°</td>
<td>83.9°</td>
<td>94.1°</td>
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<tr>
<td>Low</td>
<td>92.1°</td>
<td>2.2°</td>
<td>87.0°</td>
<td>97.5°</td>
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</table>

p-value 0.001*

* highly significant with p<0.01

Table 1b: Mean MDTAs of all observers individually

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<td>B</td>
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<tr>
<td>C</td>
<td>93.9° ~ 2.5°</td>
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<tr>
<td>D</td>
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<td>E</td>
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p-value 0.274 0.856 0.686

Table 2a: differences between MDTAs of men and women

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Table 2b: differences between MDTAs in left and right sides

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* highly significant with p<0.01
Table 3: Measurement error between observers in degrees

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Table 4: Kappa for HIGH

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<td>0.78*</td>
<td>0.83**</td>
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<td>0.88**</td>
<td>0.89**</td>
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<tr>
<td>B</td>
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<tr>
<td>C</td>
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<td>0.86**</td>
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<tr>
<td>Average κ</td>
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* good association; ** high association

Table 5: Kappa for MIDDLE

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<tr>
<td>Average κ</td>
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* good association; ** high association

Table 6: Kappa for LOW

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<td>0.83**</td>
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<tr>
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<td>0.83**</td>
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<tr>
<td>B</td>
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<td>0.79*</td>
<td></td>
<td>0.78*</td>
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<tr>
<td>C</td>
<td></td>
<td></td>
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<td>0.82**</td>
</tr>
<tr>
<td>Average κ</td>
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</table>

* good association; ** high association
alignments in the coronal plane. Numerous linear and angular relationships around the ankle joint have been described in the literature.\textsuperscript{1,2,4,6,7,10,13,15–17,22,23} In the frontal plane, the MDTA or Tibia Articular Surface (TAS) angle has been described as 88 degrees,\textsuperscript{8} as 91 to 93 degrees,\textsuperscript{3} and 87.4 ± 2.7 degrees.\textsuperscript{4} The lateral distal tibial angle (LDTA), has a norm of 89 degrees ± 3 degrees.\textsuperscript{17,18} Since it has not always been reported in the literature, according to our measurements the MDTAs of other authors may have been based on ‘low’ mortise views of the ankle. We have found a mean value of 92.1 degrees with a SD of 2.2 degrees in our mortise views. In contrast, the entire lower leg images resulted in a mean of 94.6 ± 2.6 degrees, a larger angle than in any previous report.

In cases of foot or ankle deformity, it is important to determine alignment relative to the tibia.\textsuperscript{16,17} When long cassette images of the whole lower leg are made with the beam focused on the diaphysis of the tibia, X-rays pass
through the ankle joint under a certain angle depending on the distance of the radiation source. The outline of the tibial plafond will therefore be different in entire lower leg images as compared with those on mortise view images. This may be the explanation for the differences in mean angles we found. In our opinion, the ideal standard method would consist of acquisition two images of the lower leg: one focused on the knee joint, the other focused on the ankle joint, thus sending the X-rays “parallel” to the joint surfaces. Imaging software could reconstruct the tibia, providing correct joint surface angles of both the knee and ankle. This could make planning of correction osteotomies more accurate and consistent.

References

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CHAPTER 7

THE ROLE OF THE FIBULA IN DISTAL TIBIAL VARUS AND VALGUS

Published as:

Introduction

Valgus and varus malalignment of the ankle joint may be caused by trauma, neurological disorders, genetic predisposition and other unidentified factors, and result in asymmetrical joint loading.\cite{1-5} This may cause wear of the articular cartilage in areas that are normally accustomed to less loading. Osteoarthritis may also develop in the presence of ligamentous laxity and muscular imbalance.\cite{6} The nature of eccentric osteoarthritis of the ankle is not well understood, but, despite this, correction of angular deformities by supramalleolar and calcaneal osteotomies have become more popular.\cite{2,5,7-9} There is limited data about the biomechanical changes that occur after corrective osteotomy. Consequently, it is not currently possible to plan the precise level and degree of correction of an osteotomy, nor is it possible to accurately predict its outcome. The ankle joint has been the subject of many biomechanical studies, in which cadaver specimens have been modified to simulate pathological processes that affect the tibiotalar joint.\cite{10-14} Our study aimed to describe the effect of varus and valgus deformity of the distal tibia on the contact area and force transmission through the tibiotalar joint. We believe this to be of importance to our understanding of the predisposition of malalignment in the coronal plane to the development of osteoarthritis.

Materials and Methods

We used 17 fresh-frozen cadaveric lower legs; of which 11 were tested with an intact fibula (group A), and as a consequence of our findings in the remaining six we osteotomised the fibula directly above the level of the syndesmosis (group B). Before testing them, the limbs were thawed at room temperature for at least 24 hours. A normal range of movement in the ankle joint was established clinically, and malalignment was excluded radiologically. The specimens were prepared by disarticulation at the knee joint. The tibial epicondyles were removed with an oscillating saw and the medullary canal opened with a drill. A customised load transmitter with a stem in the tibial medullary canal was used to apply the axial load. The skin and subcutaneous tissues were removed down to the tarsus. The ankle ligaments and interosseous membra-
ne were preserved. Each leg was mounted into a load frame (Instron model 8872; Instron Corp., Canton, Massachusetts) to simulate a single-leg barefoot stance (Fig. 1). The foot was strapped to a friction plate with a band which only covered the forefoot. Cyclical loading of the limb was then performed 20 times with a load of 700 N. The preconditioning cycle was sufficient to absorb all plastic deformation of the lower leg.

Figure 1: The disarticulated lower leg mounted in an Instron actuator. The leg is free-standing, secured only by a forefoot strap and the pressure of the axial load.

Figure 2: The skin and muscles have been removed and the osteotomy fashioned. An Instron ankle sensor is carefully inserted to avoid wrinkles.
Pressure measurements were obtained using a TekScan 5033 ankle sensor (TekScan Inc., Boston, Massachusetts) calibrated according to the manufacturer’s guidelines. A custom-made calibration jig was mounted to the Instron actuator as previously described.\textsuperscript{15,16} The total matrix area of the ankle sensor is 1023 mm\(^2\) (46 by 32 sensels, 38.3 mm by 26.7 mm), which gives a spatial resolution of 0.695 mm\(^2\) per sensel. The sensor was gently placed into the tibiotalar joint space from the front. Special care was taken to prevent it wrinkling or folding (Fig. 2). The loading pattern consisted of a pre-load of 50 N maintained for five seconds, followed by a load increase up to 700 N within one second. The 700 N load was maintained for two seconds before decreasing to an after-load of 50 N.

Angular deformities of the distal tibia were created. In order to determine the height of the wedge (H) to be removed, the width of the distal tibia (W) was measured with a calliper at a point 10 mm above the anterolateral corner of the ankle mortice. The height of a 15° wedge to be removed was then calculated (H = \(\tan 15° \times W\)).\textsuperscript{17} A Kirschner (K−) wire was inserted approximately 15 mm above a line perpendicular to the tibial cortex, from medial to lateral so that it perforated the lateral cortex 10 mm above the joint line. A second K-wire was placed according to the calculation of the wedge height. In order to secure the lateral cortex of the tibia, a one-third tubular plate was placed on the lateral side, taking care not to interfere with the movement of the distal tibiofibular joint. The wedge was removed with an oscillating saw. Aluminium wedges of 5°, 10°, 15°, 20°, 25° and 30° were used to create the 5°, 10° and 15° of varus position, the neutral position, and 5°, 10° and 15° of valgus deformity in the supramalleolar area (Fig. 3 and Table I). The wedges were firmly secured using a custom-made device which prevented displacement of the wedge. After osteotomy, the specimen was placed back into the load frame and a baseline measurement was made with the 15° wedge in position. The specimen was tested at 700 N and the static pressure distributions recorded by computer.

Two K-wires were used to secure the TekScan pressure sensor to avoid displacing it. In order to ensure that it had not been displaced during testing, the collateral ligaments of the ankle joint were divided after the testing cycle and the position of the sensor confirmed before removing the fixation pins.

The order of the experiments was randomised prior to testing by
random wedge selection. Contact area, force transmitted and pressure were captured at 50 Hz for each measurement. The sensitivity of the sensors was set to ‘high-2’. When the sensitivity is set to ‘low’, greater pressures can be applied but the difference between the sensels needs to be higher in order to pick up details. Data analysis was performed with I-scan software version 3.75 (TekScan Inc.). The threshold sensitivity of the videos was set to 0.10 MPa in order to reduce interference of irregularities, such as pressure on the sensor outside of the joint area.

Figure 3: An aluminium wedge is inserted and held in place with a custom-made device. A third tubular plate is used to strengthen the lateral cortex of the tibia.

Table 1: Size of inserted wedges and corresponding resulting supramalleolar angles

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<th>Inserted Wedge</th>
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<th>Valgus Deformity</th>
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<tbody>
<tr>
<td>0°</td>
<td>15°</td>
<td></td>
</tr>
<tr>
<td>5°</td>
<td>10°</td>
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<tr>
<td>10°</td>
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<td>15°</td>
<td>0°</td>
<td>0°</td>
</tr>
<tr>
<td>20°</td>
<td></td>
<td>5°</td>
</tr>
<tr>
<td>25°</td>
<td></td>
<td>10°</td>
</tr>
<tr>
<td>30°</td>
<td></td>
<td>15°</td>
</tr>
</tbody>
</table>
Statistical analysis

A power analysis revealed that testing with six specimens resulted in sufficient power to detect a difference of one MPa with a SD of 0.8 and a significance level of 0.05: 11 specimens would provide a power of 98.6%, and six specimens a power of 86.5%, if two-sided testing were selected. Linear mixed model (LMM) analyses were performed to estimate mean change of the dependent variable (contact area, force transmitted, mean pressure and peak pressure) from the neutral position to 5°, 10° and 15° of valgus- or varus position as the main effect. The best fitting variance-covariance structure was assessed with the aid of the Akaike’s Information Criterion. \(18\) This is a measure of the relative goodness of fit of a statistical model. It can be said to describe the trade-off between accuracy and complexity of the model. Additionally, paired t-tests were performed to verify the significance of differences seen between the varus, valgus and neutral positions in group B. A p-value < 0.05 was considered to be statistically significant for all analyses.

Results

In each specimen three baseline measurements were made in group A before the distal tibial osteotomy, after the osteotomy of the tibia with the 15° wedge in situ, and after the series of experiments. No significant differences were found between the contact areas (mean difference 7.1 mm\(^2\), \(p = 0.86\)), forces (mean difference 17.9 N, \(p = 0.70\)) and pressures (mean difference 0.08 Mpa, \(p = 0.37\)) before and after the series of measurements.

One specimen in group A (female, 78 years old) accidentally sustained a fracture of the fibula at the level of the suprasyndesmotic fibular osteotomy and was included in group B for evaluation. The pronation-abduction fracture occurred during loading of an ankle with a valgus deformity of 15°.

In group A the baseline values before experimentation were: mean contact area 408 mm\(^2\) (SD 111.2), mean tibiotalar force 436 N (SD 101.7), mean pressure 1.22 MPa (SD 0.52) and mean peak pressure 2.59 MPa (SD 0.44). In group B the baseline values before experimentation were: mean contact area 535.2 mm\(^2\) (SD 113.5), mean tibiotalar force 498.7 N (SD 62.6),
mean pressure 0.91 MPa (SD 0.32) and mean peak pressure 2.00 MPa (SD 0.40).

**Valgus position group A**

In 5° of valgus of the distal tibia there was a mean reduction in contact area of 34 mm² (95% confidence interval (CI) 16 to 52). In 10° of valgus the mean reduction in contact area was 95 mm² (95% CI 58 to 132) and in 15° of valgus 147 mm² (95% CI 85 to 208) (Tables II and III, Fig. 4a). In 5° of valgus there was a mean reduction in tibiotalar force transmission of 46 N (95% CI 21 to 70), in 10° of valgus 92 N (95% CI 54 to 131), and in 15° of valgus 130 N (95% CI 83 to 177) (Tables II and III, Fig. 4b). However, with increasing valgus tilt the decreasing contact area remained on the anteromedial side of the tibiotalar joint (Fig. 5). We had anticipated that the calcaneum would shift laterally with the valgus position of the tibiotalar joint, and hence leading to lateral overload (Fig. 6).

Table 2: Estimated changes of each of the four parameters, per degree of valgus or varus produced in Group A (n = 11)

<table>
<thead>
<tr>
<th>per degree</th>
<th>Estimate</th>
<th>(95% CI**)</th>
<th>p †</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact area (mm²)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>valgus position</td>
<td>-9.78</td>
<td>(-12.83; -6.72)</td>
<td>0.00</td>
</tr>
<tr>
<td>varus position</td>
<td>1.07</td>
<td>(-1.94; 4.08)</td>
<td>0.48</td>
</tr>
<tr>
<td>Tibiotalar force (N)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>valgus position</td>
<td>-8.69</td>
<td>(-11.01; -6.36)</td>
<td>0.00</td>
</tr>
<tr>
<td>varus position</td>
<td>0.16</td>
<td>(-2.06; 2.38)</td>
<td>0.89</td>
</tr>
<tr>
<td>Mean pressure (MPa)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>valgus position</td>
<td>0.01</td>
<td>(0.00; 0.02)</td>
<td>0.01</td>
</tr>
<tr>
<td>varus position</td>
<td>0.00</td>
<td>(-0.01; 0.00)</td>
<td>0.18</td>
</tr>
<tr>
<td>Peak pressure (MPa)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>valgus position</td>
<td>0.02</td>
<td>(0.00; 0.03)</td>
<td>0.04</td>
</tr>
<tr>
<td>varus position</td>
<td>-0.01</td>
<td>(-0.02; 0.00)</td>
<td>0.17</td>
</tr>
</tbody>
</table>

* significant with p<0.05
** CI, confidence interval
† linear mixed-model analysis
Table 3: Changes observed in the mean contact area, tibiotalar force, mean and peak pressure compared with the neutral position, resulting from the supramalleolar deformities tested in Group A (n = 11)

<table>
<thead>
<tr>
<th></th>
<th>Contact area (mm²)</th>
<th>Tibiotalar force (N)</th>
<th>Mean pressure (MPa)</th>
<th>Peak pressure (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5° (% change)</td>
<td>10° (% change)</td>
<td>15° (% change)</td>
<td></td>
</tr>
<tr>
<td>Valgus</td>
<td>-34 (-8%)</td>
<td>-95 (-23%)</td>
<td>-147 (-36%)</td>
<td></td>
</tr>
<tr>
<td>Varus</td>
<td>32 (8%)</td>
<td>32 (8%)</td>
<td>16 (4%)</td>
<td></td>
</tr>
<tr>
<td>Valgus</td>
<td>-46 (-11%)</td>
<td>-92 (-21%)</td>
<td>-130 (-30%)</td>
<td></td>
</tr>
<tr>
<td>Varus</td>
<td>21 (5%)</td>
<td>19 (4%)</td>
<td>12 (0%)</td>
<td></td>
</tr>
<tr>
<td>Valgus</td>
<td>0,00 (0%)</td>
<td>0,08 (7%)</td>
<td>0,20 (16%)</td>
<td></td>
</tr>
<tr>
<td>Varus</td>
<td>0,02 (2%)</td>
<td>-0,05 (-4%)</td>
<td>0,06 (-5%)</td>
<td></td>
</tr>
<tr>
<td>Valgus</td>
<td>-0,05 (-2%)</td>
<td>0,17 (7%)</td>
<td>0,26 (10%)</td>
<td></td>
</tr>
<tr>
<td>Varus</td>
<td>-0,04 (-2%)</td>
<td>0,10 (4%)</td>
<td>-0,12 (-5%)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4: Box plots showing top left) contact area changes in group A resulting from the different varus and valgus positions, top right) tibiotalar force changes in group A resulting from the different varus and valgus positions, bottom left) mean pressure changes in group A resulting from the different varus and valgus positions and bottom right) peak pressure changes in group A resulting from the different varus and valgus positions. The transverse line represents the median, the box the lower and upper quartiles and the whiskers the 95% confidence intervals.
Figure 5: Three read-outs of the ankle sensor are projected over the talus with the talar head and neck pointing up and the medial side on the right. Warmer colours indicate higher pressures. In 15° varus without a fibular osteotomy there is a pressure shift in a posterolateral direction; in 15° valgus without a fibula osteotomy there is a pressure shift anteromedially.

Figure 6: Schematic drawings of the experiments as observed with and without the additional fibular osteotomy in valgus (group A, upper row) and varus (group B, lower row).
Table 4: Paired samples t-test showing the differences in means of each of the four main parameters, for the 15° varus and 15° valgus positions compared with the neutral position in cases with an added fibula osteotomy (group B, n = 6)

<table>
<thead>
<tr>
<th>Pairs</th>
<th>Mean difference (95%CI**)</th>
<th>% difference</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact area (mm²)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valgus 15 Neutral</td>
<td>-180.67 (-298.61; -62.72)</td>
<td>-34%</td>
<td>0.01 *</td>
</tr>
<tr>
<td>Varus 15 Neutral</td>
<td>-40.17 (-165.45; 85.12)</td>
<td>-7%</td>
<td>0.45</td>
</tr>
<tr>
<td>Tibiotalar force (N)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valgus 15 Neutral</td>
<td>-120.48 (-220.76; -20.21)</td>
<td>-24%</td>
<td>0.03 *</td>
</tr>
<tr>
<td>Varus 15 Neutral</td>
<td>-146.38 (-303.92; 11.15)</td>
<td>-29%</td>
<td>0.06</td>
</tr>
<tr>
<td>Mean pressure (MPa)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valgus 15 Neutral</td>
<td>0.02 (-0.34; 0.37)</td>
<td>2%</td>
<td>0.91</td>
</tr>
<tr>
<td>Varus 15 Neutral</td>
<td>0.05 (-0.41; 0.51)</td>
<td>6%</td>
<td>0.79</td>
</tr>
<tr>
<td>Peak pressure (MPa)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valgus 15 Neutral</td>
<td>0.42 (-0.64; -0.19)</td>
<td>21%</td>
<td>0.00 *</td>
</tr>
<tr>
<td>Varus 15 Neutral</td>
<td>0.05 (-0.22; 0.32)</td>
<td>3%</td>
<td>0.66</td>
</tr>
</tbody>
</table>

* significant with p<0.05)
** CI, confidence interval

Figure 7: Box plots showing top left) contact area changes in group B resulting from the 15° varus and valgus positions, top right) tibiotalar force changes in group B resulting from the 15° varus and valgus positions, bottom left) mean pressure changes in group B resulting from the 15° varus and valgus positions and bottom right) peak pressure changes in group B resulting from the 15° varus and valgus positions. The transverse line represents the median, the box the lower to upper quartiles and the whiskers the 95% confidence interval.
Valgus position group B

Only when a fibular osteotomy was added to 15° of distal valgus of the tibia was there a mean contact area reduction of 181 mm² (95% CI 62.72 to 298.61) with a shift to the posterolateral joint space. When a fibular osteotomy was added to a distal tibial deformity of 15° of valgus there was a mean reduction in tibiotalar force transmission of 120 N (95% CI 20.21 to 220.76) (Table IV, Figs 6, 7a and 7b).

Varus position group A

In 5° of varus there was a mean increase in contact area of 32 mm² (95% CI 3 to 62). The mean increases in 10° and 15° of varus were 32 mm² (95% CI −8 to 73; p = 0.15) and 16 mm² (95% CI −18 to 50; p = 0.37) respectively, but these differences were not statistically significant using paired t-tests. (Tables II and III, Fig. 4a). In 5° degrees of varus, there was a mean increase in tibiotalar force transmission of 21 N (95% CI 1 to 42). In 10° and 15° of varus, the mean increases were 19 N (95% CI −5 to 43; p = 0.15) and 2 N (95% CI −25 to 30; p = 0.87) respectively, but these differences were not statistically significant, using paired t-tests (Tables II and III, Fig. 4b). As found with valgus deformity, as varus tilting of the tibiotalar joint increased, the decreasing contact area remained unexpectedly on the posterolateral side of the tibiotalar joint (Fig. 5). We had expected the entire hindfoot, which was not immobilised, to adopt a varus position and produce anteromedial overload (Fig. 6).

Varus position group B

When a fibular osteotomy was added to a distal tibial deformity of 15° of varus there was a non-significant decrease in mean contact area of 40 mm² (95% CI −85.12 to 165.45; p = 0.45, paired t-test). When a fibular osteotomy was added to a distal tibial deformity of 15° of varus there was a non-significant decrease in the mean tibiotalar force transmission of 146 N (95% CI −11.15 to 303.92; p = 0.06, paired t-test) (Table IV and Fig. 7). Again, only when the fibular osteotomy was added was there a shift in loading anteromedially (Fig. 6).
Discussion

Both varus and valgus deformity of the distal tibia caused significant changes in the contact area of the tibiotalar joint. There was a mean reduction in contact area of up to 36% in 15° of tibial valgus, a mean increase in contact area of approximately 8% in 15° of tibial varus and a mean reduction in tibiotalar force transmission of up to 30% in 15° valgus. There was a mean increase in tibiotalar force transmission of about 5% with the ankle in 15° of varus. However, a mean decrease of 29% in tibiotalar force transmission was seen with 15° of varus deformity in combination with a fibular osteotomy, probably because the medial tilting of the talus directed the vector of force through the medial malleolus which was outside the area of our sensor.

The second significant finding was of paradoxical pressure distribution after supramalleolar tibial osteotomy when the fibula was left intact. With distal tibial varus we found lateral pressure overload. Only when the fibula was divided did the hindfoot adopt a varus position and the pressure shift medially. An identical phenomenon was seen with supramalleolar valgus (Fig. 6).

We reviewed the literature about contact area and pressure in the normal ankle joint, changes due to altered foot position, fibular malreduction, and angular deformities of the tibia. It has been shown that rotational deformities result in a significant decrease in the contact area and an increase in peak pressures. Tarr et al noted that the more distal the angular deformity of the tibia the greater the changes in the contact area in the ankle joint. The contact area of the ankle can decrease by up to 30% when the distal fibula is divided and translated by 1 mm to 2 mm. By manipulating the distal fibula into a varus or valgus position by 1°, the contact area is reduced by more than 50%: with 1 mm of lateral displacement of the talus the contact area is reduced by 42%. Displacement or shortening of the fibula by 2 mm or more, or lateral rotation of 5° or more, significantly increases the contact pressure across the ankle joint. Changes in the distal fibula play an important role in determining the contact areas and pressure distribution at the ankle. Our data show that the effect of the fibula on the characteristics of the tibiotalar joint is more marked with valgus deformity than with varus.

Ting et al showed that the tibiotalar contact area decreases significantly when subtalar motion is restricted by fixing the subtalar joint. Osteo-
tomies of the hindfoot not only affect the tibiotalar but also the subtalar joint. Subtalar joint compensation occurs particularly in a valgus ankle, as inversion has been shown to be greater (25°, SD 4) than eversion (15°, SD 6) in a three-dimensional CT study.

Hayashi et al, using a spring model, showed that the complex varus inclinations of the ankle and subtalar joint, but not the independent varus inclination of the ankle alone, cause medial stress concentration in the ankle. They concluded that the crucial factor was the varus inclination of the subtalar joint. The subtalar joint might be able to compensate for distal tibial varus with a progressive valgus inclination up to a certain point, but after this it tilts into varus, thereby drastically shifting the tibiotalar pressure distribution medially. Additional fibular deformity or ligamentous instability must therefore contribute to the progression of osteoarthritis of the ankle in patients with distal deformity of the tibia, especially where there is chronic lateral instability and varus deformity.

We observed this combined tibiotalar and subtalar tilting only after additional fibular osteotomy. The lateral ligamentous instability, however, was not tested in our set-up: the lack of monitoring of the subtalar joint may be a potential source of bias and is a weakness of our study. The strength of our study is that we used the limbs from through-knee amputees with an intact tibio-fibular complex as have been used elsewhere. We chose to apply pressure to the tibial plateau to ensure physiological loading of the fibula. Additionally, direct intra-articular measurements were performed using a high resolution sensor. We used the approximated equivalent of one full body weight to load the ankle, although the peak load through the ankle joint can be almost four times body weight during walking. In our study, the deltoid ligament was not divided, to allow talar lateral shift as had been done in previous studies, nor had it ruptured – therefore the changes in contact area and pressure were solely the result of the supramalleolar osteotomies. We also simulated natural barefoot standing to allow the foot to adjust to a neutral ground-force situation.

We recognise the limitations of using a static cadaver model. Dynamic muscle forces were not assessed which may therefore limit the interpretability of our results. This is a potential source of bias as osteotomies around the ankle joint change the mechanical axes. Additionally, cartilage deformation may have occurred during repeated loading. During weight-bearing, about
42.4% of the contact area has a contact strain higher than 15%. Cartilage may undergo considerable deformation under normal loading conditions. We tried to compensate for this by randomising the order of the experiments. Finally, this was an in vitro study with different legs which differed in age and gender.

In conclusion, we examined the effect of supramalleolar varus and valgus malalignment on various characteristics of the tibiotalar joint. We had assumed that a supramalleolar varus osteotomy would cause medial overloading of the tibiotalar joint and supramalleolar valgus would lead to lateral shift. The opposite was observed. The restricting role of the fibula was revealed by performing an osteotomy directly above the syndesmosis: only when this additional osteotomy was made did the expected changes in loading occur. Furthermore, the findings of the present study support the belief that supramalleolar osteotomies are justified, since significant tibiotalar pressure changes occur with distal tibial varus and valgus malalignment.

References

CHAPTER 8

THE ROLE OF DISTAL TIBIAL VARUS AND VALGUS ON ANKLE JOINT PRESSURES

Published as:
CHAPTER 8 - VARUS AND VALGUS, PRESSURE DISTRIBUTION

Introduction

Malalignment of the hindfoot has been found to be one of the main risk factors for osteoarthritis (OA) of the ankle joint. Earlier reports described excessive cartilage wear particularly in the presence of associated ligamentous instability and muscular imbalance. It has been suggested that asymmetric OA with frontal plane deformity can be addressed with realignment surgery. However, no biomechanical data on the effect of supramalleolar osteotomies has been published and clinical data on the outcome of this procedure is sparse. Therefore recommendations for the treatment of asymmetric osteoarthritis remain arbitrary.

To get a more deeper understanding of the nature of supramalleolar deformities, we sought to characterize and quantify the effect of distal tibial malalignment on the intra-articular changes of pressure and force transmission in the ankle joint. In this cadaveric study, we introduced the concept that two types of supramalleolar deformities should be recognized: an isolated frontal plane deformity with preserved joint congruency and a frontal plane deformity in combination with impaired congruency of the ankle joint.

Materials and methods

We assessed the intra-articular pressure distribution in the ankle joint for various supramalleolar varus and valgus deformities. In a first Group A, 11 specimens (mean specimen age 67 (range, 62 to 86) years; eight male, three female) were placed in a loading apparatus, deformities created and the intra-articular pressure changes recorded. To exclude a bias resulting from the offset of the calcaneal tuberosity due to the supramalleolar deformity (Figure 1) the experiments were carried out twice: once with the position of the calcaneus fixed on the base plate (Figure 1B) and once with the calcaneus displaced medially or laterally according to the degree of the created deformity in the supramalleolar area (displacement x = sin (a) × H; x: offset, a: angle of deformity, H: Height of the osteotomy). Because of the unexpected results in this setup, a third set of measurements was analyzed (Group B). In these six additional specimens (mean specimen age 68 (range, 57 to 86) years; five
male, one female) an additional osteotomy of the fibula above the syndesmosis was performed to mimic incongruency within the ankle mortise.

Prior to testing, all limbs were allowed to thaw at room temperature for at least 24 hours. Bony malalignment was excluded radiologically and a normal range of motion in the ankle joint verified clinically. The specimens were prepared by disarticulation at the level of the knee joint, paying attention not to damage the proximal tibio-fibular joint. The tibial plateau was then flattened using an oscillating saw. The skin and subcutaneous tissue were removed and the ligaments, the interosseous membrane and capsules preserved.

For both Groups A and B, angular deformities of up to 15 degrees varus and valgus were created with a custom-designed plate-wedge (Figure 2). These are the maximum deformities that are considered for supramalleolar correction in clinical studies. 11 To achieve this deformity a wedge of bone that resulted in a deformity of 15 degrees varus was removed from the supramalleolar area after having secured the lateral cortex with a 1/3 tubular plate anterolaterally. Subsequently, aluminium wedges of 5 degrees, 10 degrees, 15 degrees, 20 degrees, 25 degrees, and 30 degrees were used to create deformities from 15 degrees varus to 15 degrees valgus. In Group B, where an osteotomy of the fibula was performed, only three conditions were compared: neutral, 15 degrees valgus and 15 degrees varus. The order in which the deformities were created was randomized prior to testing. The fibula osteotomy in Group B was carried out with an oscillating saw in an oblique direction: from distally anterior to proximally posterior, starting proximal to the syndesmosis. The direction of the cut allowed unrestricted shortening of the fibula in valgus deformities. Before the first and after the last test, neutral alignment was restored with a 15-degree wedge and the results compared.

Pressure measurements were taken using Tekscan 5033 pressure sensors (TekScan Inc., South Boston, MA). Anterior and posterior ankle arthrotomies were performed in order to introduce the sensors. The system consisted of a thin, flexible pressure sensor (0.10 mm) that output data to proprietary Tekscan software via a scanning handle. The sensors were two-point calibrated to a load of 700 N according to the manufacturer’s instructions, using a specially fabricated calibration jig mounted onto the testing device similar to that used by other authors. 3, 27 The sensitivity of the sensors was set to ‘high-2’. The measurements were processed with I-scan© software version
3.75. The threshold sensitivity was set to 0.10 MPa in order to reduce interference of irregularities. The software presented an x-y coordinate grid on the sensor. Using the ‘center of force’ tool and the ‘peak pressure’ tool, the location was measured for each of the two parameters on the sensor for every varus or valgus deformity in all specimens. The total matrix area was 1023 mm$^2$ (46 × 32 sensels, 38.3 mm × 26.7 mm), resulting in a spatial resolution of 0.695 mm$^2$ per sensel.

Each leg was mounted onto a load frame (Instron model 8872, Instron Corp., Canton, MA) to simulate single-leg stance (Figure 2). The load transmitter on the tibial side consisted of an intramedullary stem which was attached to a plate. The plate had a small cavity which served as a receiver for the spherical male die part of the loading apparatus. This allowed for free axial rotation and angulation of the tibia during the loading process. Vertical alignment was adjusted with a pendulum which was attached to the loading apparatus. The ankle was plantarflexed to expose the talar dome and the tip of the pendulum centered over the talar dome. To avoid displacement of the Tekscan pressure sensors, two pins were used to secure the sensor onto the talar dome (one anterior at the talar neck and one posterior above the subtalar joint).

The limbs were preconditioned by cyclic loading (20 times with a load of 700 N). Thereafter the deformities were created and static axial compression was applied, starting from 50 N preload to 700 N. Maximal load was then held for two seconds prior to complete unloading. Center of force transmission and peak pressure were captured at 50 Hz. The shift of mean peak pressure and center of force were calculated in relation to the neutral position.

Statistical analysis

Repeated measures analysis of variance (Friedman two-way ANOVA for ranks) was performed for all parameters to assess differences between the groups. The Wilcoxon test was used for pairwise comparisons. The level of statistical significance was $p = 0.05$. A power analysis revealed that testing with six specimens resulted in sufficient power to detect a difference of one megapascal with a standard deviation of 0.8 and a significance level of 0.05; eleven specimens resulted in a power of 98.6%, and six specimens resulted in a power of 86.5%, when two-sided testing was selected.
Figure 1: Illustration of a normally aligned ankle (a), an ankle with a supramalleolar valgus deformity with a fixed heel (b) and the setup after a compensatory translation (x) of the calcaneal tuberosity (c).

Figure 2: Test set-up. Wedges of different sizes were used to simulate various degrees of angular deformity in the supramalleolar area: 1) cadaveric leg, stripped of soft tissue, 2) custom plate with a stem attached which inserted into the tibial marrow cavity for axial loading, 3) Instron actuator.
Results

One specimen (female, 78 years old) was excluded from the study after a fracture of the fibula occurred during loading of the ankle with a deformity of 15 degrees valgus. Compensatory medial/lateral translation of the calcaneal tuberosity did not change the intra-articular measurements. The presented results represent the non-translated configuration.

Group A

Intact fibula (n = 11). Supramalleolar varus deformity in this group led to a posterolateral shift of the center of force and peak pressure. Valgus deformities showed a shift of both parameters in an anteromedial direction. Changes occurred concurrently with increasing deformity (Figure 3). Significant changes were mainly found in the valgus group (p < 0.05) whereas the varus group showed only tendencies (Table 1).

Group B

Osteotomized fibula (n = 6). The shift of the center of force and peak pressure in this group was in an anteromedial direction for varus deformities and posterolateral direction for valgus deformities (Figure 4). With the exception of the anterior transfer in the varus deformities, all changes were statistically significant (p < 0.05) (Table 2). The mean control measurement on return to 0 degrees showed no significant change for the shift of mean peak pressure and for the shift of center of force in both groups (Wilcoxon test, p > 0.05). The largest deviation was found for the mean peak pressure in Group A (anterior shift, mean 0.8 mm).
CHAPTER 8 - VARUS AND VALGUS, PRESSURE DISTRIBUTION

Figure 3: Illustration of the shift of the center of force and mean pressure for the specimens without a fibular osteotomy. Illustration of the different deformities form 15 degrees varus to 15 degrees valgus, including the standard error of the mean. mm, millimeter.

Figure 4: Illustration of the shift of the center of force and mean pressure for the specimens with a fibular osteotomy. Illustration of the measures for 15 degrees varus, neutral and 15 degrees valgus, including the standard error of the mean. mm, millimeter.
### Table 1a: Supramalleolar Valgus with Intact Fibula (n = 11)

<table>
<thead>
<tr>
<th></th>
<th>5°</th>
<th>10°</th>
<th>15°</th>
<th>Sig.</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>95% CI</td>
<td>mean</td>
<td>95% CI</td>
<td>mean</td>
</tr>
<tr>
<td>Center of force shift to anterior [mm]</td>
<td>0.63*</td>
<td>0.25 - 1.01</td>
<td>1.64*</td>
<td>1.00 - 2.26</td>
<td>2.78*</td>
</tr>
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<td>Center of force shift to medial [mm]</td>
<td>0.67</td>
<td>-0.07 - 1.42</td>
<td>1.55*</td>
<td>0.06 - 3.04</td>
<td>1.84*</td>
</tr>
<tr>
<td>Peak pressure shift to anterior [mm]</td>
<td>3.34</td>
<td>-0.40 - 7.08</td>
<td>4.95*</td>
<td>0.70 - 9.21</td>
<td>6.85*</td>
</tr>
<tr>
<td>Peak pressure shift to medial [mm]</td>
<td>2.31</td>
<td>0.22 - 4.40</td>
<td>3.94*</td>
<td>1.10 - 6.78</td>
<td>5.09*</td>
</tr>
</tbody>
</table>

* significant compared to neutral position; ** significant changes between the different groups; mm, millimeters; CI, confidence interval. p < 0.05.

### Table 1b: Supramalleolar Varus with Intact Fibula (n = 11)

<table>
<thead>
<tr>
<th></th>
<th>5°</th>
<th>10°</th>
<th>15°</th>
<th>Sig.</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>95% CI</td>
<td>mean</td>
<td>95% CI</td>
<td>mean</td>
</tr>
<tr>
<td>Center of force shift to anterior [mm]</td>
<td>0.43</td>
<td>-0.08 - 0.95</td>
<td>0.54</td>
<td>-0.13 - 1.20</td>
<td>0.63*</td>
</tr>
<tr>
<td>Center of force shift to lateral [mm]</td>
<td>0.33</td>
<td>-0.16 - 0.81</td>
<td>1.07</td>
<td>-0.47 - 2.61</td>
<td>0.65</td>
</tr>
<tr>
<td>Peak pressure shift to anterior [mm]</td>
<td>0.14</td>
<td>-0.26 - 0.54</td>
<td>0.21</td>
<td>-0.59 - 1.01</td>
<td>0.9</td>
</tr>
<tr>
<td>Peak pressure shift to lateral [mm]</td>
<td>0.61</td>
<td>-0.02 - 1.24</td>
<td>0.90</td>
<td>-0.01 - 1.81</td>
<td>0.29</td>
</tr>
</tbody>
</table>

* significant compared to neutral position; ** significant changes between the different groups; mm, millimeters; CI, confidence interval. p < 0.05.

### Table 2a: Supramalleolar Valgus - Osteotomized Fibula (n = 11)

<table>
<thead>
<tr>
<th></th>
<th>15° - fib#</th>
<th>mean</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center of force shift to posterior [mm]</td>
<td>1.98*</td>
<td>0.93 - 3.04</td>
<td></td>
</tr>
<tr>
<td>Center of force shift to lateral [mm]</td>
<td>2.1*</td>
<td>1.16 - 3.04</td>
<td></td>
</tr>
<tr>
<td>Peak pressure shift to posterior [mm]</td>
<td>6.72*</td>
<td>0.78 - 12.65</td>
<td></td>
</tr>
<tr>
<td>Peak pressure shift to lateral [mm]</td>
<td>2.43*</td>
<td>1.24 - 3.63</td>
<td></td>
</tr>
</tbody>
</table>

* significant compared to neutral position; CI, confidence interval. p < 0.05.

### Table 2b: Supramalleolar Varus - Osteotomized Fibula (n = 11)

<table>
<thead>
<tr>
<th></th>
<th>15° - fib#</th>
<th>mean</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center of force shift to anterior [mm]</td>
<td>1.58*</td>
<td>1.14 - 2.03</td>
<td></td>
</tr>
<tr>
<td>Center of force shift to medial [mm]</td>
<td>1.6*</td>
<td>0.47 - 2.73</td>
<td></td>
</tr>
<tr>
<td>Peak pressure shift to anterior [mm]</td>
<td>3.13</td>
<td>-2.87 - 9.14</td>
<td></td>
</tr>
<tr>
<td>Peak pressure shift to medial [mm]</td>
<td>3.52*</td>
<td>0.80 - 6.23</td>
<td></td>
</tr>
</tbody>
</table>

* significant compared to neutral position; CI, confidence interval. p < 0.05.
Discussion

In order to get a deeper understanding of the biomechanical changes in the ankle joint of a malaligned hindfoot, we performed a cadaveric study simulating various degrees of varus and valgus deformities. Two groups of specimens were assessed: isolated supramalleolar deformities and deformities in combination with incongruency of the ankle mortise. In both groups the changes of the center of force and pressure within the ankle joint were analyzed.

Earlier in vitro studies of load transfer across the tibio-talar joint focused on the effect of a calcaneal displacement osteotomy \(^{2,6,10,15}\) cavovarus deformity, \(^{9}\) flatfoot deformity \(^{4,6}\) tibiotalar incongruence \(^{13,23,26}\) tibial malrotation, \(^{18}\) and tibial deformities on different heights of the tibia. \(^{21}\) The present study is, to the best of our knowledge, the first quantitative analysis of intra-articular pressure distribution with a supramalleolar deformity.

Corrective osteotomies in the supramalleolar area aim to unload the medial compartment in varus deformities and the lateral compartment in valgus deformities. \(^{1,11,14,19,20}\) Our model, however, did not suggest that a supramalleolar varus deformity inevitably leads to a medial overload or that a valgus deformity inevitably leads to lateral overload. We found that an isolated change of the distal tibial articular surface angle lead to a paradox shift of the center of force and peak pressure in an anteromedial direction in valgus deformities and in a posterolateral direction in varus deformities. In a second group, an osteotomy of the fibula was added to the frontal plane deformity in order to exclude the fibula and to simulate incongruency of the ankle joint. In this group we found an anteromedial transfer in varus deformities and a posterolateral shift in valgus deformities. These findings are in accordance with earlier observations in cavovarus feet \(^{9}\) and in planovalgus deformities. \(^{4}\)

We believe that the unexpected shift in Group A was due to a tension band effect of the collateral ligaments of the ankle (Figure 5). Secondly, the fibula may restrict the adjustment of the talus within the ankle mortise. This hypothesis is supported by earlier reports that analyzed the etiology and the nature of hindfoot malalignment \(^{4,9,17}\) and the development of asymmetric ankle joint osteoarthritis. \(^{5,16}\)

Based on these findings, we suggest that in congruent joints, e. g.,
joints with maintained interosseous ligament complex and collateral ligaments, an isolated correction of the distal tibial joint surface angle may not re-establish a physiological load pattern in the tibiotalar joint. In these patients the ligaments and the fibula may prevent the normalization of the tibiotalar load transfer. Balancing these joints may require additional procedures such as ligament balancing and / or an osteotomy of the fibula (‘osseous balancing’ of the joint). This may also be the case in large deformities where the fibula may hinder the talus from following the tibial articular surface. In the second group, probably the majority of clinical cases, the frontal plane deformity is associated with an unstable or incongruent ankle mortise. Clinically, this would characteristically be the case in a longstanding deformity, with or without arthritic changes, including the collateral ligaments and the interosseous ligament complex. Data from this study leads us to suggest that an isolated correction of the distal tibial joint angle without addressing the fibula may be the main step in these cases to normalize the force/pressure distribution in the tibiotalar joint.

Earlier biomechanical studies on frontal plane deformities focused on intra-articular changes which occurred in a medio-lateral direction. Davitt et al. found that the center of force moved about 1.5 mm medially in a medial displacement osteotomy of 1 cm, and Steffensmeier et al. found a 1 mm lateral shift in a lateral displacement osteotomy. We observed that the intra-articular changes did not only occur in a medio-lateral but also in an antero-posterior direction. A varus deformity of 15 degrees in the supramalleolar area led to a shift of 1.6 mm anteriorly and 1.6 mm medially. A valgus deformity of 15 degrees led to a shift of 2.0 mm posteriorly and 2.1 mm laterally. These studies emphasize that many deformities associated with asymmetric osteoarthritis of the ankle may have an underlying multiplanar pathology, i.e., not an isolated frontal plane deformity.

The strength of the study is that we used through-knee amputations which maintained the entire tibio-fibular complex intact. Additionally, direct intra-articular measurements were performed. Limitations include that this was a cadaveric, biostatic model. Dynamic forces from the muscles and soft tissue were not included. The heelcord may especially play a significant role in intra-articular load distribution in varus or valgus hindfoot deformities. Furthermore, load transfer via the medial and lateral gutter was not captured.
Especially in valgus deformities, the fibula may take part in the load transfer. Finally, the effect of the subtalar joint remains unclear in supramalleolar deformities. An earlier study described the effect of varus deformity on the subtalar joint and showed that valgus inclination of the subtalar joint progressed linearly with increasing varus deformity of the tibiotalar joint until the intermediate stage and converted to varus position at the later stage. In our pilot study we observed a concurrent shift of the center of pressure and force with increasing deformity and therefore abandoned the initial setup of subtalar joint fixation.

Figure 5: Tension band effect of the lateral collateral ligaments in varus malalignment (A) and restriction of the adjustment of the talus within the mortise by the fibula / interosseous ligament complex in valgus malalignment (B).
CHAPTER 8 - VARUS AND VALGUS, PRESSURE DISTRIBUTION

Conclusion

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 with 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 single frontal plane deformity. The changes of load distribution / force transfer across the ankle joint occur in a biplanar pattern and not only in a medio-lateral direction.

References

7. Hayashi, K; Tanaka, Y; Kumai, T; Sugimoto, K; Takakura, Y: Correlation of compensatory alignment of the subtalar joint to the progression of primary osteoarthritis of the ankle. Foot Ankle Int. 29(4):400 – 406, 2008.


PART V
GENERAL DISCUSSION,
CONCLUSIONS AND SUMMARY
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.\(^1,2\) Reports on the long-term outcome address primarily the development of posttraumatic osteoarthritis.\(^3,4\) 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.\(^5,7\) 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.\(^8\) 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.\(^9,10\) 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.\(^11\) 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.\(^12\) 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,\(^13\) 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.\(^14-22\) Marginal osteophytes were first described as an early sign of osteoarthritis of the knee joint by Kellgren and Lawrence in 1957.\(^9\) This appears to be the most sensitive radiographic sign of articular cartilage degeneration within the knee joint.\(^23\) Many radiographical classifications have been developed over the past decades. For the ankle, for example, the Kannus\(^24\) the Takakura\(^25-27\) and the van Dijk\(^28\) 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. 37 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
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 misdiagnosed 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 reconstruction 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,\textsuperscript{53} persisting ligamentous instability,\textsuperscript{73} the development of arthrofibrosis\textsuperscript{74} and open fractures.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{81} Osteochondral lesions, either avascular or traumatic in origin, eventually progress into ankle osteoarthritis.\textsuperscript{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.\textsuperscript{84;85}

Furthermore the alignment of the hindfoot in the coronal plane is known to play a role in knee fractures.\textsuperscript{86} In ankle osteoarthritis more than half of the patients have varus or valgus malalignment.\textsuperscript{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.\textsuperscript{55} Also the influence of medializing and lateralizing calcaneus osteotomies has been studied in vitro.\textsuperscript{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.\textsuperscript{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 osteoarthrits. 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. 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 (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 traumata 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, 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.

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. 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.\textsuperscript{98} 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.\textsuperscript{99} 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.\textsuperscript{100} 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.\textsuperscript{101} 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 capabi-
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 malleolus 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 syndesmosis without medial injury conservative treatment is a valid option. Pre-existing deltoid insufficiency has not been taken into account in decision making about ankle fracture stability. Theoretically a lax deltoid ligament is mechanically 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 displacement 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 receive 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 malalignment and asymmetrical osteoarthritis of the ankle joint. For pre-operative 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}

**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


CHAPTER 10

SUMMARY AND SAMENVATTING
In chapter 1 a general introduction on ankle anatomy, ankle fractures and ankle fracture classifications is given, as well as an overview of the development of ankle fracture treatment, current results of ankle fracture treatment. The aim and outline of this thesis is presented.

In chapter 2 a review of the literature is presented. The aim of this literature review is to systematically gather the highest level of available evidence on the long-term outcome after operatively treated ankle fractures in the English, German and Dutch literature. A search term with Boolean operators was constructed. The search was limited to humans and adults and the major databases were searched from 1966 to 2008 to identify studies relating to functional outcome, subjective outcome and radiographic evaluation at least 4 years after an operatively treated ankle fracture. Of the 42 initially relevant papers, 18 met our inclusion criteria. A total of 1822 fractures were identified. The mean sample-size weighted follow-up was 5.1 years. The initial number of patients that were included in the studies was 2724, which results in a long-term follow-up success rate of 66.9%. Regarding the fracture reduction we found 4 papers reporting on 106 fractures. Of the fractures that were classified according to Danis–Weber, 736 were eligible for correlation with the long-term outcome. In 442 fractures a comparison was possible between supination–external rotation stage 2 and 4 of the Lauge-Hansen classification. Only one study reported on the influence of initial cartilage lesions on the outcome. Regarding the involvement of the posterior malleolus, two studies reported on the long-term outcome. None of the studies addressed the influence of hindfoot varus or valgus on the long-term outcome after ankle fracture. Only 79.3% of the optimally reduced fractures show good to excellent long-term outcome. The Weber A type fractures do not show a better long-term outcome than Weber B type fractures. Recommendations for future research were formulated.

In chapter 3 the role of the initial cartilage lesions accompanying ankle fractures is described. The role of the location and severity of the initial cartilage lesions associated with an ankle fracture in the development of posttraumatic osteoarthritis has not been established, to our knowledge. We performed a long-term follow-up study of a consecutive, prospectively included cohort
of 288 ankle fractures that were treated operatively between June 1993 and November 1997. Arthroscopy had been performed in all cases in order to classify the extent and location of cartilage damage. One hundred and nine patients (47%) were available for follow-up after a mean of 12.9 years. The main outcome parameters were the American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot score for clinical evaluation and a modified Knaposttraumatic osteoarthritis score for radiographic assessment of the development of posttraumatic osteoarthritis. Cartilage damage anywhere in the ankle joint was associated with a suboptimal clinical outcome (odds ratio, 5.0 [95% confidence interval = 1.3 to 20.1]; p = 0.02) and with a suboptimal radiographic outcome (odds ratio = 3.4 [95% confidence interval = 1.0 to 11.2]; p = 0.04). An association was also found between the development of clinical signs of osteoarthritis and a deep lesion (>50% of the cartilage thickness) on the anterior aspect of the talus (odds ratio = 12.3 [95% confidence interval = 1.4 to 108.0]; p = 0.02) and a deep lesion on the lateral aspect of the talus (odds ratio = 5.4 [95% confidence interval = 1.2 to 23.5]; p = 0.02). A deep lesion on the medial malleolus was associated with the development of clinical signs of osteoarthritis (odds ratio = 5.2 [95% confidence interval = 1.9 to 14.6]; p < 0.01) and radiographic signs of osteoarthritis (odds ratio = 2.9 [95% confidence interval = 1.1 to 7.9]; p = 0.03) of osteoarthritis. There was no significant correlation between cartilage lesions on the fibula and the long-term outcome. Our findings show that initial cartilage damage seen arthroscopically following an ankle fracture is an independent predictor of the development of posttraumatic osteoarthritis. Specifically, lesions on the anterior and lateral aspects of the talus and on the medial malleolus correlate with an unfavorable clinical outcome.

In chapter 4 an overview of the diagnosis and treatment of deltoid ligament lesions is given. The supination–external rotation or Weber B type fracture exists as a stable and an unstable type. The unstable type has a medial malleolus fracture or deltoid ligament lesion in addition to a fibular fracture. The consensus is the unstable type and best treated by open reduction and internal fixation. The diagnostic process for a medial ligament lesion has been well investigated but there is no consensus as to the best method of assessment. The number of deltoid ruptures as a result of an external rotation mechanism
is higher than previously believed. The derivation of the injury mechanism could provide information of the likely ligamentous lesion in several fracture patterns. The use of the Lauge-Hansen classification system in the assessment of the initial X-ray images can be helpful in predicting the involvement of the deltoid ligament but the reliability in terms of sensitivity and specificity is unknown. Clinical examination, stress radiography, magnetic resonance imaging, arthroscopy, and ultrasonography have been used to investigate medial collateral integrity in cases of ankle fractures. None of these has shown to possess the combination of being cost-effective, reliable and easy to use; currently gravity stress radiography is favoured and, in cases of doubt, arthroscopy could be of value. There is a disagreement as to the benefit of repair by suture of the deltoid ligament in cases of an acute rupture in combination with a lateral malleolar fracture. There is no evidence found for suturing but exploration is thought to be beneficial in case of interposition of medial structures.

In chapter 5 the comparison is made of the results at a mean follow-up of 13 years (11 to 14) of two groups of supination-external rotation type-4 fractures of the ankle, in one of which there was a fracture of the medial malleolus and in the other the medial deltoid ligament had been partially or completely ruptured. Of 66 patients treated operatively between 1993 and 1997, 36 were available for follow-up. Arthroscopy had been performed in all patients pre-operatively to assess the extent of the intra-articular lesions. The American Orthopaedic Foot and Ankle Society hind-foot score was used for clinical evaluation and showed a significant difference in both the total and the functional scores ($p < 0.05$), but not in those for pain or alignment, in favour of the group with a damaged deltoid ligament ($p < 0.05$). The only significant difference between the groups on the short-form 36 quality-of-life score was for bodily pain, again in favour of the group with a damaged deltoid ligament. There was no significant difference between the groups in the subjective visual analogue scores or in the modified Kannus radiological score. Arthroscopically, there was a significant difference with an increased risk of loose bodies in the group with an intact deltoid ligament ($p < 0.005$), although there was no significant increased risk of deep cartilage lesions in the two groups. At a mean follow-up of 13 years after operative treatment of a supination-external rotation type-4 ankle fracture patients with partial or complete rupture of the
medial deltoid ligament tended to have a better result than those with a medial malleolar fracture.

In chapter 6 a description is given of the difference between the medial distal tibial angle (MDTA) when measured on whole lower limb radiographs and mortise radiographs of the ankle. A total of 48 legs were included of 24 healthy volunteers. Standard radiographs were obtained of the whole lower leg. Mortise radiographs were obtained of the ankle. The MDTA was measured on the digitized radiographs by three orthopaedic residents, one orthopaedic surgeon and one biomechanical movement scientist. For each leg, the angles measured from the two images were compared. The inter-observer reliability of each method was calculated. The MDTA as measured on whole lower leg images (94.6 ± 2.6 degrees) was significantly different compared with the angle measured on mortise ankle images (92.1 ± 2.2 degrees) (p < 0.01). The mean measurement difference between observers was less than 1 degree. Reliability of the measurements was good with a high association (= 0.85) between observers for the angles measured on the whole lower leg images and also a high association (= 0.83) between the observers for the mortise ankle image measurements. The MDTA is not the same on whole lower leg images and mortise views of the ankle. There was an excellent interobserver reliability for the angles measured. Clinical Relevance: Foot and ankle surgeons should take this into account when planning coronal deformity correction of the distal tibia. We believe whole lower leg images should be used to assess the medial distal tibial angle.

In chapter 7 the role of the fibula in distal tibial varus and valgus is established. It has been suggested that a supramalleolar osteotomy can return the load distribution in the ankle joint to normal. However, due to the lack of biomechanical data, this supposition remains empirical. The purpose of this biomechanical study was to determine the effect of simulated supramalleolar varus and valgus alignment on the tibiotalar joint pressure, in order to investigate its relationship to the development of osteoarthritis. We also wished to establish the rationale behind corrective osteotomy of the distal tibia. We studied 17 cadaveric lower legs and quantified the changes in pressure and force transfer across the tibiotalar joint for various degrees of varus and valgus deformity in
the supramalleolar area. We assumed that a supramalleolar osteotomy which created a varus deformity of the ankle would result in medial overload of the tibiotalar joint. Similarly, we thought that creating a supramalleolar valgus deformity would cause a shift in contact towards the lateral side of the tibiotalar joint. The opposite was observed. The restricting role of the fibula was revealed by carrying out an osteotomy directly above the syndesmosis. In end-stage ankle osteoarthritis with either a valgus or varus deformity, the role of the fibula should be appreciated and its effect addressed where appropriate.

In chapter 8 pressure changes that occur in the tibiotalar joint caused by supramalleolar deformities are presented. Distal tibia coronal plane malalignment predisposes the ankle joint to asymmetric load. The purpose of this cadaveric study was to quantify changes in pressure and force transfer in an ankle with a supramalleolar deformity. Materials and Methods: Seventeen cadaveric lower legs were loaded with 700 N after creating supramalleolar varus and valgus deformities. The fibula was left intact in 11 specimens and osteotomized in six. Tekscan® sensors were used to measure the tibiotalar pressure characteristics. Results: In isolated supra-malleolar deformity, the center of force and peak pressure moved in an anteromedial direction for valgus and posterolateral direction for varus deformities. The change was in an anteromedial direction for varus and in a posterolateral direction for valgus deformities in specimens with an osteotomized fibula. Conclusion: Two essentially different groups of varus and valgus deformities of the ankle joint need to be distinguished. The first group is an isolated frontal plane deformity and the second group is a frontal plane deformity with associated incongruency of the ankle mortise. Clinical Relevance: Our findings underline the complexity of asymmetric osteoarthritis of the ankle joint. In addition, results from this study provide useful information for future basic research on coronal plane deformity of the hindfoot and for determining appropriate surgical approaches.

In chapter 9 a general discussion is made on the conclusions drawn from our observations, the definition of osteoarthritis, the role of obesity and diabetes, the time between fracture and the onset of osteoarthritis, the role of anatomical reduction and the concept of talar shift, the deltoid ligament, malalignment in the coronal plane, and the role of cartilage lesions in ankle fractures.
In hoofdstuk 1 wordt zowel een algemene introductie gegeven over de anatomie van de enkel, enkelfracturen en hun classificaties, als een overzicht gegeven over de historische ontwikkeling van de behandelmethoden van enkelfracturen. Het doel en overzicht van dit proefschrift wordt uiteengezet.

In hoofdstuk 2 wordt een literatuurbeschouwing gepresenteerd. Het doel van dit literatuuroverzicht is, om op een systematische manier het beste beschikbare bewijs weer te geven, wat betreft de langetermijns uitkomsten van de operatieve behandeling van enkelfracturen in de Engelse, Duitstalige en Nederlandse literatuur. Een zoekopdracht is geformuleerd op de wijze van “boolean” data typering. De zoekstrategie werd beperkt tot volwassenen en slechts gerenommeerde databanken werden geraadpleegd. Er werd gezocht op artikelen tussen 1966 en 2008, om studies te identificeren die op zijn minst een follow up duur hadden van 4 jaar of langer, na een geopereerde enkelfractuur. Van de 42 initieel relevante papers voldeden 18 aan de inclusiecriteria. In totaal werden 1822 enkelfracturen beschreven. De gemiddeld gewogen follow up duur was 5,1 jaar. Er waren oorspronkelijk 2724 patienten geincludeerd, wat tot een succespercentage van 66.9% overgebleven participanten leidt. Wat betreft de rapportage van de fractuurrepositie, werden 4 papers gevonden waarin 106 fracturen werden beschreven. Van de fracturen die volgens Danis-Weber waren geclassificeerd, kon van 736 een verband beschreven worden tussen fractuurtype en langetermijns resultaten. In 442 fracturen kon een vergelijking gemaakt worden tussen type 2 en 4 supinatie-exorotatie fracturen volgens de Lauge-Hansen classificatie. Slechts één studie beschreef de invloed van kraakbeenschade op de langetermijns uitkomst. Er waren twee studies, die de rol van een posterieure malleolus fractuur op de langetermijns uitkomst bespraken. Geen enkele studie beschreef de rol van een varus of valgus achtervoet op de langetermijns uitkomst. Van de operatief optimaal gerepositioneerde fracturen, had slechts 79,3% een goede tot excellente langetermijns uitkomst. Weber type A fracturen hadden geen betere resultaten dan Weber type B fracturen. Er werden aanbevelingen voor vervolgonderzoek geformuleerd.
In hoofdstuk 3 wordt de rol van kraakbeenschade, opgelopen bij enkelfracturen, beschreven. Tot op heden is de invloed van de kraakbeenschade, die bij enkelfracturen optreedt, op de langetermijns uitkomst niet opgehelderd. Er wordt een cross-sectionele follow up studie beschreven van een prospectief geïncludeerd cohort van 288 enkelfracturen, waarbij tijdens fractuurbehandeling ook een arthroscopie was verricht om de initieele schade in kaart te brengen. De patienten werden geïncludeerd van juni 1993 tot november 1997. Honderdnegentientien (119) patienten waren beschikbaar voor controle, gemiddeld 12,9 jaar na fractuurbehandeling. Als uitkomstmaat werden de AOFAS score gebruikt voor beschrijving van het klinische resultaat en een gemodificeerde Kannus arthrose score voor het radiologische resultaat. Kraakbeenschade, aanwezig op welke locatie dan ook in het enkelgewricht, was geassocieerd met een suboptimale klinische uitkomst (odds ratio 5,0; 95% betrouwbaarheids interval 1,3 - 20,1; p=0,02) en een suboptimale radiologische uitkomst (odds ratio 3,4; 95% betrouwbaarheids interval 1,0 - 11,2; p=0,04). Er werd ook een relatie gevonden tussen de ontwikkeling van klinische tekenen van arthrose en diepe laesies (>50% van de kraakbeendikte) op de anterieure talus (odds ratio 12,3; 95% betrouwbaarheids interval 1,4 - 108; p=0,02) en diepe laesies op de laterale talus (odds ratio 5,4; 95% betrouwbaarheids interval 1,2 - 23,5; p=0,02). Een diepe laesie op de mediale malleolus was ook een voorspeller voor de ontwikkeling van klinische tekenen van arthrose (odds ratio 5,2; 95% betrouwbaarheids interval 1,9 - 14,6; p<0,01) en radiologische tekenen van arthrose (odds ratio 2,9; 95% betrouwbaarheids interval 1,1 - 7,9; p=0,03). Er werd geen significant verband gevonden tussen kraakbeenschade op de fibula en negatieve langetermijns uitkomsten. De resultaten wijzen erop, dat initiële kraakbeenschade, die optreedt bij enkelfracturen, een onafhankelijke voorspeller is voor de ontwikkeling van posttraumatische enkel arthrose. Met name de laesies op de anterieure en laterale talus en op de mediale malleolus, zijn gecorreleerd met een inferieur klinisch resultaat.

In hoofdstuk 4 wordt een overzicht gegeven van de diagnose en behandeling van letsel aan het mediale collaterale (deltoid) ligament. Supinatie-exorotatie of Weber B type fracturen bestaan als stabiele en instabiele variant. De instabiele versie heeft of een mediale malleolus fractuur, of een deltoid ruptuur, bij een distale fibulafractuur. Volgens de huidige norm wordt de instabiele variant
bij voorkeur operatief behandeld door open repositie en interne fixatie. De te volgen diagnostische procedure bij een verdenking op een deltoidruptuur is ruimschoots onderzocht, echter er is nog geen consensus bereikt over de optimale methode. Er blijkt dat deltoidrupturen frequenter voorkomen bij exorotatie type fracturen dan voorheen werd gedacht. Derhalve is het beschrijven van het fractuurmechanisme van toegevoegde waarde, op de vermoedelijke ligamentaire schade in diverse enkelfracturen. De Lauge-Hansen classificatie van enkelfracturen voorziet in de mechanische oorzaak bij het bestuderen van roentgenfoto’s, en kan dus helpen in het voorspellen van een deltoidruptuur. Echter de betrouwbaarheid hiervan is niet bekend. Fysische diagnostiek, stressopnamen, arthroscopie en echografie zijn alle onderzocht op hun betrouwbaarheid om een deltoidruptuur aan te tonen, maar ook hier is niet bekend welke het meest kosten-effectief is en een hoogste gebruiksgemak heeft. Momenteel zijn zwaartekracht stress roentgenopnamen het meest in zwang. Bij twijfelgevallen kan arthroscopie een waardevolle toevoeging zijn. Er is discussie wat betreft het wel of niet operatief behandelen (dat wil zeggen hechten) van een deltoidruptuur in het geval van een combinatie met een laterale malleolusfractuur. Er is geen bewijs gevonden dat hechten betere resultaten oplevert, maar het wordt geadviseerd mediaal te openen en exploreren als er interpositie van het deltoid in de mediale goot blijkt te zijn.

In hoofdstuk 5 wordt een klinische langetermijns follow up studie beschreven, die het resultaat vergelijkt tussen twee groepen supinatie-exorotatie type 4 fracturen. In de ene groep hebben patienten een mediale malleolusfractuur, in de andere een deltoidruptuur, opgelopen bij een distale fibulafractuur van het Weber B type. Van de 66 initieel geopereerde patiënten tussen 1993 en 1997, waren 36 beschikbaar voor follow up. In alle patiënten had er een arthroscopie plaatsgevonden om de intra-articulaire schade te documenteren. De AOFAS score werd gebruikt om de klinische resultaten weer te geven. Deze liet een significant verschil zien in de totale en functionele scores (p<0,05), maar niet in de subscores voor pijn en alignement, in het voordeel van de groep met een beschadigd ligamentum deltoideum. Er was een significant verschil tussen de twee groepen, wat betreft de SF-36 score voor pijn, ook hier in het voordeel van de groep met een beschadigd deltoid. Er was geen significant verschil gevonden tussen de groepen wat betreft VAS scores of voor radiologische scores.
Tijdens initiële arthroscopie werd een verschil gevonden tussen de groepen wat betreft corpora libera. De groep met een mediale malleolusfratuur had meer corpora libera (p<0,005), alhoewel er niet meer diepe kraakbeenlaesies werden gezien. Na gemiddeld 13 jaar na operatieve behandeling van supinatie-exorotatie type 4 fracturen, hebben patiënten met een partiële of complete deltoidruptuur een betere uitkomst dan degenen met een mediale malleolusfractuur.

In hoofdstuk 6 wordt een beschrijving gegeven van het verschil tussen de mediale distale tibiahoek (MDTA), gemeten op roentgenfoto’s van de enkel en het gehele onderbeen. In totaal werden 48 onderbenen van 24 vrijwillige deelnemers gebruikt om aan te meten. Er werden gestandaardiseerde röntgenopnamen gemaakt. De MDTA werd door verschillende artsen gemeten en de betrouwbaarheid van de metingen, alsook de gemiddelde hoeken, werden weergegeven. De MDTA gemeten op beelden van het gehele onderbeen (94,6 ± 2,6 graden), verschilt significant met de hoek zoals gemeten op mortise opnamen van de enkel (92,1 ± 2,2 graden) (p < 0.01). De gemiddelde meetafwijking tussen beoordelaars onderling was minder dan 1 graad. Betrouwbaarheid van de meetmethode was goed, met een hoge associatie (0,85) tussen beoordelaars voor hoeken op gehele onderbeensopnamen en een hoge associatie (0,83) tussen beoordelaars voor hoeken op mortise opnamen. De klinische relevantie van dit onderzoek bestaat uit de aanbeveling, dat orthopedisch chirurgen die osteotomieën plannen rond de enkel, rekening dienen te houden met het soort röntgenfoto’s waarop gemeten wordt. De MDTA is niet het zelfde op mortise opnamen en gehele onderbeensopnamen. Er wordt geadviseerd om te meten op gehele onderbeensopnamen, waarbij zowel op de enkel als de knie gericht is.

In hoofdstuk 7 wordt de rol van de fibula beschreven in varus en valgus afwijkingen van de distale tibia. Supramalleolaire osteotomieën worden gebruikt om de drukverdeling in het tibiotalaire gewricht te herstellen, in het geval van belastingsas afwijkingen. Er is echter een tekort aan biomechanisch bewijs om de klinische resultaten te onderbouwen. Er werd een biomechanische studie uitgevoerd met als doel, om het effect van een varus en valgus afwijking in de distale tibia op het enkelgewricht te simuleren. Hiermee werd ook beoogd
een verklaring te vinden voor de goede resultaten die met supramalleolare correctie osteotomieën zijn behaald. In 17 kadaver onderbenen werden de drukken en krachtverdeling in het tibiotalaire gewricht gequantificeerd met behulp van druksensoren in het gewricht, voor verschillende varus en valgus afwijkingen in de distale tibia. Verondersteld was, dat een varus afwijking zou resulteren in een drukverschuiving naar de mediale zijde van het enkelgewricht en een valgus afwijking zou resulteren in een drukverschuiving naar de laterale zijde. Het tegenovergestelde werd waargenomen. De fibula bleek een belangrijke rol te spelen in dit krachtspeel. Door een additionele fibula osteotomie uit te voeren op het niveau juist boven de syndesmose, werd duidelijk dat de fibula bij varus en valgus afwijkingen in de distale tibia een restrictieve rol kan spelen. De congruïteit van de mortise is een belangrijk aspect in het behandelen van asymmetrische arthrose van het enkelgewricht, waarbij de rol van de fibula moet worden meegenomen in het behandelplan.

In hoofdstuk 8 worden de drukveranderingen in het enkelgewricht als gevolg van supramalleolare osteotomieen weergegeven. In een kadaverstudie werden 17 onderbenen blootgesteld aan een axiale druk van 700 N na het creëren van varus of valgus afwijkingen in de distale tibia. In 11 exemplaren werd de fibula intact gelaten en in 6 doorgenomen. Tekscan sensoren werden gebruikt om de intra-articulaire druk te meten in het tibio-talaire gewricht. In geïsoleerde supramalleolare valgus afwijkingen, verplaatste het drukcentrum en de piekdruk in een anteromediale richting. In geïsoleerde supramalleolare varus afwijkingen verplaatste het drukcentrum en de piekdruk zich in een posterolaterale richting. In de exemplaren waar ook een fibulaosteotomie had plaatsgevonden, verplaatste het drukcentrum en de piekdruk zich in anteromediale richting bij varus en posterolaterale richting bij valgusafwijkingen. Er blijkt een essentieel verschil te bestaan tussen afwijkingen met en zonder mortise incongruïteit. De bevindingen reflecteren de complexiteit van asymmetrische arthrose van het enkelgewricht. Resultaten van deze biomechanische studie kunnen van waarde zijn voor toekomstige studies naar afwijkingen in het coronale vlak rondom het enkelgewricht en om nauwkeuriger de uitkomsten van chirurgische procedures te voorspellen.

In hoofdstuk 9 worden de resultaten uit voorgaande hoofdstukken bediscussieërd en van commentaar voorzien.
PART VI
ADDENDA
Een proefschrift schrijven is teamwork. Ik wil iedereen, die me op welke manier ook heeft geholpen, hartelijk bedanken. In het bijzonder:

**Professor dr. C.N. van Dijk**, promotor en opleider, beste prof, als oudste co-assistent vroeg ik u, of ik onderzoek kon doen naar enkelprothesen. U schreef direct een aanbevelingsbrief aan professor Hintermann. Een betere start van een promotietraject had ik niet durven wensen. U heeft me, behalve als promovendus, ook als opleidingsassistent aangenomen. Ik was al in voet- en enkelchirurgie geïnteresseerd geraakt, waardoor ik bij u, als internationaal gerenommeerd enkelspecialist, precies op de juiste plek was. Als geen ander kunt u een assistent uw gedachtenstappen uitleggen en door uw ogen naar een probleem laten kijken. Mijn hartelijke dank voor alles wat u me tot dusver hebt geleerd.


**Dr. ir. L. Blankevoort**, beste Leendert, jouw scherpe blik en heldere kritiek maken elk artikel en elk proefschrift beter. Onze wetenschappelijke samen-
werking in de afgelopen jaren was voor mij zeer waardevol. Bedankt voor het slijpen van de eerste versie tot een leesbaar boek.


Dr. P. Kloen, beste Peter, je hebt me destijds, als student, de ideale start gegeven: de eerste papers, boekhoofdstukken, en een duwtje richting de toekomstig opleider. Bedankt voor alles wat je me hebt geleerd; zowel wat betreft wetenschappelijke, als klinische en operatieve vaardigheden.

Prof. dr. G.M.M.J. Kerkhoffs, beste Gino, zowel je bijdrage aan mijn proefschrift als je bijdrage aan mijn opleiding zijn van grote waarde. Wat is het een feest om in de kliniek met je samen te werken. Je bent een alleskunner en je weet het beste uit je assistenten te halen.


L. Bolliger MSc., Chef de Baracke, liebe Lilianna, dein Mountainbike fährt immer noch! Nächstes Jahr wird es wieder mitkommen und zwischen Basel und Liestal pendeln. Dir will ich danken, dass du mich so herzlich aufgenommen
DANKWOORD

hast in der Forschungsgruppe. Du hast an vielen Projekten teilgenommen und mich dabei grossartig unterstützt.


Mw. M. Mammel, vriendin van mijn schoonouders, bedankt voor uw hulp met het samenstellen van de dankwoorden in het Duits.

Dr. ir. A. van der Veen, technisch medewerker van het experimenteel laboratorium in het VUmc, beste Albert, zonder jouw hulp hadden we de Instron niet eens aan kunnen zetten. Je hebt ons uitstekend begeleid.


Marga en Rosalie, secretariaat AMC, bedankt voor jullie ondersteuning.
Dr. J.N. Doornberg, paranimf, beste Job, jij hebt me destijds aan Peter Kloen voorgesteld en zo is het orthopedisch balletje gaan rollen. Omdat ik een half jaar eerder in het Lucas met de vooropleiding begon, mocht ik jouw eerste gammanagel superviseren. Een unicum, want jij ligt al jaren kilometers op ons allen voor. Jouw tomeloze inzet, enthousiasme, professionaliteit en integriteit gaan je tot grote hoogte brengen. Ik respecteer je niet alleen als collega, maar ben je ook dankbaar voor de vriendschap die we hebben opgebouwd in de afgelopen jaren. Zondagochtend Artis met de jongens, schaatsen, of een stukje door de weitjes van Davos: ‘work hard, play hard’.

Drs. M.P.J. van den Bekerom, paranimf, beste Michel, je hebt me onder je hoe-de genomen toen ik als oudste co-assistent in het AMC kwam en me het boek van Hintermann gegeven. Eigenlijk ligt bij jou de basis van dit proefschrift. Je hebt een grote bijdrage geleverd aan de helft van mijn artikelen, bovendien weet je meer van enkelfracturen dan wie ook. Ik mag me derhalve gelukkig prijzen met jou aan mijn zijde bij de verdediging. Jouw carrière heeft een fraaie vlucht genomen via je fellowship in Breda. Je bent ook goed geland in het OLVG. Bedankt dat je mijn paranimf wilt zijn.


Stein, Bram, Paul en Wouter, amices van ‘00, jullie heb ik de afgelopen tijd door opleiding en promotie te weinig aandacht gegeven. Bedankt voor jullie vriendschap.

Henk en Henriëtte, schoonouders, jullie namen me liefdevol in de familie op.

Pa en ma, wat zijn jullie een goede ouders en lieve Popa en Momi voor de jongens. Bedankt voor al jullie interesse, steun, tijd, toewijding en zorg.

Mariken, je bent mijn alles. Wat ben ik gelukkig met jou en onze kereltjes. Je hebt me altijd gesteund waar het kon en regelmatig afgeleid waar het moest. Dit proefschrift is zowel door jou, als ondanks jou, nu eindelijk af.
CURRICULUM VITAE
Sjoerd Stufkens was born in Bilthoven on July 14th 1980. He graduated from het Nieuwe Lyceum in 1998. With support of a Fulbright grant he travelled to Meadville, Pennsylvania, to attend a freshman year at Allegheny College. In 1999 he obtained his propedeuse in Medical Biology, after which he studied Medicine at the University of Amsterdam from 2000 on. In 2005 he escaped to Gerlos, Austria, for six months as a skiing instructor before he started his rotations to obtain his medical degree in 2007. Thereafter he went to Liestal, Switzerland, for a research fellowship with professor B. Hintermann, and returned in 2008 to extend the research fellowship under supervision of professor C.N. van Dijk at the AMC in Amsterdam. He started his general surgery training program in 2009 at the Lucas Andreas Ziekenhuis in Amsterdam under supervision of dr. E.Ph. Steller. In 2011 he continued the orthopedic surgery training program at the AMC in Amsterdam under supervision of professor C.N. van Dijk and from 2013 on at the Slotervaartziekenhuis in Amsterdam under supervision of dr. H.M. van der Vis. He will visit professor B. Hintermann in Liestal again in 2014 for six months, this time as an orthopedic resident. The main focus of this fellowship will be on foot and ankle surgery. Switzerland and the Alps have been attracting Sjoerd since a very young age. It is not a coincidence that work and play meet there each time, for the author of this thesis is passionate about mountaineering and skiing. In 2010 Sjoerd married Mariken Volman, with whom he has two sons. In 2011 Hugo was born, followed by Thomas in 2013. They reside in Amsterdam, awaiting for what the future ‘holds in petto’.
The vast majority (70-78%) of ankle osteoarthritis is of posttraumatic origin. The quality of the reduction of intra-articular fractures is of paramount importance for a satisfactory outcome in all joints. Accordingly, the most important aspect of conservative or surgical treatment of ankle fractures, is achieving anatomical reduction, thereby restoring the congruity of the mortise. It remains to be answered, why a significant part of the operatively - anatomically - reduced ankle fractures still result in posttraumatic osteoarthritis. Not yet fully recognized is the possibly adverse effect of intra-articular cartilage lesions that are often seen after ankle fractures. In this thesis we address the role of these intra-articular cartilage lesions. In addition the role of the deltoid ligament in ankle fractures, and the role of the alignment of the hindfoot on tibiotalar pressure distribution are clarified.