HALLUX VALGUS AND THE FIRST TARSOMETATARSAL JOINT:

CLINICAL AND BIOMECHANICAL ASPECTS

Monster, 2 april 2003

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Deze CD is deel van de uitgave van het proefschrift ‘Hallux valgus and the first tarsometatarsal joint: clinical and biomechanical aspects’ door F.W.M. Faber, orthopedisch chirurg in het Leyenburg Ziekenhuis te Den Haag.

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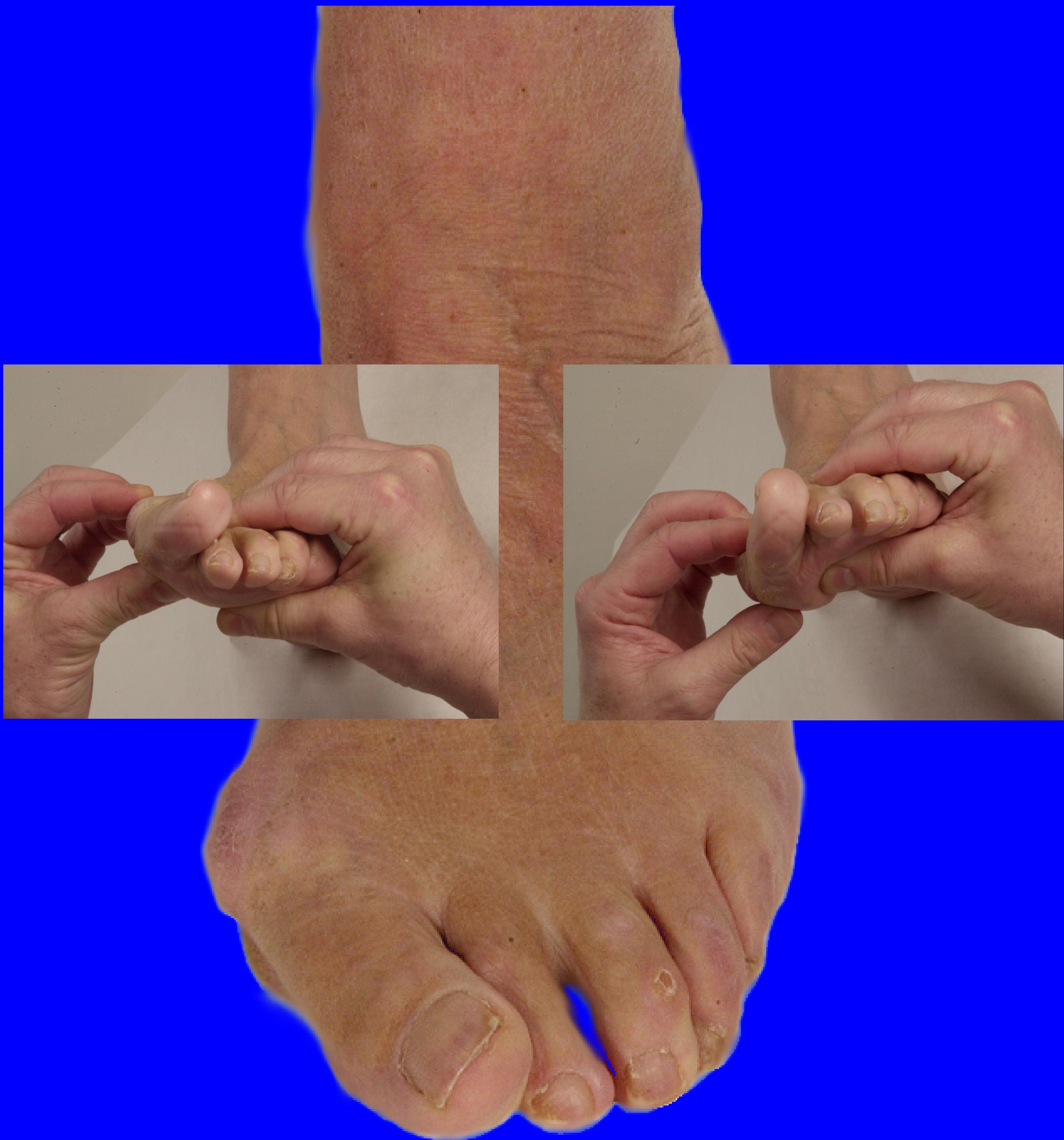

F.W.M. Faber

Uitnodiging

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de openbare verdediging
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Hallux valgus and the first tarsometatarsal joint: clinical and biomechanical aspects

door F.W.M. Faber

De promotie vindt plaats op
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te Rotterdam

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in de foyer onder de collegezaal

Frank Faber
Van Scorel 14
2681 NZ Monster
0174-240905

Stellingen

1. Hypermobiliteit van het TMT 1 gewricht is nog niet met een eenvoudig en universeel toepasbaar instrument objectiveerbaar te meten.

2. Met Doppler Imaging of Vibrations is het mogelijk een objectieve waarde te verkrijgen voor de mate van stijfheid van het TMT 1 gewricht.

3. De stijfheidsmeting van het TMT 1 gewricht door middel van Doppler Imaging of Vibrations voegt additionele informatie toe aan de klinische TMT 1 mobiliteitsmeting.

4. De röntgenologische TMT 1 mobiliteitsmeting door middel van de gemodificeerde Coleman block test kan de klinische diagnose hypermobiliteit van het TMT1 gewricht objectief ondersteunen.

5. Correctie van een hallux valgus volgens Hohmann en Lapidus geeft twee jaar na de operatie een vergelijkbaar resultaat, zowel bij klinisch vastgestelde aan- als afwezige hypermobiliteit van het TMT 1 gewricht.

6. De uitdrukking ‘ik heb zoiets van’ wordt meestal verkeerd gebruikt, namelijk in plaats van ‘ik denk’; eigenlijk impliceert het dat men een vergelijkbaar voorwerp van een bepaald materiaal in bezit heeft.

7. Plaatsing van het osteosynthese plaatje aan de dorsale zijde van de fibula bij Weber-B fracturen is een bruikbaar alternatief voor de conventionele methode, die bestaat uit het inbrengen van één of meer interfragmentaire compressie schroefjes met een lateraal neutralisatie plaatje. *FWM Faber, AJG Nollen, FAAM Croiset van Uchelen, Ned Tijdschr Orthop 1994;1:5-8.*

8. Het Nederlandse volk zou zich moeten schamen voor de verhouding tussen het aantal postmortale nierdonaties en het aantal patiënten op de wachtlijst voor een niertransplantatie.

9. Een verbod op het gebruik van de mobiele telefoon in bus of trein zal, gezien de stijgende ergernis hierover, het aantal reizigers in het openbaar vervoer vergroten.

10. Zorgen moet je doen, niet maken. (Loesje)

11. Orthopeden zijn soms net als kinderen: indien men ze een hamer geeft, verandert de hele wereld in een spijker.

Stellingen behorend bij het proefschrift *Hallux valgus and the first tarsometatarsal joint: clinical and biomechanical aspects.*

Monster, 2 april 2003

F.W.M. Faber

HALLUX VALGUS AND THE FIRST TARSOMETATARSAL JOINT: CLINICAL AND BIOMECHANICAL ASPECTS

HALLUX VALGUS AND THE FIRST TARSOMETATARSAL JOINT:

CLINICAL AND BIOMECHANICAL ASPECTS

HALLUX VALGUS EN HET EERSTE TARSOMETATARSALE GEWRICHT:

KLINISCHE EN BIOMECHANISCHE ASPECTEN

Proefschrift

ter verkrijging van de graad van doctor aan de
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en volgens besluit van het College voor Promoties.

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Franciscus Wilhelmus Maria Faber

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aan mijn moeder

Publications and papers based on studies in this thesis

Mobility of the first tarsometatarsal joint in relation to hallux valgus deformity: anatomical and biomechanical aspects.
Frank W.M. Faber, Gerrit-Jan Kleinrensink, Menno W. Verhoog, Annemieke H. Vijn, Christiaan J. Snijders, Paul G.H. Mulder, Jan A.N. Verhaar.
Foot Ankle Int 1999;20:651-656.

Doppler Imaging of Vibrations as a tool for quantifying first tarsometatarsal joint stiffness.
F.W.M. Faber, G.J. Kleinrensink, H.M. Buyruk, P.G.H. Mulder, H.J. Stam, C.J. Snijders, R. Stoeckart.
Clin Biomech 2000;15:761-765.

Quantification of first tarsometatarsal joint stiffness in hallux valgus patients.
F.W.M. Faber, P.E.Zollinger, G.J. Kleinrensink, L. Damen, P.G.H. Mulder, C.J. Snijders, J.A.N. Verhaar.
Clin Biomech 2001;16:714-716.

Mobility of the first tarsometatarsal joint in hallux valgus patients: a radiographic analysis.
Frank W.M. Faber, Gerrit-Jan Kleinrensink, Paul G.H. Mulder, Jan A.N. Verhaar.
Foot Ankle Int 2001;22:965-969.

No difference in results between the Hohmann and Lapidus procedure in hallux valgus patients; a prospective, blinded randomized trial in 101 feet.
F.W.M. Faber, P.G.H. Mulder, J.A.N. Verhaar.
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Mobiliteit van het tarsometatarsale 1 gewricht: een anatomische studie.
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Mobility of the first tarsometatarsal joint in relation to hallux valgus deformity: anatomical and biomechanical aspects.
FWM Faber, GJ Kleinrensink, CJ Snijders, PGH Mulder, JAN Verhaar.
Poster presentation, Meeting of the European Foot and Ankle Society, Stockholm, June 15-17, 2000.

Contents

1 Introduction

1.1 Anatomy and pathogenesis of hallux valgus deformity

Hallux valgus is defined as a lateral deviation of the great toe and a medial deviation of the first metatarsal. The first author who made this definition was Hueter [Hueter 1870]. An increased angle between the first and second metatarsals is often associated with a hallux valgus deformity. An association between the magnitude of the hallux valgus angle and the first-second intermetatarsal angle exists [Hardy and Clapham 1952]. They concluded that the metatarsus primus varus is secondary to an increased hallux valgus angle. Lapidus however, considers the human foot with a metatarsus primus varus as an atavistic type of foot, with a predisposition to forming a hallux valgus deformity [Lapidus 1934]. Although cause and consequence of hallux valgus and metatarsus primus varus remain unclear, it is obvious that these two are related [Hansen 2000, Sarrafian 1983, Truslow 1925].

The first metatarsophalangeal joint consists of two joints: the concave base of the phalanx of the big toe opposites the convex head of the first metatarsal and the plantar two-thirds of the head of the first metatarsal forms two trochlear surfaces for the two sesamoid bones [Saraffian 1983]. This sesamoid complex makes the first metatarsophalangeal joint the most difficult of all the metatarsophalangeal joints The muscles and tendons that control the great toe can be divided into four groups around the first metatarsophalangeal joint [Van Haeff 1958, Mann and Coughlin 1993]:

1. dorsal: the tendons of the extensor hallucis longus and brevis muscle, passing centrally and inserting into the distal and proximal phalanges, respectively.
2. plantar: the tendons of the flexor hallucis longus and brevis muscle. The medial and lateral heads of the latter inserting into the medial and lateral sesamoid. Distally, the sesamoids are attached to the base of the proximal phalanx by the plantar plate. The flexor hallucis longus tendon is located plantar to the sesamoid complex and inserts into the distal phalanx
3. medial: the abductor hallucis inserting into the medial sesamoid and medial plantar tubercle of the proximal phalanx

4. lateral: the adductor hallucis, with its oblique head inserting into the plantar base of the proximal phalanx and the transverse head inserting into the lateral sesamoid.

The head of the first metatarsal is able to act completely free of the sesamoid-phalangeal complex, which is actively stabilized by the intrinsic muscles [Dereymaekers 1996]. Because none of these tendons insert to the first metatarsal head itself, it is susceptible to extrinsic deforming forces.

In the normal, well aligned position of the great toe, the abductor hallucis muscle provides major support at the medial side, whereas the adductor hallucis muscle provides stability on the lateral side. When, irrespectively to the cause, the hallux is chronically into a valgus position, the deformity will become irreversible and progressive. The structures at the lateral side of the metatarsophalangeal joint will become contracted and at the medial side attenuated [Inman 1973]. The adductor hallucis muscle, inserting at the plantar aspect of the proximal phalanx, will exert a rotational force on the great toe, pronating it as the phalanx deviates laterally. The imbalance progresses and the adductor hallucis, abductor hallucis and flexor hallucis brevis rotate in a lateral direction, leaving the thin dorsal half of the joint capsule at risk for further deformation. The medial and lateral sesamoid will subluxate laterally, although actually it is the first metatarsal that deviates medially away from the sesamoid complex. The ridge separating the medial and lateral sesamoid groove is gradually smoothed out offering little resistance anymore to lateral displacement. The medial sesamoid is becoming located in a central position plantar to the first metatarsal head. In a severe deformity the lateral sesamoid migrates to the lateral aspect of the first metatarsal head and lies vertically dorsal to the medial sesamoid, located in the lateral groove. The abductor hallucis, which is the only muscle that has an medially deviating force on the big toe in the normal situation, will than act as an flexor/adductor increasing the deformity [Miller 1975, Libotte et al. 1985]. The other extrinsic and intrinsic muscles, the extensor hallucis longus and brevis and flexor hallucis longus and brevis, laterally deviated from the longitudinal axis now, will also act as a deforming force [Sanders 1995, Snijders et al. 1986]. This will cause progressive subluxation of the metatarso-phalangeal joint and a progressive deformity.

In some cases however, the progressive displacement of the hallux into valgus is not leading to an incongruity or subluxation of the metatarsophalangeal joint. This is ascribed to a different anatomical constitution of the joint: the distal metatarsal articular surface is facing more laterally [Coughlin 1996]. This anatomical variant gives rise to another type of hallux valgus deformity. The metatarsophalangeal joint will stay congruent, although the intermetatarsal angle enlarges. The basic deformity here consists of an enlarged bunion, which is pressed against the shoe and as the dynamic deformity of the hallux valgus is occurring, there is progressive enlargement of the medial eminence, to varying degrees. This type of hallux valgus is more frequently found in juveniles [Coughlin 1995].

1.2 Aetiology

Perhaps more than any other disorder of the foot, theories of the initial aetiology of hallux valgus are multiple. There is little doubt that the deformity has more than one cause. The most important extrinsic and intrinsic are

1.2.1 Shoes

Constrictive shoewear is regarded as the primary culprit. Although it is the most important extrinsic factor, the majority of people wearing shoes do not develop a hallux valgus deformity. So, other predisposing factors seem to be required too. In a Chinese population the incidence of hallux valgus in the shoe wearing population was 33% versus 1.9% in those who habitually went barefoot [Sim-Fook and Hodgson 1958]. In Japan hallux valgus was essentially an unknown deformity prior to the introduction of Western style shoes and operations for the deformity were rarities before 1970 [Kato and Watanabe 1981]. Other studies of partially unshod population [Shine 1965] and the unshod populations in New Guinea [MacLennan 1966], South Africa [Wells 1931, Grabe 1999], West Africa [Barnicot and Hardy 1955], Belgian Congo [Engle and Morton 1931], Solomon Islands [James 1939] gave similar results. A hallux valgus deformity is a rarity when no shoes are worn.

1.2.2 Type of foot

Different types of feet are considered to play an aetiologic role in the development of a hallux valgus deformity. Three types are distinguished [Viladot 1973): Greek foot, in which the second toe is the longest; Egyptian foot, in which the big toe is the longest and squared foot, with equal length of the first and second toe. For the metatarsals three types are distinguished also: index minus, with a short first metatarsal; index plus, with a long first metatarsal and index plus-minus, with equal length of the first and second metatarsal. The metatarsus index minus type is believed to predispose to the development of a hallux valgus deformity, especially with an Egyptian big toe and shoe wearing [Dereymaeker 1996, Viladot 1973]. Barouck even states that a surgical goal should be to create a Greek type of foot [Barouck 1993].

1.2.3 Generalized ligamentous laxity

In symptomatic hallux valgus patients a correlation was found with mild generalized hypermobility [Carl et al.1988). The genetically predisposed lax ligamentous structures as the metatarsophalangeal joint and tarsometatarsal joint may be traumatized by environmental stimuli such as shoe wearing, leading to a hallux valgus deformity.

1.2.4 Pes planus

A flatfoot with heel valgus and pronation is related to a hallux valgus deformity [Inman 1974, Kalen and Brechner 1988]. Pronation of the foot imposes a longitudinal rotation on the first ray (metatarsals and phalanges). This rotation places the axis of the metatarsophalangeal joint in an oblique plane relative to the floor. In this position the big toe is less able to withstand the deforming pressures exerted upon it by the shoe or by weight bearing.

1.2.5 Heredity

The female predilection for a hallux valgus deformity is well known. The ratio of male versus female patients varies from 1:3 [Hewitt et al. 1953] to 1:9 [Mann and Coughlin 1981] and even 1:15 [Hardy and Clapham 1951]. A positive family history in more than fifty percent of the patients is reported [Mitchell et al. 1958, Glynn et al. 1980]. These observations do not prove a genetic or hereditary cause, because extrinsic factors between males and females, especially shoe wear, should also be taken into account.

1.2.6 Metatarsus primus varus

The question of what is first: metatarsus primus varus or a hallux valgus deformity is still unsolved. According to Hardy and Clapham [1951] the metatarsus primus varus is secondary to the hallux valgus deformity. Truslow [1925] considered a metatarsus primus varus as the primary deformity. Lapidus [1934] concluded the same, considering a metatarsus primus varus as an 'atavistic' foot, which never became fully developed. Here a relation is made with heredity in case of a congenital metatarsus primus varus.

1.3 Surgical Procedures

1.3.1 General considerations

The goal of operative correction of a hallux valgus deformity is to correct all pathological elements and maintain a biomechanically functional forefoot. There is a large diversity of surgical procedures to correct a hallux valgus deformity; more than 100 procedures are described [Crenshaw 1987, Mann and Coughlin 1993]. This indicates that not one procedure is universally applicable for all deformities. In general, an orthopaedic surgeon should be familiar with at least two or three of these procedures as far as the indication, surgical technique and after treatment is concerned, to be able to treat all patients with a hallux valgus deformity.

The choice of the corrective procedure will depend on the results of the anamnesis, physical examination and radiographic evaluation.

The operative procedures can be grouped into certain types:

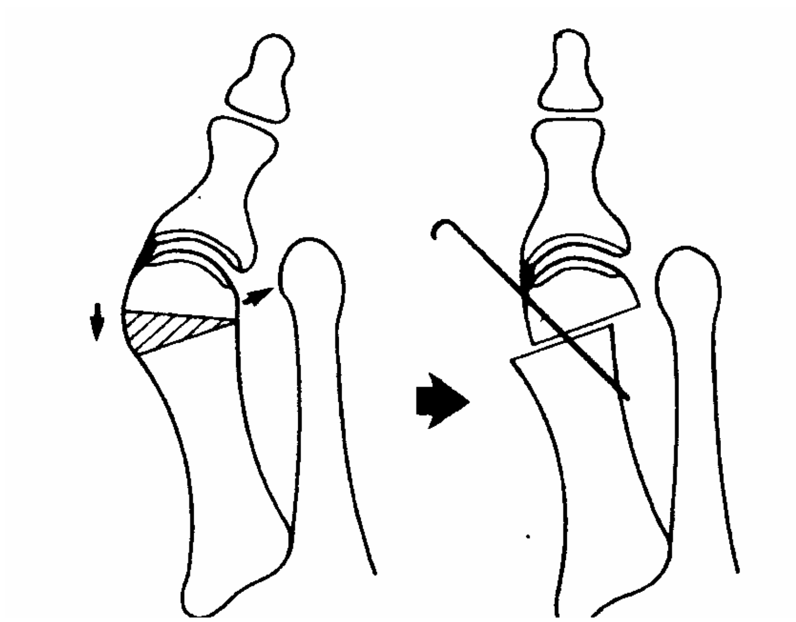
1. osteotomy of the proximal phalanx of the big toe (Akin)
2. osteotomy of the distal first metatarsal (Hohmann, Mitchell, Wilson, chevron)
3. soft tissue procedure of the first metatarsal-phalangeal joint (McBride)
4. osteotomy of the shaft of the first metatarsal with a soft tissue procedure of the first metatarsal-phalangeal joint (Scarf)
5. osteotomy of the base of the first metarsal (open wedge, closed wegde or dome) with a soft tissue procedure of the first metatarsal-phalangeal joint
6. arthrodesis of the first tarsometatarsal joint with a soft tissue procedure of the first metatarsal-phalangeal joint (Lapidus)
7. osteotomy of the first cuneiform bone with a soft tissue procedure of the first metatarsal-phalangeal joint
8. resection arthroplasty of the first metatarsal-phalangeal joint (Brandes, Keller)
9. arthrodesis of the first metatarsal-phalangeal joint
10. a combination of two or more of the above mentioned procedures

The two procedures used in the prospective randomised clinical trial, the Hohmann and the Lapidus procedure, are further described in detail.

1.3.2 Hohmann

See figure 1. General or spinal anaesthesia is used and the patient is a supine position with a tourniquet. A dorso-medial incision is centered over the MTP 1 joint. The dorso-medial cutaneus nerve is protected. On the plantar-medial side the tendon of the abductor hallucis muscle is freed and cut distally. Subcapitally a tranverse incision in the periosteum is made. With an oscillating saw an osteotomy perpendicular to the shaft of MT 1 is performed and a wegde shaped piece of bone is removed. The base of the wedge must be medial and plantar. The size of the wedge depends on the size of the deformity. The capital fragment is shifted laterally four to five millimeters and care is taken to ensure that the capital fragment is tilted plantarward. Fixation is achieved with a K-wire, which is drilled through the bone from distal-medially to proximal-laterally. This K-wire is left protruding through the skin distally, thus facilitating removal in the out-patient clinic. The periosteum is sutured and the tendon of the abductor hallucis muscle is reattached dorso-medially to the joint capsule of the MTP 1 joint. The skin is closed in a routine fashion. A well molded below-knee plaster of paris splint is applicated.

Figure 1 Hohmann procedure

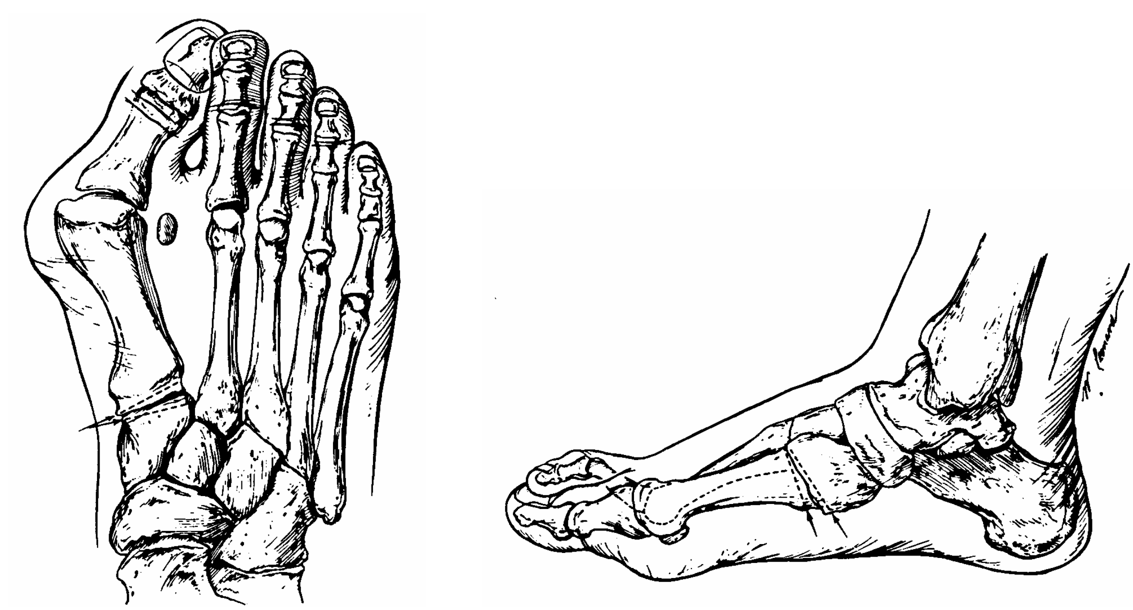


1.3.3 Lapidus

See figure 2. General or spinal anaesthesia is used and the patient is in a supine position with a tourniquet. A dorsal incision just laterally to the tendon of the extensor hallucis longus is made. The cutaneous nerves are protected. In the first intermetatarsal space a lateral capsulotomy is performed. The oblique and transverse parts of the adductor hallucis muscle are released from the base of the proximal phalanx and the lateral sesamoid bone and the transverse metatarsal ligament is cut. A second incision is then centered over the medial eminence. The cutaneous nerve is protected. The MTP 1 capsule is longitudinally incised and the medial eminence is resected with an oscillating saw parallel with the medial cortex of MT 1. A small strip of capsule of approximately three millimeters is excised, enabling reefing of the medial capsule during closing of the wounds.

Then proximally in the first incision the TMT 1 joint is exposed and the cartilage is removed with an oscillating saw. Care is taken to remove as little bone as possible, removing a bit more laterally and plantarly. This enables correction of MT 1: this is tilted laterally and plantarly. Multiple perforations of the subchondral bone of MT 1 and the first cuneiform with a small K-wire is performed to enhance fusion. The fixation of the TMT 1 arthrodesis is with two 3.5 mm cortical lag screws. Closure of the medial capsule is performed with interruptured sutures and the subcutaneous tissue and skin are closed in a routine fashion. A well molded below-knee plaster of paris splint is applicated.

Figure 2 Lapidus procedure



1.4 Survey of the literature on TMT 1 mobility

1.4.1 General considerations

Despite the fact that the question of what is first: metatarsus primus varus or a hallux valgus deformity is still unsolved, the position of the first metatarsal is important. The first metatarsal bone can only be in varus position, if some mobility in the first tarsometatarsal joint occurs. Medial deviation in the tranversal plane and dorsiflexion deviation in the sagittal plane are considered as factors causing the pain from the bunion and metatarsalgia, because of lesser metatarsal overload [Klaue 1991, Myerson 1990, Sangeorzan and Hansen 1989].
So, the hallux valgus deformity is somehow related to mobility of the TMT 1 joint. Some authors consider instability/hypermobility of the TMT 1 joint as a causal factor for a hallux valgus deformity [Hansen 1996, Lapidus 1934, Sangeorzan and Hansen 1989]. Others neglect this joint and the importance of its mobility in their recommendations for hallux valgus surgery [Coughlin 1995, Geissele and Stanton 1990, Mann and Coughlin 1981]. If a causal relation betweeen TMT 1 hypermobility and hallux valgus exists, it seems logical to correct this cause with the surgical procedure chosen for the hallux valgus deformity. Consequently, a Lapidus procedure is advocated [Bednarz and Manoli 2000, Butson 1980, Hofbauer and Grossmann 1996, Johnson and Kile 1994, Lapidus 1934, Mauldin et al. 1990, Myerson 1990, Myerson et al. 1992, Saffo et al. 1989, Sangeorzan and Hansen 1989].

1.4.2 Normal mobility of the TMT 1 joint.

1.4.2.1 In vitro studies.

In the cadaver study of Wanivenhaus and Pretterklieber [1989] on hundred feet dorsal displacement in the TMT 1 joint was found as the most important direction of mobility. Abduction and adduction movement in this joint was only possible in ten percent of the specimens.
Ouzounian and Shereff [1989] reported in ten feet more dorsiflexion-plantarflexion mobility than supination-pronation mobility in the TMT 1 joint.
Mizel [1993] performed a cadaver study on twelve feet. After applying a dorsiflexion force he found no ‘appreciable movement’ of the first metatarsal until the plantar first metatarsal-first cuneiform ligament was cut.

Bohne et al. [1997] studied the stabilizing role of the peroneus longus tendon in ten cadaver feet. The deforming force was medially directed on the first metatarsal. The authors concluded that the peroneus longus tendon is a strong retaining mechanism of the first metatarsal.

Gellman et al. [1987] found in fifteen specimens a contribution of the tarsometatarsal joints to the total foot and ankle mobility of 21 percent of the dorsiflexion, 10 percent of the plantarflexion, 12 percent of the inversion and 16 percent of the eversion.

1.4.2.2 In vivo studies

Lundberg et al. [1989] performed a röntgen stereophotogrammetrical study on eight healthy volunteers. This experiment confirmed the existence of (little) plantarflexion and dorsiflexion in the TMT 1 joint.

Lundberg et al. [1989] also studied pronation and supination in this group with the same method of röntgen stereophotogrammetry. In the TMT 1 joint only a little rotation (pronation and supination) around the transversal axis was demonstrated.

Fritz and Prieskorn [1995] performed a radiographic study to first tarsometatarsal motion in hundred feet of healthy volunteers. They found a range of motion of the TMT 1 joint in the sagittal plane of 4.37°.

Hypertrophy of the second metatarsal is considered as a sign of first ray hypermobility [Myerson et al. 1992, Sangeorzan and Hansen 1989]. Prieskorn et al. [1996] studied radiographic hypertrophy of the second metatarsal in hundred asymptomatic feet. In their group of healthy volunteers they found no correlation between mobility of the TMT 1 joint in the sagittal plane and radiographic hypertrophy of the second metatarsal.

Summarized, in the *in vitro* and *in vivo* studies there is general agreement on the existence of motion in the TMT 1 joint, although the opinions differ about degree and direction of this motion.

1.4.3 Hypermobility of the TMT 1 joint in hallux valgus patients

1.4.3.1 In vivo studies

Klaue et al. [1994] found a difference in sagittal mobility of the first ray between thirteen hallux valgus patients and fifty-six asymptomatic persons: the mobility was significantly larger in the hallux valgus group. The measurements were performed with a special device and the deforming force was not standardized.

Ito et al. [1999] studied radiographically sagittal mobility in thirty-two painful and twenty-two painless hallux valgus patients and twenty-three normal feet. They found significant differences between the hallux valgus feet and the normal feet. These differences concerned the lateral talar-first metatarsal angle.

Romasch et al. [1990] performed a radiographic study with stress in the transversal plane in hallux valgus patients. In an attempt to distinguish between feet suitable for a soft tissue procedure and feet requiring an osteotomy of the first metatarsal, they applied transversal stress on the forefoot. The authors concluded that mobility and the shape of the TMT 1 joint should be concerned in pre-operative decision making.

In the study of Lee and Young [2001] sixty hallux valgus patients were compared with forty healthy volunteers. With as simple plastic device to quantify clinical mobility in the sagittal plane more mobility of the first ray was found in hallux valgus patients. Also, thirty-eight percent of the hallux valgus patients was considered hypermobile.This study concerned the first ray and not selectively the TMT 1 joint.

Similar results were reported by Glasoe et al. [2001]: a statistically significant larger amount of dorsal mobility of the first ray was found in a group of fourteen hallux valgus patients, compared with fourteen healthy volunteers. The measurements were performed using a special device that was shown to be reliable [Glasoe et al. 1999, Glasoe et al. 2000]. This study did not measure selectively the TMT 1 joint, but the whole first ray.

Summarized, there are indications that hypermobility of the TMT 1 joint could be a relevant factor in a hallux valgus deformity, although no exact definition of hypermobility is given.

1.5 Aim of the present study.

Although in general hypermobility in the TMT 1 joint is mentioned as a factor favouring the Lapidus procedure [Coughlin 1996, Johnson and Kile 1994, Myerson et al. 1992] TMT 1 hypermobility cannot be established reliably. To assess TMT 1 hypermobility the clinical test as described by Klaue [1991] is generally performed, but the reliability and reproducibility of this subjective test are unknown. No studies on the intra- and interobsever variability of this test have been published previously.

Both the controverse of the importance of TMT 1 hypermobility and the lack of objective, reliable and reproducible TMT 1 mobility measurements have lead to the following questions, which are the subject of this study:

1. does hypermobility of the TMT 1 joint exists in hallux valgus patients?
2. if this is the case, should this hypermobility be corrected in the surgical procedure for the hallux valgus deformity?
3. is there a good correlation between the clinical and radiographic TMT 1 (hyper)mobility measurement?
4. which procedure, a Lapidus or a Hohmann, gives better short term results in relation to TMT 1 hypermobility and irrespectively of TMT 1 hypermobility?

In *Chapter 2* an in vitro study in nine cadaver feet is described to investigate the relation between the mobility of the TMT 1 joint in the sagittal and transversal plane. Also, a possible stabilizing effect of three muscles (tibialis anterior muscle, flexor hallucis longus muscle and the peroneus longus muscle) on this joint is studied in both planes.

Chapter 3 deals with the first step to quantify TMT 1 mobility in a non-invasive, objective and patient friendly way. Recently a method using low energy vibrations has been developed to measure joint stiffness in vivo. This method, Doppler Imaging of Vibrations, was shown to be reproducible and reliable for the sacro-iliac joint. This study was performed to determine whether this technique was also applicable to the TMT 1 joint and if so, to obtain reference values for Doppler Imaging of Vibrations measured stiffness of the TMT 1 joint of healthy volunteers without a hallux valgus. 46 TMT 1 joints of 23 healthy subjects were tested.

The next step in objectivation of TMT 1 joint mobility is described in *Chapter 4*. The same technique is applied to 32 TMT 1 joints in 20 hallux valgus patients and related to clinical TMT 1 mobility measurements by two independent observers. Thus, the relation between the clinical TMT 1 mobility test and the stiffness measurement of the TMT 1 joint with Doppler Imaging of Vibrations was studied.

In *Chapter 5* another test of TMT 1 mobility in a different group of hallux valgus patients is described. A radiographic analysis of TMT 1 mobility in hallux valgus patients is made. This was also related to the clinical TMT 1 mobility measurement. In 94 patients with a hallux valgus deformity clinical TMT 1 mobility was compared with a radiographic TMT 1 stress-measurement. The results could also be compared to the radiographic TMT 1 mobility in a previous study on healthy subjects.

In *Chapter 6* the results of a prospective randomised trial between two surgical procedures to correct a hallux valgus deformity (Hohmann versus Lapidus) are described. 87 consecutive patients with 101 hallux valgus deformities were treated and the follow-up was at least two years. Pre-operatively TMT 1 mobility was tested clinically. The clinical results were determined by obtaining the AOFAS score [Kitaoka 1994] pre- and post-operatively, as well as a pain score and a patient satisfaction score. The radiographic results were also determined.

2 Mobility of the first tarsometatarsal joint in relation to hallux valgus deformity: anatomical and biomechanical aspects

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2.1 Abstract

Hypermobility of the first tarsometatarsal (TMT 1) joint is suggested to be an important factor in the etiology and progression of hallux valgus deformity. Hypermobility of the TMT 1 joint is tested clinically in the sagittal plane, but an important deformation also exists in the transversal plane: metatarsus primus varus. This in vitro study was undertaken to investigate the relation between the mobility of the TMT 1 joint in these two planes and to investigate the correlation of the mobility with morphological variables. A second aim was to study the possible stabilizing effect of the tibialis anterior muscle, flexor hallucis longus muscle, and peroneus longus muscle (PL) on the TMT 1 joint. Nine embalmed human specimens were tested under standardized conditions. A 30-N force was applied to the head of the first metatarsal (MT 1) to pull in either the dorsal or medial direction. To simulate muscle force, 21 N was applied to the three tendons: all seven possible combinations of muscle action were tested in each plane of motion. Angular displacements were measured using 2-D LED video registration. TMT 1 mobility is a relevant factor in MT 1 mobility in the sagittal and transversal planes, the PL has a stabilizing effect on this joint and the effect of the flexor hallucis longus on this joint is different in both planes. When considering a Lapidus procedure for surgically correcting a hallux valgus, the mobility of MT 1 in the transversal plane should also be assessed, but so far no objective clinical test in this plane has been described.

2.2 Introduction

Controversy still exists about the role of mobility of the first tarsometatarsal (TMT 1) joint in relation to hallux valgus. Some authors described hypermobility of this joint as a major factor in the etiology of the hallux valgus complex. Consequently they advocated inclusion of a

TMT 1 arthrodesis for correcting a hallux valgus (Lapidus procedure) [Hansen 1996, Lapidus 1934, Sangeorzan and Hansen 1989]. Hypermobility in the TMT 1 joint is generally mentioned as a factor favoring the Lapidus procedure [Butson 1980, Hansen 1996, Hofbauer and Grossman 1996, Johnson and Kile 1994, Lapidus 1934, Mauldin et al. 1990, Myerson 1990, Myerson et al. 1992, Saffo et al. 1989, Sangeorzan and Hansen 1989]. However, TMT 1 hypermobility cannot yet be quantified. A clinical test was described by Klaue [Klaue 1991], but its reliability and reproducibility are still unclear. Several studies measured (hyper)mobility in this joint objectively: a biomechanical study [Klaue et al. 1994], two radiographic studies with stress in the transversal plane [Johnson and Kile 1994, Romash et al. 1990], and a radiographic study with stress in the sagittal plane [Fritz and Prieskorn 1995]. In cadaver studies [Bohne et al. 1997, Mizel 1993, Ouzounian and Shereff 1989, Wanivenhaus and Pretterklieber 1989], there is general agreement on the existence of motion in this joint, although the opinions differ about degree and direction of this motion. An in vivo experiment confirmed the existence of (little) plantarflexion and dorsiflexion in the TMT 1 joint [Lundberg et al. 1989] as well as a little pronation and supination [Lundberg et al. 1989].
The role of the stabilizing factors of this joint in the sagittal and transversal planes is not yet clear. According to Mizel [Mizel 1993], the first metatarsal first cuneiform ligament is the most important stabilizing factor in the sagittal plane. Bohne [Bohne et al. 1997] ascribed a significant role to the peroneus longus muscle (PL) in stabilizing TMT 1 in the transversal plane.
The purposes of this study were (1) to compare TMT 1 joint motion in the sagittal plane (dorsal displacement) with motion in the transversal plane (medial displacement); (2) to investigate the relative contribution of the TMT 1 joint to the total first ray mobility in these two planes; (3) to investigate the role of three possible dynamic stabilizers of the TMT 1 joint: the tibialis anterior muscle (TA), the flexor hallucis longus muscle (FHL), and the PL; and (4) to study the correlation between TMT 1 mobility and morphologic TMT 1 variables.

2.3 Materials and methods

Nine embalmed below knee amputated nonpaired human specimens (two right feet, seven left feet) were studied. The mean age at the time of death was 90 years (range, 81-95 years). The skin and subcutaneous tissues were dissected. Flexor and extensor retinacula around the ankle were left intact. The plantar fascia, all intrinsic foot muscles and the flexor digitorum longus muscle were removed. All ligaments and joint capsules as well as the FHL, TA and PL were spared. Sutures were placed through two drill holes in the first metatarsal (MT 1) head, leaving the FHL free, to apply a 30-N loading force in two directions (medial and dorsal). Sutures were also placed proximally to the ankle through the the FHL, TA, and PL. To simulate muscle force, these tendons were loaded with 21 N. The specimens were placed in a specially designed positioning apparatus, which provided a firm fixation of the tibia, the os calcis and the four lateral metatarsal heads with the ankle positioned in 90 degrees (Fig 1). To reduce the effect of tissue creep, the experiments were conducted after preloading the MT 1 by 40 N in the two directions. After replacing the foot to its neutral position the tendons were preloaded by 21 N. Again the foot was brought back to its neutral position. This was controlled by exact needle point contact of two markers: one on the foot and one on the bottom plate. Thereafter the experiments were started.

To enable the computerized video registration of bone rotations, reflective markers were placed in the MT 1, first cuneiform, and navicular bones (two markers in each bone). In the bottom plate, two markers were placed as references. These markers were illuminated by an infrared light source mounted to the video camera. An infrared filter in front of the camera lens ensured good contrast in the video images. With the help of a video image processing board (Vision Dynamics VCS512-II) in a personal computer, the image coordinates of the centers of the markers were determined. From these coordinates, the angular displacements of the bones were calculated.

Each experiment was executed twice. First, the camera was placed to register marker displacements in the sagittal plane. Subsequently, the camera was moved to register displacements in the transversal plane.

Calculation of Angular Displacements

The angular displacement in the TMT 1 joint was calculated by subtracting the displacement of the first cuneiform from the displacement of MT 1; the angular displacement of the cuneonavicular joint was calculated by subtracting the displacement of the navicular bone from the cuneiform; the angular displacement of the talocalcaneonavicular joint was calculated by subtracting the bottom plate reference from the displacement of the navicular bone. This was done in the transversal and sagittal planes separately.

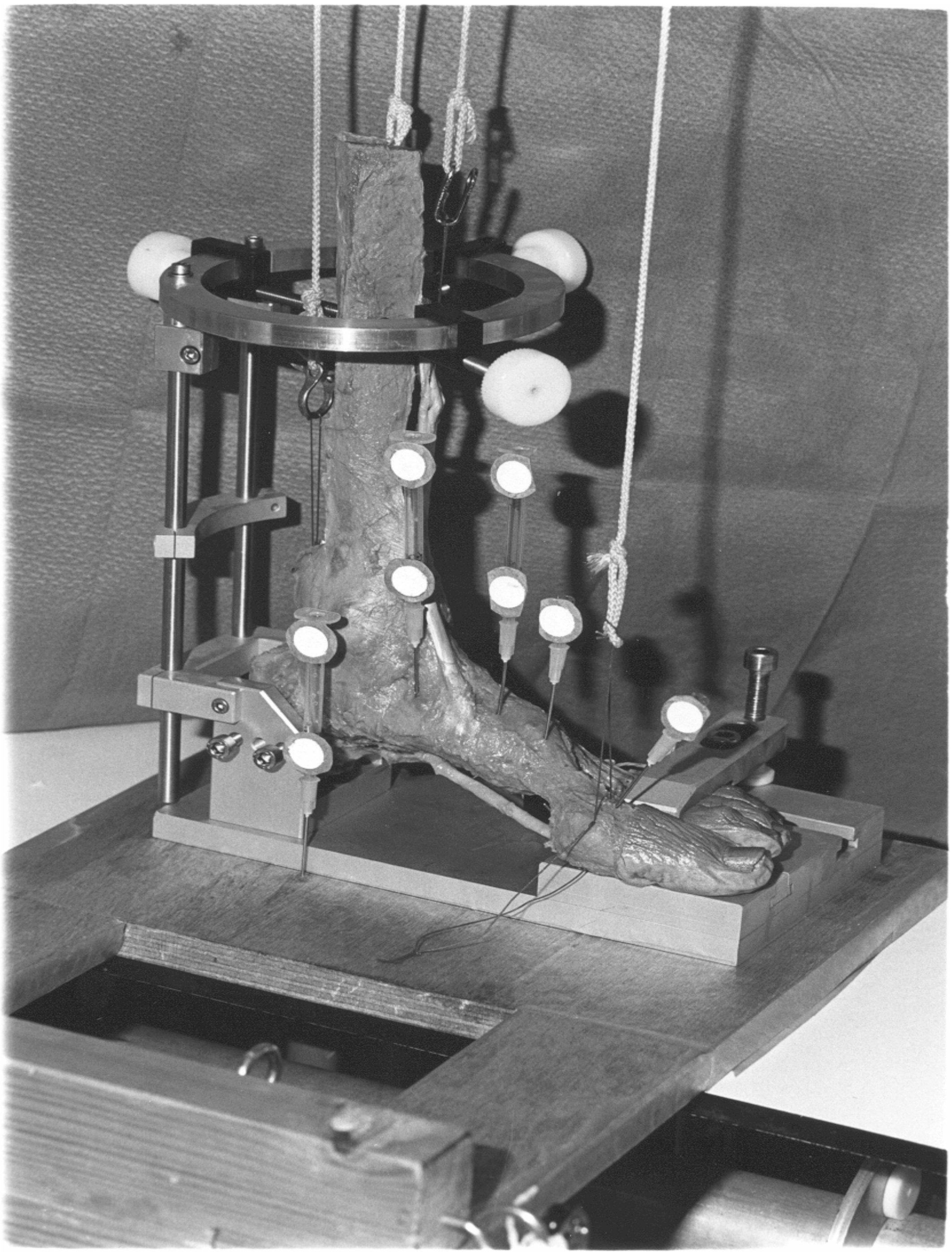

Figure 1.

Positioning apparatus with specimen and markers

Simulated Muscle Force

To study the effect of muscle force on the angular displacement of the TMT 1 joint, the experiment was executed in the following sequence: first a 30-N force was applied to MT 1 and the displacement was measured. After resetting the foot to its neutral position, 21 N was applied to a tendon followed by application of 30 N to MT 1, and again the displacement was measured. The foot was reset to its neutral position, and another tendon was loaded with 21 N followed by application of 30 N to MT1. This was done for the TA, FHL and PL separately and in combination. All seven possible combinations were tested and in both the transversal and sagittal planes. All eight measurements (with and without simulated muscle force) were repeated in a reversed sequence, and the average of the two angular displacements was taken for statistical analysis. The experiments were conducted without loading the tibia; measurements were performed at constant room temperature and air humidity. The specimens were kept moist throughout the experiment. The hallux valgus angle was noted before the experiment. After the measurements the specimens were dissected further to assess the length of MT 1 and the following TMT 1 parameters: height, width, and shape (C-shape, S-shape, or linear) [Fritz and Prieskorn 1995]; number of facets (1 or 2) [Wanivenhaus and Pretterklieber 1989]; degree of arthrosis; and the existence of a joint between MT 1 and MT 2 [Romash et al. 1990]. Also, the degree of arthrosis of the metatarsophalangeal joint was registered. The arthrotic lesions were classified as follows: 0 = no arthrosis, 1 = loss of cartilage, and 2 = loss of cartilage and osteophytes.

During this total dissection, the position of the markers in the bones was double checked. All of the markers had been placed in the correct bones.

Statistics

The Student's t-test for paired samples was used for comparing the medial with the dorsal angular displacement of the MT 1 and TMT 1 angular displacement. Repeated measures analysis of variance (RM-ANOVA) was used for testing the effect of simulated muscle force on TMT 1 angular displacement in both dorsal and medial directions. Also, all interactions between TA, FHL and PL were tested from these eight combinations. The (co)variance structure of the within-foot error term was assumed to be of type "compound symmetry" (i.e., all variances the same and all 28 covariances the same). The Pearson correlation test was used for testing linear relationships between TMT 1 angular displacement and numeric variables as hallux valgus angle, MT 1 length, and TMT 1 height and width. One-way ANOVA was used for testing the dependence of TMT 1 angular displacement on TMT 1 shape, degree of arthrosis, and the existence of a joint between MT 1 and MT 2. For each test statistical significance was set at $P < 0.05$.

2.4 Results

Dorsal and Medial MT 1 Displacement and the Relative Contribution of the TMT 1 Joint to Total First Ray Angular Displacement

We found no statistically significant difference in angular displacement of MT 1 or TMT 1 in the dorsal direction compared with the medial direction (Student's *t*-test; Table 1).

Table 1

Angular Displacement of MT 1 and TMT 1 (n = 9)

	Average angular displacement (°)	Standard deviation	*p* value (paired *t*-test) Student's
MT 1			0.068
Dorsal	3.8	1.9	
Medial	2.5	0.8	
TMT 1			0.760
Dorsal	2.4	1.6	
Medial	2.2	0.8	

MT 1, first metatarsal; TMT 1 first tarsometatarsal joint.

In the medial direction, the relative contribution of the TMT 1 joint to the total motion of the first ray showed a significant difference when compared with the contribution of the cuneonavicular joint and the talocalcaneonavicular joint (Table 2). An average of 82% of the angular displacement took place in the TMT 1 joint (Student's *t*-test; $P < 0.001$ for both joints). For the dorsal direction, the average was 57%. This difference was significant only when compared with the talocalcaneonavicular joint (Student's *t*-test; $P < 0.001$) and not when compared with the cuneonavicular joint (Student's *t*-test; $P = 0.099$).

Table 2

Relative Contribution of the Three Joints to the Total First Ray Angular Displacement (n = 9)

	Dorsal			Medial		
	TMT 1	Cuneo-navicular	Talocalcaneo-navicular	TMT 1	Cuneo-navicular	Talocalcaneo-navicular
average (%)	57	35	8	82	6	12
Standard deviation	17	20	8	14	5	10

Influence of Simulated Muscle Force on TMT 1 Angular Displacement

The main effects of loading of TA, FHL and PL on TMT 1 angular displacement in the dorsal and medial directions are shown in Table 3. The constant (0) is the angular displacement with application of 30 N to MT 1 without loading of the tendons. The coefficient is the change in outcome if the factor muscle loading goes from off to on, as estimated by the linear model underlying the RM-ANOVA, given the other factors in the model. The FHL and the PL had a significant stabilizing effect on the TMT 1 angular displacement in the dorsal direction ($P = 0.0034$ and 0.0001, respectively). For the medial direction this effect could not be demonstrated. The FHL had a significant increasing effect on the TMT 1 angular displacement in the medial direction (coefficient + 0.1; $P = 0.0119$). None of the four interactions (three first order and one second order) was significant when tested separately in a hierarchical fashion (*p* values of all interactions not less than 0.30).

Table 3

TMT 1 Angular Displacement with Simulated Muscle Force

	Coefficient	Standard error	p Value
Dorsal			
constant (0)	2.4	0.488	
TA	0	0.043	0.7475
FHL	-0.1	0.043	0.0034
PL	-0.4	0.043	0.0001
Medial			
constant (0)	2.2	0.318	
TA	0.1	0.049	0.2424
FHL	0.1	0.049	0.0119
PL	-0.1	0.049	0.3054

TMT 1, first tarsometatarsal joint; TA, tibialis anterior muscle; FHL, flexor hallucis longus muscle; PL, peroneus longus muscle; constant (0), angular TMT 1 displacement with application of 30 N to MT 1, no loading of the tendons.

The coefficient is the change in outcome if the factor muscle loading goes from off to on, as estimated by the linear model underlying the repeated measures ANOVA.

The effects of combination are obtained from adding the effects; there is no interaction, meaning that there is no additional effect above this total effect: p values of interactions are not smaller than 0.30.

Correlation Between Angular Displacement and Morphological Variables

The anatomic and geometric parameters of the specimens are shown in Table 4. The hallux valgus angle, MT 1 length, and TMT 1 height and width were not significantly correlated with the TMT 1 angular displacement in the dorsal or medial direction (Pearson's correlation coefficient ranging from 0.167 to 0.383). For the shape of TMT 1, arthrosis of TMT 1 and MTP 1, the number of facets of TMT 1 and the existence of a joint between MT 1 and MT 2, no significant relation could be demonstrated with the TMT 1 angular displacement (ANOVA; p values ranging from 0.112 to 0.961).

Table 4

Anatomic and Geometric Variables of the Specimens

Foot	Hallux valgus angle	Length MT 1 (cm)	Height TMT 1 (cm)	Width TMT 1 (cm)	Shape TMT1[a]	Arthrosis TMT 1[b]	Arthrosis MTP 1[b]	Number of facets TMT 1	Joint MT 1-2[c]
1	37	5.9	2.6	1.6	3	1	1	1	0
2	39	6.2	2.9	1.6	3	0	1	1	1
3	19	6.1	2.9	1.7	2	0	1	2	0
4	18	6.2	2.9	1.4	3	1	1	1	0
5	26	6.2	2.8	1.6	2	1	1	1	0
6	22	6.5	3	1.5	3	0	2	2	1
7	29	6	2.4	1.9	3	0	2	1	0
8	31	5.9	2.8	1.9	1	0	1	2	0
9	15	6.5	3	1.7	3	1	2	2	0

MT 1, first metatarsal; TMT 1, first tarsometatarsal joint; MTP 1, first metatarsophalangeal joint

[a] C-shape = 1, S-shape = 2, linear = 3

[b] 0 = no arthrosis, 1 = loss of cartilage, 2 = loss of cartilage and osteophytes

[c] 0 = no joint, 1 = joint between proximal MT 1 and MT 2

2.5 Discussion

Hypermobility of the TMT 1 joint is generally considered an indication for including this joint in the surgical correction of hallux valgus [Butson 1980, Hansen 1996, Hofbauer and Grossman 1996, Johnson and Kile 1994, Lapidus 1934, Mauldin et al. 1990, Myerson 1990, Myerson et al. 1992, Saffo et al. 1989, Sangeorzan and Hansen 1989]. However, TMT 1 hypermobility cannot yet be quantified and there are conflicting reports of in vitro studies about the normal mobility in this joint [Gellman et al. 1987, Ouzounian and Shereff 1989, Wanivenhaus and Pretterklieber 1989]. The clinical test for hypermobility of TMT 1 as described by Klaue [Klaue 1991] only assesses motion in the dorsoplantar direction. This test does not make an exact distinction between TMT 1 and total first ray mobility. An estimation of the mobility of MT 1 in the mediolateral direction is also important in the preoperative evaluation of hallux valgus, because correction of the metatarsus primus varus is an important aim in hallux valgus surgery. However, to our knowlegde, a clinically consistent test for isolated measurements of TMT 1 mobility in the transversal plane is not yet described. A possibility is to have the patient stand on the edge of a block with MT 2 to MT 5 resting on this block and MT 1 hanging free. Then medial and lateral displacement of MT 1 could probably be estimated.

This study was performed only on embalmed human specimens. Although embalming might have an influence on joint mobility, Wanivenhaus and Pretterklieber [Wanivenhaus and Pretterklieber 1989] found “significantly equal results” in the embalmed and fresh specimens. The influence of embalming is relevant for comparing absolute differences in mobility between embalmed and nonembalmed specimens. However, the purpose of this anatomical-biomechanical study was to analyze relative displacements in two directions as a result of a deforming force and (combinations of) simulated muscle contractions.

Dorsal and Medial MT 1 Displacement and the relative contribution of the TMT 1 Joint to Total First Ray Angular Displacement

In the present experiment, no statistical difference between angular displacement of MT 1 and in TMT 1 in the sagittal plane and transversal plane was found (i.e., mobility of MT 1 and TMT 1 in the medial direction was as great as in the dorsal direction). TMT 1 mobility found in this study is in accordance with the studies of Ouzounian and Shereff [Ouzounian and Shereff 1989] and Gellman et al [Gellmann et al. 1987]. Mizel [Mizel 1993] demonstrated significant dorsal displacement of MT 1 only after sectioning the first metatarsal first cuneiform ligament. The difference between Mizel’s results and ours can be explained by methodology: radiographic versus video registration and inclusion of hallux valgus specimens in our experiment.

Wanivenhaus and Pretterklieber [Wanivenhaus and Pretterklieber 1989] found only in a minority of specimens TMT 1 mobility in the transversal plane, but several factors differ from our study: (1) the applied force was not described and could be different, (2) the dissection protocol was not exactly the same (in our study, the plantar fascia and the intrinsic foot muscles were removed), (3) the presence of hallux valgus was not mentioned and (4) the

specimens in our study were older. In the older specimens the ligaments and capsules could be more degenerated, thus allowing more mobility; Wanivenhaus and Pretterklieber [Wanivenhaus and Pretterklieber 1989] also observed more mobility in the older specimens.
That we found in our study no significant difference between angular displacements in the dorsal and medial directions might have some clinical consequences. The clinical test for hypermobility in the TMT 1 joint is performed only in the sagittal plane [Klaue 1991]. Our results support the need for a TMT 1 stability test in the transversal plane.
Our results indicated (Table 2) that the relative contribution of the TMT 1 mobility to total first ray mobility was more pronounced in the medial than in the dorsal direction. This could be explained on an anatomical basis by the strong stabilizing effect of the Lisfranc ligament [Sarrafian 1983], allowing little mobility of the first cuneiform in the medial direction. These findings further emphasize the aforementioned need for objective clinical TMT 1 stability testing, especially in the transversal plane.

Influence of Simulated Muscle Force on TMT 1 Angular Displacement

We found a significantly stabilizing effect of the PL on the TMT 1 joint against dorsal displacement. This is in accordance with the widely known strong first ray plantar flexion activity of this muscle [Gardner 1975]. In contrast to Bohne et al. [Bohne et al. 1997], we could not demonstrate this effect for medial displacement. This could be attributed to the differences in experimental set-up: Bohne et al. did radiographic measurements in non-hallux valgus specimens with serial cutting of possible stabilizing structures and the applied force differed.
The FHL has been described previously as a relevant factor in the existence and potential factor in the recurrence of hallux valgus [Sanders et al. 1995, Snijders et al. 1986]. On biomechanical grounds one could expect a counteracting effect of the FHL against dorsiflexion of the first ray in the sagittal plane and an increasing effect on medial displacement of the MT 1 in the transversal plane Snijders et al. 1986]. This was also demonstrated in our experiment, and for both directions the results were significant.

Correlation between Angular Displacement and Morphological Variables

According to Lapidus [Lapidus 1934] an “atavistic” type of foot, with a metatarsus primus varus and a short MT 1, is prone to develop a hallux valgus deformity. This author advocated a correction in the joint that causes the deformity: the TMT 1 joint. We could not find a correlation between the TMT 1 angular displacement and the length of MT 1 or other numeric parameters such as hallux valgus angle and height and width of the TMT 1 joint. Also, no correlation was found between TMT 1 angular displacement and the shape of TMT 1, arthrosis of TMT 1 and MTP 1, the number of facets of TMT 1, and the existence of a joint between MT 1 and MT 2. This is in accordance with Fritz and Prieskorn [Fritz and Prieskorn 1995]. Wanivenhaus and Pretterklieber [Wanivenhaus and Pretterklieber 1989] described only the shape, height, and width of the TMT 1 joints without investigating a relation with the found mobility. In other cadaver studies, these parameters were not investigated at all Gellmann et al. 1987, Mizel 1993, Ouzounian and Shereff 1989]. Either these relations are not clear or the number of measured feet was too small to demonstrate such a correlation.

2.6 Conclusions

In our experiment, we found no difference between angular displacement in the dorsal and medial directions of MT 1 and TMT 1. The relative contribution of the TMT 1 mobility to the total first ray mobility was larger in the medial than in the dorsal direction. This raises the question of whether a clinical test of first ray (hyper)mobility in the transversal plane in the evaluation of hallux valgus and metatarsus primus varus should be developed and evaluated. The FHL and PL had a statistically significant stabilizing effect on the TMT 1 joint against a dorsal displacing force. This effect of the PL could not be demonstrated against a medial displacing force. The FHL had a statistically significant increasing effect on the TMT 1 angular displacement in the medial direction.

3 Doppler Imaging of Vibrations as a tool for quantifying first tarsometatarsal joint stiffness

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3.1 Abstract

Objective. To assess whether first tarsometatarsal joint stiffness can be measured by Doppler Imaging of Vibrations and if so, to assess reference values.

Design. Repeated *in vivo* Doppler Imaging of Vibrations measurements at the first tarsometatarsal joint in healthy persons.

Background. Clinical hypermobility of the first tarsometatarsal joint is an important factor in a hallux valgus deformity. No objective and non-invasive test is available to quantify first tarsometatarsal joint mobility. Doppler Imaging of Vibrations, a technique recently developed to measure joint stiffness, might be an effective tool to quantify stiffness of this joint.

Methods. Vibrations were applied to the head of the first metatarsal in 46 feet of 23 healthy subjects and picked up by a transducer at both sides of the first tarsometatarsal joint. A pilot study was performed on three *patients* with hypermobility of the first tarsometatarsal joint. Measurements are expressed in threshold units related to Colour Doppler Imaging.

Results. The values of the threshold units were found to be very similar in healthy persons, with a good repeatibility; 95% of the healthy persons had a threshold unit below 3.4. No significant difference was found between the left and right foot, nor between male and female subjects. Also there was no significant correlation with age or weight of the subjects. In the three patients with first tarsometatarsal hypermobility we found threshold units above 5.

Conclusions. With Doppler Imaging of Vibrations first tarsometatarsal joint stiffness can be measured in healthy persons in a non-invasive and objective way. In a pilot study three patients with first tarsometatarsal hypermobility showed lower stiffness values than the healthy subjects.

Relevance

This study presents a new method for quantification of first tarsometatarsal joint stiffness and provides reference values in healthy persons. First measurements on patients gave promising results to future use of this method for assessment of clinical hypermobility in hallux valgus patients.

3.2 Introduction

Controversy exists on the relation between mobility of the first tarsometatarsal (TMT 1) joint and hallux valgus. Some authors [Hansen 1996, Lapidus 1934, Sangeorzan and Hansen 1989] describe hypermobility of this joint as a major factor in the etiology of the hallux valgus complex. Consequently, they advocate a Lapidus procedure (i.e. TMT 1 arthrodesis with repositioning of the first metatarsal in combination with a first metatarso-phalangeal soft tissue procedure) for correction of the hallux valgus [Hansen 1996, Lapidus 1934, Sangeorzan and Hansen 1989]. Others neglect this joint and the importance of its mobility in their recommendations for hallux valgus surgery [Coughlin 1995, Geissele and Stanton 1990, Mann and Coughlin 1981]. Although in general hypermobility in the TMT 1 joint is mentioned as a factor favouring the Lapidus procedure [Hansen 1996, Lapidus 1934, Sangeorzan and Hansen 1989, Coughlin 1996, Johnson and Kile 1994, Myerson et al. 1992], TMT 1 hypermobility cannot be quantified adequately. One clinical test has been described by Klaue [Klaue 1991], but the reliability and reproducibility are not clear. Other studies on the (hyper)mobility of this joint concern an *in vivo* [Klaue et al. 1994] and *in vitro* [Faber et al. 1999] biomechanical study, two radiographic studies with stress in the transversal plane [Johnson and Kile 1994, Romash et al. 1990] and a radiographic study with stress in the sagittal plane [Fritz and Prieskorn 1995]. However, these studies do not solve the problem of normal versus abnormal TMT 1 mobility, since they concern *in vitro* studies, lack the use of a standardized force and/or additional x-rays are required for measurements.
In general, mobility of a joint depends on active factors (such as muscle action) and passive factors (such as joint shape, ligaments and cartilage structure and thickness). These passive factors are responsible for the amount of passive stiffness of the joint. Stiffness of a joint can be defined as the amount of deformation of the joint due to a certain deforming force. In the clinical situation this is difficult to measure. Therefore, mostly mobility is estimated by manipulation only. As a consequence, for some joints mobility cannot be measured

adequately. Recently a method using low energy vibrations has been developed to measure joint stiffness in vivo [Buyruk et al. 1995]. This method, Doppler Imaging of Vibrations, was shown to be reproducible and reliable for the sacro-iliac joint [Buyruk et al.(1) 1995, Buyruk et al.(2) 1995]. The sacro-iliac joint is an articulatio plana with small maximal physiological mobility: translations of approximately 1.5 mm and rotations of approximately 4° were measured by röntgen stereophotogrammetry in vivo [Sturesson 1999]. So, motion in the sacro-iliac joint is difficult to assess clinically when compared with, for example, the elbow or knee joint. For the TMT 1 joint, also a plane joint (articulatio plana), comparable difficulties in clinical measurement of mobility are encountered. The test of Klaue [Klaue 1991], for instance, estimates first metatarsal mobility in the TMT 1 joint in the **sagittal** plane, but causes movements in all joints of the medial column of the foot. No clinical test is available to assess TMT 1 mobility in the **transversal** plane selectively.

Here, Doppler Imaging of Vibrations could be a valuable tool, although it has not yet been used to assess TMT 1 stiffness. The principle of this method is that vibrations are applied to a protuberance of a bone parallel to the plane of the flat joint surfaces at some distance. Simultaneously the vibration intensity of the bones at both sides of the joint is measured by means of Doppler [Buyruk 1995]. When a joint is loose the intensity of the vibrations will differ more than when a joint is stiff. Since low energy vibrations (200 Hz) and ultrasound (Colour Doppler Imaging) is used, the method is non-invasive and patient friendly.

The aims of this study were: (1) to determine whether normal TMT 1 stiffness complies with similarity of the measurements from Doppler Imaging of Vibrations and (2) to assess the precision of Doppler Imaging of Vibrations measurements for the TMT 1 joint (repeatibility) (3) to obtain reference values for Doppler Imaging of Vibrations measured stiffness of the TMT 1 joint of healthy volunteers without a hallux valgus and (4) to determine in a pilot study whether patients with clinically TMT 1 hypermobility have a different Doppler Imaging of Vibrations measured stiffness.

3.3 Methods

3.3.1 Population

Twenty-three healthy persons were tested, 13 men and 10 women: mean age 25.6 (range 17-57 years); mean weight 69.4 (range 51-105 kg) and mean length 176.3 (range 158-192 cm).

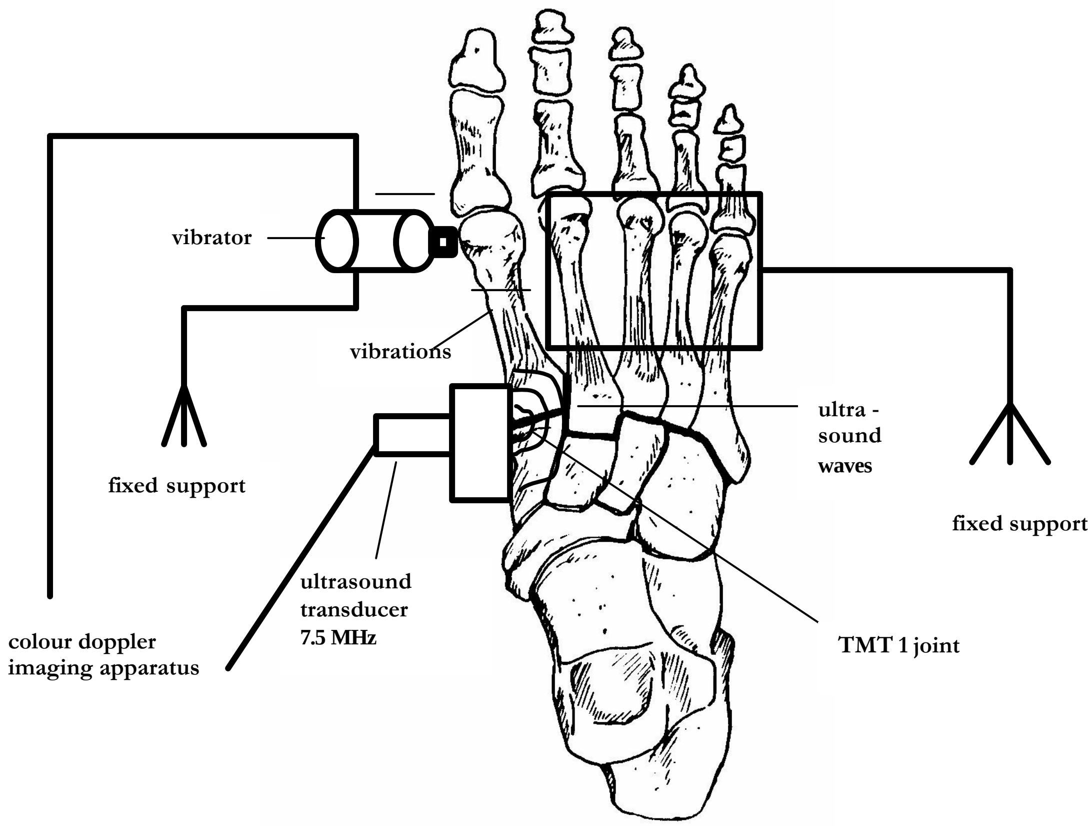
Excluded from the study were persons with complaints of the feet, cavus or flatfoot deformity, hallux valgus deformity, operations on the feet, and inflammatory diseases as rheumatoid arthritis. Persons with chronic ankle instability were also excluded, as well as persons with arthrosis of the first metatarso-phalangeal joint. The latter was tested by walking tip-toe and clinical measurement of the first metatarso-phalangeal joint mobility. In addition, three patients with a hallux valgus deformity and clinical TMT 1 hypermobility were tested. All subjects gave their written informed consent.

3.3.2 Joint stiffness measurement

The experimental set-up for Doppler Imaging of Vibrations [Buyruk 1997] was similar to that used in the *in vivo* sacro-iliac joint measurements [Buyruk 1995]. A drawing of the experimental set-up is shown in figure 1. Excitations were generated by a Derritron VP3 vibrator with a frequency range between 1.4 and 20000 Hz (Derritron Electronics Ltd, Hastings, England). A Colour Doppler Imaging scan (Quantum Angio Dynograph 1, Philips Ultrasound Inc., Santa Ana, California, USA) was used to produce the Doppler Imaging of Vibrations images. Vibrations with an amplitude not exceeding 0.1mm and a frequency of 200 Hz were applied to the medial side of the head of the first metatarsal near the metatarso-phalangeal joint. These vibrations with low energy have been shown to be safe and useful for this kind of measurements [Buyruk 1995]. The vibrations propagate proximally in the foot hrough the first metatarsal to the TMT 1 joint. In a loose joint only a part of the vibration energy will be transmitted to the adjacent bone. The vibrations at both sides of the joint are picked up by the Colour Doppler Imaging transducer which covers the two parts of the TMT 1 joint: the medial cuneiform and the first metatarsal. The intensity of the vibration pixels of the first metatarsal and medial cuneiform appear simultaneously on the monitor at high threshold values (dimension dB). Using the threshold button on the control panel of the Colour Doppler Imaging apparatus allows measurements by comparing the vibrating intensity at the side of the first metatarsal and at the side of the medial cuneiform as follows. At first, a threshold level is found at which the colour of the vibrating medial cuneiform disappears and changes to grey scale. Next, a second threshold level is found for the first metatarsal. Since the threshold levels are directly related to the vibration intensity of the bone, a large difference between the threshold levels of the medial cuneiform and the first metatarsal indicates a large difference of intensity between the adjacent bones. This implies an unstiff joint. A small difference, or the absence of it, implies a stiff joint. This difference in threshold levels is expressed in **threshold units**. This (indirect) method of measurement is chosen, because TMT 1 stiffness values with the dimension N/m or Nm/rad can at present not be determined in vivo non-invasively. The measurements were performed in unloaded position, so stiffness values found are representative for the neutral zone.

FIGURE 1
Experimental set-up of the Doppler Imaging of Vibrations stiffness measurement.

The vibrator is placed against the head of the first metatarsal; the ultrasound transducer is placed over the first tarsometatarsal joint and the foot rests on a support. The first tarsometatarsal joint is indicated.



3.3.3 Methodology

All persons were tested in a standard position: supine on a bed in a relaxed semi-sitting position with the tested foot resting on a support, to exclude the influence of muscle tension. For calculation of the repeatibility, measurements were performed three times and both feet were tested. Between the measurements the subject removed the foot from the support and performed some bending and stretching exercises with the knee and ankle. Testing occurred by one examiner, in the same room, at constant room temperature.

3.3.4 Data analysis

Data were collected in an Excel 5.0 file and the statistical program SPSS was used for analysis. The Mann-Whitney test and the paired Wilcoxon test were used for testing the dependency of the Doppler Imaging of Vibrations threshold units on gender and side, respectively. Spearman's rank correlation coefficient was used to test a monotonic relationship of threshold units with age and weight. Balanced three-way analysis of variance with random effects was used for estimating total variance of threshold units and its components: inter-individual and intra-individual. The latter component was further subdivided in between-feet (nested intra-individual) and within feet. Estimated intra-individual variance was used to calculate the repeatibility. Estimated total variance and mean were used to calculate the 95^{th} percentile (P95) in healthy persons.

3.4 Results

As seen in Table 1 the TMT 1 stiffness levels in threshold units ranged from 0 to 4. There was a small inter-individual variance component in this group of healthy subjects. The total variance of threshold units was mainly due to intra-individual variability. This intra-individual variance is the total of between-feet (nested intra-individual) and within-feet variance. The total variance equals 0.83, i.e. the sum of 0.09 (inter-individual variance) and 0.74 (intra-individual variance); the latter component is the sum of 0.26 (between-feet nested intra-individual) and 0.48 (within-feet). The mean threshold units equals 1.88. The P95 of the threshold units distribution can be calculated as 1.88 + 1.6449 x v0.83 = 3.4. This implies

Table 1.
Characteristics of the population and threshold units of the three measurements of the left and right foot
(*n* = 23)

	age	length	weight	threshold units					
	(years)	(cm)	(kg)	left 1	right 1	left 2	right 2	left 3	right 3
mean	25.6	176.3	69.4	1.70	1.78	2.0	1.96	2.09	1.74
range	17-57	158-192	51-105	0-3	0-4	0-4	0-3	1-4	0-3
SD	7.8	9.1	9.6	0.63	0.63	0.61	0.84	0.72	0.84

that 95% of the healthy population has a threshold unit below 3.4.
Repeatibility is calculated as the value that will not be exceeded by 95% of the absolute differences between two repeated measurements of the threshold units in the same subject: 1.96 x v(2 x 0.74) = 2.4.
There was no significant difference of the threshold units (intra-individual averages) between the left and right foot (Wilcoxon test: p=0.61) and no significant difference between female and male subjects (Mann-Whitney Test; p= 0.17).
The scattergrams of the threshold units versus the age and weight of the 23 subjects are shown in figure 2 and 3 respectively. These figures show the absence of a significant correlation with age or weight (Spearman’s rank correlation coefficients resp 0.16 and 0.09, with p-values 0.47 and 0.69, respectively).
In a pilot study, three hallux valgus patients (mean age 41.9 years; range 30-75) with clinically hypermobile TMT 1 joints were found to have mean threshold units of 6.33 (range 5-8; SD 1.16).

Figure 2

Plot of threshold units with age

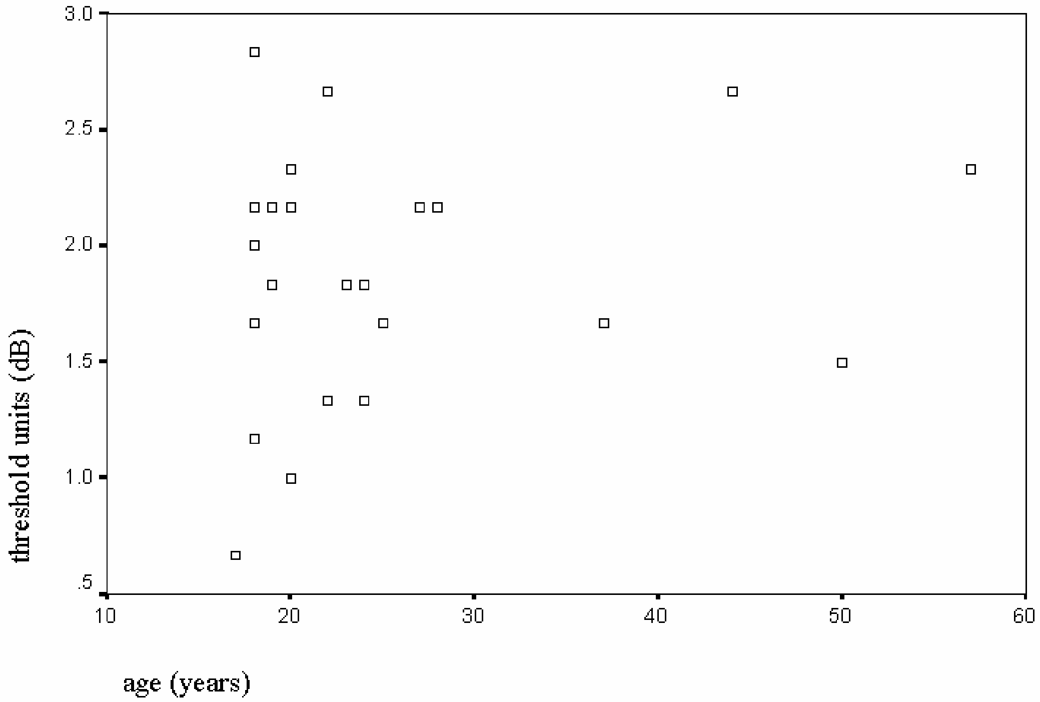
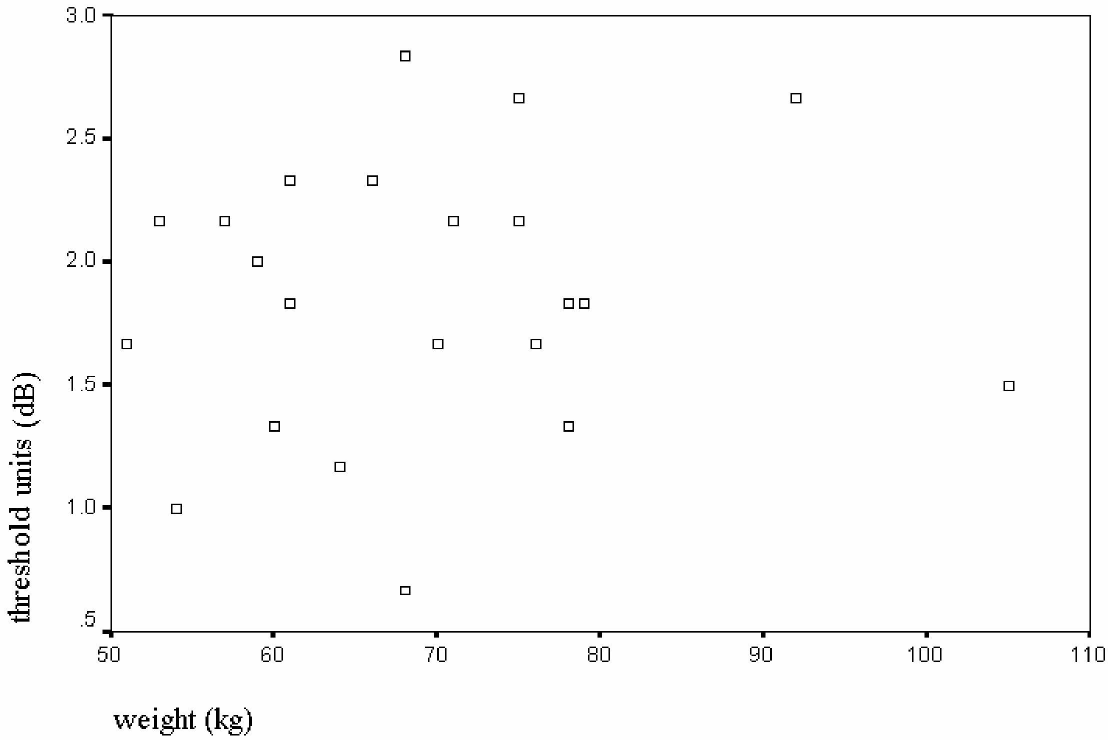


Figure 3

Plot of threshold units with weight



3.5 Discussion

The choice for a Lapidus procedure in the treatment of a hallux valgus deformity is mainly based on the diagnosis of hypermobility of the TMT 1 joint [Hansen 1996, Lapidus 1934, Sangeorzan and Hansen 1989, Johnson and Kile 1994, Myerson et al. 1992]. However, non-specific tests such as the clinical test described by Klaue [Klaue 1991] have been used to assess whether the TMT 1 joint is hypermobile. TMT 1 mobility in vivo has been examined radiographically by Fritz and Prieskorn [Fritz and Prieskorn 1995] in healthy volunteers. In the sagittal plane the normal range of motion was 4.3°. Lundberg et al.[Lundberg et al.1989] found no motion above 2° in the TMT 1 joint with röntgen stereophotogrammetry in eight healthy volunteers. Both studies were performed weight bearing.

In the present study we applied Doppler Imaging of Vibrations to assess the stiffness of the TMT 1 joint. To exclude the influence of muscle tension, we performed the experiment without weight bearing, with the foot resting on a support to measure the amount of passive stiffness. Because of the very small amplitude of the vibration, far below the physiological range of motion of joints, Doppler Imaging of Vibrations does not give an indication of the maximal excursions of a joint, but of the amount of stiffness. In unloaded position this stiffness reflects the neutral zone. It is clear that stiffness and mobility of a joint are related.

It proved to be possible to visualize the vibration differences at both sides of the TMT 1 joint. In a previous study with the use of Doppler Imaging of Vibrations on the sacro-iliac joints Buyruk et al. studied the subjects in three sessions with three repetitions [Buyruk et al. 1995]. Since no difference between the sessions was found, we restricted measurements to one session. Our test population consisted of men and women aged between 17 and 57 years; both feet were measured. The repeatibility of 2.4 represents a good precision of the measurements. It means that a difference larger than 2.4 threshold units between two repeated measurements may be indicative for a real change in stiffness, other conditions remaining the same. The relatively small inter-individual variance of 0.09 (as compared to a total variance of 0.83) we found, confirms the high similarity of the stiffness levels between healthy subjects with normal TMT 1 joints. This implies that healthy persons with normal stiffness of the TMT 1 joint could not be distinguished from one another, but might be expected to be distinguishable from subjects with unstiff TMT 1 joints. The relatively low threshold units of the TMT 1 joint found in healthy subjects (< 4) compared to hypermobile TMT 1 joints (>5) indicate that in normal healthy persons the TMT 1 joint is a stiff joint. This is in accordance with the broadly accepted clinical finding of stability of the medial column in the normal foot and is in line with the data of Lundberg et al. [Lundberg et al. 1989]; using roentgen stereophotogrammetry they found very little movement for the *in vivo* TMT 1 joint. Also in the cadaver study of Ouzounian and Shereff [Ouzounian and Shereff 1989] little movement of the TMT 1 joint was found. So, the relatively low values found in the present study are not surprising. We presently apply this technique to hallux valgus patients to correlate Doppler Imaging of Vibrations findings with the clinical mobility test as described by Klaue [Klaue 1991]: displacement of the first metatarsal head more than 10 mm is considered as hypermobility of the TMT 1 joint. For the sacro-iliac joint no such clinical mobility test exists, because excursions of this joint physiologically do not exceed 1.5 mm. This is beyond human observability and an order of a magnitude smaller than the Klaue test. The preliminary results of the first three patients with clinically definite hypermobile TMT 1 joints are promising: three women had threshold units with a mean of 6.33 (range 5-8; standard deviation 1.16). Obviously, these threshold units are much larger than those of normal feet, with a reference P95 value of 3.4 and a range of 0-4.

No correlation was found between threshold units and age or weight, whereas in the study of Wanivenhaus and Pretterklieber [Wanivenhaus and Pretterklieber 1989] *in vitro* TMT 1 joint mobility was relatively high in old persons. The authors ascribed this to possible degeneration of the ligaments around this joint. These discrepancies may be due to *in vivo-in vitro* differences, methodological differences and a lower mean age of the investigated population in our study: 25.6 years (range 17-57 years) versus 68 years (range 20-92 years).

No significant difference was found between male and female subjects. This is a relevant result, because in the clinical situation patients with a hallux valgus deformity are predominantly women; according to Mann and Coughlin [Mann and Coughlin1996] the ratio is 9:1.

As to be expected, no significant difference was found between left and right feet. This is in accordance with the previous sacro-iliac joint study on healthy subjects [Byuruk 1995].

3.6 Conclusions

The results of this pilot study show that Doppler Imaging of Vibrations can be used for assessing stiffness of the TMT 1 joint in healthy persons. A threshold unit, measured by Doppler Imaging of Vibrations, less than 3.4 can be considered as a reference P95 value for the stiffness of the TMT 1 joint in healthy persons. Although preliminary data obtained in hallux valgus patients with, clinically assessed, hypermobile TMT 1 joints show much higher threshold units, it is necessary to evaluate further the clinical value of stiffness measurements by Doppler Imaging of Vibrations in hallux valgus patients in relation to TMT 1 (hyper)mobility.

4 Quantification of first tarsometatarsal joint stiffness in hallux valgus patients

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Clin Biomech 2001;16:714-716.

4.1 Abstract

Objective. Comparison of the clinical mobility test of the first tarsometatarsal joint with Doppler Imaging of Vibrations measurement of the stiffness of this joint in hallux valgus patients.

Design. Clinical testing of first tarsometatarsal joint mobility was related to independent Doppler Imaging of Vibrations measurement of first tarsometatarsal joint stiffness.

Background. Hypermobility of the first tarsometatarsal joint has consequences for the surgical treatment of hallux valgus deformity. However, the clinical test is subjective. Doppler Imaging of Vibrations could be helpful in quantification of the stiffness of this joint.

Methods. Clinical examination of the mobility of 32 first tarsometatarsal joints in 20 hallux valgus patients was compared with Doppler Imaging of Vibrations stiffness measurements performed by an independent observer.

Results. There was a statistically significant relation between the clinical test and the stiffness measurement by Doppler Imaging of Vibrations.

Conclusion. Doppler Imaging of Vibrations proves to be a method to quantify first tarsometatarsal joint stiffness and could contribute to a rational policy for the surgical treatment of hallux valgus deformity.

Relevance

The clinical test to establish hypermobility of the first tarsometatarsal joint is subjective. Doppler Imaging of Vibrations offers objective criteria and quantification of first tarsometatarsal joint stiffness. This provides additional information for the choice of the surgical procedure to correct hallux valgus deformity.

4.2 Introduction

The role of hypermobility of the first tarsometatarsal (TMT 1) joint in the etiology and surgical treatment of a hallux valgus deformity is still controversial. In general, in hallux valgus surgery, hypermobility of the TMT 1 joint is considered a factor requiring correction by a Lapidus procedure [Coughlin 1996, Myerson et al. 1992, Sangeorzan and Hansen 1989]. This is a TMT 1 arthrodesis with repositioning of the first metatarsal bone in combination with a first metatarso-phalangeal soft tissue procedure. However, TMT 1 hypermobility cannot be quantified adequately; with the only clinical test available, Klaues test [Klaue 1991], TMT 1 (hyper)mobility cannot be assessed objectively. In general, mobility of a joint is related to stiffness of this joint. Recently, a method using vibrations has been developed to measure joint stiffness in flat joints (articulatio plana) *in vivo*: Doppler Imaging of Vibrations (DIV) [Buyruk et al. 1995]. The principle of this method is explained in a previous study [Buyruk et al 1995]. Since low energy vibrations (200 Hz) and ultrasound (Colour Doppler Imaging) is used, this non-invasive method is patient friendly. DIV was shown to be reproducible and reliable for the sacro-iliac joint [Buyruk et al 1995]. In a previous study we applied this technique to the TMT 1 joint [Faber et al. 2000]. This study concerned healthy volunteers (without hallux valgus deformity) and produced DIV reference values for TMT 1 joint stiffness. In the present study DIV was applied to the TMT 1 joint in hallux valgus patients.

The aim of the present study was to relate the outcomes of the clinical test for TMT 1 joint mobility to DIV stiffness measurements of the TMT 1 joint.

4.3 Methods

Patients with a painful hallux valgus deformity who were planned for operative correction were asked to participate. Excluded were patients with systemic inflammatory diseases, patients who underwent previous operations on the foot and patients with clinical or radiographic arthritis of the first metatarso-phalangeal or TMT 1 joint. The study was approved by the medical ethical committee of the University Hospital Dijkzigt. All patients gave their written informed consent.

Twenty patients were included in the study. After applying the exclusion criteria, 32 feet remained for examination. The clinical TMT 1 mobility test was performed according to Klaue[4]. All feet were independently examined twice by two investigators. After clinical testing a third, independent, investigator performed DIV measurements of TMT 1 stiffness as described in a previous study [Faber et al. 2000].

The Kruskal-Wallis test for non parametrical one-way analysis of variance was used for comparing the DIV measurements with the clinical test. Statistical significance was set at $p < 0.05$.

4.4 Results

The relation between the clinical test and the DIV measurement is shown in Table 1. The relation is studied in two ways. First, the feet were divided into three groups according to the clinical examination: 9 TMT 1 joints *not* hypermobile (i.e. both observers found a stable joint at both examinations), 17 *indistinctly* mobile (one or two of the four observations differed) and 6 *unequivocally* hypermobile (both observers found a hypermobile joint at both examinations). A statistically significant relation was demonstrated between these groups and the DIV values (Kruskal-Wallis test; $p = 0.008$). This means low DIV values for clinically non-hypermobile TMT 1 joints and high DIV values for clinically hypermobile joints.

Table 1.
Results of clinical mobility and DIV stiffness measurements of the TMT 1 joint. (n=32)

	mean DIV[1)] **stiffnes** (in threshold units)	**standard deviation**	**statistical significance**
not hypermobile (n=9) (4 similar observations)	2.56	1.01	
indistinctly mobile (n=17) (2 or 3 similar observations)	3.98	1.42	p = 0.008
hypermobile (n=6) (4 similar observations)	5.11	1.67	
not hypermobile (n=15) (3 or 4 similar observations)	3.09	1.21	
indistinctly mobile (n=5) (2 similar observations)	4.00	2.04	p = 0.049
hypermobile (n=12) (3 or 4 similar observations)	4.58	1.57	

[1)] DIV = Doppler Imaging of Vibrations

In the upper part of the table joints were assigned not hypermobile, indistinctly mobile or hypermobile by applying stricter criteria. For example in the upper half of the table, a joint was named 'hypermobile' when *all* four observations were similar; in the lower part 'hypermobile' was assigned to a joint when three *or* four observations were similar.
In both stratification strategies statistical significance was reached.

When groups were differently stratified (when three of the four observations were the same this was considered as *unequivocal*) the results were: 15 TMT 1 joints *not* hypermobile, 5 *indistinctly* mobile and 12 *unequivocally* hypermobile. Again, the same statistically significant relation is found (Kruskal-Wallis test p = 0.049).

4.5 Discussion

The choice for a Lapidus procedure in the surgical treatment of hallux valgus deformity is mainly based on the clinical diagnosis of hypermobility of the TMT 1 joint [Coughlin 1996, Myerson et al. 1992, Sangeorzan and Hansen 1989]. However, only non-specific, subjective tests such as the clinical test described by Klaue [Klaue 1991] can be used to assess TMT 1 hypermobility. Valid and objective tests with quantifiable results are not available but, considering the consequences, are certainly needed.

In general, stability of a joint depends on active factors (such as muscle action) and passive factors (such as joint shape, ligaments and cartilage structure and thickness). These passive factors are responsible for the amount of passive stiffness of the joint. Because of the very small amplitude of the vibrations (far below the physiological range of motion of joints) DIV does not give an indication of the maximal excursions of a joint, but gives a measure of stiffness. Somehow, stiffness and mobility of a joint are related. So, DIV stiffness measurements of the TMT 1 joint could be helpful in distinguishing between clinically hypermobile and non-hypermobile TMT 1 joints.

A previous study with this method on the TMT 1 joint in healthy subjects provided reference values: 95 percent of the subjects had a stiffness value below 3.4 [Faber et al. 2000]. This means the normal TMT 1 joint is stiff. Our results show a statistically significant relation between clinically tested TMT 1 mobility and DIV stiffness measurement. DIV values were proportionally related to clinically assessed mobility values: high DIV stiffness values in clinically hypermobile TMT 1 joints and low values in non-hypermobile TMT 1 joints. Considering this, DIV could be a helpful tool in stratifying the diffuse group of ‘indistinctly mobile’ TMT 1 joints. When the clinical test is not unequivocal, a DIV stiffness value of, for example, 5 threshold units could be the cut–off point from which a patient should be classified as having a hypermobile TMT 1 joint and hence a rational choice for a Lapidus procedure can be made.

In conclusion: DIV stiffness measurement of the TMT 1 joint, as an objective test with quantifiable results, provides additional information to the clinical TMT 1 mobility test. Thus, it can support and rationalize the choice for a specific surgical procedure in hallux valgus deformity.

5 Mobility of the first tarsometatarsal joint in hallux valgus patients: a radiographic analysis

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Foot Ankle Int 2001;22:965-969.

5.1 Abstract

Hypermobility of the first tarsometatarsal (TMT 1) joint in the sagittal plane plays a role in the etiology and treatment of the hallux valgus complex. However, objective quantification of this mobility is still a problem. We performed a radiographic analysis of TMT 1 mobility in the sagittal plane in 94 hallux valgus patients aged 15- 65 years. We examined 94 feet with symptomatic hallux valgus deformity requiring operative correction. Excluded were patients with osteoarthritis, inflammatory diseases or previous operations on the foot. The TMT 1 mobility was tested with a clinical test and by radiographic measurement using the modified Coleman block test.

The mean mobility of the TMT 1 joint in the sagittal plane in the patient group was 12.9° (SD 4.80). In addition, there was a statistically significant difference between two subgroups: patients with and without clinical TMT 1 hypermobility. No correlation of TMT 1 (hyper)mobility and radiographic second ray hypertrophy was found.

This simple method can produce additional information to the clinical TMT 1 hypermobility test in the sagittal plane.

5.2 Introduction

The role of hypermobility of the first tarsometatarsal joint in the etiology and treatment of the hallux valgus complex is still unclear. In general, hypermobility in the TMT 1 joint in hallux valgus patients is considered to be a factor requiring correction [Coughlin 1996, Hansen 1996, Hofbauer and Grossman 1996, Johnson and Kile 1994, Myerson 1990]. So, additional to a first metatarsophalangeal (MTP1) soft tissue procedure, a TMT 1 arthrodesis can be performed (Lapidus procedure) [Butson 1980, Lapidus 1934, Mauldin et al. 1990, Myerson et al. 1992, Saffo et al. 1989, Sangeorzan and Hansen 1989]. However, TMT 1 hypermobility cannot be quantified adequately. The clinical test to determine TMT 1 hypermobility in the sagittal plane is generally performed [Bednarz and Manoli 2000, Bordelon 1996], but its interpretation is subjective and no clear criteria are given for the classification 'hypermobility'. Klaue describes the most precise clinical criteria concerning when to classify the TMT 1 joint as hypermobile [Klaue 1991]. Several studies have been performed to measure (hyper)mobility in the TMT 1 joint in an objective and quantifiable way. They have different methodological disadvantages. The biomechanical study of Klaue [Klaue et al. 1994] showed a significant difference in TMT 1 mobility in the sagittal plane when feet with and without a hallux valgus deformity were compared. However, a special device was used, and the applied force was not standardized. Glasoe [Glasoe et al. 1999] also reported about TMT 1 mobility using another special device on cadavers and later on hallux valgus patients [Glasoe et al. 2001]. Their device was shown to be reliable [Glasoe et al. 1999] and an increased mobility was demonstrated in hallux valgus patients [Glasoe et al. 2001]. This device, however, is not widely available. Ito also described increased mobility in the sagittal plane in hallux valgus patients, but the radiographic measurements were not specific for the TMT 1 joint [Ito et al. 1999]. Lundberg performed a roentgen stereophotogrammetrical study in healthy volunteers [Lundberg et al. 1989]. This required an invasive procedure: implantation of tantalum markers. At the moment in daily practice, the clinician, who has to decide whether to perform a Lapidus procedure or not on a certain patient, has to rely on qualitative parameters to assess TMT 1 hypermobility. The direct measurement of TMT 1 hypermobility is described by Bednarz and Klaue [Bednarz and Manoli 2000, Klaue 1991]: with the ankle in neutral position, the metatarsals II-V are stabilized with one hand. The other hand is dorsiflecting the first metatarsal (MT 1) head. Hypermobility of the TMT 1 joint is defined as displacement more than 8 to 10 mm without a firm endpoint [Klaue 1991]. Because the interpretation of these parameters is subjective and previously described testing devices [Glasoe et al. 2001, Klaue et al. 1994] not available, a simple test without requiring special equipment is needed in order to support the clinical diagnosis of hypermobility of the TMT 1 joint. Fritz [Fritz and Prieskorn 1995] performed a radiographic study using the body weight to create stress in the sagittal plane to provide a reference value for TMT 1 mobility in healthy subjects. Except for a simple wooden block, this method (the modified Coleman block test) does not require special equipment to assess objective and quantifiable values for TMT 1 mobility. We used this modified Coleman block test in symptomatic hallux valgus patients.

Indirectly, clinical signs of second ray overload in hallux valgus deformity can be an indication of TMT 1 hypermobility in the sagittal plane [Hofbauer and Grossman 1996, Klaue et al. 1994, Myerson 1990]. Radiographically this is represented by hypertrophy of the medial cortex of the second metatarsal (MT2) [Myerson et al. 1992, Sangeorzan and Hansen 1989]. We studied radiographic second ray hypertrophy, assessed by plain radiography, in our group of symptomatic hallux valgus patients. Prieskorn evaluated thickness of MT2 in healthy subjects, without first ray instability [Prieskorn et al. 1996]. They found no correlation between TMT 1 motion and thickness of the medial cortex of MT2.

The purpose of the current study, performed on hallux valgus patients, was to

1) define a radiographic value for TMT 1 mobility in hallux valgus patients
2) determine whether a distinction could be made with this radiographic measurement between clinically hypermobile and non-hypermobile TMT 1 joints and
3) investigate whether TMT 1 mobility, as assessed by plain radiography, was correlated to second ray hypertrophy, also assessed by plain radiography .

5.3 Patients and methods

In 94 patients (90 female and 4 male) 109 feet had symptomatic hallux valgus deformity requiring operative correction, not being a MTP 1 arthrodesis. From the 15 patients with bilateral involvement, only one side, the first foot to be operated, was included in this study. Excluded were patients younger than 15 years and older than 65 years, patients with rheumatoid or other inflammatory diseases and patients who previously had an operation on the symptomatic foot. Also excluded were patients with osteoarthritis of the TMT 1 joint and patients with moderate or severe osteoarthritis of the MTP 1 joint. To define moderate or severe osteoarthritis the following parameters were used: 1) a total range of motion less than 50° degrees and/or 2) grade 3 or 4 radiographic osteoarthritis [Mann et al. 1992]. Before examination all patients gave their written informed consent; the study was approved by the local medical ethical committee. All patients were examined clinically by the same observer (FF). Routine examination for a hallux valgus deformity was performed, including the TMT 1 mobility test as described previously [Bednarz and Manoli 2000, Bordelon 1996, Klaue 1991, Myerson 1990]. With the ankle in neutral position, the metatarsals II-V were stabilized with one hand. The other hand was dorsiflecting the first metatarsal (MT 1) head. Hypermobility of the TMT 1 joint is defined according to Klaue [Klaue 1991] as displacement more than 8 to 10 mm without a firm endpoint. After clinical examination standardized weightbearing dorsoplantar (tube angle 15°) and lateral X-rays (tube distance 100cm) were obtained. Additional lateral films were taken with the TMT 1 joint in dorsiflexion and in plantarflexion utilizing the modified Coleman block test (weight bearing as described by Fritz [Fritz and

Prieskorn 1995]). X-rays were taken with the patient standing on a wooden platform. For the X-ray taken in dorsiflexion, the first ray was on a Plexiglas strut and the rest of the forefoot was allowed unrestricted plantarflexion. For the plantarflexion view, the first ray was allowed to plantarflex as far as possible (without the metatarsal head being restricted) and the rest of the forefoot was stabilized on the Plexiglas strut. On the dorsoplantar view the MTP 1 angle was measured: the angle between the mid-longitudinal axis of MT 1 (drawn by bisecting the diaphyseal portions) and the line connecting the midpoints of the proximal and distal articular surfaces of the proximal phalanx. The intermetatarsal angle was defined as the angle between the mid-longitudinal axis of MT 1 and MT 2, both drawn by bisecting the diaphyseal portions [Smith et al. 1984]. The medial cortical thickness, intramedullary canal width and entire shaft width of MT 2 were measured midshaft. On the lateral X-rays, measurements of the TMT 1 dorsiflexion and plantarflexion views were performed according to Fritz [Fritz and Prieskorn 1995]: the horizontal line was drawn from the corner of the cuneiform opposite to the corner of the first metatarsal at the TMT 1 joint to the dorsal edge of the head of MT1. The vertical line was drawn from this same corner to the plantar corner of the cuneiform opposite to the plantar corner of the base of MT 1. These two lines make an angle in both views. The difference between the angles in dorsiflexion and plantar flexion is considered as a measure for passive mobility of the TMT 1 joint: radiographic sagittal range of motion (RSROM) (Fig. 1). The same examiner, using the same reference points and angles, measured all radiographs. The radiographs were read independently from the clinical data. This same examiner was also present for positioning the patients for each radiograph. In this way, variability in measurements and position was reduced as much as possible.

Figure 1a. TMT 1 joint plantarflexion radiograph: the angle is 84°.

Figure 1b. TMT 1 joint dorsiflexion radiograph: the angle is 106°.

The difference between the angles in dorsiflexion and plantar flexion is the radiographic sagittal range of motion (RSROM): 22°. Note the plantar widening of the TMT 1 joint in the dorsiflexion radiograph.

TMT 1 = first tarsometatarsal

Statistics

Data were collected in Excel 5.0 and SPSS was used for statistical analysis. The unpaired Student's *t*-test was used for comparing the TMT 1 RSROM in the two groups (clinically hypermobile and non-hypermobile). Logistic regression analysis was used for estimating the probability of hypermobility as a function of TMT 1 RSROM. Sensitivity and specificity in relation to the presence or absence of hypermobility were plotted against various cut-off levels of TMT1 RSROM. The Pearson correlation test was used for testing linear relationships between the TMT 1 RSROM and numeric variables as thickness of the medial cortex of MT2 (MCMT2), ratio of the thickness of the medial cortex of MT2 divided by the intramedullary canal of MT2 (MC/MK MT2), and the ratio of the thickness of the medial cortex of MT2 divided by the entire midshaft width of MT2 (MC/shaft MT2). For each test statistical significance was set at $P < 0.05$.

5.4 Results

The mean age of the patients was 41.4 years (range 15-63 years); mean weight 66,6 kg (range 43-95 kg) and mean length 165 cm (range 150-182 cm).

The mean MTP 1 angle was 32° (range 14°- 53°) and the mean intermetatarsal angle was 13° (range 7°- 22°). In 60 feet the TMT 1 joint was clinically considered to be hypermobile and in 34 feet as non-hypermobile. These two groups were comparable regarding mean age (41.8 vs 40.8 years respectively), and mean Kitaoka score [Kitaoka 1994] (57.1 vs. 57.3 respectively); the mean MTP 1 angle differed slightly: 33.0° versus 29.9° respectively.

Table 1 shows the mean TMT 1 RSROM in the total group and in the two subgroups of clinically hypermobile and non-hypermobile TMT 1 joints. A statistically significant difference between these two groups was found: Student's *t*-test; p =0.002.

Table 1.

Radiographic sagittal range of motion of the first tarsometatarsal joint..

RSROM	**total group (N = 94)**	**TMT 1 hypermobility (N = 60)**	**normal TMT 1 mobility (N = 34)**
mean (degrees)	12.9	14.0	10.8
range (degrees)	2-26	4-26	2-18
standard deviation	4.80	4.77	4.20
p value		0.002	

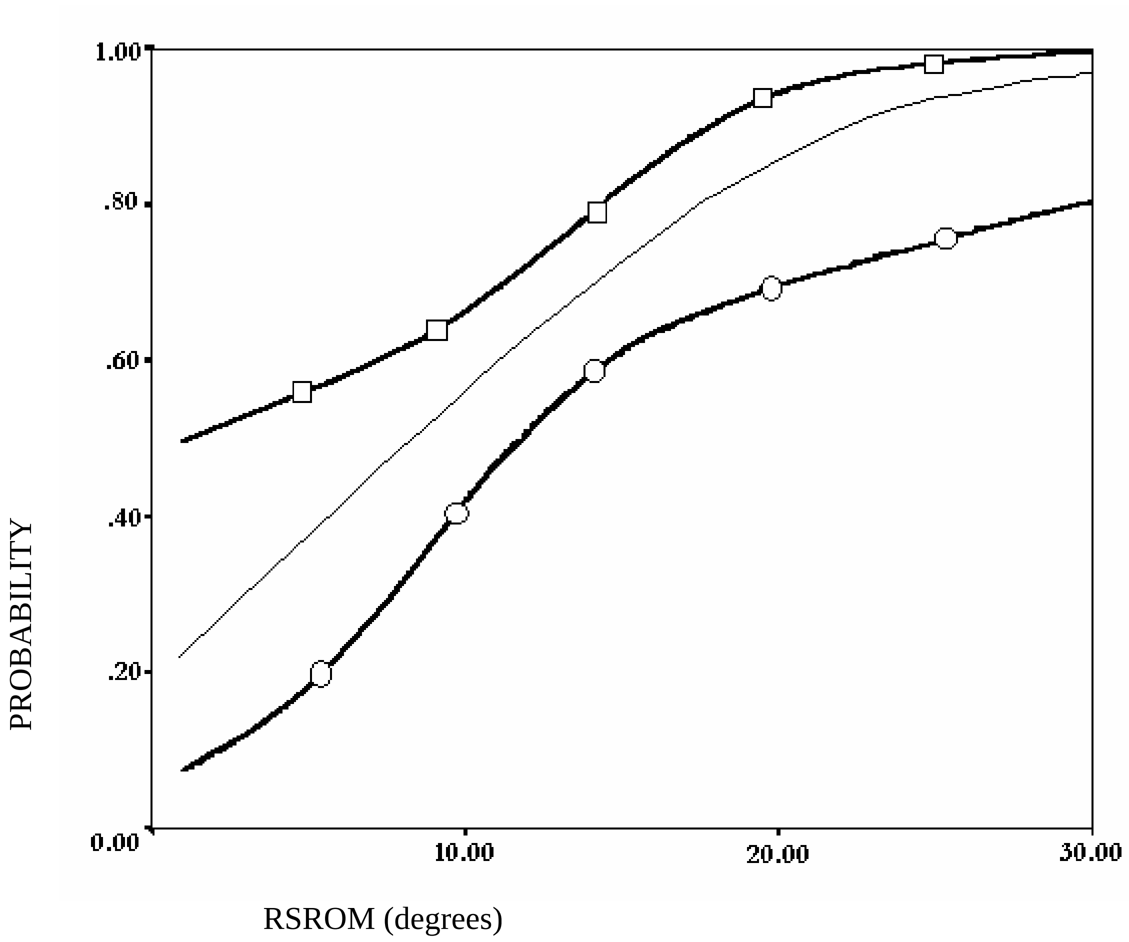
RSROM = radiographic sagittal range of motion

TMT1 = first tarsometatarsal joint

Figure 2 shows the probability of clinical TMT 1 hypermobility as a logistic function of the measured number of RSROM degrees. Of these 94 patients, 60 patients had clinical TMT1 hypermobility. For a proper (unbiased) generalization of the estimated RSROM-dependent probability, it has to be assumed that the prevalence of TMT1 hypermobility (60 out of 94 patients) is more or less representative for the population of hallux valgus patients presenting to an orthopedic surgeon. With 60 out of 94 patients the estimated probabilities are still imprecise; this imprecision is reflected in the 95 % confidence limits for the true probability. For example when a patient has a TMT 1 RSROM of 15°, there is a chance of 0.73 (95% confidence limits: 61-84) that the patient has a clinically hypermobile TMT 1 joint.

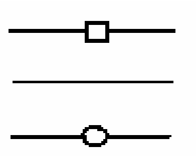
Figure 2.

Plot of the values of TMT 1 RSROM and the probability of hypermobility.



TMT 1 = first tarsometatarsal

RSROM = radiographic sagittal range of motion



= 95% upper confidence limit

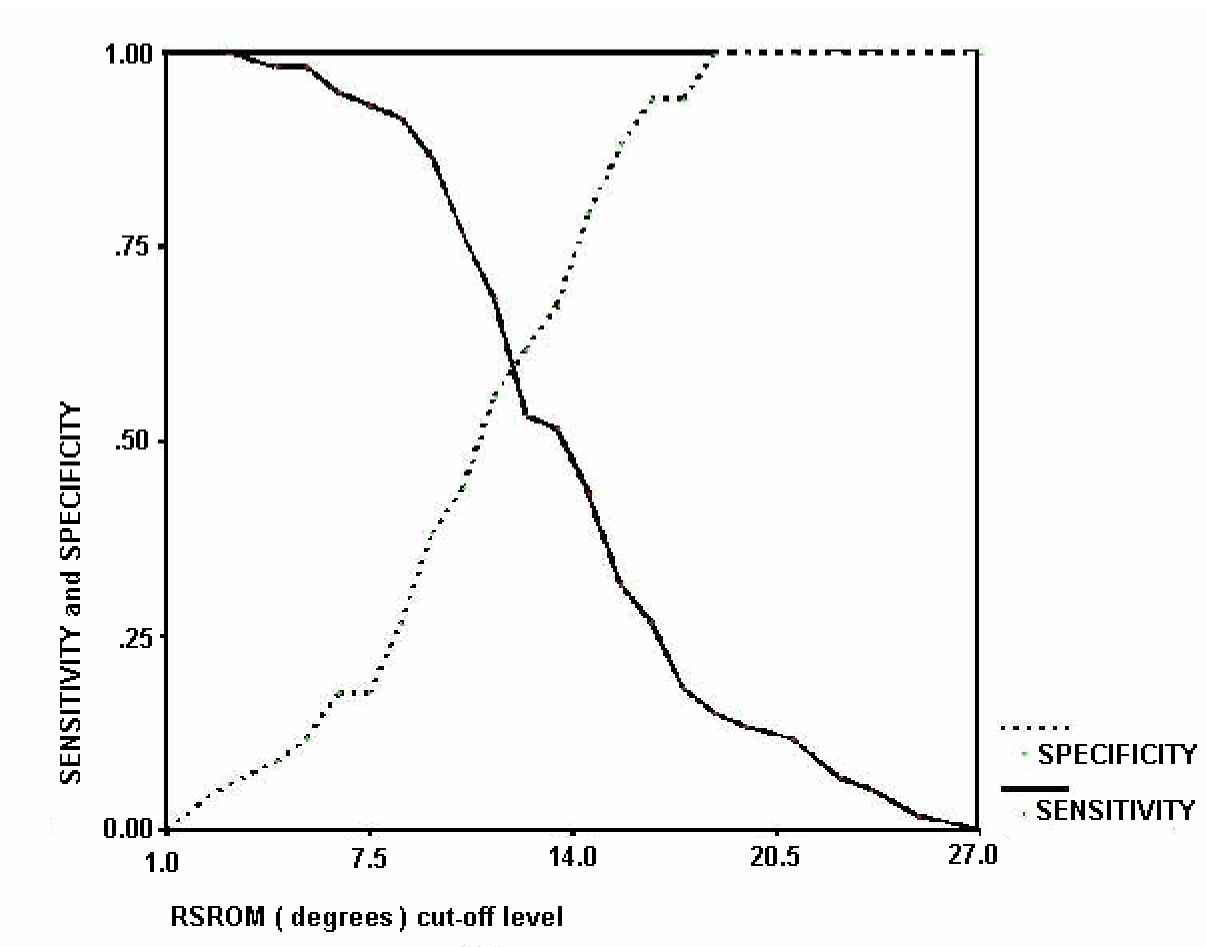
= logistic regression analysis

= 95% lower confidence limit

Considering the RSROM as a diagnostic testing variable its sensitivity and specificity at various cut-off levels of the number of RSROM degrees can be estimated. Patients above the cut-off level are considered to be positive for hypermobility and patients below the cut-off level negative (Fig. 3). The higher the cut-off level is chosen for RSROM, the higher the specificity and the lower the sensitivity. These parameters for using RSROM as a diagnosting testing variable are independent of the prevalence of TMT 1 hypermobility in the population studied.

Figure 3.

Specificity and sensitivity at various cut-off levels of RSROM.



RSROM = radiographic sagittal range of motion

Table 2 shows the correlations between the TMT 1 RSROM and other numeric variables representative for second ray hypertrophy (Pearson's correlations coefficient) and P values. There was no significant correlation between the RSROM and MCMT2, MC/MK MT2 and MC/shaft MT2 neither for the whole group nor for one of the two subgroups.

Table 2.

Correlations between the radiographic sagittal range of motion of the first tarsometatarsal joint and other numeric variables.
(r = Pearson's correlation coefficient and p = p value)

	total **N = 94**	**hypermobility** **N = 60**	**normal mobility** **N = 34**
MCMT 2	r = -0.03 (p = 0.795)	r = -0.04 (p = 0.765)	r = -0.15 (p = 0.403)
MC/MK MT 2	r = -0.14 (p = 0.182)	r = -0.23 (p = 0.074)	r = 0.00 (p = 0.994)
MC/shaft MT 2	r = 0.09 (p = 0.400)	r = -0.12 (p = 0.357)	r = -0.13 (p = 0.464)

MCMT2 : thickness of the medial cortex of the second metatarsal.
MC/MK MT2 : ratio of the thickness of the medial cortex of MT2 divided by the intramedullary canal of MT2.
MC/shaft MT2: ratio of the thickness of the medial cortex of MT2 divided by the entire midshaft width of MT2.

5.5 Discussion

Hypermobility of the TMT 1 joint in the sagittal plane in patients with a hallux valgus may be a relevant factor in deciding which operative procedure should be chosen for correction. However, the reliability and reproducibility of the subjective clinical test generally used [Bednarz and Manoli 2000, Bordelon 1996, Klaue 1991], to determine TMT 1 hypermobility in the sagittal plane are unknown. Besides, this test causes movements in all joints of the first ray. So, a specific and objective test is needed. Fritz [Fritz and Prieskorn 1995] decribed a simple and objective test in a group of healthy persons. They found mean (± SD) motion of the TMT 1 joint in the sagittal plane to be 4.37° (± 3.4°). In our group of hallux valgus patients presented in this study, we found much higher values: 12.9° (± 4.8°). This is an indication that in hallux valgus patients an increased TMT 1 mobility exists in the sagittal plane. This is in accordance with the results of Glasoe, who also found more dorsal mobility of the first ray in hallux valgus patients compared to control subjects [Glasoe et al. 2001].

Our results are also in line with the radiographic study of Ito [Ito et al. 1999] and the biomechanical study of Klaue [Klaue et al. 1994]. The first study showed a difference in mobility in the sagittal plane when patients with a painful hallux valgus were compared with patients with painless hallux valgus deformity; the second study reported a difference between hallux valgus patients and normal feet. This mobility concerned the whole first ray and not exclusively the TMT 1 joint. As in the study of Fritz [Fritz and Prieskorn 1995], our study concerned exclusively the TMT 1 joint. Rush also studied sagittal motion of the first metatarsal [Rush et al. 2000] . They found an increased plantarflexion of the first ray when comparing a corrected position of MT 1 with a varus position of MT 1. Because this study was performed on cadavers and we did not make radiographs with MT 1 in realigned position, the results can hardly be compared.

When TMT 1 mobility in hallux valgus patients with clinically assessed hypermobility in this joint was compared with that of patients without TMT 1 hypermobility, a statistically significant difference was shown. However, because of the great overlap in values, we could not determine one value (cut-off point) to define TMT 1 hypermobility. However, as is shown in Figure 2, the chance of TMT 1 hypermobility increases with higher values of the RSROM. Also, as is shown in Figure 3, if one chooses a higher cut-off level for the RSROM the specificity increases but the sensitivity decreases. So, although we could not obtain one specific radiographic value to define TMT 1 hypermobility, this objective measurement with a simple strut may be used in addition to the clinical test to distinguish between hypermobility and non-hypermobility of the TMT 1 joint in hallux valgus patients.

Hypertrophy of the medial cortex of MT 2, assessed radiographically, is considered to be a sign of hypermobility of the TMT 1 joint [Myerson et al. 1992, Sangeorzan and Hansen 1989]. In a group of 100 healthy subjects, Prieskorn found no correlation between TMT 1 motion in the sagittal plane and parameters like the MCMT2, and the ratio's MC/MK MT 2 and MC/shaft MT2 [Prieskorn et al. 1996]. They suggest that in hallux valgus patients there could be a higher correlation. Because of differences in foot size, the ratio's of MC/MK MT 2 and MC/shaft MT 2 are more useful than the absolute value of MC MT 2. Yet, we found no correlation for all of these parameters with the TMT 1 radiographic sagittal range of motion in our patient group. An explanation for this could be the small values and small differences in the values of the ratio's, which would require an even larger number of patients to make statistical relationships significant. From a clinical point of view, these measurements do not seem to be relevant.

In conclusion, our study on hallux valgus patients showed that with the modified Coleman block test the TMT 1 mobility in the sagittal plane is larger than in a previous study in healthy subjects. Furthermore, with this method a statistically significant difference was found between clinically hypermobile and non-hypermobile TMT 1 joints. So, this simple and objective method could be a valuable tool in distinguishing between hypermobility and non-hypermobility of the TMT 1 joint. No correlation between TMT 1 mobility in the sagittal plane and radiographic second ray hypertrophy was found.

6 No difference in results between the Hohmann and Lapidus procedure in hallux valgus patients; a prospective, blinded randomized trial in 101 feet

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Submitted.

6.1 Abstract

Background: The role of hypermobility of the first tarsometatarsal joint in the etiology of hallux valgus deformity is controversial. Consequently, the necessity of including an arthrodesis of this joint in hallux valgus surgery is questionable.

Methods: A prospective blinded randomized study was performed to compare a distal osteotomy of the first metatarsal (Hohmann procedure) and an arthrodesis of the first tarsometatarsal joint combined with a first metatarsal-phalangeal soft tissue procedure (Lapidus procedure) for correction of a symptomatic hallux valgus deformity. 101 feet of eighty-seven patients were operated: fifty Hohmann procedures and fifty-one Lapidus procedures were performed. The mobility of the first tarsometatarsal joint was determined pre-operatively by clinical examination. Based on this examination, two subgroups were distinguished: feet with hypermobile (sixty-eight) versus feet with non-hypermobile first tarsometatarsal joints (thiry-three). The follow-up period was two years.

Results: There was a statistically significant improvement of the American Orthopaedic Foot and Ankle Society hallux metatarsophalangeal-interphalangeal scale (AOFAS) and in pain score in both procedures. With the numbers available, there was no statistically significant difference between the two procedures, nor did this difference significantly depend on subgroup (hypermobile versus non-hypermobile). Also, the satisfaction rate did not differ between the two procedures, nor between the two subgroups. The radiographic results of the two methods were also similar, except for shortening of the first metatarsal, which was significantly larger in the Hohmann group. Complications necessitating re-operation occurred in the Hohmann group once for non-union, and twice for undercorrection/recurrence of the hallux valgus deformity. In the Lapidus group these numbers were once for non-union and once for undercorrection/recurrence; also seven times screw removal under local anaesthesia had to be performed.

Conclusions: These short term results of both procedures were satisfactory and comparable to previous reports about these procedures. On clinical assessment, the statistically non-significant difference in results of both procedures also did not show a statistically significant modification by subgroup (hyper- versus non-hypermobile first tarsometatarsal joints). Thus, the theory that in hallux valgus patients with hypermobile first tarsometatarsal joints a Lapidus procedure should be performed is not supported by this study.

6.2 Introduction

Controversy still exists about the role of (hyper)mobility of the first tarsometatarsal (TMT 1) joint in the etiology of hallux valgus. Recently, studies have been performed to assess (hyper)mobility in the TMT 1 joint [Faber et al. 2001, Glasoe et al. 2001, Ito et al. 1999, Klaue et al. 1994]. These publications report a relation between a painful hallux valgus deformity and hypermobility of the first ray in the sagittal plane.
Some authors described hypermobility of the TMT 1 joint as a major factor in the etiology of the hallux valgus complex. Consequently they advocated inclusion of a TMT 1 arthrodesis in the surgical procedure for correcting a hallux valgus (Lapidus procedure) [Hansen 1996, Lapidus 1934, Sangeorzan and Hansen 1989]. Others neglected this joint and the importance of its mobility in their recommendations for hallux valgus surgery [Coughlin 1995, Geissele and Stanton 1990, Mann and Coughlin 1981].
In general, the surgical procedures for correction of a symptomatic hallux valgus deformity and reports of individual procedures are numerous. Despite this, prospective studies which directly compare the results of two different procedures are relatively uncommon.
A frequently used method is a distal osteotomy of the first metatarsal (MT1): the Hohmann osteotomy, first described by Hohmann in 1925 [Hohmann 1925]. Several authors reported about this procedure [Christensen and Hansen 1995, Copin 1991, Piper et al. 2000, Rowe and Coutinho 1985, Tangen 1971]. The method is simple and the results were usually good, so this operation gained great popularity, especially in Europe. Only three studies comparing the Hohmann procedure with other techniques were published [Das De 1984, Grace et al. 1988, Udin and Dutoit 1992] and all three are retrospective. None of these authors discussed the role of hypermobility of the TMT 1 joint in relation to the hallux valgus deformity. However, hypermobility in the TMT 1 joint in hallux valgus patients is considered to be a factor requiring correction by a Lapidus procedure [Couhlin 1995, Hansen 1996, Hofbauer and Grossman 1996, Johnson and Kile 1994, Lapidus 1934, Mauldin et al. 1990, Myerson 1990,

Myerson et al. 1992, Saffo et al. 1989, Sangeorzan and Hansen 1989]. The results of this procedure were also usually good, but no comparative studies have been performed. Also, TMT 1 hypermobility cannot be quantified adequately. There is a clinical test to determine TMT 1 hypermobility in the sagittal plane [Bednarz and Manoli 2000, Bordelon 1996, Klaue 1991], but its interpretation is subjective and its reliability and reproducibility are still unclear. Therefore, recent studies have been performed to measure (hyper)mobility in the TMT 1 joint in an objective and quantifiable way [Faber et al. 2001, Glasoe et al. 2001, Ito et al. 1999, Klaue et al. 1994, Lee and Young 2001]. These reports indicated that a painful hallux valgus deformity and hypermobility of the first ray in the sagittal plane are related: more mobility was found in hallux valgus patients than in healthy volunteers and/or hypermobility was associated with pain. So, the question is whether TMT 1 hypermobility in a hallux valgus deformity is relevant enough to be corrected or not. To investigate this, we performed a prospective, blinded and randomized study between two procedures: the Lapidus and the Hohmann procedure.

The purpose of the present study was to 1) compare the short term outcomes of these two procedures, and 2) investigate whether the results of this comparison differed between two subgroups of patients (hypermobile versus non-hypermobile TMT 1 joints as clinically assessed).

6.3 Materials and methods

Between October 1997 and July 2000 101 feet in eighty-seven patients (eighty-four female and three male) had symptomatic hallux valgus deformity requiring operative correction, not being a first metatarso-phalangeal (MTP 1) arthrodesis. Fourteen patients were operated on both feet. Excluded were patients younger than fifteen years and older than sixty-five years, patients with rheumatoid arthritis or other inflammatory diseases and patients who previously had an operation on the symptomatic foot. Also excluded were patients with osteoarthritis of the TMT 1 joint and patients with moderate or severe osteoarthritis of the MTP 1 joint. The definition of moderate or severe osteoarthritis was based on:

1. range of motion: a total range of motion less than 50 degrees and/or
2. radiography: grade 3 or 4 radiographic osteoarthritis [Mann et al. 1992].

Before examination all patients gave their written informed consent; the study was approved by the local medical ethical committee. All patients were examined clinically by the same observer (FF). Routine examination for a hallux valgus deformity was performed according to the protocol that was developed. This protocol consisted of a Visual Analog Scale for pain and a score on the American Orthopaedic Foot and Ankle Society (AOFAS) hallux metatarsophalangeal-interphalangeal scale [Kitaoka et al. 1994]. This score incorporates both subjective and objective factors into numeric scales to describe pain, function and alignment. The minimum is zero and the maximum 100. See Table 1. Also, clinical measurements of the hallux valgus angle, forefoot width and deformities of the lesser toes were noted. The satisfaction of the patients was measured by a six point scale (very satisfied/satisfied/quite satisfied/fairly satisfied/unsatisfied/very unsatisfied) and at two years follow-up the patients were asked whether they would choose the procedure again. Also, the TMT 1 mobility test was performed, as described previously [Bednarz and Manoli 2000, Klaue et al. 1994, Myerson 1990]. With the ankle in neutral position, the metatarsals II-V were stabilized with one hand. The other hand was dorsiflecting the first metatarsal head. Hypermobility of the TMT 1 joint was defined according to Klaue [Klaue 1991] as displacement more than eight to ten millimeters without a firm endpoint. After clinical examination standardized weightbearing dorsoplantar (tube angle 15°) and lateral x-rays (tube distance 100 cm) were obtained. On the dorsoplantar view the MTP 1 angle was measured: the angle between the mid-longitudinal axis of MT 1 (represented by a line drawn bisecting the diaphyseal portions) and the line connecting the midpoints of the proximal and distal articular surfaces of the proximal phalanx. The intermetatarsal angle was defined as the angle between the mid-longitudinal axis of MT 1 and MT 2, both represented by a line drawn by bisecting the diaphyseal portions [Smith et al. 1984].

Randomization was guaranteed by producing sealed envelopes (one for each patient) containing the procedure to follow (Hohmann or Lapidus) before the start of the study. After clinical and radiographic examination of the patient the relevant envelope was opened in order to communicate the randomised type of operation to the patient. Fourteen patients were operated on the other foot too, during the time of the study. They underwent exactly the same randomization procedure for the second foot. The operations were all performed by or under supervision of the same author (FF).

Table 1.

The AOFAS hallux metatarsophalangeal-interphalangeal scale

I. Pain (40 points)	
none	40
mild, occasional	30
moderate, daily	20
severe, almost always present	0
II. Function (45 points)	
Activity limitations	
no limitations	10
no limitations of daily activities, such as employment responsibilities, limitations of recreational activities	7
limited daily and recreational activities	4
severe limitation of daily and recreational activities	0
Footwear requirements	
fashionable, conventional shoes, no insert required	10
comfort footwear, shoe insert	5
modified shoes or brace	0
MTP joint motion (dorsiflexion plus plantar-flexion)	
normal or mild restriction (75° or more)	10
moderate restriction (30°-74°)	5
severe restriction (less than 30°)	0
IP joint motion (plantarflexion)	
no restriction	5
severe restriction (less than 10°)	0
MTP-IP stability (all directions)	
stable	5
definitely unstable or able to dislocate	0
Callus related to hallux MTP-IP	
no callus or asymptomatic callus	5
callus, symptomatic	0
III. Alignment (15 points)	
good, hallux well aligned	15
fair, some degree of hallux malalignment observed, no symptoms	8
poor, obvious symptomatic malalignment	0

Description of the procedures.

Both procedures were performed under general or spinal anaesthesia and the patient was in a supine position with a tourniquet.

The Hohmann procedure

See figure 1.

A dorso-medial incision is centered over the MTP 1 joint. The dorso-medial cutaneus nerve is protected. On the plantar-medial side the tendon of the abductor hallucis muscle is freed and

Figure 1

Weightbearing AP and lateral radiograph, showing hallux valgus deformity (left) and after Hohmann procedure (right)

cut distally. Subcapitally a tranverse incision in the periosteum is made. With an oscillating saw an osteotomy perpendicular to the shaft of MT 1 is performed and a wegde shaped piece of bone is removed. The base of the wedge must be medial and plantar. The size of the wedge depends on the size of the deformity. The capital fragment is shifted laterally four to five millimeters and care is taken to ensure that the capital fragment is tilted plantarward. Fixation is achieved with a K-wire, which is drilled through the bone from distal-medially to proximal-laterally. This K-wire is left protruding through the skin distally, thus facilitating removal in the out-patient clinic. The periosteum is sutured and the tendon of the abductor hallucis muscle is reattached dorso-medially to the joint capsule of the MTP 1 joint. The skin is closed in a routine fashion. A well molded below-knee plaster of paris splint is applicated.

<u>The Lapidus procedure</u>

See figure 2.

A dorsal incision just laterally to the tendon of the extensor hallucis longus muscle is made. The cutaneous nerves are protected. In the first intermetatarsal space a lateral capsulotomy is performed. The oblique and transverse parts of the adductor hallucis muscle are released from the base of the proximal phalanx and the lateral sesamoid bone and the tranverse metatarsal ligament is cut. A second incision is then centered over the medial eminence. The cutaneous nerve is protected. The MTP 1 capsule is longitudinally incised and the medial eminence is resected with an oscillating saw parallel with the medial cortex of MT 1. A small strip of capsule of approximately three millimeters is excised, enabling reefing of the medial capsule during closure of the wounds.

Then proximally in the first incision the TMT 1 joint is exposed and the cartilage is removed with an oscillating saw. Care is taken to remove as little bone as possible, removing a bit more laterally and plantarly. This enables correction of MT 1: this is tilted laterally and plantarly. Multiple perforations of the subchondral bone of MT 1 and the first cuneiform with a small K-wire is performed to enhance fusion. The fixation of the TMT 1 arthrodesis is with two 3.5 mm cortical lag screws. Closure of the medial capsule is performed with interruptured sutures and the subcutaneous tissue and skin are closed in a routine fashion. A well molded below-knee plaster of paris splint is applicated.

Figure 2

Weightbearing AP and lateral radiograph, showing hallux valgus deformity (left) and after Lapidus procedure (right)

The aftercare was the same for the two procedures: two weeks in a non-weightbearing plaster of paris splint and after removal of the stitches, a weight-bearing cast for six more weeks. When the x-ray showed good bone healing at this time, which was normally the case at eight weeks post-operatively, the patient was allowed unprotected weightbearing and ankle and toe exercises were given. Physiotherapy was not a part of routine aftercare. The follow-up measurements were at six months, and one and two years post operatively. During these visits, the examiner was blinded for the procedure that had been done, by applying tape on the dorsal and medial side of the foot (hiding possible scars) by the nurse, prior to the assessment.

Statistics.

Analysis of covariance (ANCOVA) was used for analyzing the difference in the AOFAS score between the two methods of operation and the modification of this difference by the existence of hypermobility in the TMT 1 joint. In this ANCOVA adjustment was made for the baseline AOFAS score. ANCOVA with adjustment for baseline was also used for MTP 1 anlge, MT 1-2 angle, length of MT 1 and forefoot width. The exact trend test was used to test differences in changes from baseline sesamoid position between the two operations.

The Mann-Whitney test was used for comparing pain score (and its change from baseline) and post operative satisfaction score between the two methods of operation, also separately in the hypermobile and non-hypermobile subgroups. The paired t-test was used for testing changes from baseline AOFAS score, MTP 1 angle, MT 1-2 angle, length of MT 1 and forefoot width within either treatment group. The Wilcoxon signed ranks test was used for testing changes from baseline pain score within either treatment group.

For each test statistical significance was set at $p < 0.05$.

6.4 Results

Preoperatively, the two groups were comparable according to age, the MTP 1 angle, MT1-2 angle, pain score, AOFAS score and occurrence of clinical TMT 1 hypermobility. See Table 2. All ranges are given from lowest to highest.

Table 2.

Pre-operative characteristics of the population.

(n=101)

	mean age in years (range)	mean painscore (VAS)	mean AOFAS score (range)	mean MTP 1 angle in degrees (range)	mean MT1-2 angle in degrees (range)	TMT 1 hypermobile	TMT 1 non-hypermobile
Lapidus (N=51)	42.6 (16-63)	6.1 (1-10)	57.6 (47-75)	33.3 (18-50)	13.4 (7-18)	36 (71%)	15 (29%)
Hohmann (N=50)	40.0 (15-63)	5.9 (0-10)	56.2 (20-85)	30.5 (14-52)	12.9 (8-22)	32 (64%)	18 (36%)

No patients were lost to follow-up, although one patient emigrated just before the two year follow-up visit. His results at the one year follow-up visit were considered as the end point.

Additional procedures: in eighteen feet additional correction of hammertoe deformities was performed at the same time of the hallux valgus correction: eight toes in the Lapidus group and ten toes in the Hohmann group. An osteotomy of the fifth metatarsal was performed in one foot (Lapidus group).

Clinical results.

The mean *AOFAS score* at 24 months follow-up was 88.6 (range 60-100) for the Lapidus group and 89.6 (range 55-100) for the Hohmann group. In either group this was a statistically significant difference compared to the pre-operative score (paired t-tests, $p < 0.0005$). However, adjusted for baseline there was a non-significant difference of 1.37 points (SE = 1.93; $p = 0.480$) in improvement of the AOFAS score between the two procedures, which result also did not significantly differed between the hypermobile and non-hypermobile subgroups (ANCOVA, $p = 0.341$).

The *pain score* on the VAS scale improved to 1.4 (range 0-8) for the Lapidus group (Wilcoxon test $p<0.0005$) and 1.6 (range 0-5) for the Hohmann group (Wilcoxon test $p<0.0005$). There was no statistically significant difference between the two procedures in pain reduction (Mann-Whitney test $p = 0.585$). For the hypermobile and non-hypermobile subgroups these p-values were respectively 0.581 and 0.884.

When the *satisfaction rate* on the six point scale of the Lapidus procedure was compared to that of the Hohmann procedure, no statistically significant difference was found (Mann-Whitney test $p = 0.950$). This also holds for the comparison between hypermobile and non-hypermobile subgroups (p-values respectively 0.372 and 0.460).

In the Lapidus group forty-three procedures (84%) were considered so satisfactory by the patients that they would choose to have the procedure again, and four procedures (8%) were considered so unsatisfactory that the patients would not have the procedure again; about four procedures (8%) the patients were indecisive. For the Hohmann group these numbers were respectively thirty-eight (76%), nine (18%) and three (6%).

Radiographic results

The results of the radiographic analysis are listed in Table 3.

The mean MTP 1 angle was 13.3 degrees (range -16 to 30) in the Lapidus group and 9.9 degrees (range -10 to 36) in the Hohmann group. For both groups this was a statistically significant difference compared to the pre-operative MTP 1 angle (paired t-tests, $p < 0.0005$). The mean change of the MTP 1 angle was –20.1 degrees (range -45 to -4) for the Lapidus

Table 3.

Radiographic results.

	MTP1 angle in degrees (range)	change MTP 1 angle in degrees (range)	MT 1-2 angle in degrees (range)	change MT1-2 angle in degrees (range)	change sesamoid position (range)	change MT 1 length in mm (range)	forefoot width cm (range)	change forefoot width (cm)
Lapidus (N=51)	13.3 (-16 to 30)	-20.1 (-45 to -4)	5.6 (-4 to 13)	-7.9 (-18 to 2)	-1.5 (-3 to 0)	-0.02 (-0.57 to 0.69)	8.5 (6.8 to 11.1)	-0.77 (-2.08 to 0.48)
Hohmann (N=50)	9.9 (-10 to 36)	-20.7 (-42 to -7)	4.9 (0 to11)	-8.0 (-16 to -2)	-1.3 (-3 to 0)	-0.48 (-1.24 to 0.02)	8.5 (6.7 to 10.0)	-0.66 (-2.42 to 0.13)
p value		0.282		0.383	0.304	0.000*		0.424
effect		-1.78		-0.595		-0.464		0.094
SE		1.65		0.679	exact	0.048		0.117
		ANCOVA		ANCOVA	trend test	ANCOVA		ANCOVA

*significant
SE = standard error

procedure and –20.7 degrees (range -42 to -7) for the Hohmann procedure. There was a non-significant difference of –1.78 degrees (SE = 1.65; p = 0.282) in improvement of the MTP 1 angle between the two procedures (ANCOVA adjusted for baseline).

The mean MT1-2 angle was 5.6 degrees (range -4 to 13) in the Lapidus group and 4.9 degrees (range 0 to 11) in the Hohmann group. For both groups this was a statistically significant difference compared to the pre-operative MT1-2 angle (paired t-tests, $p < 0.005$). The mean change of the MT1-2 angle was -7.9 degrees (range -18 to 2) for the Lapidus procedure and -8.0 degrees (range -16 to -2) for the Hohmann procedure. There was a non-significant difference of –0.595 degrees (SE = 0.679; $p = 0.383$) in improvement of the MT1-2 angle between the two procedures (ANCOVA adjusted for baseline).

The mean change of the sesamoid position was -1.5 (range -3 to 0) for the Lapidus procedure and -1.3 (range -3 to 0) for the Hohmann procedure. There was no statistically significant difference in improvement of the sesamoid position between the two procedures (exact trend test; $p = 0.304$).

The mean shortening of MT1 was calculated as follows: length of MT 1 post operative minus length MT 1 pre-operative. A correction for an artificial length difference due to a possible slightly different position of the x-ray beam was made by multiplying the length MT 1 post operative by the ratio (length MT2 pre-operative / length MT 2 post operative). The mean pre-operative length of MT 1 was 6.6 cm (range 5.4-7.6) in the Lapidus group and 6.5 cm (range 5.5-7.7) in the Hohmann group. The mean change of MT1 length was –0.02 mm (range -0.57 to 0.69) in the Lapidus group and -0.48 mm (range -1.24 to 0.02) in the Hohmann group. This was a statistically significant difference of –0.464 mm (SE = 0.048; $p < 0.0005$, using ANCOVA adjusted for baseline).

The mean reduction of forefoot width was calculated in the same manner: distance between MT 1 and 5 post operative minus distance between MT 1 and 5 pre-operative. A correction for a bias due to a possible slightly different position of the x-ray beam was made by multiplying the width MT 1-5 post operatively by the ratio (length MT2 pre-operative / length MT 2 post operative). The mean pre-operative forefoot width was 9.3 cm (range 8 to 10,6) in the Lapidus group and 9.1 cm (range 8 to 10.4) in the Hohmann group. The mean post operative forefoot width was 8.5 cm (range 6.8 to 11.1) in the Lapidus group and 8,5 cm (range 6.7 to 10.0) in the Hohmann group. The change of forefoot width was -0.77 cm (range -2.08 to 0.48) in the Lapidus group and -0.66 cm (range -2.42 to 0.13) in the Hohmann group. There was a non-significant difference of 0.0094 cm (SE = 0.117; $p = 0.424$) in reduction of forefoot width between the two procedures (ANCOVA adjusted for baseline).

Complications

Superficial wound infection occurred in two patients in the Lapidus group and seven times in the Hohmann group. All were treated succesfully with oral antibiotics and premature removal of the K-wire in six patients. No deep infections occurred.

In two patients, both in the Lapidus group, *reflex sympathetic dystrophy* occurred, which was treated with re-admission for intravenous mannitol combined with dimethylsulfoxide spray application in one patient and only dimethylsulfoxide spray application in the other patient. The latter patient had a good result at the two year follow-up visit (AOFAS score eigthy-five, very satisfied and would choose the same procedure again), the former patient had a fair result (AOFAS score eighty-two, fairly unsatisfied, indecisive about choosing the same procedure again).

No *neuromas* of the dorsal medial cutaneous nerve, nor of the deep peroneal nerve were observed. Transient hypaesthesia of one of these nerves was found in eighteen patients: eleven in the Hohman group and seven in the Lapidus group.

Delayed union occurred four times in the Hohmann group and was treated succesfully by prolonging the cast immobilization for three weeks in three patients. One patient developed a symptomatic non-union, which necessitated re-operation. With autologic spongiosa and refixation with a memory staple the osteotomy healed. This ended in a bad result: AOFAS score 55, due to pain, hallux varus, shortening of MT1 and transfer metatarsalgia. In the Lapidus group non-union occurred five times: four patients were completely asymptomatic, one patient needed a re-operation: autologic spongiosa and refixation with lag screws. This ended in a good result: AOFAS score 90 and the patient was satisfied.

A re-operation because of *undercorrection and/or recurrence* was necessary in one patient in the Lapidus group: a chevron osteotomy was performed and the end result was excellent. In the Hohmann group a re-operation was necessary two times. A distal metatarsophalangeal soft tissue procedure was performed once, and this was combined with a proximal MT 1 osteotomy in the other patient. Both outcomes were good: AOFAS score seventy-five and quite satisfied with the end result in one patient, AOFAS score eighty-five and quite satisfied in the other patient.

Screw removal: despite countersinking of the screw heads, seven patients had complaints of the screws, necessitating removal under local anaesthesia, including one correction of the scar, which had become unsatisfactory after a superficial wound infection.

A *hallux varus* deformity developed in the Hohmann group in one patient, who had the re-operation for non-union. In the Lapidus group three times a hallux varus deformity occurred: two times completely asymptomatic and in one patient causing only cosmetic complaints, according to this patient not enough to be reoperated.

Transfer metatarsalgia, defined by the development of pain and callosities under the lesser metatarsal heads, occurred in four patients in the Hohmann group and two patients in the

Lapidus group. These were successfully treated conservatively with an inlay.
Deep venous thrombosis did not occur and no cases of *osteonecrosis* of the head of MT 1 were encountered.

6.5 Discussion

In healthy persons little mobility in the TMT 1 joint is found. Lundberg et al. found no motion above 2° in the TMT 1 joint with röntgen stereophoto-grammetry in eight healthy volunteers [Lundberg et al. 1989]. In a radiographical study, in healthy volunteers the normal range of motion in the sagittal plane was 4.3° [Fritz and Prieskorn 1995]. Recent reports indicated that a painful hallux valgus deformity and hypermobility of the first ray in the sagittal plane are related [Faber et al. 2001, Glasoe et al. 2001, Ito et al. 1999, Klaue and Hansen 1994, Lee and Young 2001]. Consequently, hypermobility of the TMT 1 joint in the sagittal plane in patients with a hallux valgus could be a relevant factor in deciding which operative procedure should be chosen for correction: a Lapidus procedure or a different one, without inclusion of an arthrodesis of the TMT 1 joint.
In the present prospective study the Lapidus procedure was compared with the Hohmann procedure. Comparison of the *clinical results* of both procedures with previous studies has to be done with some caution since the research designs differ considerably (the follow-up period, minor differences in the operative technique and aftertreatment and the fact that not a universal score to measure the outcome was used). Furthermore, all previous studies on the Lapidus and Hohmann procedure were retrospective. The present study has a randomized, prospective design with pre- and postoperative determination of the AOFAS score. Hence, results of different treatment procedures are better comparable. In the present study the results of the Lapidus procedure were good: an improvement of the AOFAS score from a mean of 58 to 89 and 76% of the procedures is considered so satisfactory by the patients that they would undergo the same procedure again. This is in line with previous studies, which reported 73% very satisfactory and 18% satisfactory results [Mauldin et al. 1990], 77% totally relieved and 15 % partially relieved [Myerson et al. 1992], 42% excellent and 32% good clinical result [Sangeorzan and Hansen 1989], and even 96% satisfied and would undergo the same procedure again [Bednarz and Manoli 2000]. In the latter study these numbers were: for pain relief: 61% totally satisfied and 19% satisfied with reservations. For postoperative appearance: 68% totally satisfied and 16 % satisfied with reservations. Comparison of our results of the Hohmann procedure with previous reports shows similar results. In the present

study the mean AOFAS score improved from a mean of 56 to 90 and 84% of the procedures is considered so satisfactory by the patients that they would undergo the same procedure again. Other studies reported from 35% excellent and 42% good results [Grace et al. 1988], 55% excellent and 33% good results [Christensen and Hansen 1995], 29% excellent and 60% good results [Piper et al. 2000] and 61% excellent and 36 % good results [Tangen 1971] to even 97% satisfactory results [Rowe and Coutinho 1985].

Our results did not show a significant difference in satisfaction between the two procedures. This is an interesting result, because all the patients fulfilling the inclusion criteria were enrolled in the prospective study, while the Hohmann procedure is generally recommended for mild to moderate hallux valgus deformity [Copin 1991, Tangen 1971, Warrick and Edelman 1984] and the Lapidus procedure for a hallux valgus deformity with TMT 1 hypermobility [Couhlin 1996, Hansen 1996, Hofbauer and Grossman 1996, Johnson and Kile 1994, Lapidus 1934, Mauldin et al. 1990, Myerson 1990, Myerson et al. 1992, Sangeorzan and Hansen 1989]. However, the exact definition of TMT 1 hypermobility is still unclear and all previous studies presenting the results of the Lapidus procedure, as our study, relied on the clinical diagnosis of TMT 1 hypermobility. Also, we did not find a significant difference in satisfaction between the two subgroups hypermobile and non-hypermobile TMT 1 joints, whether these patients underwent a Lapidus or a Hohmann procedure. A possible explanation for this finding could be the indistinct definition of TMT 1 hypermobility. The clinical test and its interpretation is subjective and the validity unknown. Several studies have been performed to determine (hyper)mobility in the TMT 1 joint in an objective and quantifiable way. They have different methodological disadvantages. In a biomechanical study a significant difference in TMT 1 mobility in the sagittal plane was demonstrated, when feet with and without a hallux valgus deformity were compared [Klaue et al. 1994]. However, a special device was used, and the applied force was not standardized. An increased mobility of the TMT 1 joint in hallux valgus patients was also shown by Glasoe et al.[Glasoe et al. 2001]. This also required also a special device, which is not easily available. Lateral stress radiography using a simple strut demonstrated significant difference in TMT 1 mobility between clinically hypermobile and non-hypermobile TMT 1 joints [Faber et al. 2001]. However, not one specific radiographic value to define TMT 1 hypermobility could be found and so this objective measurement could only be used in addition to the clinical test. Increased mobility of the first ray in hallux valgus patients compared with normal subjects was also found by Lee and Young using a simple plastic device to quantify mobility [Lee and Young 2001]. However, the applied force was not standardized and total first ray mobility was measured and not selectively TMT 1 mobility. So, although there are several indications of the relation between TMT 1 (hyper)mobility and a symptomatic hallux valgus deformity, there is no uniform valid method to quantify TMT 1 hypermobility objectively. The clinical test could be too unreliable to distinguish between hypermobile and non-hypermobile TMT 1 joints, which explainis the lack of difference in clinical result between the two subgroups in this study.

Considering the *radiographic results* of both procedures a significant reduction of the MTP 1 angle and MT1-2 angle compared with the pre-operative values was achieved. These results are in line with other reports, mentioning the radiographic results of the Lapidus [Bednarz and Manoli 2000, Mauldin et al. 1990, Myerson 1990, Myerson et al. 1992, Sangeorzan and Hansen 1989] and the Hohmann procedure in separate analyses [Das De 1984, Grace et al. 1988, Piper et al. 2000, Rowe and Coutinho 1985, Udin and Dutroit 1992, Warrick and Edelman 1984]. Considering the number of interventions of the present study, for these two criteria no significant difference was found between the two procedures. However, one statistically significant difference between the Lapidus and Hohmann procedure was observed: less amount of shortening of MT 1 in the Lapidus group. Shortening of MT 1 is related to transfer metatarsalgia, which we observed in six feet (four in the Hohmann group and two in the Lapidus group). Transfer lesions can also be caused by unintended elevation of the MT 1 head. The occurrence of transfer lesions vary in other studies from 13% to 59 % for the Hohman procedure [Das De 1984, Grace et al. 1988, Rowe and Coutinho 1985] and from 0% to 14% for the Lapidus procedure [Bednarz and Manoli 2000, Butson 1980, Mauldin et al. 1990, Myerson et al. 1992, Saffo et al. 1989, Sangeorzan and Hansen 1989]. The higher incidence of transfer lesions, in our study and in previous reports seems a disadvantage of the Hohmann procedure. Our follow-up period is two years and the incidence of transfer lesions could increase with time.

There is no difference between the two procedures in incidence of most of the complications as transient hypaesthesia, reflex sympathetic dystrophy, and re-operations for delayed union/non-union (one patient in both groups) or recurrence/undercorrection (one patient in the Lapidus group and two patients in the Hohmann group).

The most striking difference is the (superficial) infection rate of 3.9% in the Lapidus group versus 14% in the Hohmann group. The latter is also considerably higher than the 2% reported in other series [Das De 1984, Udin and Dutoit 1992]. This is probably caused by the percutaneous K-wire. Although these superficial infections were easily treated with oral antibiotics and/or premature removal of the K-wire, this led us to adjust the method of fixation using only internal fixation now.

Another evident difference between the two methods is the re-operation rate for screw removal in the Lapidus group: 7 patients (13,7%). This was necessary despite countersinking of the screw heads. Although all screws were easily removed under local anaesthesia, this can be seen as a slight disadvantage of the Lapidus procedure. The fixation of the TMT 1 arthrodesis with screws is considered essential for maintaining the position [Bednarz and Manoli 2000, Myerson et al. 1992, Sangeorzan and Hansen 1989] and consequently we continue to do this.

The last apparent difference between the two methods is the incidence of hallux varus: 3 patients (5.9%) in the Lapidus group versus one (2%) in the Hohmann group. Although no re-operations were necessary, this is a possible disadvantage for the Lapidus procedure. Other series reported incidences between 1.5% and 15,7% [Mauldin et al. 1990, Myerson et al. 1992, Sangeorzan and Hansen 1989]. Although some authors advise to use intra-operative fluoroscopy to control the position of MT 1 after the TMT 1 arthrodesis [Hofbauer and Grossman 1996, Sangeorzan and Hansen 1989], it is not sure whether this could always prevent the complication of hallux varus. For instance, an incidence of 11% of hallux varus is also described when only a distal metatarsal phalangeal soft tissue procedure is performed [Mann and Coughlin 1981].

Conclusions: the short term results of the Hohmann and Lapidus procedure for correction of a hallux valgus deformity were satisfactory and comparable to previous reports about these procedures. There was no relevant difference in outcome between the two methods in the total group of 101 feet. Although TMT 1 hypermobility can be seen as related to symptomatic hallux valgus deformity, the results for the subgroups of hypermobile TMT 1 joints, as assessed clinically, versus non-hypermobile TMT 1 joints were not statistically significantly different. The theory that in hallux valgus patients with hypermobile TMT 1 joints a Lapidus procedure should be performed is not supported by this study.

7 General discussion and conclusion

Hallux valgus is a frequently encountered deformity in the Western world. There is little doubt that the aetiology of this deformity is multicausal. The most important extrinsic and intrinsic are: shoes, type of foot, generalized ligamentous laxity, pes planus, heredity and metatarsus primus varus. These causes probably overlap: a metatarsus primus varus can be cuased by generalized ligamentous laxity, which can have a heriditary background. Although the question of what is first: metatarsus primus varus [Truslow 1925] or hallux valgus [Hardy and Clapham 1951] is still unanswered, it is clear that the varus position of the first metatarsal bone can only exist when there is *mobility* somewhere in the first ray. The joints of the first ray are the talo-navicular joint, the navicular-first cuneiform joint and the first tarso-metatarsal joint (TMT 1 joint). The relation between a hallux valgus deformity and the mobility of this TMT 1 joint was the subject of this thesis.

There is general agreement on the existence of motion in this joint, although the opinions differ about degree and direction of this motion. Several cadaver studies produced evidence for this [Bohne et al. 1997, Mizel 1993, Ouzounian and Shereff 1989, Wanivenhaus and Pretterklieber 1989]. Also, an in vivo experiment in healthy volunteers confirmed the existence of (little) dorsiflexion in the TMT 1 joint [Lundberg et al.(1) 1989] as well as (little) pronation and supination [Lundberg et al.(2) 1989]. In our cadaver study, we found that the TMT 1 joint has a relevant contribution in the total mobility of the first ray, as well in the sagittal as in the tranversal plane [Faber et al. 1999].
There is controversion about the existence of excessive mobility or *hypermobility* of the TMT 1 joint and, related to this, also about the consequences of this possible hypermobility.
Hypermobility in the TMT 1 joint, leading to metatarsus primus varus, could be the cause of development of a hallux valgus deformity [Lapidus, 1934]. Hypermobility of the TMT 1 joint can also be considered as a consequence of the hallux valgus deformity and the metatarsus primus varus. Several authors, who consider TMT1 hypermobility as a relevant factor in a hallux valgus deformity, advocate the combination of a soft tissue correction of the first metatarso-phalangeal joint with an arthrodesis of the TMT 1 joint for correction of a hallux

valgus deformity: the Lapidus procedure [Butson 1980, Hansen 1996, Hofbauer and Grossman 1996, Johnson and Kile 1994, Lapidus 1934, Mauldin et al. 1990, Myerson 1990, Myerson et al. 1992, Saffo et al. 1989, Sangeorzan and Hansen 1989]. Satisfactory results of this procedure are described by these authors, all in retrospective studies.

Others neglect this joint and the importance of its mobility in their recommendations for hallux valgus surgery [Coughlin 1995, Geissele and Stanton 1990, Mann and Coughlin 1981]. These authors describe comparable results of their surgical procedures, also in retrospective studies.

The problem is that all authors considering hypermobility of the TMT 1 joint a relevant factor, rely on the clinical test for establishing TMT 1 hypermobility [Bednarz and Manoli 2000, Hofbauer and Grossman 1996, Johnson and Kile 1994, Klaue 1991, Myerson et al. 1992, Sangeorzan and Hansen 1989]. However, this clinical test is subjective, and the reliability and reproducibility are unclear. A recent study about the intra- and interobserver agreement of clincally assessed first ray mobility confirmed the questionable reliability of this clinical test [Glasoe et al. 2002].

Because establishing TMT 1 hypermobility may have consequences (performing a Lapidus procedure or not), there is a need for an objective and quantifiable test to distinguish hypermobile from non-hypermobile TMT 1 joints. Ideally, this test should be reliable, reproducible and patient friendly (non-invasive and without radiographs). Other studies have been performed on this subject. A biomechanical study of Klaue showed a significant difference in TMT 1 mobility in the sagittal plane when feet with and without a hallux valgus deformity were compared [Klaue 1994]. However, a special device was used and the applied force was not standardized. Glasoe also investigated TMT 1 mobility using another special device on cadavers and later on hallux valgus patients [Glasoe et al. 1999, Glasoe et al. 2001]. Their device was shown to be reliable and an increased mobility was demonstrated in hallux valgus patients. Lee used the combination of clinical test with a simple plastic device and also found increased mobility of the first ray in hallux valgus patients [Lee and Young 2001]. These studies all have certain disadvantages: special devices are needed, the applied force is not standardized or the TMT 1 joint is not selectively measured.

In an effort to find a reliable, reproducible and patient friendly method to objectivate TMT 1 hypermobility we performed two studies with Doppler Imaging of Vibrations (DIV). This recently developed method uses low energy vibrations and ultrasound to measure joint

stiffness in vivo and was shown to be reproducible and reliable for the sacro-iliac joint [Buyruk et al. (1) 1995, Buyruk et al. (2) 1995].
We found that this technique was applicable to the TMT 1 joint and showed good repeatibility in healthy volunteers [Faber et al. 2000]. Next we applied this technique to hallux valgus patients and related these stiffness measurements to the clinical TMT 1 mobility test. Although there was intra- and interobserver variability of the clinical test, we found a statistically significant relation between the DIV measured TMT 1 stiffness test and the clinical TMT 1 mobility test [Faber et al. (1) 2001]. But, the DIV method has two major disadvantages: no sharp distinction between hypermobile and non-hypermobile could be found and it requires the equipment and training of the method. This makes this method unsuitable for general orthopedic practice, like the other studies requiring special devices which are not widely available [Klaue et al. 1994, Glasoe et al. 2001].

Because pre-operative radiographs are always required planning the surgical procedure for a hallux valgus correction, we sought for a radiographic test to determine TMT 1 hypermobility in an objective and quantifiable way. Fritz and Prieskorn described the modified Coleman block test in healthy volunteers, using the body weight to create stress in the sagittal plane [Fritz and Prieskorn 1995]. Except for a simple wooden block, this method does not require special equipment. We used this test in symptomatic hallux valgus patients and tried to relate this to the clinical test of TMT 1 mobility. We found much higher values of radiographic TMT 1 mobility in the sagittal plane than Fritz and Prieskorn in their group of healthy volunteers [Faber et al. (2) 2001, Fritz and Prieskorn 1995]. Our study also showed that this radiographic measurement was statistically significant different between patients with or without clinically assessed hypermobility in the TMT 1 joint. However, because of the great overlap in values, we could not determine one radiographic value (cut-off point) to define TMT 1 hypermobility.

So, we found a relation between clinically assessed TMT 1 hypermobility and the objective DIV method and the radiographic method. However, we could not find strict criteria by neither method, to define TMT 1 hypermobility. A possible explanation for this is that the distinction of the mobility of the TMT 1 joint in hypermobile and non-hypermobile is too artificial. This mobility could be a gliding scale between stiff, less stiff, mobile and hypermobile. Future studies could be performed comparing repeated, blinded clinical TMT 1 mobility tests with röntgen stereophoto-grammetry measurements of TMT 1 mobility in hallux valgus patients, additional to the RSA study already performed on healthy volunteers [Lundberg et al. (1) 1989].

Despite our efforts with these two methods, the exact definition of hypermobility of the TMT 1 joint remains unclear. However, we found a relation between these measurements and the clinically assessed TMT 1 hypermobility. This is still the only test used by clinicians to decide whether to perform a Lapidus procedure or not [Bednarz and Manoli 2000, Hofbauer and Grossman 1996, Johnson and Kile 1994, Klaue 1991, Myerson et al. 1992, Sangeorzan and Hansen 1989]. Although the reported results of the Lapidus procedure are good, no prospective, comparative studies have been performed between the Lapidus and another operative hallux valgus procedure. We performed a prospective randomised study between a distal osteotomy (Hohmann procedure) and the Lapidus procedure in an effort to determine whether TMT 1 hypermobility is a relevant factor. Pre-operatively the clinical mobility of the TMT 1 joint was tested. The short term clinical results did not differ and also the radiographic results were basically equal for the two operations. Also, no difference was found between the two subgroups of clinically hypermobile and non-hypermobile TMT 1 joints. This is remarkable, because one would have expected in the hypermobile group a better result when a Lapidus procedure was performed. Possible explanations for this are: 1. the clinical test may be too unreliable to distinguish between hypermobile and non-hypermobile TMT 1 joints; 2. the follow-up period is relatively short: two years. When a TMT 1 arthrodesis has been performed, it could be possible that the incidence of late recurrence of a hallux valgus deformity is lower than in the Hohmann procedure, because MT 1 cannot shift back into varus position. However, so far our study does not support the theory that in hallux valgus patients with clinically assessed hypermobility of the TMT 1 joint a Lapidus procedure should be performed. The Lapidus procedure has some disadvantages compared with other hallux valgus procedures:

1. it sacrifices a midfoot joint, of which hypermobility as the cause for the hallux valgus deformity is still unclear.
2. it is considered techniqually demanding [Hofbauer and Grossman 1996, Myerson et al. 1992, Sangeorzan and Hansen 1989].
3. the aftertreatment is more prolonged than in other hallux valgus surgical procedures: a below knee plaster of paris immobilization between six and ten weeks with different regimes of weight bearing has been recommended [Bednarz and Manoli 2000, Butson 1980, Hofbauer and Grossman 1996, Mauldin et al. 1990, Myerson et al. 1992, Saffo

et al. 1989, Sangeorzan and Hansen 1989]. For other types of surgical procedures these values range between no cast immobilization at all to six weeks a below knee cast with full weight bearing [Christensen and Hansen 1995, Coughlin 1996, Klosok et al. 1993, Piper et al. 2000].

So, the exact significance of TMT 1 hypermobility and the correction of it in patients with a hallux valgus deformity should be subject for further research. A prospective randomised clinical trial between the Lapidus procedure and an basal MT 1 osteotomy with the same distal soft tissue procedure could give an answer to the influence of the mobility of the TMT 1 joint and to the possible benefits performing an arthrodesis of this joint. Ideally pre-operative testing of TMT 1 (hyper)mobility, clinically as well as as with other methods, should be included in this study.

In conclusion: in hallux valgus patients there seems to be an increased TMT 1 mobility, but there is still no simple and general applicable method to assess TMT 1 *hyper*mobility objectively and produce quantifiable results. Even the relevance of TMT 1 hypermobility in hallux valgus surgery is still unclear. Ideas for further investigations are discussed above.

8 Summary

This thesis describes a series of cadaver, experimental, radiographic and clinical studies on the relation between a hallux valgus deformity and mobility of the first tarsometatarsal (TMT 1) joint.

In the general introduction a brief review of the anatomy and the pathogenesis of a hallux valgus deformity is given and the aetiology is described. *Chapter 1* continues with an overview of the different surgical procedures for correction of a hallux valgus deformity, with special attention to the two procedures used in the clinical study: the Hohmann and the Lapidus procedure. A survey of the literature on TMT 1 mobility is given and the aims of the present study are pointed out.

In *Chapter 2* an in vitro study in nine cadaver feet is described to investigate the relation between the mobility of the TMT 1 joint in the sagittal and transversal plane. Also, a possible stabilizing effect of three muscles (tibialis anterior muscle, flexor hallucis longus muscle and the peroneus longus muscle) on this joint is studied in both planes. It was concluded that TMT 1 mobility is a relevant factor in both the sagittal and the transversal plane. Both the peroneus longus and flexor hallucis longus muscle had a stabilizing effect on the TMT 1 joint against a dorsal deforming force. The flexor hallucis longus muscle had an increasing effect on the TMT 1 displacement in the transversal plane.

Chapter 3 deals with the first step to quantify TMT 1 mobility in a non-invasive, objective and patient friendly way. A new technique, Doppler Imaging of Vibrations, was used to measure TMT 1 stiffness. 46 TMT 1 joints of 23 healthy subjects were tested. The results showed that the technique was applicable to the TMT 1 joint. The measurements had a good repeatibility and confirmed the normal TMT 1 stiffness in healthy subjects.

Application of this technique to 34 TMT 1 joint in 20 hallux valgus patients and relating this to clinical TMT 1 mobility measurements by two independent observers is decribed in *Chapter 4*. The definition of clinically hypermobile versus non-hypermobile was defined in two ways: 1) four similar observations to conclude hypermobility or non-hypermobilty and 2) three or four similar observations to conclude hypermobility or non-hypermobility. In both

stratification strategies there was a statistically significant relation between the clinical TMT 1 mobility test and the stiffness measurement of the TMT 1 joint with Doppler Imaging of Vibrations. This emphasizes the need for objective tests to examine TMT 1 mobility.

In *Chapter 5* a radiographic analysis of TMT 1 mobility in hallux valgus patients is described. In 94 patients with a hallux valgus deformity the clinical TMT 1 mobility test was performed and a radiographic TMT 1 stress-measurement. The mean radiographic TMT 1 mobility with this method was larger than in a previous study on healthy subjects. Also a statistically significant difference existed between patients with and without clinical TMT 1 hypermobility. This indicates that TMT 1 hypermobility and a hallux valgus deformity are related and that this radiographic test can produce useful additional information to the clinical TMT 1 mobility test.

The results of a prospective randomised trial between two surgical procedures to correct a hallux valgus deformity (Hohmann versus Lapidus) are described in *Chapter 6*. 101 hallux valgus deformities in 87 consecutive patients were treated and the follow-up was at least two years. Pre-operatively, TMT 1 mobility was tested clinically and two subgroups were distinguished: 68 hypermobile and 33 non-hypermobile TMT 1 joints. The clinical results, determined by obtaining the AOFAS (American Orthopaedic Foot and Ankle Society) score pre- and post-operatively, did not differ between the two methods, nor did the pain score and the patient satisfaction score. Also, no difference was found between the two subgroups of clinically hypermobile and non-hypermobile TMT 1 joints. The radiographic results were also basically equal. This indicates that performing a Lapidus procedure in a hallux valgus deformity with clinically assessed TMT 1 hypermobility remains questionable.

In *Chapter 7* the overall findings of this thesis are discussed. The TMT 1 stiffness measurements by Doppler Imaging of Vibrations and the radiographic stress measurements of the TMT 1 joint in hallux valgus patients were related to the clinical assessment of TMT 1 hyper-mobility. However, with neither method a sharp distinction between hypermobile and non-hypermobile could be made. The prospective, randomised clinical study, comparing the Hohmann with the Lapidus procedure, showed no difference in clinical results at short term follow-up. So, the exact significance of TMT 1 hypermobility and the surgical correction of it in patients with a hallux valgus deformity remain subject for future research.

9 Samenvatting

Dit proefschrift beschrijft een serie kadaver, experimentele, röntgenologische en klinische studies naar de relatie tussen een hallux valgus en de mobiliteit in het eerste tarsometatarsale (TMT 1) gewricht.

In *Hoofdstuk 1* wordt door middel van een algemene inleiding een kort overzicht gegeven van de anatomie en de pathogenese van een hallux valgus deformiteit. Tevens worden de etiologische factoren beschreven. Vervolgens wordt een overzicht gegeven van de verschillende chirurgische procedures, die gebruikt worden om een hallux valgus te corrigeren. De twee procedures die in de klinische studie gebruikt zijn, de Hohmann en de Lapidus procedure, worden uitvoerig beschreven. Een overzicht van de literatuur over TMT 1 mobiliteit wordt gegeven en de doelen van het proefschrift worden uiteengezet.

In *Hoofdstuk 2* wordt een in vitro studie beschreven bij 9 kadaver voeten. Hiermee werd de relatie bestudeerd tussen de mobiliteit van het TMT 1 gewricht in het sagittale en transversale vlak. Tevens werd een mogelijk stabiliserend effect van drie spieren (de m. tibialis anterior, m. flexor hallucis longus en m. peroneus longus) op dit gewricht in deze twee vlakken onderzocht. De conclusie was dat TMT 1 mobiliteit een relevante factor is in zowel het sagittale als in het transversale vlak. Zowel de m. peroneus longus als de m. flexor hallucis longus hadden een stabiliserend effect op het TMT 1 gewricht tegen een naar dorsaal gerichte kracht. De m. flexor hallucis longus had een versterkend effect op de TMT 1 verplaatsing in het transversale vlak.

Hoofdstuk 3 behandelt de eerste stap om TMT 1mobiliteit op een niet invasieve, objectieve en patiëntvriendelijke manier te quantificeren. Een nieuwe techniek, 'Doppler Imaging of Vibrations' werd gebruikt om de TMT 1 stijfheid bij 46 TMT 1 gewrichten van 23 gezonde personen te meten. Het bleek dat de techniek goed toepasbaar was op het TMT 1 gewricht. De metingen hadden een goede meetnauwkeurigheid en bevestigden de normale stijfheid van het TMT 1 gewricht in gezonde personen.

In *Hoofdstuk 4* wordt deze techniek op 34 TMT 1 gewrichten in 20 hallux valgus patiënten toegepast en gerelateerd aan klinische TMT 1 mobiliteitsmetingen door twee onafhankelijke onderzoekers. De definitie van klinisch hypermobiel/niet hypermobiel werd op twee manieren bepaald: 1) vier dezelfde observaties om hypermobiel of niet-hypermobiel te concluderen en 2) drie of vier dezelfde observaties om hypermobiel of niet-hypermobiel te concluderen. Via beide stratificatie methoden was er een statistisch significante relatie tussen de klinische TMT 1 mobiliteits meting en de stijfheids meting van het TMT 1 gewricht met Doppler Imaging of Vibrations. Dit benadrukt de behoefte aan objectieve testen om TMT 1 mobiliteit te beoordelen.

In *Hoofdstuk 5* wordt een röntgenologische analyse beschreven van TMT 1 mobiliteit in hallux valgus patiënten. Bij 94 patiënten met een hallux valgus werd de klinische TMT 1 mobiliteitstest verricht en een röntgenologische TMT 1 stress meting. De gemiddelde röntgenologische TMT 1 mobiliteit was met deze methode groter dan in een eerdere studie bij gezonde personen. Tevens bestond er een statistisch significant verschil tussen patiënten met en zonder klinische TMT 1 hypermobiliteit. Dit vormt een aanwijzing dat TMT 1 hypermobiliteit en hallux valgus gerelateerd zijn en dat deze röntgenologische test nuttige informatie kan opleveren, additioneel aan de klinische TMT 1 mobiliteitstest.

De resultaten van een prospectieve, gerandomiseerde studie tussen twee chirurgische procedures, die gebruikt worden om een hallux valgus te corrigeren (Hohmann versus Lapidus) worden beschreven in *Hoofdstuk 6*. 101 halluces valgi van 87 opeenvolgende patiënten werden geopereerd en de follow-up was tenminste twee jaar. Pre-operatief werd de klinische TMT 1 mobiliteitstest verricht en twee subgroepen werden onderscheiden: 68 hypermobiele en 33 niet hypermobiele TMT 1 gewrichten. De klinische resultaten, verkregen door pre- en post-operatief de AOFAS (American Orthopaedic Foot and Ankle Society) score te meten, verschilden niet tussen de twee operatie methoden. Evenmin was er een verschil in pijn score en patiënt tevredenheid score. Tevens werd er geen verschil gevonden tussen de twee subgroepen klinisch hypermobiel en niet hypermobiel TMT 1 gewricht. De röntgenologische resultaten waren ook voor bijna alle criteria gelijk. Dit geeft aanwijzingen dat de plaats van de Lapidus procedure bij de behandeling van een hallux valgus bij klinisch vastgestelde TMT1 hypermobiliteit nog onduidelijk blijft.

In *Hoofdstuk 7* worden de belangrijkste bevindingen van dit proefschrift besproken. De TMT 1 stijfheidsmetingen met Doppler Imaging of Vibrations en de röntgenologische stress metingen van het TMT 1 gewricht bij hallux valgus patiënten werden gerelateerd aan de klinische meting van TMT 1 hypermobiliteit. Met beide methoden kon echter geen scherp onderscheid gemaakt worden tussen hypermobiel en niet hypermobiel. De prospectieve gerandomiseerde klinische studie, die de resultaten van de Hohmann en de Lapidus procedure vergelijkt, toonde geen verschil aan in klinische resultaten bij korte termijn follow-up. De exacte betekenis van TMT 1 hypermobiliteit en de operatieve correctie hiervan bij patiënten met een hallux valgus blijven aldus onderwerp voor verder onderzoek in de toekomst.

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12 Curriculum vitae

Franciscus Wilhelmus Maria Faber werd op 4 augustus 1960 geboren in Voorburg. Hij volgde zijn middelbare schoolopleiding aan het St. Bonifatius College te Utrecht en behaalde zijn gymnasium-ß diploma in 1978. Van 1978 tot 1985 studeerde hij Geneeskunde aan de Rijksuniversiteit Utrecht. Tijdens zijn studie was hij als student assistent werkzaam bij het Anatomisch Laboratorium van de Rijksuniversiteit Utrecht ten behoeve van de dissectie-practica. In 1985 legde hij zijn artsexamen af.

Na diverse assistentschappen en het vervullen van de dienstplicht bij de 25^{e} afdeling Pantserluchtartillerie in de Prins Maurits kazerne te Ede, volgde hij in 1990-1991 de vooropleiding algemene heelkunde in het Leyenburg Ziekenhuis te Den Haag (opleider Dr. W.M. Oosterwijk). De opleiding tot orthopedisch chirurg vond plaats in het St. Joseph Ziekenhuis te Veldhoven (opleider Dr. A.J.G. Nollen) van 1992-1996. De academische stage werd gevolgd in het Academisch Ziekenhuis Maastricht (opleider Prof. Dr. A.J. van der Linden). In oktober 1995 liep de auteur stage in het Harborview Medical Center te Seattle bij Dr. S.T. Hansen. Tijdens deze stage is het idee voor dit proefschrift ontstaan.

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