THE HALLUX VALGUS COMPLEX

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Front and back pages:
Three-dimensional reconstructions (ISG software on Allegro) of the magnetic resonance images (Philips, Gyroscan) of the foot of a patient with the hallux valgus complex. It shows the deviation of the flexor hallucis longus tendon (gray) in relation to the skeleton (yellow). The skin (purple) at the level of the first tarso-metatarsal and metatarso-phalangeal joint is also reconstructed in order to indicate the spatial orientation of the foot.

THE HALLUX VALGUS COMPLEX

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PROEFSCHRIFT

ter verkrijging van de graad van doctor
aan de Erasmus Universiteit Rotterdam
op gezag van de Rector Magnificus
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en volgens het besluit van het College voor Promoties

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Voor mijn vader en moeder
Voor mijn andere vrienden

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Chapter I

General Introduction

GENERAL INTRODUCTION

The mass of the foot skeleton weighs less than two hundred grams and is composed of twenty-eight bony elements. The use of an organ that involves so many articulations with separate bones, showing a variety of forms, must result in individually different ways of functioning. Nevertheless, an attempt is made to discover recurring structural and functional patterns in the foot.

Many persons suffer from foot disorders and most of these complaints are related to the forefoot.[1-3] Within this framework, attention focuses on the obliqueness of the big toe: the hallux valgus. Frequently the valgus deviation of the hallux is one aspect of a conglomeration of forefoot deformities and symptoms - termed the hallux valgus complex.[4,5] Different theories exist concerning the origin of the hallux valgus complex,[6-13] however, in many patients the etiology remains unclear. Patients with hallux valgus of unknown origin represent the so-called idiopathic form of hallux valgus. It is generally accepted that some types of narrow footwear with a pointed nose may influence the development of this abberation.[14] This study does not intend to address the various foot deformities, complaints and etiologic factors, but will discuss the implications of a biomechanical model described by Snijders et al.[15]

This model states that in the presence of valgus deviation of the hallux, of whatever origin, the valgus position will increase during contraction of the hallux flexors, and that varus deviation of the first metatarsal increases at the same time. As this model was based on in vivo measurements in healthy volunteers, a logical continuation is to investigate whether the model is also applicable in patients. An immediate question is whether the unfavourable mechanical phenomena can be removed by surgical intervention. Kelikian mentions the existence of some 130 surgical methods to treat hallux valgus.[16] In individual cases some specific guidelines are available related to the age of the patient, the existence of degenerative changes, the severity of the deformity, and previous treatment.[13,17-21] In general, the following groups can be distinguished:[19] the osteotomy of the hallux or first metatarsal,[22] the arthrodesis of the first metatarso-phalangeal or tarso-metatarsal joint,[23] the arthroplasty,[24] artificial implant,[25] soft tissue procedures,[26] and bunionectomy.[27] The biomechanical model predicts a principal difference in mechanical functioning between the group undergoing first metatarsal osteotomy and those undergoing arthrodesis of the first metatarso-phalangeal joint.

In order to verify the biomechanical model, symptomatic patients from these two main groups were selected for this study. The patient population was from the University Hospital Rotterdam, Dijkzigt; and the choice of procedure was restricted to the modified Hohmann osteotomy and arthrodesis of the first metatarso-phalangeal joint. As a guideline for the choice of operation, an osteotomy was the preferred procedure if the patient was young, had sufficient range of motion of MTP_1 in the sagittal plane (dorsiflexion > 50°-60°), and there were no signs of osteoarthritis of the MTP_1 joint on the X-ray. In other cases arthrodesis was preferred. Comparison of the modified Hohmann osteotomy and arthrodesis of MTP_1 gives the impression of an attempt to compare apples and pears. However, this study focuses on biomechanics and not on clinical criteria. It is claimed that the biomechanical model is valid for all types of first metatarsal osteotomies and arthrodeses of MTP_1 in all patients, independent of clinical features like age and degenerative changes. Analysis of the patients was done by study of the medical records, and by use of non-invasive and ethically acceptable methods for data acquisition. Because this work focuses on biomechanical aspects, data acquired in a weight-bearing position are preferred. Biomechanical parameters which are of particular interest in the hallux valgus complex are: the pressure of the hallux on the sub-soil, and the synchronous widening of the forefoot. To this end, a specific measuring apparatus has been developed. X-rays (see Appendix) and ink footprints are necessary in order to assess the individual geometry and pathology of the foot. With the biomechanical model in mind a number of new geometrical parameters are introduced.

Based on the model and the available methods of measurement the following aims were formulated for the study.

- Validation of the model in patients, by assessment of the relationship between toe pressure and forefoot width (Chapter II).
- To test the prediction that a difference exists between widening of the forefoot (induced by muscle force) after a first metatarsal osteotomy, and after arthrodesis of the first metatarso-phalangeal joint (Chapter III).
- Inclusion of parameters other than the valgus and varus angle, and the related forefoot width, to the biomechanical model (Chapter IV).
- Investigation of biomechanics and functioning in daily living of patients before and after first ray surgery (Chapter V).

REFERENCES

1 Foot and Footwear Foundation. [Stichting Voet en Schoeisel] Bejaardenenquête. Waalwijk, The Netherlands, 1978.

2 Hung LK, Ho YF, Leung PC. Survey of foot deformities among 166 geriatric inpatients. Foot Ankle 1985; 5: 156-164.

3 Herschel H, Van Meel PJ. Metatarsalgie. Ned Tijdschr Geneeskd 1982; 45: 2056-2061.

4 Jahss MH. Disorders of the hallux and the first ray. In: Jahss MH, editor. Disorders of the foot and ankle. Philadelphia, London, Toronto, Mexico City, Rio de Janeiro, Sydney, Tokyo, W.B. Saunders Company, 1991: 943-1174.

5 Kelikian H. Introduction. In: Hallux valgus, allied deformities of the forefoot and metatarsalgia. Philadelphia, London, W.B. Saunders Company, 1965: 1-5.

6 Barnicot NA, Hardy RH. The position of the hallux in West Africans. J Anatomy 1955; 89: 355-361.

7 Camper P. Dissertation on the best form of shoe. Clin Orthop 1975; 110: 2-5.

8 Carl A, Ross S, Evanski P, Waugh T. Hypermobility in hallux valgus. Foot Ankle 1988; 8: 264-270.

9 Heylings DJA. Hallux valgus and abductor hallucis; personal thoughts on their connection. Chiropodist 1990; August: 162-164.

10 Kalen V, Brecher A. Relationship between adolescent bunions and flatfeet. Foot Ankle 1988; 8: 331-336.

11 Kato T, Watanabe S. The etiology of hallux valgus in Japan. Clin Orthop 1981; 157: 78-81.

12 Mann RA, Coughlin MJ. Hallux valgus - Etiology, anatomy, treatment and surgical considerations. Clin Orthop 1981; 157: 31-41.

13 Scranton PE, Rutkowski R. Anatomic variations in the first ray: Part I. Anatomic aspects related to bunion surgery. Clin Orthop 1980; 151: 244-255.

14 Sim-Fook L, Hodgson AR. A comparison of foot forms among the non-shoe and shoe-wearing Chinese population. J Bone Joint Surg 1958; 40A: 1058-1062.

15 Snijders CJ, Snijder JG, Philippens MM. Biomechanics of hallux valgus and spreadfoot. Foot Ankle 1986; 5: 327-332.

16 Kelikian H. Hallux valgus, allied deformities of the forefoot and metatarsalgia. Philadelphia, W.B. Saunders Company, 1965.

17 Bonney G, Macnab I. Hallux valgus and hallux rigidus. A critical survey of operative results. J Bone Joint Surg 1952; 34B: 366-385.

18 Edgar MA. Hallux valgus and associated conditions. In: Klenerman L, editor. The foot and its disorders. Oxford, London, Edinburgh, Melbourne, Blackwell Scientific Publications, 1976: 83-129.

19 Helal B. Surgery for adolescent hallux valgus. Clin Orthop 1981; 157: 50-63.

20 Johnson KA. Bunion of the great toe. In: Surgery of the foot and ankle. New York, Raven Press, 1989: 1-34.

21 Mann RA. The great toe. Orthop Clinics North America 1989; 20: 519-533.

22 Jahss MH, Troy AI, Kummer F. Roentgenographic and mathematical analysis of first metatarsal osteotomies for metatarsus primus varus: a comparative study. Foot Ankle 1985; 5: 280-321.

23 Myerson M. Metatarsocuneiform arthrodesis for treatment of hallux valgus and metatarsus primus varus. Orthopedics 1990; 13: 1025-1031.

24 Turnbull T, Grange W. A comparison of Keller's arthroplasty and distal metatarsal osteotomy in the treatment of adult hallux valgus. J Bone Joint Surg 1986; 68B: 132-137.

25 Swanson AB, Lumsden RM, DeGroot Swanson G. Silicone implant arthroplasty of the great toe. Clin Orthop 1979; 142: 30-43.

26 McBride ED. The McBride bunion hallux valgus operation. J Bone Joint Surg 1967; 49A: 1675-1683.

27 Kelikian H. So-called conservative operations. In: Hallux valgus, allied deformities of the forefoot and metatarsalgia. Philadelphia, London, W.B. Saunders Company, 1965: 136-162.

Chapter II

Medial deviation of the first metatarsal head as a result of flexion forces in hallux valgus

SUMMARY

The aim of this study is to explain how bunions develop and why pain occurs in or under the metatarsals. We started with the biomechanical model of Snijders et al. which states that, contraction of flexor muscles of the hallux worsens the valgus angle and causes medial deviation of the first metatarsal head. The present study was designed to validate the model in patients. Whilst pressing the hallux downward, simultaneously the force under the toe and the medial deviation of the first metatarsal head were measured in 8 normal subjects, 10 subjects with hallux valgus but no complaints, and in 17 preoperative patients. It was demonstrated that: (1) when the subjects with hallux valgus push the great toe on the ground, the first metatarsal head moves in a medial direction; thus the foot widens. In the normal subjects, the foot generally became narrower. (2) The greater the valgus deviation of the hallux, the greater the effect of the toe flexors. (3) The maximal applicable flexion force on the hallux is significantly smaller in the symptomatic group compared with subjects without deformity, and asymptomatic subjects with valgus deviation of the hallux. The implications of these findings for both conservative and surgical therapy are discussed. Recurrence of deformity after first metatarsal osteotomy is explained by the action of the hallux flexors. The stable result of arthrodesis of the first metatarso-phalangeal joint is expected to be accompanied by narrowing of the foot due to contraction of the flexor muscles.

INTRODUCTION

There is a high incidence of foot complaints, the majority of which involve the forefoot.[1] Painful bunions (appearing with hallux valgus) often occur.[2,3] Hallux valgus is frequently part of a complex of forefoot deformities that can also include metatarsus primus varus, bunionette of the fifth metatarsal, dislocation of the sesamoids, pronation of the hallux, hammer toes, claw toes and overriding toes; thus we speak of the "hallux valgus complex".[3,4]

Several questions concerning the hallux valgus complex remain a matter of discussion. How do bunions develop? Does disturbed muscle balance at the first metatarso-phalangeal joint (MTP_1) (with a changed position of the tendons) play an important part in the pathogenesis of the hallux valgus complex?[3-7] What is the relationship between dynamic plantar load distribution and pain in or under the metatarso-phalangeal joints? What causes recurrence of deformity after surgery?

In order to address these questions, without considering possible etiology,[3-9] we started with the biomechanical model of Snijders et al.[10] This model describes the forces in the anatomical structures that are involved during toe pressure. These parameters are presented in a three-dimensional configuration (Fig. II.1). According to this model, contraction of the hallux flexors causes an increase in both the valgus angle of the hallux and the varus deviation of the first metatarsal. This model has been previously validated in asymptomatic subjects only. The model indicates that once hallux valgus developed, the mechanical conditions worsen, which can eventually lead to pathology.[10] This provided the rationale to investigate the medial deviation of the first metatarsal head due to flexion forces in patients.

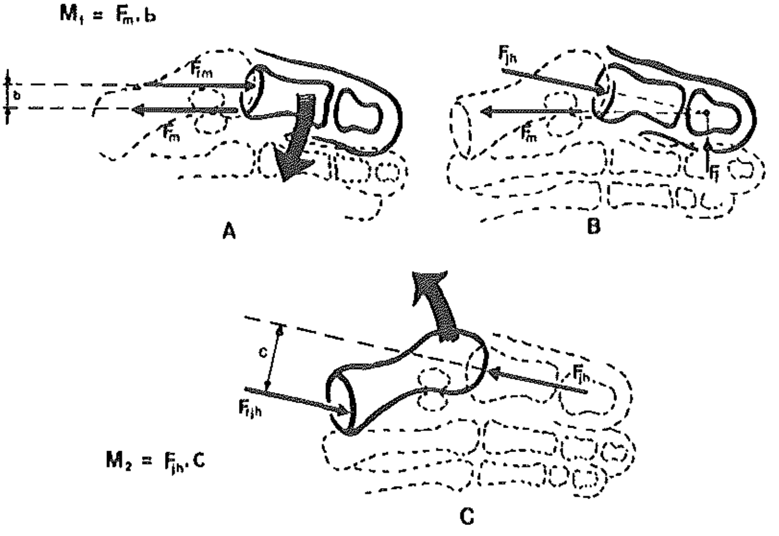


Fig. II.1. Schematic presentation of the biomechanical model of Snijders et al.[10] showing the relationship between hallux valgus and splayfoot. A, The resultant flexor force (F_m) and its reaction force in the joint (F_{rm}) together form a couple with the moment $M_1 = F_m.b$, which causes the valgus angle to increase. B, Equilibrium is achieved by, e.g., the friction force (F_f) from the ground. F_m and F_f cause the joint reaction force (F_{jh}). C, Force F_{jh}, exerted by the toe on the first metatarsal, and the reaction force (F_{rjh}) in the proximal joint form an anticlockwise couple with the moment $M_2 = F_{jh}.c$, causing the varus angle to increase.

Investigation and description of the mechanisms involved in the hallux valgus complex are expected to give better insight into treatment procedures. This will indicate more clearly whether conservative or surgical treatment is more appropriate, and could inform as to the most effective surgical method.

According to Grieve and Rashdi,[11] Hutton and Dhanendran[12] and Stokes et al.,[13,14] the walking pattern of hallux valgus patients differs from those of normal subjects. The toe pressures are lower and the load on the MTP joints shifts to the lateral side.[12-14] The load on the hallux diminishes with increasing hallux angle.[11,12] This raises the question as to whether these phenomena are due to a lower than normal potential flexion force, or to a reduced use of the toe forces to accommodate pain in the first ray. Decreased activity in the flexor muscles could lead to a decrease in the maximal producible toe force.

According to the literature, the altered plantar load distribution might lead to pain under or in the (lateral) MTP joints.[15] Bonney and Macnab[16] and Moynihan[17] reported a high percentage of metatarsalgia in their groups of hallux valgus patients (45% and 22%, respectively), which indicates that the extent of valgus deviation of the hallux alone is associated with pain under or in the (lateral) MTP joints. In order to investigate one of the possible factors in the changed walking pattern, we needed to quantify the potential flexion force on the hallux and compare this force in patients with that in healthy subjects.

The following questions were addressed:

1. Does the flexion force on the hallux increase the varus deviation of the first metatarsal?
2. What is the correlation between the effect of the flexion force (medial or lateral deviation of the first metatarsal head) and the extent of the valgus deviation of the hallux?
3. Is the isometrically measured maximal flexion force of normal subjects different from that in subjects with complaints and/or valgus deviation of the hallux?
4. What is the correlation between the maximal flexion force on the hallux and the extent of the valgus deviation of the hallux?

MATERIAL AND METHODS

Subjects

Measurements were made in three groups: Group 1, without hallux valgus and without foot complaints (8 subjects); Group 2, with (idiopathic) hallux valgus but without foot complaints (10 subjects); and Group 3, patients with (idiopathic) hallux valgus who later underwent corrective operation (17 subjects).

Clinical features

Although this study focuses mainly on biomechanics, a limited number of relevant clinical characteristics were assessed to gain insight to the patients involved. The presence of hallux pronation was determined. Further, diminished sagittal range of motion (ROM) of MTP_1 was estimated on sight (by APS) and is defined as passive dorsiflexion less than 60° and/or plantar flexion less than 10°. The ROM is the angle between the longitudinal axis of the hallux and the plantar contact surface of the foot.

Force and displacement

We measured the vertical force produced by the hallux with the subject standing and pressing on a toe force transducer (Philips, strain gauge type) that was adaptable to different anatomy (Figs. II.2-4). A displacement of the first metatarsal head in the horizontal plane was determined by means of a contactless distance transducer (Turck Bi 10-M30-LIU) (Figs. II.3 and II.5). This transducer works according to an inductive principle. Here, the intensity of a magnetic field recorded by a sensor is influenced by the displacement of a small steel disk adjusted to the medial aspect of the first metatarsal head. Therefore, a range of 4.3 mm widening or narrowing of the foot could be recorded contactless. Good fixation of the steel disk to the first metatarsal head during the toe force measurements was necessary. This was achieved using a piece of Velcro fastened to the disk and to a very thin elastic (with a negligible effect on biomechanics) encompassing the first two toes (Fig. II.5).

Fixation of the foot to prevent pronation or supination during toe pressure was achieved using an immobile Perspex block placed against the medial malleolus. By touching the block with minor force the subject received tactile information as to the constant position of the foot against the block, giving a firm blockade of pronation in the tarsus (Fig. II.3). Based on earlier pilot studies, this proved to give the most satisfying adjustment compared with other more passive possibilities: e.g. supporting the foot and lower leg with a clamp, use of adhesive tape, or Velcro strips. These techniques seemed counterproductive due to the chance to push off. Finally, with reference to the biomechanical model, the big toe was prevented from sliding on the toe force transducer by providing sufficient friction (see F_f in Fig. II.1).

The subjects, leaning against a wall and striving for an equal distribution of body weight over both feet (Fig. II.2), were asked to press a series of seven predetermined toe force values, at equal force intervals, and ranging from 2.75-22.0 N. The subjects read these toe force values on a meter (biofeedback); each force value was repeated three times. In the three successive series the subjects pressed, respectively, an increasing, decreasing and increasing order of force values. Further, the subjects were asked to press

Fig. II.2. Photograph of the measuring devices and the correct body posture.

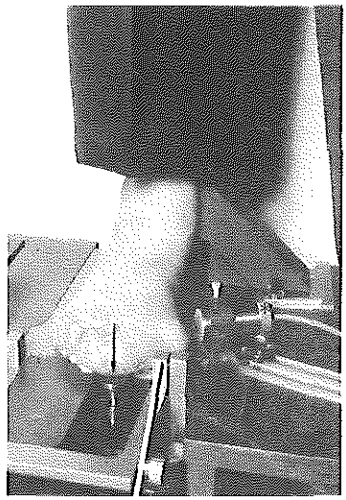


Fig. II.3. Position of the foot in relation to the toe force transducer (arrow), the contactless distance transducer (*) and the block against the medial malleolus.

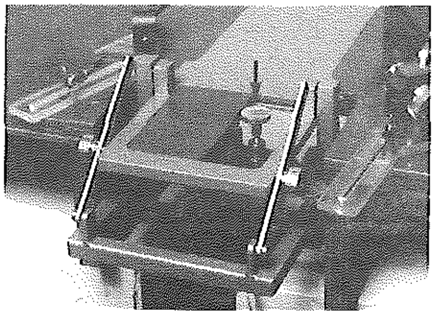


Fig. II.4. The toe force transducer (arrow), which is adaptable to different anatomy.

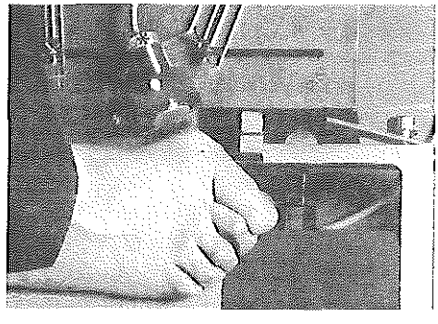


Fig. II.5. Position of the contactless distance transducer (*) and the steel disk on the skin at the level of the first metatarsal head.

three times with maximum toe force. During these latter measurements, in contrast with the other force measurements, an accurate fixation of the foot was not always possible. Therefore, the displacement of the first metatarsal head during maximum force was not consistently measured and analysed. Data registration was done using a two-channel pen recorder.

Statistical analysis

The results are presented in a graph with the flexion force (F) on the horizontal axis and the displacement of the first metatarsal head (d) on the vertical axis. The relationship between the parameters is determined by means of a regression line (d = *a* x F) (Fig. II.6). This regression line is determined for flexion force values ≥ 2 N and ≤ 10 N. Several subjects were unable to produce small force values on command; or were unable to press the hallux while maintaining a sound fixation of the foot, with forces greater than 10 N. Only within this range did each person have sufficient measured

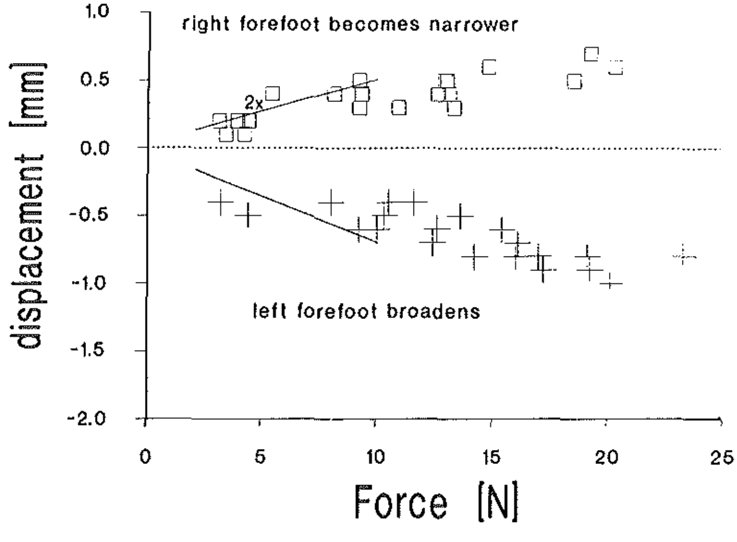


Fig. II.6. An illustrative example of measuring values obtained from one patient with a normal right foot and hallux valgus left. The left forefoot (bottom) broadens and the normal foot (top) narrows with increasing toe force. Right: r_s=0.784, P=0.001, left: r_s=-0.794, P<0.001.

values to achieve interindividually comparable regression lines. The value and the sign of the regression coefficient (*a*) form a parameter which represents the measured phenomenon in a simple way, in spite of the lack of low flexion force values (< 2 N) and the restricted quality of the fit to a larger range of force values. With positive measuring values of the displacement of the first metatarsal head (above the dotted line in Fig. II.6), the forefoot became narrower during toe pressure ($a > 0$). With negative values, the forefoot broadened (first metatarsal head to medial) during toe pressure.

In the analysis the results of only one foot per subject were used. The reason is that the subjects, and not their feet, are the mutually independent observational units. In Group 1, the side (right or left foot) with the smallest print hallux angle (measured by ink footprints) was evaluated. This side is considered to be representative of the healthy situation and may form the most useful control group, against the deviated situation in Groups 2 and 3. In Groups 2 and 3, the side with the largest print or X-ray hallux angle was evaluated. Based on 5 repeated measurements in 4 subjects, the total inaccuracy in the measurements of force and displacement is estimated at ±5%.

RADIOGRAPHY AND FOOTPRINTING MAT

The position of the hallux and the first metatarsal of 15 of the clinical patients (Group 3) were determined with the help of the preoperative X-rays (AP, standing). The X-rays of 2 patients were missing or had an insufficient view of the structures to be investigated. No X-rays were taken of most of the asymptomatic subjects (Group 1: one subject with X-rays, Group 2: no X-rays available) because these were measured in a separate study in a non-clinical setting. Therefore, we described the structure of the forefeet by means of static ink footprints. The print hallux angle was used as a parameter (PrHA = the angle between the tangent along the hallux and the medial side of the ball of the foot and the tangent along the medial side of the heel and the medial side of the ball of the foot; Fig. II.7). In 12 patients (Group 3) the PrHA was also determined.

The PrHA is a useful parameter, as evidenced by measurements in 11 subjects in whom a significant correlation (Fig. II.8) was found with the hallux angle measured by X-ray (XHA = the angle between the axes of the first metatarsal and the proximal phalanx; Fig. II.7). Only for these subjects was both an X-ray and a footprint available; they included 1 subject from Group 1 and 10 subjects from Group 3. We could draw a regression line for XHA from 14°-47° using the following equation: PrHA = -4.50° + 0.828 x XHA. The Spearman rank test gave a correlation coefficient (r_s) of 0.911 with P=0.004.

Most hallux valgus patients have a XHA > 15°.[18] We defined an abnormal hallux valgus complex as XHA > 15° or PrHA > 8° (Fig. II.8).

The measured intermetatarsal$_{1\text{-}2}$ angle ($IMTA_{1\text{-}2}$) is the angle between the axes of the first and second metatarsals (Fig. II.7).

The presence of degenerative changes in the MTP_1 joint and/or the interphalangeal joint of the hallux was determined using the classification of Grace et al.[19] and concerned in particular: osteophytes, irregularity, flattening, sclerosis, cysts and joint narrowing.

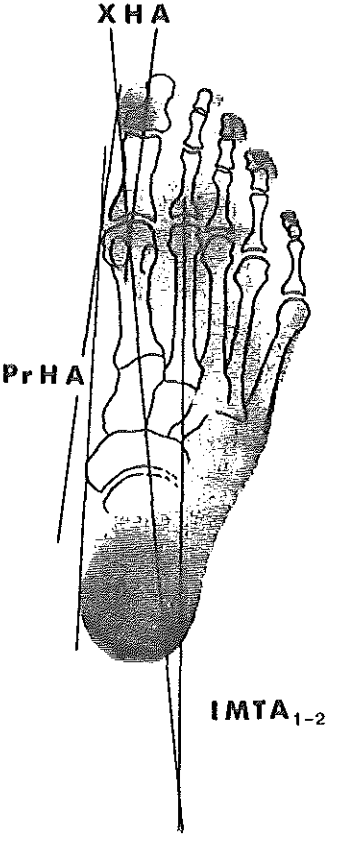


Fig. II.7. Illustration of a method to assess the hallux angle (XHA and PrHA) and the intermetatarsal$_{1\text{-}2}$ angle ($IMTA_{1\text{-}2}$) by means of X-ray and a footprinting mat.

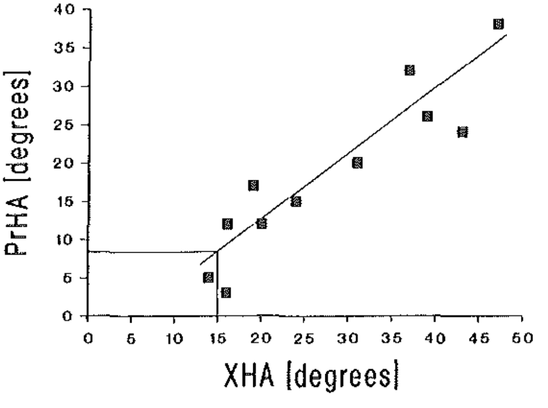


Fig. II.8. The statistically significant relationship between the X-ray hallux angle (XHA) and the print hallux angle (PrHA) from unilateral measurements of 11 patients. r_s=0.911; P=0.004.

RESULTS

Clinical features, footprinting mat and radiography

Group 1:
Measurements were made in 8 persons without hallux valgus (7 females, 1 male; age range 27-75 years, average 47 years; PrHA range 0°-4°, average 0.3°).

Group 2:
Included 10 persons with hallux valgus but with no complaints and no therapy (9 females, 1 male; age range 21-77 years, average 44 years; PrHA range 10°-32°, average 16.0°).

Group 3:
Comprised 17 female patients with clinical hallux valgus, 15 of whom underwent corrective operation one day after the measurements (age range 18-76 years, average 49 years; PrHA range 3°-38°, average 22.6°; XHA range 16°-47°, average 30.4°; $IMTA_{1-2}$ range 6°-24°, average 13.1°). Six patients in Group 3 showed obvious degenerative changes in MTP_1.

One person in Group 2 and 5 in Group 3 had pronation of the hallux. Subjects with diminished passive dorsiflexion (< 60°) and/or plantar flexion (< 10°) of MTP_1 included one in Group 1, two in Group 2, and seven in Group 3. Pain was experienced during the passive dorsiflexion or plantar flexion in one in Group 1, one in Group 2, and five subjects in Group 3.

Force and displacement

The average regression lines of the three groups are shown in Fig. II.9.

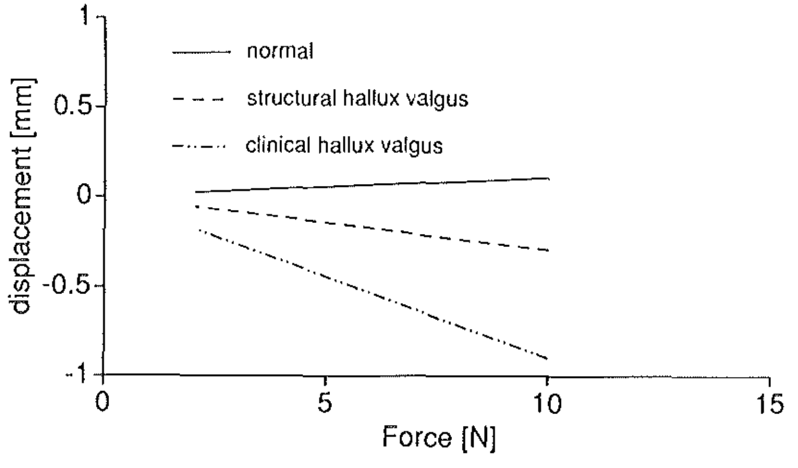


Fig. II.9. Relationship between flexion force and displacement (see Fig. II.6). Average of the regression lines obtained from three different groups (unilateral): normal subjects (Group 1); persons with structural hallux valgus but without complaints and therapy (Group 2); and preoperative patients with clinical hallux valgus (Group 3).

Group 1:
In the 8 normal persons (PrHA ≤ 8°) the following occurred: the foot narrowed during toe pressure in 6 subjects and broadened in 2 subjects (Table II.1).

Group 2:
Of the 10 subjects with anatomical aberrations but without complaints (PrHA > 8°), the foot broadened in all subjects during toe pressure (Table II.1).

Group 3:
Of the 17 (preoperative) patients with hallux valgus (XHA > 15° and/or PrHA > 8°), the foot broadened in all patients during toe pressure (Table II.1). During toe pressure, displacement of the first metatarsal in the medial direction increased up to 2.4 mm.

Table II.1. Calculated values of the regression coefficient (*a*) as a determinant of forefoot narrowing (*a* > 0) or broadening (*a* < 0).

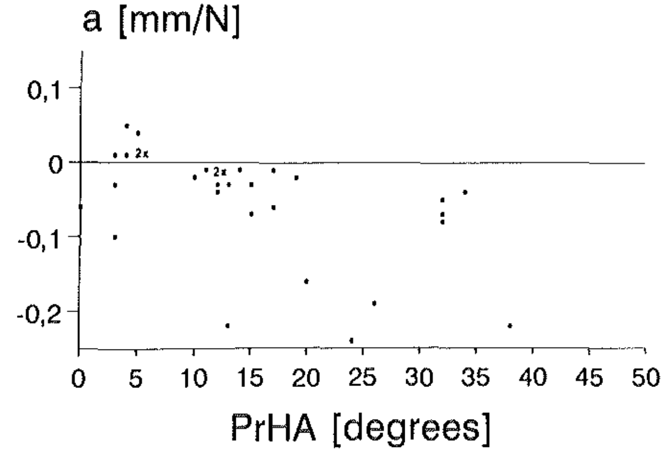
Group 1 (n=8): Normal	**Group 2 (n=10): Structural hallux valgus**	**Group 3 (n=17): Clinical hallux valgus**	
+0.05	-0.01	-0.01	-0.09
+0.05	-0.01	-0.02	-0.09
+0.04	-0.01	-0.03	-0.10
+0.01	-0.02	-0.04	-0.16
+0.01	-0.02	-0.04	-0.19
+0.01	-0.03	-0.05	-0.22
-0.03	-0.03	-0.06	-0.24
-0.06	-0.03	-0.07	
	-0.06	-0.08	
	-0.07	-0.08	
Mean (SD):			
+0.01 (0.04)	-0.03 (0.02)	-0.09 (0.07)	

For average regression coefficients (*a*) of the studied groups, the Mann-Whitney U-test revealed significant differences between: Groups 1 and 2 ($P<0.05$); Groups 1 and 3 ($P<0.001$); and between Groups 2 and 3 ($P<0.01$).

Deformity and displacement

For all subjects in whom PrHA was determined, a statistically significant but moderate correlation between PrHA and the regression coefficient (*a*) was found (r_s=-0.586, P=0.002). Another correlation was found between XHA and *a* (r_s=-0.619, P=0.017) (Fig. II.10).

No statistically significant correlations were found between $IMTA_{1\text{-}2}$ and XHA, PrHA, *a* or the maximal flexion force.



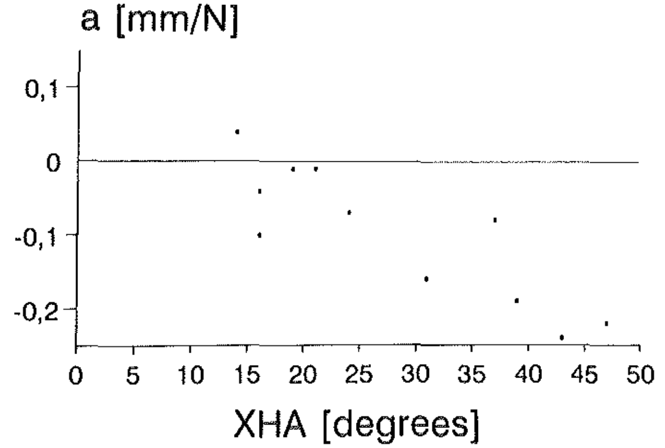


Fig. II.10. The regression coefficient of the regression line (displacement = *a* × force) was used as a parameter of the broadening or narrowing effect of the flexion force on the forefoot. Top: The relationship between *a* and the print hallux angle (unilateral; n=30) (Spearman rank correlation coefficient = -0.586; P=0.002). Bottom: The relationship between *a* and the X-ray hallux angle (unilateral; n=16) (Spearman rank correlation coefficient = -0.619; P=0.017). The greater the valgus deviation, the greater the widening effect (*a* is more negative).

Maximal force

The maximal force that the hallux could develop by pressing downward (unilateral) was on average: Group 1, 76 N (range 32-105 N); Group 2, 66 N (range 33-124 N); and in Group 3, 42 N (range 10-80 N). In response to our question, no patient reported any restriction due to pain in their attempt to achieve maximal force.

According to the Mann-Whitney U-test, there are significant differences between the average maximal force of the normal subjects (Group 1) and those with clinical hallux valgus (Group 3) ($P<0.01$). Subjects with hallux valgus but without complaints (Group 2) compared to Group 3 also showed a significant difference in maximal toe force ($P<0.05$).

For all groups together, a significant but weak correlation was found between maximal force and PrHA (Spearman rank correlation coefficient = -0.417; $P=0.030$).

There was no statistically significant correlation between maximal force and age, XHA, the presence of hallux pronation, range of passive mobility of MTP_1, and the presence of pain during passive dorsiflexion and plantar flexion of MTP_1.

DISCUSSION

The present study was designed to investigate and quantify in patients the degree of deformation of the foot due to tension in the flexor muscles.

Initially, in order to characterize the subject's forefoot, the extent of the valgus deviation of the hallux was measured. The assessed relationship between the valgus angle, determined by means of a static footprint, and the valgus angle of the weight-bearing radiograph offered a method to measure deformity when X-rays were not available. This footprint parameter is also relevant for disciplines that do not have X-rays at their direct disposal.

After designing a test bench, subjects were asked to press on a force transducer and simultaneously the translation of the head of the first metatarsal in the horizontal plane was recorded. During downward pressure of the hallux the subjects experienced no pain, which provides an argument for realistic measurement of (maximal) force. In the analyses, the sign and value of the regression coefficient form a parameter which represents the measured phenomenon in a simple way. This parameter serves as a practical method to compare normal subjects with the hallux valgus groups.

Biomechanics predicts a widening of the foot in patients with hallux valgus.[10] In controls with small hallux angles or straight great toes, the widening is predicted to be less or even absent. In this study, the mechanics proved to be as expected. The results of this study may have clinical importance for both conservative and surgical therapy.

Pain caused by a bunion can be relieved by wearing appropriate footwear that provides sufficient room for the toes,[20-22] or using a bunion shield made of felt or silicone.[23] Relief of pain in or under the MTP joints may be achieved by means of a pad proximal to the metatarsal heads,[20] a metatarsal arch support,[24] a hollow made in the sole or inlay under the specific metatarsal head,[20] a shock-absorbing insole,[25] a stiffening of the medial side of the shoe sole,[24] a metatarsal bar under the shoe sole,[4,20,24] or a rocker sole.[21] An obvious approach to correct malformation of the first ray are exercises which lead to corrective muscle action.[22,26] However, this mutilation of the foot has a precarious prognosis. Muscles strong enough and with proper lever arms to straighten the great toe are not available, while the still active hallux flexors tend to worsen the deformity. As far as we know, no convincing reports concerning the corrective action of orthoses, such as night splints, exist. This leads to a discussion concerning the effect of surgical treatment. From a biomechanical viewpoint, an intervention that permanently eliminates the foot-widening effect will be seen as the treatment of choice.

There are many recurrences of first ray deformity and complaints after first metatarsal osteotomy.[27-29] From the measurements made in this study, one possible explanation for recurrence was found: when the pathogenetic flexion forces still exist, they will continue to produce deviation of the hallux and the first metatarsal.

Arthrodesis of MTP_1, with appropriate dorsiflexion and valgus position of the toe, permanently controls the alignment of MTP_1.[17,27,30-35,37] Furthermore, the biomechanical model (Fig. II.1) shows that, when toe and first metatarsal form one mechanical entity, the pull of the hallux flexors will not cause a medial deviation of the first metatarsal head, but can produce a narrowing effect, dependent on the geometry of the structures involved.[10] Although the biomechanical model provides a basis for the choice of arthrodesis, it must be emphasized that in the final choice for each individual, other aspects must also be taken into consideration. These include medical aspects (simplicity of the surgical technique, mobility of the inter-phalangeal joint,[17,30,31,33,36]) or functional (kind of personal activities[33] and footwear[17,33]) and cosmetic factors (the ability to achieve an optimal fusion position.[17,30-32]) Comparing patients before and after surgery may serve to prove the anticipated positive biomechanical effect of arthrodesis of MTP_1. The measurement procedures used in this study can also be applied in postoperative patients.

In gait, the plantar load on the hallux diminishes with an increasing hallux angle.[11,12] It should be established whether the cause of this change in pressure or force distribution can be attributed to pain (antalgic walking pattern), or to decrease in the effective muscle force, or to other origins. The results of this study demonstrate a weak relationship between the isometrically assessed maximal flexion force on the hallux and the valgus deviation. Other possible factors, such as age and MTP_1 characteristics, did not significantly correlate with the maximal flexion force. In a static situation in 8 healthy subjects (Group 1) an average maximal flexion force of 76 N was measured, and in 17 preoperative patients (Group 3), an average of 42 N. It is assumed that the latter group is less capable to exert the required force to oppose a normal load (105 N)[12] on the hallux during walking. This lack of effective force could be a factor in the development of an altered dynamic plantar load distribution with a diminished maximum force (66 N)[12] being exerted on the hallux. However, it could also be an effect of prolonged inactivity of flexor muscles.

The clinical relevance of the change of plantar load distribution is assumed to be related to pain under or in the MTP joints. Bonney and Macnab[1] and Moynihan[17] reported high incidences of metatarsalgia in their groups of hallux valgus patients. This could indicate a (causal) relationship between the extent of valgus deviation of the hallux and presence of pain under or in the MTP joints. However, these reports do not consider whether metatarsalgia could have been caused by arthritic MTP joints or secondarily by lesser toe deformities.[16,17] On the other hand, in 1975 Henry and Waugh[15] reported that "if the big toe does not bear weight after operation, the patient is likely to develop metatarsalgia and callosities."

CONCLUSIONS

1. When subjects with hallux valgus push the great toe on the ground, the first metatarsal head moves in the medial direction; in other words the foot widens. In subjects without hallux valgus, the foot generally becomes narrower.
2. The displacement of the first metatarsal in the medial direction increases up to 2.4 mm during toe pressure.
3. The maximal applicable flexion force on the hallux is statistically significantly smaller in the symptomatic group compared with subjects without deformity, and asymptomatic subjects with valgus deviation of the hallux.
4. Radiographically determined hallux angles show a significant correlation with hallux angles measured by means of an ink footprint, with the latter giving a smaller value.

REFERENCES

1 Herschel H, Meel PJ van. Metatarsalgie. Ned Tijdschr Geneeskd 1982; 45: 2056-2061.

2 Foot and Footwear Foundation. [Stichting Voet en Schoeisel.] Bejaardenenquête. Waalwijk, The Netherlands, 1978.

3 Jahss MH. Disorders of the foot. Philadelphia, W.B. Saunders Company, 1982.

4 Kelikian H. Hallux valgus, allied deformities of the forefoot and metatarsalgia. Philadelphia, W.B. Saunders Company, 1965.

5 Debrunner HU. Ätiologie und Pathogenese des Hallux Valgus. In: Blauth W, editor. Der hallux valgus. Berlin, Heidelberg, New York, Tokyo, Springer-Verlag, 1986: 38-43.

6 Mann RA, Coughlin MJ. Hallux valgus - Etiology, anatomy, treatment and surgical considerations. Clin Orthop 1981; 157: 31-41.

7 Scranton PE, Rutkowski R. Anatomic variations in the first ray: Part I. Anatomic aspects related to bunion surgery. Clin Orthop 1980; 151: 244-255.

8 Feldkamp M. Der Hallux valgus bei Zerebralparese. In: Blauth W, editor. Der Hallux valgus. Berlin, Heidelberg, New York, Tokyo, Springer-Verlag, 1986: 79-82.

9 Goldner JL. Hallux valgus and flexus associated with cerebral palsy: Analysis and treatment. Clin Orthop 1981; 157: 98-104.

10 Snijders CJ, Snijder JGN, Philippens MM. Biomechanics of hallux valgus and spreadfoot. Foot Ankle 1986; 5: 327-332.

11 Grieve DW, Rashdi T. Pressures under normal feet in standing and walking as measured by foil pedobarography. Ann Rheumatic Diseases 1984; 43: 816-818.

12 Hutton WC, Dhanendran M. The mechanics of normal and hallux valgus feet - a quantitative study. Clin Orthop 1981; 157: 7-13.

13 Stokes IAF, Hutton WC, Evans MJ. The effects of hallux valgus and Keller's operation on the load-bearing function of the foot during walking. Acta Orthop Belg 1975; 41: 695-704.

14 Stokes IAF, Hutton WC, Stott JRR, Lowe LW. Forces under the hallux valgus foot before and after surgery. Clin Orthop 1979; 142: 64-72.

15 Henry APJ, Waugh W. The use of footprints in assessing the results of operations for hallux valgus. J Bone Joint Surg 1975; 57B: 478-481.

16 Bonney G, Macnab I. Hallux valgus and hallux rigidus, a critical survey of operative results. J Bone Joint Surg 1952; 34B: 366-385.

17 Moynihan FJ. Arthrodesis of the metatarso-phalangeal joint of the great toe. J Bone Joint Surg 1967: 49B: 544-551.

18 Piggott H. The natural history of hallux valgus in adolescence and early adult life. J Bone Joint Surg 1960; 42B: 749-760.

19 Grace D, Hughes J, Klenerman L. A comparison of Wilson and Hohmann osteotomies in the treatment of hallux valgus. J Bone Joint Surg 1988; 70B: 236-241.

20 Lake NC. The foot. London, Baillière, Tindall and Cox, 1943.

21 Milgram JE. Office measures for relief of the painful foot. J Bone Joint Surg 1964; 46A: 1095-1116.

22 Yale I. Podiatric medicine. Baltimore, The Williams & Wilkins Company, 1974: 244-246.

23 Coates IS. Silicone orthodigita and shielding. J Amer Podiatr Assoc 1976 Suppl; 66: 1-33.

24 Stewart JDM. Traction and orthopaedic appliances. Edinburgh, London, New York, Churchill Livingstone, 1975.

25 Scranton PE. Metatarsalgia: diagnosis and treatment. J Bone Joint Surg 1980; 62A: 723-723.

26 Hohmann G. Hallux valgus und Spreizfuß. In: Fuß und Bein; ihre Erkrankungen und deren Behandlung. München, Verlag von J.F. Bergmann, 1948: 156-158.

27 Haeff PAJ van. De operatieve behandeling van de hallux valgus. Thesis, Nijmegen, The Netherlands, 1958.

28 Hattrup SJ, Johnson KA. Chevron osteotomy: analysis of factors in patients dissatisfaction. Foot Ankle 1985; 5: 327-332.

29 Imhoff A, Baumgartner R, Blauth W, Büsch HG, Lamprecht E. Fehlschläge nach Hallux-valgus-Operationen und ihre Behandlung. In: Blauth W, editor. Der Hallux valgus. Berlin, Heidelberg, New York, Tokyo, Springer-Verlag, 1986: 105-117.

30 Fitzgerald JAW. A review of long-term results of arthrodesis of the first metatarsophalangeal joint. J Bone Joint Surg 1969; 51B: 488-493.

31 Fitzgerald JAW, Wilkinson JM. Arthrodesis of the metatarso-phalangeal joint of the great toe. Clin Orthop 1981; 157: 70-77.

32 Gregory JI, Childers JL, Higgins KR, Krych SM, Harkless LB. Arthrodesis of the first metatarsophalangeal joint: a review of the literature and long-term retrospective analysis. J Foot Surg 1990; 29: 369-374.

33 Harrison MHM, Harvey FJ. Arthrodesis of the first metatarsophalangeal joint for hallux valgus and rigidus. J Bone Joint Surg 1963; 45A: 471-480.

34 Lipscomb PR. Arthrodesis of the first metatarsophalangeal joint for severe bunions and hallux rigidus. Clin Orthop 1979; 142: 48-54.

35 Raymakers R, Waugh W. The treatment of metatarsalgia with hallux valgus. J Bone Joint Surg 1971; 53B: 684-687.

36 Salis-Soglio G von, Thomas W. Arthrodesis of the metatarsophalangeal joint of the great toe. Arch Orthop Traumat Surg 1979; 95: 7-12.

Chapter III

Biomechanical analysis of the effects of osteotomy and arthrodesis for hallux valgus and metatarsus primus varus

SUMMARY

On the basis of a biomechanical model two essentially different postoperative effects on the first ray alignment were predicted and measured. The medial deviation of the first metatarsal head due to flexion forces on the hallux was measured in patients with clinical idiopathic hallux valgus, who underwent a modified Hohmann osteotomy (8 patients) or an arthrodesis of MTP_1 (10 patients). We found: (1) Flexion forces exerted by the preoperative hallux result in widening of the forefoot. (2) After a modified Hohmann osteotomy widening of the forefoot on average diminished significantly, but was still present; this might explain the recurrence of bunions. (3) After an arthrodesis flexion forces can lead to a narrowing effect on the forefoot. (4) Postoperatively, both the osteotomy and arthrodesis groups showed a slight, but statistically non-significant decrease (from 37-25 N and from 36-31 N, respectively) of the isometrically determined average maximal applicable flexion force. These small hallux loads may cause, or result from, a deviation in gait pattern.

INTRODUCTION

Many surgical procedures for the treatment of hallux valgus and metatarsus primus varus are known,[1,2] illustrating the problem in deciding which operation is best. Moreover, the operation does not always result in a permanent success for the patient. New complaints and/or recurrences of symptomatic deformity may develop,[3-6] leading to the risk of re-operation. Imhoff et al. report that 10% of 124 patients showed a valgus angle greater than 25° after a Hohmann osteotomy.[6]

The present study seeks to establish the best choice of surgical procedure based on a biomechanical analysis using the model of Snijders et al.[7] This model describes the forces in the anatomical structures that play a role during toe pressure. The involved parameters are presented in a three-dimensional configuration. According to this model, contraction of the displaced hallux flexors causes an increase of both the valgus angle of the hallux and the varus deviation of the first metatarsal (Fig. II.1). Without considering possible etiology,[2,8-13] the model indicates that once a hallux valgus has developed, the mechanical conditions worsen, which can lead to pathology.[7] In Chapter II and a previous publication[14] we described the verification of the model with measurements in normal subjects, asymptomatic subjects with hallux valgus and patients with clinical hallux valgus.

According to Snijders' model the effects of a first metatarsal osteotomy and an arthrodesis of the first metatarso-phalangeal joint (MTP_1) are predicted to be essentially different. In some cases the choice between these surgical procedures is associated with different clinical features. Therefore, the patient groups undergoing these procedures may show differences in age and characteristics of the MTP_1 joint (pain or range of motion in the sagittal plane). We emphasize that the present study focuses mainly on the biomechanics of these surgical methods. The results may provide additional insight into the effects of both procedures and contribute to the decision-making process in the choice of operation.

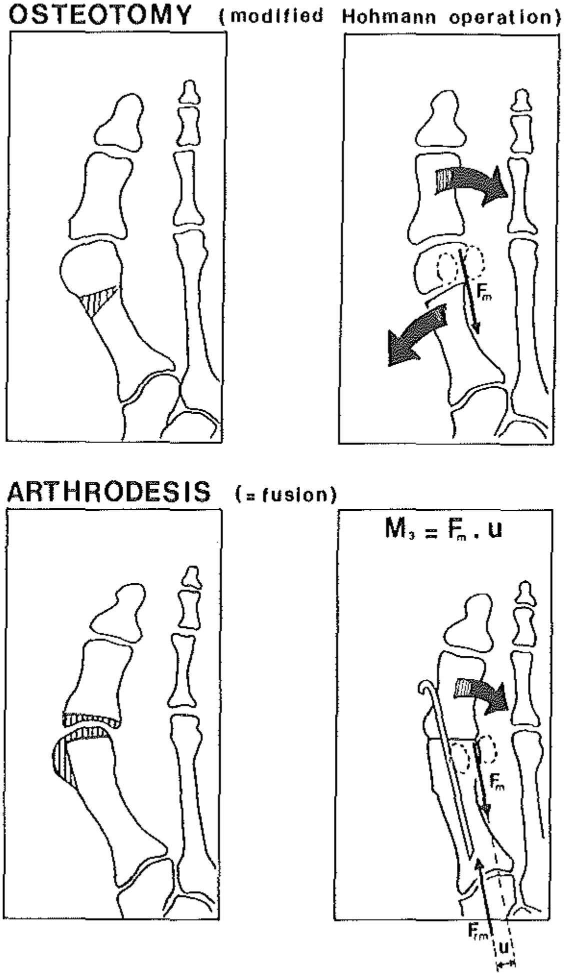


Fig. III.1. The two surgical techniques and the predicted postoperative effects of the resultant flexor force (F_m) and its reaction force in the joint ($F_{r\,m}$). After arthrodesis a favourable moment M_3 with lever arm u could exist.

The biomechanical model predicts that when the deviated position of the muscles and the attendant deforming forces and moments still exist after a first metatarsal osteotomy, these forces again will cause the development of the hallux valgus and metatarsus primus varus with accompanying complaints.[15,16] Further, the model predicts that after arthrodesis of MTP_1, the footwidening effect of flexion forces on the hallux can be diminished or even changed to a foot narrowing effect (Fig. III.1: moment M_3). The measure of the arm (u) of the moment and thus the measure of the effect depends on the position of the tendons and on the location of the "bone-on-bone contact point" in the first tarso-metatarsal joint.

Besides bunion pain, pain in or under the MTP joints also plays a role in hallux valgus patients. The presence of pain in or under the (lateral) MTP joints is assumed to be related to the distribution of plantar pressure during walking.[17,18] A relationship between a decreased load on the hallux and pain under the lateral MTP joints is reported by Henry and Waugh.[17] The maximal flexion force on the hallux, measured in a static situation, might give a rough indication of the load which can be opposed by the hallux during walking.

The following questions were addressed:

1. Does the flexion force on the hallux increase the varus deviation of the first metatarsal in patients selected for a modified Hohmann osteotomy or arthrodesis of MTP_1?
2. After either surgical procedure, can a significant decrease in the widening effect of the forefoot (due to activity of the hallux flexors) be demonstrated?
3. Is the widening effect on the forefoot of the hallux flexors significantly different between both surgical procedures?
4. How large is the isometrically determined maximal applicable flexion force on the hallux before and after surgery?

MATERIAL AND METHODS

Subjects

Measurements were made in 18 female patients with clinical idiopathic hallux valgus, who underwent a modified Hohmann osteotomy (8 patients, average age 32 years, range 18-45 years), or arthrodesis of MTP_1 (10 patients, average age 58 years, range 40-76 years). Patients with evidence of a previous foot operation (except a simple bunionectomy) or hallux valgus as a result of gout, rheumatoid arthritis, poliomyelitis or spastic paralysis were excluded from the study. Eight normal subjects without hallux valgus and without foot complaints were measured according to the present protocol and served as a control group. The latter subjects were also described in Chapter

II and a previous publication.[14]

Surgical methods

The modified Hohmann osteotomy (Fig. III.1) is a medial closing wedge osteotomy through the metatarsal neck with a limited lateral shift of the head, fixed with two Vicryl sutures. At the same time, a re-insertion of the distal tendon of the abductor hallucis to the dorso-medial aspect of the proximal phalanx is performed.

Arthrodesis is a fusion of MTP_1 combined with a resection of the bunion; fixation is attained with the help of a Rush pin (Fig. III.1). The desired position of fusion of MTP_1 in the horizontal plane has a hallux angle of 20°.[19-21] In the studied patients the surgeons intended to fix the hallux in a horizontal position, or in a few degrees of dorsiflexion. If the patient expressed the wish to wear high-heeled shoes postoperatively, a greater degree of dorsiflexion was chosen.

As a guideline for the choice of operation, an osteotomy was the preferred procedure if the patient was young, had sufficient range of motion of MTP_1 in the sagittal plane (dorsiflexion > 50°-60°), and there were no signs of osteoarthritis of the MTP_1 joint on the X-ray. In other cases arthrodesis was preferred.

Clinical features

Although this study focuses mainly on biomechanics, a limited number of relevant clinical characteristics was assessed to gain insight to the patients involved. The number of patients with bunion pain due to shoe-fitting problems, pain in or under the lateral MTP joints, hallux pronation and an over- or underriding hallux was determined. Further, diminished sagittal range of motion (ROM) of MTP_1 was estimated on sight (by APS) and is defined as passive dorsiflexion less than 60° and/or plantar flexion less than 10°. The ROM is the angle between the longitudinal axis of the hallux and the plantar contact surface of the foot. MTP_1 was declared painful if the patient experienced pain during passive dorsi- or plantarflexion.

Radiography and footprinting mat

The position of the hallux and the first metatarsal was determined using the weight-bearing AP X-ray. The hallux angle (HA) is defined as the angle between the axes of the first metatarsal and the proximal phalanx. After a distal metatarsal osteotomy there may be an improvement of the functional inter-metatarsal angle due to a lateral displacement of the first metatarsal head.[22,23] We did not consider quantification of the surgical lateral shift of the first metatarsal head because this change is not a result of the studied flexion forces. Instead we used the inter-metatarsal$_{1\text{-}2}$ angle ($IMTA_{1\text{-}2}$) which is defined as the angle between the axes of the first and second metatarsals. This parameter gives information on the change in position of the first metatarsal shaft as a result of several forces acting on the first ray.

The presence of degenerative changes in MTP_1 was determined using the classification of Grace et al.[3] and concerned in particular: osteophytes, flattening, irregularity, sclerosis, cysts and decreased joint space.

In the 8 normal subjects without hallux valgus and without foot complaints no X-rays were available. The structure of these forefeet was assessed by means of static ink footprints. The print hallux angle was used as a parameter (PrHA = the angle between the tangent along the hallux and the medial side of the ball of the foot and the tangent along the medial side of the heel and the medial side of the ball of the foot) (See Chapter II; Fig. II.7).

Force and displacement

The vertical force produced by the hallux was measured with the patient standing and pressing on a toe force transducer (Philips, strain gauge type) which was adaptable to different anatomy (Figs. II.2-4). Simultaneously, a displacement of the first metatarsal head in the horizontal plane was determined by means of a contactless distance transducer (Turck Bi 10-M30-LIU) (Figs. II.3 and II.5). This transducer works according to an inductive principle. Here, the intensity of a magnetic field recorded by a sensor is influenced by the displacement of a small steel disk adjusted to the medial aspect of the first metatarsal head. A range of 4.3 mm of widening or narrowing of the foot could be recorded contactless.

Fixation of the foot to prevent pronation or supination during toe pressure was achieved using an immobile Perspex block placed against the medial malleolus. By touching the block with minor force, the patient received tactile information as to the constant position of the foot against the block, giving a firm blockade of pronation in the tarsus (Fig. II.3).

The patients, leaning against a wall and striving for an equal distribution of body weight over both feet (Fig. II.2), were asked to press a series of 7 predetermined toe force values, at equal force intervals, and ranging from 2.75-22.0 N. The patients read these toe force values from a meter (biofeedback); each force value was repeated three times. Further, the subjects were asked to press three times with maximum toe force. During these latter measurements, in contrast with the other force measurements, an accurate fixation of the foot was not always possible. Therefore, the displacement of the first metatarsal head during maximum force was not consistently measured and analysed. Data registration was done using a two-channel pen recorder. For a more detailed description of the technical procedures we refer to Chapter II.

The measurements were made one day prior to surgery and repeated at follow-up (osteotomy average 279 days, range 230-407 days; arthrodesis average 314 days, range 221-513 days).

Statistical analysis

The results are presented in a graph with the flexion force on the horizontal axis and the displacement of the first metatarsal head on the vertical axis. The relationship between the parameters is determined by means of a regression line ($d = a \times F$) (Fig. II.6). This regression line is determined for flexion force values ≥ 2 N and ≤ 10 N. Several subjects were unable to produce small force values on command; or were unable to press the hallux while maintaining a sound fixation of the foot, with forces greater than 10 N. Only within this range did each person have sufficient measured values to achieve interindividually comparable regression lines. The value and the sign of the regression coefficient (*a*) form a parameter which represents the measured phenomenon in a simple way, in spite of the lack of low flexion force values (< 2 N) and the restricted quality of the fit to a larger range of force values. With positive measuring values of the displacement of the first metatarsal head (above the dotted line in Fig. II.6), the forefoot became narrower during toe pressure ($a > 0$). With negative values, the forefoot broadened (first metatarsal head to medial) during toe pressure. In the analysis the results of only one foot per subject were used. The reason is that the subjects, and not their feet, are the mutually independent observational units. In the normal group, the side of the foot with the smallest PrHA value was evaluated. In the patient groups, the side with the largest HA value was evaluated.

RESULTS

Radiography and clinical features

Pre- and postoperative characteristics of the two study groups with regard to HA, $IMTA_{1-2}$, range of motion of MTP_1, painful MTP_1 and degenerative changes of MTP_1 are shown in Table III.1. A comparison before and after surgery with regard to pain and toe deformities is shown in Table III.2.

Table III.1. Radiographic and clinical characteristics before and after osteotomy or arthrodesis.

	Osteotomy (n=8)		Arthrodesis (n=10)	
	Before	**After**	**Before**	**After**
HA	31 (16-43)	21 (16-34)	33 (16-47)	18 (6-32)
$IMTA_{1-2}$	12 (6-20)	11 (8-17)	15 (10-24)	14 (8-24)
Degenerative changes MTP_1	1	1	5	-
Diminished ROM MTP_1	2	3	5	10
Painful MTP_1 (passive)	2	2	2	0

HA; $IMTA_{1-2}$: average values and (range) are in degrees
MTP_1 parameters: number of patients
ROM = range of motion

Table III.2. Number of patients with bunion pain due to shoe-fitting problems, pain in or under the lateral MTP joints, hallux pronation and an over- or underriding hallux after osteotomy (OS: n=8) and arthrodesis (AD: n=10).

	Bunion pain		Pain in/under MTP_{2-5}		Hallux pronation		Under-/overriding hallux	
	OS	AD	OS	AD	OS	AD	OS	AD
Disappeared	5	8	0	1	0	4	1	3
Still present	3	2	0	3	0	2	0	0
New	0	0	2	3	0	1	0	0
Still absent	0	0	6	3	8	3	7	7

Force and displacement

In the 8 normal subjects the foot narrowed during toe pressure in 6 ($a > 0$), and broadened in 2 subjects ($a < 0$) (Table III.3). The average value of (a) for the normal group was significantly greater (more positive) than the average preoperative values of the osteotomy group (P=0.004) and the arthrodesis group (P=0.002) (Mann-Whitney U-test) (Fig. III.2).

Before osteotomy and arthrodesis all forefeet broadened whilst pressing the big toe downward. The regression coefficient (a) has a negative sign. (Fig. III.2, Table III.3). No significant difference was found between the average values of parameter (a) of the osteotomy and arthrodesis groups.

After osteotomy widening of all forefeet diminished but was still present:

$a < 0$ (Fig. III.2, Table III.3). The average value of (a) was significantly diminished compared with the average value before osteotomy (Wilcoxon matched pairs signed-ranks test: P=0.022).

After arthrodesis the forefeet still widened in 3 patients, remained the same width in 1 patient, and became narrower ($a > 0$) in 6 patients during toe pressure. The average value of a now has a positive sign (Fig. III.2, Table III.3) and was significantly different from the average value before arthrodesis (Wilcoxon matched pairs signed-ranks test: P=0.011).

There is a significant difference between the average value of (a) in the postoperative osteotomy group and: (1) the normal group (P=0.043) and (2) the postoperative arthrodesis group (P=0.028) (Mann-Whitney U-test). No significant difference was found between the average value of (a) of the normal group and the postoperative arthrodesis group (Mann-Whitney U-test: P=0.525).

Table III.3. The regression coefficient of the regression line ($d = a \times F$) is used as a parameter to indicate the effect of the flexion force on the forefoot width. If a (mm/N) has a negative value the foot widens, whereas a positive value indicates a narrowing foot.

Normals (n=8)	**Osteotomy (n=8)**		**Arthrodesis (n=10)**	
	Before	**After**	**Before**	**After**
+0.01	-0.02	-0.01	-0.01	-0.05
+0.01	-0.03	-0.03	-0.04	0.00
+0.01	-0.06	-0.03	-0.04	+0.03
+0.04	-0.07	-0.03	-0.06	+0.04
+0.05	-0.09	-0.02	-0.08	-0.02
+0.05	-0.10	-0.02	-0.08	-0.04
-0.03	-0.13	-0.05	-0.09	+0.01
-0.06	-0.24	-0.05	-0.16	+0.04
			-0.19	+0.01
			-0.22	+0.01
Mean (SD):				
+0.01 (0.04)	-0.09 (0.07)	-0.03 (0.01)	-0.10 (0.07)	0.00 (0.03)

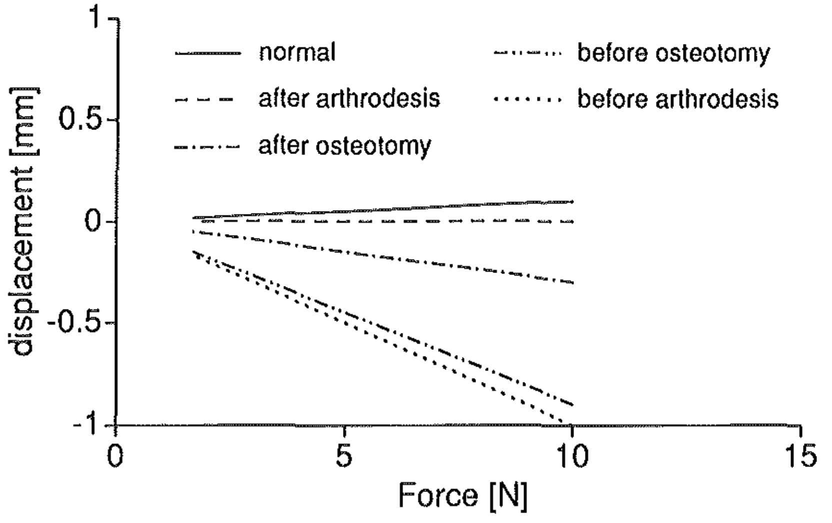


Fig. III.2. Relationship of displacement and flexion force. Average of the regression lines obtained from 5 different situations (unilateral): before osteotomy; before arthrodesis; after osteotomy; after arthrodesis; and in normal subjects (without hallux valgus and without foot complaints).

Deformity and displacement

For the hallux angle and the regression coefficient (*a*) a significant moderate correlation was found for the entire preoperative group (n=18) (r_s=-0.475, P=0.050) (Fig. III.3). For the postoperative osteotomy group the Spearman rank test showed a relationship between the HA and (*a*) with a correlation coefficient of -0.734 and P=0.052. The HA and (*a*) after arthrodesis showed no significant correlation.

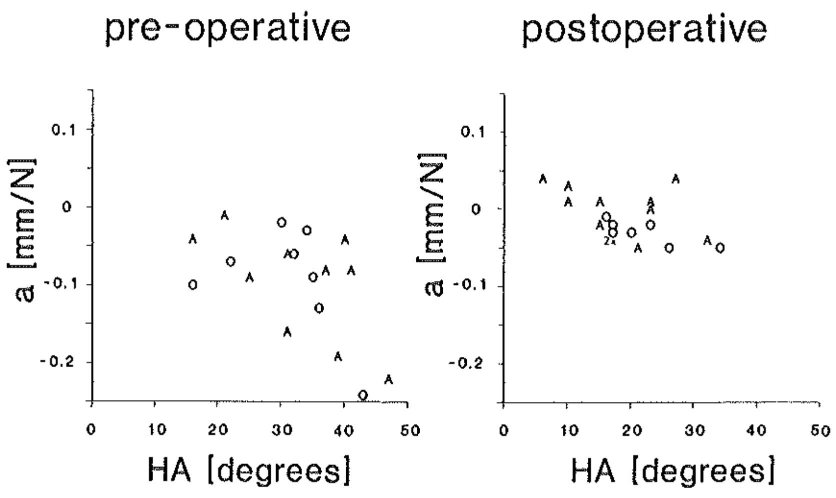


Fig. III.3. The relationship between the hallux angle (HA) and the regression coefficient (*a*) before and after osteotomy (O) and arthrodesis (A). For the whole preoperative group this moderate correlation is significant (r_s=-0.475, P=0.050).

Maximal force

In response to our question, no patient reported any restriction due to pain in their attempt to achieve maximal force. The average values are shown in Table III.4.

The average value of the maximal force of the normal group was significantly greater than the average values of the patients in the preoperative (osteotomy: P=0.007, arthrodesis: P=0.009) and postoperative periods (osteotomy: P=0.003, arthrodesis: P=0.004) (Mann-Whitney U-test).

For both the osteotomy and arthrodesis groups, no significant differences were found between the pre- and postoperative values of the maximal force. Also no significant differences were seen between the two patient groups with regard to the maximal force.

No statistically significant correlations were found between the maximal flexion force and age, HA, or $IMTA_{1-2}$.

Table III.4. The maximal flexion force (F_{max}) exerted during downward pressure of the hallux.

		Normals (n=8)	Osteotomy (n=8)		Arthrodesis (n=10)	
			Before	After	Before	After
F_{max} [N]	Mean	76	37	25	36	31
	Range	32-105	16-68	11-40	10-80	4-83
	SD	25	19	12	20	23

DISCUSSION

In this study, a biomechanical analysis focusing on the effect of flexion forces on foot width, predicts arthrodesis to be the method of choice.

In the 18 preoperative hallux valgus patients, flexion forces on the hallux, exerted during downward pressure on the ground, resulted in an unfavourable medial deviation of the first metatarsal head, corresponding to a widening of the forefoot (Fig. III.2).

After osteotomy this widening effect, as well as the valgus position of the hallux, had significantly diminished after surgery, but still existed. When the pathogenetic flexion forces still act on the first ray, deviation of the hallux and first metatarsal may recur over time, leading to complaints. When an unfavourable effect is measured within 1 year, this effect is expected to worsen at later follow-up.

Arthrodesis of MTP_1 permanently controls the alignment of the first ray.[1,4,18-21,24-26] Furthermore, the measurements show that when toe and first metatarsal form one mechanical entity, the strain exerted by the hallux flexors will not only cause a significant decrease in the medial deviation of the first metatarsal head, but can even produce a narrowing effect on the forefoot. The latter effect corresponds with the mechanics observed in normal forefeet (see Chapter II and Fig. III.2).

Comparison of the modified Hohmann osteotomy and arthrodesis of MTP_1 gives the impression of an attempt to compare apples and pears. However, this study focuses on biomechanics and not on clinical criteria. Furthermore, it is claimed that the biomechanical model is valid for all types of first metatarsal osteotomies and arthrodeses of MTP_1 in all patients, independent of clinical features like age and degenerative changes.

In a static situation in 8 subjects without hallux valgus an average maximal force of 76 N was measured,[14] whereas in the 18 preoperative patients an average of 36 N was found (Table III.4). It is assumed that these patients are less able to exert the required force to oppose a normal load (105 N)[27] on the hallux during walking. This lack of effective force could be a factor in the development of the altered dynamic plantar load distribution with a diminished maximum force (66 N)[27] exerted on the hallux. However, it could also be an effect of prolonged inactivity of flexor muscles. In the literature, arthrodesis of MTP_1 is assumed to have a positive effect on pre-existing metatarsalgia and to prevent postoperative metatarsalgia.[17,18] We found no significant improvement in maximal force after arthrodesis as a sign of increased capacity to sustain more load on the big toe during walking. Instead, postoperatively, both the osteotomy and arthrodesis groups showed a slight, but statistically non-significant decrease (from 37-25 N and from 36-31 N, respectively) of the isometrically determined average maximal applicable flexion force (Table III.4). Thus, on average 9 or 10 months after operation an abnormal potential force can be detected, which causes, or results from, an abnormal dynamic plantar load distribution and may lead to the development of pain in or under the MTP joints.[17,18,28]

Although the results of this biomechanical study provide a basis for arthrodesis as the technique of choice, it is emphasized that in the final choice for each individual, other aspects must also be taken into consideration. This involves e.g. simplicity of a specific surgical technique,[1] pain and range of motion of the MTP_1 and inter-phalangeal joint,[18-21,24] sort of personal activities,[24] choice of footwear[18,24] and cosmetic factors (sometimes the optimal fusion position is not achieved[18-20,29]).

The results of this study indicate that the average preoperative flexion force on the hallux does not significantly decrease after both procedures, and that recurrences are less likely to occur after arthrodesis than after osteotomy. Thus, from a biomechanical viewpoint, arthrodesis is preferred to osteotomy. Therefore, on the condition that the clinical features necessitate an operation involving a permanent correction and pain relief, the indication for arthrodesis of MTP_1 could shift to a younger age group.

REFERENCES

1 Helal B. Surgery for adolescent hallux valgus. Clin Orthop 1981; 157: 50-63.

2 Kelikian H. Hallux valgus, allied deformities of the forefoot and metatarsalgia. Philadelphia, W.B. Saunders Company, 1965.

3 Grace D, Hughes J, Klenerman L. A comparison of Wilson and Hohmann osteotomies in the treatment of hallux valgus. J Bone Joint Surg 1988; 70B: 236-241.

4 Haeff PAJ van. De operatieve behandeling van de hallux valgus. Thesis, Nijmegen, The Netherlands, 1958.

5 Hattrup SJ, Johnson KA. Chevron osteotomy: analysis of factors in patients dissatisfaction. Foot Ankle 1985; 5: 327-332.

6 Imhoff A, Baumgartner R, Blauth W, Büsch HG, Lamprecht E. Fehlschläge nach Hallux-valgus-Operationen und ihre Behandlung. In: Blauth W, editor. Der Hallux valgus. Berlin, Heidelberg, New York, Tokyo, Springer-Verlag, 1986: 105-117.

7 Snijders CJ, Snijder JG, Philippens MM. Biomechanics of hallux valgus and spreadfoot. Foot Ankle 1986; 5: 327-332.

8 Debrunner HU. Ätiologie und Pathogenese des Hallux valgus. In: Blauth W, editor. Der Hallux valgus. Berlin, Heidelberg, New York, Tokyo, Springer-Verlag, 1986: 38-43.

9 Feldkamp M. Der Hallux valgus bei Zerebralparese. In: Blauth W, editor. Der Hallux valgus. Berlin, Heidelberg, New York, Tokyo, Springer-Verlag, 1986: 79-82.

10 Goldner JL. Hallux valgus and flexus associated with cerebral palsy: Analysis and treatment. Clin Orthop 1981; 157: 98-104.

11 Jahss MH. Disorders of the foot. Philadelphia, W.B. Saunders Company, 1982.

12 Mann RA, Coughlin MJ. Hallux valgus - Etiology, anatomy, treatment and surgical considerations. Clin Orthop 1981; 157: 31-41.

13 Scranton PE, Rutkowski R. Anatomic variations in the first ray: Part I. Anatomic aspects related to bunion surgery. Clin Orthop 1980; 151: 244-255.

14 Sanders AP, Snijders CJ, Van Linge B. Medial deviation of the first metatarsal head as a result of flexion forces in hallux valgus. Foot Ankle 1992; 13: 515-522.

15 Sanders AP, Snijders CJ, Van Linge B. Biomechanical analysis of the effects of osteotomy and arthrodesis for hallux valgus and metatarsus primus varus. Presented at the Symposium on Problems of the First Ray; held at the Royal Society of Medicine, London, May 9th, 1992.

16 Sanders AP, Snijders CJ, V. Linge B. Potential for recurrence of hallux valgus after a modified Hohmann osteotomy: A biomechanical analysis. Foot Ankle Int 1995; 16: 351-356.

17 Henry APJ, Waugh W. The use of footprints in assessing the results of operations for hallux valgus. A comparison of Keller's operation and arthrodesis. J Bone Joint Surg 1975; 57B: 478-481.

18 Moynihan FJ. Arthrodesis of the metatarso-phalangeal joint of the great toe. J Bone Joint Surg 1967; 49B: 544-551.

19 Fitzgerald JAW. A review of long-term results of arthrodesis of the first metatarso-phalangeal joint. J Bone Joint Surg 1969; 51B: 488-493.

20 Fitzgerald JAW, Wilkinson JM. Arthrodesis of the metatarso-phalangeal joint of the great toe. Clin Orthop 1981; 157: 70-77.

21 Salis-Soglio G von, Thomas W. Arthrodesis of the metatarso-phalangeal joint of the great toe. Arch Orthop Traumat Surg 1979; 95: 7-12.

22 Meier PJ, Kenzora JE. The risks and benefits of distal first metatarsal osteotomies. Foot Ankle 1985; 6: 7-17.

23 Smith RW, Reynolds JC, Stewart MJ. Hallux valgus assesment: Report of research committee of American Orthopaedic Foot and Ankle Society. Foot Ankle 1984; 2: 92-103.

24 Harrison MHM, Harvey FJ. Arthrodesis of the first metatarsophalangeal joint for hallux valgus and rigidus. J Bone Joint Surg 1963; 45A: 471-480.

25 Lipscomb PR. Arthrodesis of the first metatarsophalangeal joint for severe bunions and hallux rigidus. Clin Orthop 1979; 142: 48-54.

26 Raymakers R, Waugh W. The treatment of metatarsalgia with hallux valgus. J Bone Joint Surg 1971; 53B: 684-687.

27 Hutton WC, Dhanendran M. The mechanics of normal and hallux valgus feet - a quantitative study. Clin Orthop 1981; 157: 7-13.

28 Bonney G, Macnab I. Hallux valgus and hallux rigidus, a critical survey of operative results. J Bone Joint Surg 1952; 34B: 366-385.

29 Gregory JI, Childers JL, Higgins KR, Krych SM, Harkless LB. Arthrodesis of the first metatarsophalangeal joint: a review of the literature and long-term retrospective analysis. J Foot Surg 1990; 29: 369-374.

Chapter IV

The influence of arthrodesis or osteotomy on the geometry of hallux valgus and hallux rigidus

SUMMARY

Structural and functional effects of a modified Hohmann osteotomy and arthrodesis of MTP_1, as treatment of hallux valgus or hallux rigidus, are investigated. A series of (newly introduced) parameters are obtained from X-rays, visual analog scales, physical examination and dynamic footprints of 71 patients and are related to the pre- and postoperative situations. We found that the obliquity of the first tarso-metatarsal joint correlates with the degree of metatarsus primus varus and with a measure of degenerative flattening of the first metatarsal head. Realignment of the first ray after the osteotomy diminishes the (sub)luxation of the sesamoids. The reduction of the hallux valgus angle, by means of an arthrodesis, results in a narrowing effect on the forefoot. Distinct relationships between toe deformities, increased dynamic plantar pressure and hyperkeratosis under the metatarsal heads are found, emphasizing the importance of the role of the toes in the prevention or treatment of mechanically induced aberrations in the ball of the foot.

INTRODUCTION

For the orthopedic surgeon who decides to alter the skeletal morphology of the individual foot, it may be valuable to have a better insight into the different types of preoperative foot compositions and postoperative effects on skeletal parameters.

In the context of hallux valgus, several (causal) structural relationships have been proposed in the literature, including: (1) a rounded metatarsal head and the development of hallux valgus;[1,2] (2) a curved first tarso-metatarsal joint and the tendency of the metatarsal to angle medially;[1,3] (3) an oblique setting of the first tarso-metatarsal joint and an increase in the varus deviation of the first metatarsal.[1,3] Some authors[3,4] use the name "hallux valgus complex" because the valgus deviation of the hallux is frequently seen together with other aberrations of the forefoot, such as: (1) splayfoot, with metatarsus primus varus and metatarsus quintus valgus (tailor's bunionette), (2) dislocation of the sesamoids, (3) pronation of the hallux, (4) hammered, clawed and overriding toes, and (5) high pressure areas with hyperkeratosis under the metatarsal heads. Mostly, the assumed causal relationships are not based on quantitative research.[1-3]

The objectives of this study are:

1. to quantify the effects of first ray surgery on different elements of the hallux valgus complex;
2. to collect data to support the validity of the concept of the hallux valgus "complex" and
3. to assess (causal) relationships between the obliquity or curvature of the

first MTP_1 or tarso-metatarsal joint and hallux valgus or metatarsus primus varus deformity.

MATERIAL AND METHODS

Study design

At follow-up, clinical features were assessed by the author (APS) by means of visual analog scales, physical examination and dynamic footprints. For each studied group (see "Patients") the average time between surgery and follow-up was 7 years; the ranges for Groups I, II and III being 3-9, 3-9 and 3-10 years, respectively. The visual analog scales were applicable to the preoperative period, as well as at follow-up. X-rays were taken preoperatively and two months after surgery.

Patients

Eighty-four patients with idiopathic hallux valgus/rigidus were operated between 1983-1987 at the Orthopedic Department of the University Hospital Rotterdam, Dijkzigt. These patients were retrospectively divided in three groups: 20 patients with hallux valgus who underwent a subcapital wedge osteotomy of the first metatarsal (Group I); 26 patients with hallux valgus who underwent an arthrodesis of MTP_1 (Group II); and 38 patients with hallux rigidus (with or without hallux valgus) who underwent an arthrodesis of MTP_1 (Group III). The characteristics of the MTP_1 joints of these specific groups are given in Table IV.1.

A number of patients were excluded from further investigation. In Group I, one patient moved abroad, and another did not respond after a letter and telephone calls. In Group II, two did not respond, and two refused to participate because of old age and disability. In Group III, five patients did not respond, one patient died, and one was travelling. Finally, 71 patients were investigated (Group I: 18, Group II: 22 and Group III: 31).

We defined hallux valgus as a radiographic hallux angle greater than 15°. The patients with hallux rigidus had an osteoarthritic dorsal bunion on lateral X-rays. Preoperatively, diminished sagittal range of motion (ROM) of MTP_1 was estimated on sight by the surgeon, noted in the medical records and is defined as passive dorsiflexion less than 60° and/or plantar flexion less than 10°. MTP_1 was designated as painful if the patient experienced pain during daily living.

Table IV.1. Preoperative characteristics of the three studied groups.

	MTP_1			Surgical method
	Hallux valgus	ROM MTP_1	Dorsal bunion	
Group I (n=18)	Yes	Normal	No	Osteotomy
Group II (n=22)	Yes	Diminished and/or painful	No	Arthrodesis
Group III (n=31)	Yes / No	Diminished and/or painful	Yes	Arthrodesis

Hallux valgus = hallux angle >15°
Dorsal bunion = osteoarthritic dorsal bunion on lateral X-rays
ROM MTP_1 = range of passive sagittal motion of MTP_1
Diminished = dorsiflexion <60° and/or plantarflexion <10°
Painful = pain during daily living

The patients in Group I (mean age 29 years, range 15-65 years) were younger than those in Group II (mean age 53 years, range 23-73) and Group III (mean age 49 years, range 25-72) ($P<0.0001$).

Surgical methods

The modified Hohmann osteotomy[3] is a medial closing wedge osteotomy through the metatarsal neck with a limited lateral shift of the head, which is fixed with two Vicryl sutures. At the same time a re-insertion of the distal tendon of the abductor hallucis to the dorso-medial aspect of the proximal phalanx is performed (Fig. IV.1). Great care is taken to prevent dorsal migration of the osteotomized head.

The fusion of MTP_1 is combined with a resection of the bunion (Fig. IV.1). The fixation is attained with the help of a Rush pin (44 patients), two K-wires (7 patients), one K-wire (1 patient), or a combination of one K-wire with a Rush pin (1 patient). In 6 patients with an arthrodesis, in the same session, a correction of a hammered second toe (4x), a resection of a tailor's bunion (1x) or a dorsal angulation osteotomy of the third metatarsal (1x) were performed.

The average time in hospital was 5 days after osteotomy (range 1-10 days) and 6 days after arthrodesis (range 2-10 days). After osteotomy the planned 8 weeks (or 56 days) with plaster immobilisation virtually became 60 days on average (range 45-84 days). Seventeen patients wore a below-knee plaster, and one a plaster shoe. The intended 8 weeks with plaster after arthrodesis proved to be an average of 61 days in practice (range 43-109 days). In 46 cases the patients wore a below-knee plaster cast, in 7 cases a plaster shoe. Three patients after osteotomy and 26 after arthrodesis had the plastered foot loaded with gradually increasing intensity 2-4 days after surgery. Respectively, 15 and 27 patients with an osteotomy or arthrodesis followed the same regime after 4 weeks with non weight-bearing.

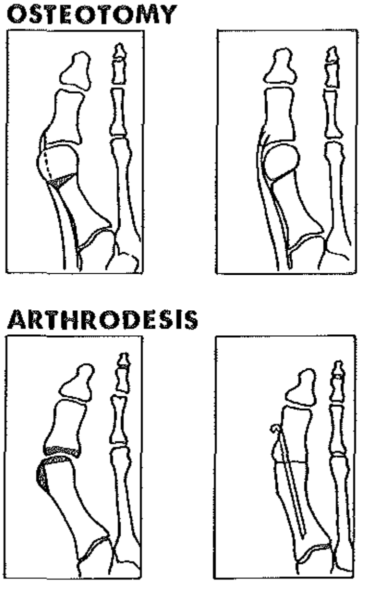


Fig. IV.1. The osteotomy, which is a modification of the Hohmann operation (the tendon of the abductor hallucis is re-inserted to the dorso-medial aspect of the proximal phalanx), and arthrodesis of MTP_1.

Radiographs

The non weight-bearing AP and lateral X-rays taken preoperatively, and taken two months after surgery were used. Twelve X-rays were missing or had an insufficient view of the structures to be investigated. The number of patients with usable and complete sets of X-rays varied for the different parameters and was 14-16 in Group I, 21-22 in Group II, and 27-29 in Group III.
The skeletal parameters were measured on the X-rays and included angles, curvatures, lengths and positions of bones. These are listed in the Appendix to Chapter IV (page 69) and are shown in Figs. IV.2-5.

In the literature we could not find unambiguous definitions of parameters to measure: (1) the forefoot width; (2) the roundness or flattening of the surfaces of the first MTP and tarso-metatarsal joints; and (3) the oblique setting of the first tarso-metatarsal joint. Therefore, we defined four skeletal parameters: forefoot width; metatarso-phalangeal$_1$ flattening; tarso-metatarsal$_1$ flattening; and tarso-metatarsal$_1$ obliquity (see Appendix to Chapter IV and Figs. IV.2-4).

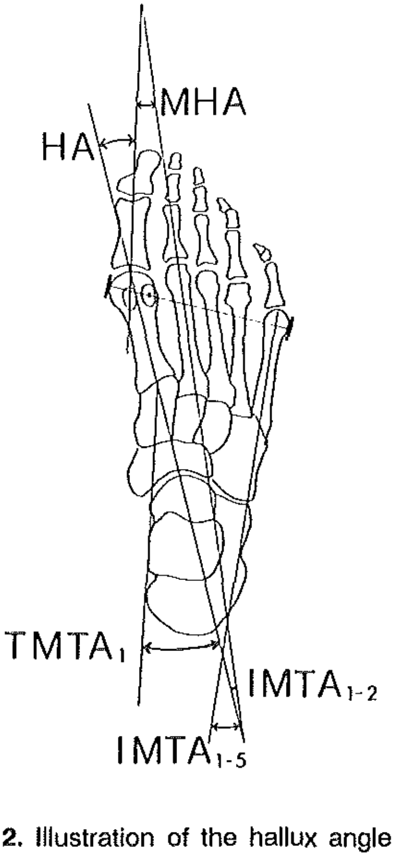


Fig. IV.2. Illustration of the hallux angle (HA), modified hallux angle (MHA), inter-metatarsal$_{1\text{-}2}$ angle (IMTA$_{1\text{-}2}$), inter-metatarsal$_{1\text{-}5}$ angle (IMTA$_{1\text{-}5}$), tarso-metatarsal$_1$ angle (TMTA$_1$) and forefoot width.

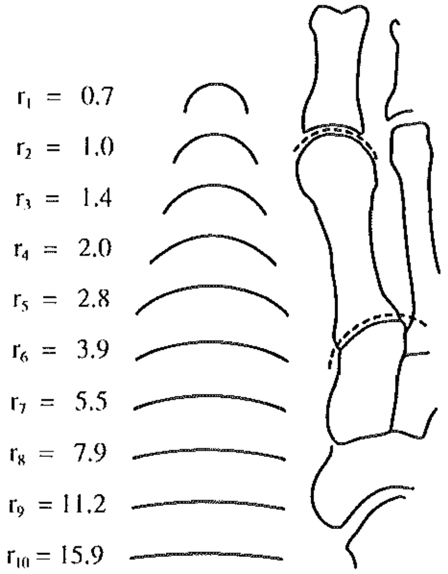


Fig. IV.3. The 10 grades of the curvature of the first metatarso-phalangeal and first tarso-metatarsal joints. The radius of each curve with grade n is defined as $r_n = \sqrt{(2^{(n-1)}/\pi \times 1.5)}$. The greater n, the more flattening of the joint.

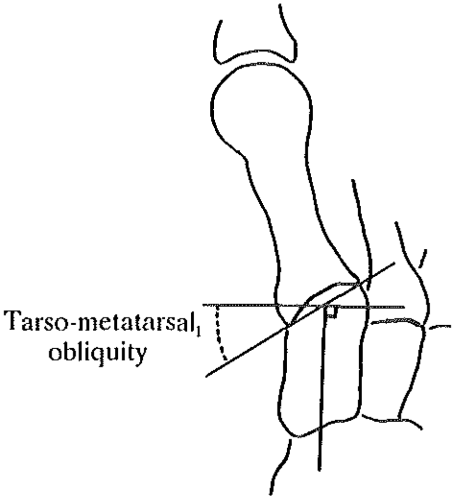


Fig. IV.4. The obliquity (angle) of the first tarso-metatarsal joint (TMT_1 obliquity).

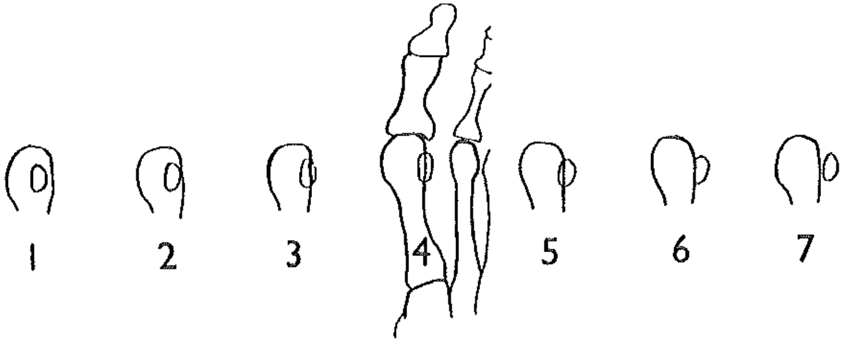


Fig. IV.5. The seven positions of the lateral sesamoid bone (according to Swanson et al.[5]). (Redrawn with permission from the publisher)

Visual analog scales

The degree of burden of bunion pain at the medial aspect of the first metatarsal head, and pain in or under the MTP joints, experienced during daily living, were assessed using visual analog scales (VAS). These scales were applicable to the preoperative situation, as well as at follow-up.

Physical examination

At follow-up, the feet were examined for the presence of hammer, claw, or mallet toes, and hyperkeratosis under the metatarsal heads.

Footprinting mat

At follow-up, dynamic recordings of the plantar pressure were made using a version of a Harris footprinting mat (Berkemann).[6,7] To measure a dynamic situation, the patient walked on the mat starting one step length in front of the mat.[8,9] The ink footprints were examined for the presence of markedly increased plantar pressure under the individual metatarsal heads.

Statistical analysis

After the formulation of hypotheses, correlations between the assessed individual parameters were estimated and tested. Spearman's rank correlation coefficients (r_s) were used for testing monotonic relationships between ordinal scaled variables and visually checked for reliability with the help of graphs. To adjust the correlations for the possibly confounding effect of the variable "time since surgery", partial rank correlations were estimated and tested. Relationships between dichotomous parameters were tested with the Fisher's exact test (two-tailed). The Mann-Whitney U-test was used for between group comparison of ordinal scaled variables and the McNemar's test for comparison of paired dichotomous variables. Only one foot side per patient was measured and analysed, namely the one with the greater preoperative hallux angle. The reason is that the patients, and not their feet, are the mutually independent observational units.

RESULTS

The measured values of the pre- and postoperative radiographic parameters are presented in Table IV.2 (see Appendix to Chapter IV; page 70).

Preoperative radiography

A description of the structure of the first MTP and tarso-metatarsal joints of the three patient groups is found in the following established relationships. The MTP_1 joints of Group I were significantly more curved than those of Group II ($P<0.05$). Group II had more distinct curvatures than Group III ($P<0.05$). The preoperative X-rays of Group II demonstrated a significant correlation between age and flattening of MTP_1 ($r_s=0.6$, $P<0.05$). The average flattening of the tarso-metatarsal$_1$ joints in the three groups did not differ significantly. The hallux valgus patients in Groups I and II showed significantly more obliquely positioned tarso-metatarsal$_1$ joints and greater tarso-metatarsal$_1$ angles, compared with the hallux rigidus patients (P<0.05) (Fig. IV.6).

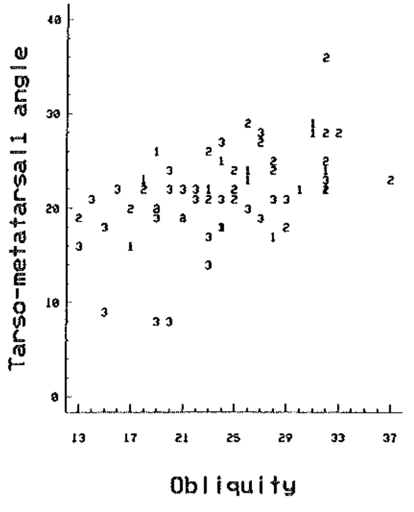


Fig. IV.6. Relationship between the preoperative obliquity of the first tarso-metatarsal joint and the tarso-metatarsal$_1$ angle in Groups I (=1), II (=2) and III (=3) (r_s=0.5, P=0.0001).

Statistically significant relationships were assessed between radiographic parameters in the preoperative situation (see Appendix to Chapter IV: Table IV.3).

Postoperative radiography

The postoperative X-rays of Group I showed that of the 15 patients undergoing osteotomy and documented sufficiently with X-rays, two months after surgery 5 patients (33%) showed a hallux angle > 25° (range: 28-35°).

Statistically significant relationships were assessed between radiographic parameters in the postoperative period (see Appendix to Chapter IV: Table IV.4).

Relationship between X-rays and clinical features

1. Bunion pain

The pre- and postoperative degrees of bunion pain were assessed with visual analog scales (0-100) and are on average, respectively: 74 and 14 in Group I; 61 and 3 in Group II; 42 and 8 in Group III. These decreases are statistically significant (Group I: $P<0.001$, Group II: $P<0.0001$, Group III: $P<0.0001$).

Before arthrodesis, the bunion pain was greater if the intermetatarsal$_{1\text{-}2}$ angle was greater ($r_s=0.5$, $P<0.05$).

At follow-up, after osteotomy, the patients experienced more severe bunion pain if the positioning of the tarso-metatarsal$_1$ joint was less oblique (partial $r_s=-0.5$, $P<0.05$). No significant correlation was established between the preoperative hallux angle, the tarso-metatarsal$_1$ angle, or the obliquity of the first tarso-metatarsal joint and the degree of burden of bunion pain in any group, at follow-up. The reduction of bunion pain was not significantly correlated with the change in the radiographic parameters, such as the inter-metatarsal$_{1\text{-}2}$ angle.

2. Pain in or under MTP joints

The number of patients with pain in or under the MTP joints in daily living (Table IV.5) showed one statistically significant change after surgery. At follow-up, in Group III, pain of MTP$_1$ disappeared in 22 patients ($P<0.0001$), while the pain was still absent in 5 patients, and still existed in 4 patients.

Table IV.5. Pain in or under the MTP joints (MTP$_{1\text{-}5}$) in daily living, before and after surgery: number of patients and (mean) scores of visual analog scales.

	Group I (n=18): Hallux valgus Osteotomy		**Group II (n=22): Hallux valgus Arthrodesis**		**Group III (n=31): Hallux rigidus Arthrodesis**	
	Before	**After**	**Before**	**After**	**Before**	**After**
MTP$_1$	4 (10)	5 (9)	1 (4)	1 (3)	26 (65)	4*(7)
MTP$_2$	0 (0)	1 (4)	0 (0)	2 (4)	1 (3)	1 (1)
MTP$_3$	0 (0)	2 (7)	0 (0)	2 (4)	1 (3)	1 (1)
MTP$_4$	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
MTP$_5$	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Significance of difference from preoperative value: * $P<0.0001$

No significant correlation was found between the (change of the) angles, sesamoid position or joint flattening and the (change of the) pain of the MTP joints. There was no statistical relationship between the degree of pain of the MTP joints and increased plantar pressure or hyperkeratosis under the metatarsal heads. After arthrodesis, 3 hallux rigidus patients experienced distinct pain in or under the first MTP joint. These patients had on average larger modified hallux angles than patients without this complaint. Possible explanations for the pain, such as a painful pseudarthrosis, could not be confirmed.

Relationships with footprint

The postoperative patients with a second hammered or clawed toe or mallet deformity (7 in Group I, 3 in Group II, 5 in Group III) had a higher incidence of hyperkeratosis (Group I: $P<0.05$), or increased plantar pressure under the second metatarsal head (Group III: $P<0.05$). The patients with increased plantar pressure under the second metatarsal head (17 in Group I, 15 in Group II, 12 in Group III) had hyperkeratosis more frequently under the second metatarsal head (Group II: $P<0.05$, Group III: $P<0.05$).

The patients who presented at follow-up with one or more hammer, claw or mallet toes, at the third to fifth ray (6 in Group I, 6 in Group II, 5 in Group III), demonstrated increased plantar pressure more frequently under the third to fifth metatarsal heads (Group II: $P<0.05$).

The increased plantar pressure under one or more of the third to fifth metatarsal heads (10 patients in Group I, 11 in Group II, 17 in Group III) was associated with the presence of hyperkeratosis under these metatarsal heads (Group III: $P<0.01$).

DISCUSSION

In this study, as the surgical methods were not randomly assigned and the age ranges of the study groups are different, inter-group comparisons have to be interpreted with great caution.

Significant positive correlations were established between the following elements of the hallux valgus complex: the (modified) hallux angle, the degree of the (sub)luxation of the sesamoids, the inter-metatarsal$_{1-2}$, inter-metatarsal$_{1-5}$ and tarso-metatarsal$_1$ angles, the degree of the obliquity of the tarso-metatarsal$_1$ joint, and of the flattening of the tarso-metatarsal$_1$ and MTP$_1$ joints. These results demonstrate that hallux valgus and other aberrations of the forefoot are associated with each other. Therefore, we support the use of the name "hallux valgus complex".[3,4]

In the attempt to meet the objectives of the present study some new or less commonly used parameters were involved. The modified hallux angle, as proposed by McRae,[10] demonstrated a strong correlation with the conventional hallux angle. This modified parameter is not only dependent on the geometry of the hallux and the first metatarsal, but is also related to the positon of the second metatarsal. Therefore, it will include additional information on the valgus or varus deviation of (a part of) the forefoot. However, with regard to most of the parameters studied, the conventional hallux angle has stronger correlations and is preferred.

With the parameters "tarso-metatarsal$_1$ obliquity" and "tarso-metatarsal$_1$ angle", significant differences between hallux valgus patients (Groups I and II) and hallux rigidus patients (Group III) were demonstrated: the first metatarsal shows more varus deviation and the TMT$_1$ joint is more obliquely positioned in the hallux valgus patients. Furthermore, the results of this study show moderately strong positive correlations between the obliquity of the tarso-metatarsal$_1$ joint and the varus deviation of the first metatarsal. These findings do not address the question whether the obliquity of the tarso-metatarsal$_1$ joint is an etiologic factor of metatarsus primus varus,[1,3] or results from remodelling of the first tarso-metatarsal joint, initiated by the development of the varus deviation of the first metatarsal.[2]

Besides the obliquity of the tarso-metatarsal$_1$ joint, a curved shape of this joint and the MTP$_1$ joint has been proposed as etiologic factors in the hallux valgus complex.[1,3] A joint with flat surfaces might be more stable.[11] This study could not confirm such a relationship, but did establish (in Group I) that flattening of the first metatarsal head (possibly a degenerative change) is more distinct if the tarso-metatarsal$_1$ joint is flat (less curved) or oblique. The assessed association between MTP$_1$ flattening and age (in Group II) may suggest a degenerative cause of the flattening of the joint. Apart from these results, quantification of the degree of flattening of TMT$_1$ was not always without difficulty. In some cases where the joint surfaces showed a more complex 3-dimensional shape, instead of a simple curved shape, only an estimation of the degree of flattening was possible.

With regard to foot function, Stokes et al.[12] found that hallux valgus is associated with a significant reduction in the load imposed on the toes and the medial side of the forefoot in walking, compared with healthy feet. They also demonstrated that a large reduction in the angle between the first and second metatarsals, produces the smallest decrease in the load on the toes, after an oblique displacement osteotomy of the first metatarsal. The results of the present study confirm that when an osteotomy or an arthrodesis results in a large reduction in the intermetatarsal$_{1\text{-}2}$ angle, the (sub)luxation of the sesamoids will diminish further. This realignment of the sesamoids may assist the recovery of a more equal distribution of the plantar pressure during gait. Furthermore, in the osteotomy group, a large reduction in the modified hallux angle is associated with a restricted realignment of the sesamoids and a small reduction in the IMTA$_{1\text{-}2}$. The opposite was expected. These three latter reductions are possibly related to the degree of the performed lateral shift and medial rotation of the first metatarsal head.

This study confirms that, the greater the reduction of the valgus angle of the hallux, by arthrodesis, the greater the reduction of the angle between the first and second metatarsals. This narrowing effect of the forefoot, after a fusion of MTP_1, has been reported by Mann[1] and explained by a biomechanical model of Snijders et al.[13] Studies by Sanders et al. demonstrated that the unfavourable forces of displaced (flexor) muscles, after the surgical change of the unstable first ray into a rigid entity, are turned into favourable forces, which lead to a narrowing effect on the forefoot. These same muscle forces are held responsible for recurrences of deformity (33% in this study) and complaints after osteotomy of the first metatarsal (see Chapters II and III).[14,16]

In the search for significant correlations between the preoperative radiographic parameters and the preoperatively experienced bunion pain, a (positive) correlation was found only for the inter-metatarsal$_{1\text{-}2}$ angle. A possible influence of the (modified) hallux angle on the degree of bunion pain, for instance, was not established. At follow-up, on average the patients experienced a significant relief in bunion pain after both surgical procedures. However, in patients with a less obliquely positioned TMT_1 joint who underwent an osteotomy, this relief was less (r_s=-0.5). The assessment of this moderate relationship may stimulate investigations on the positioning of TMT_1 in relation to postoperative complaints in future studies.

In medical practice a strong relationship between pain in the ball of the foot and hyperkeratosis (or increased plantar pressure under the metatarsal heads) is frequently assumed and used in decision-making. According to the frequency distributions found in this study, no correlations were demonstrated. This phenomenon is opposite to the cheerful reactions of patients who are treated by chiropodists. The relationships are possibly not as strong as assumed by many therapeutists. Other causes of pain, which are not expressed in increased plantar pressure and hyperkeratosis, may play their part. On the other hand, persons with high pressure areas or calluses may develop pain in the future.

The present study quantified the relationships between the presence of toe deformities, increased plantar pressure and hyperkeratosis under the corresponding metatarsal heads. These findings emphasize the importance of the role of the toes in the prevention or treatment of mechanically induced aberrations in the ball of the foot.

CONCLUSIONS

1. Assessment of statistically significant correlations between several parameters of the complex supports the use of the term "hallux valgus complex".
2. Useful parameters with regard to the curvature and obliquity of the first

tarso-metatarsal joint and the curvature of MTP_1 were introduced.

3. Positive correlations between the obliquity of the positioning of the first tarso-metatarsal joint and the varus deviation of the first metatarsal were found.
4. The greater the inter-$metatarsal_{1\text{-}2}$ angle, the greater the preoperative degree of impediment of bunion pain.
5. A large reduction in the angle between the first and second metatarsals, by a distal first metatarsal osteotomy or arthrodesis of MTP_1, is associated with a large reduction in the (sub)luxation of the sesamoids.
6. The greater the reduction of the valgus angle of the hallux, by arthrodesis, the greater the reduction of the angle between the first and second metatarsals.
7. No relationship is established between pain in or under the MTP joints and hyperkeratosis, or increased plantar pressure under the metatarsal heads.
8. Relationships between toe deformities and increased dynamic plantar pressure and hyperkeratosis under the corresponding metatarsal heads are quantitatively determined.

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REFERENCES

1 Mann RA, Coughlin MJ. Hallux valgus - etiology, anatomy, treatment and surgical considerations. Clin Orthop 1981; 157: 31-41.

2 Scranton PE, Rutkowski R. Anatomic variations in the first ray: Part I. Anatomic aspects related to bunion surgery. Clin Orthop 1980; 151: 244-255.

3 Kelikian H. Causal relations. In: Hallux valgus, allied deformities of the forefoot and metatarsalgia. Philadelphia, W.B. Saunders Co., 1965: 54-68.

4 Jahss MH. Disorders of the hallux and the first ray. In: Jahss MH, editor. Disorders of the foot and ankle. Philadelphia, London, Toronto, Mexico City, Rio de Janeiro, Sydney, Tokyo, W.B. Saunders Company, 1991: 943-1174.

5 Shereff MJ. Radiographic analysis of the foot and ankle. In: Jahss MH, editor. Disorders of the foot and ankle. Philadelphia, London, Toronto, Mexico City, Rio de Janeiro, Sydney, Tokyo, W.B. Saunders Company, 1991: 91-108.

6 Hughes J, Clark P, Klenerman L. The importance of the toes in walking. J Bone Joint Surg 1990; 72B: 245-251.

7 Silvino N, Evanski PM, Waugh TR. The Harris and Beath footprinting mat: Diagnostic validity and clinical use. Clin Orthop 1980; 151: 265-269.

8 Cavanagh PR, Ulbrecht JS. Biomechanics of the diabetic foot: A quantitative approach to the assessment of neuropathy, deformity, and plantar pressure. In: Jahss MH, editor. Disorders of the foot and ankle. Philadelphia, London, Toronto, Mexico City, Rio de Janeiro, Sydney, Tokyo, W.B. Saunders Company, 1991: 1884-1890.

9 Sanders AP, Snijders CJ, Stam HJ. A method for dynamic measuring with pressure or force platforms. J Rehabil Sciences 1993; 6: 114-123.

10 McRae R. Clinical orthopaedic examination. 3rd edn. Edinburgh, London, Melbourne, New York, Churchill Livingstone, 1990: 261.

11 Snijders CJ. Statica. In: Frankel VH, Nordin M, Snijders CJ, editors. Biomechanica van het skeletsysteem. Lochem, Gent, Uitgeversmij. De tijdstroom, ISBN 90-6087-526-5, 1984: 389-404.

12 Stokes IAF, Hutton WC, Stott JRR, Lowe LW. Forces under the hallux valgus foot before and after surgery. Clin Orthop 1979; 142: 64-72.

13 Snijders CJ, Snijder JGN, Philippens MM. Biomechanics of hallux valgus and spread-foot. Foot Ankle 1986; 5: 327-332.

14 Sanders AP, Snijders CJ, van Linge B. Medial deviation of the first metatarsal head as a result of flexion forces in hallux valgus. Foot Ankle 1992; 13: 515-522.

15 Sanders AP, Snijders CJ, V. Linge B. Potential for recurrence of hallux valgus after a modified Hohmann osteotomy: A biomechanical analysis. Foot Ankle Int 1995; 16: 351-356.

16 Shereff MJ, DiGiovanni L, Bejjani FJ, Hersh A, Kummer FJ. A comparison of nonweight-bearing and weight-bearing radiographs of the foot. Foot Ankle 1990; 10: 306-311.

17 Grace DL, Clark P, Klenerman L. A comparison of Wilson and Hohmann osteotomies in the treatment of hallux valgus. J Bone Joint Surg 1988; 70B: 236-241.

18 Hutton WC, Dhanendran M. The mechanics of normal and hallux valgus feet - A quantitative study. Clin Orthop 1981; 157: 7-13.

19 Lundberg BJ, Sulja T. Skeletal parameters in the hallux foot. Acta Orthop Scand 1972; 43: 576-582.

20 Luthje P. Long-term results of proximal metatarsal osteotomy in hallux valgus. J Amer Podiatr Med Assoc 1990; 80: 304-306.

21 Merkel KD, Katoh Y, Johnson EW, Chao EYS. Mitchell osteotomy for hallux valgus: Long-term follow-up and gait analysis. Foot Ankle 1983; 3: 189-196.

22 Smith RW, Reynolds JC, Stewart MJ. Hallux valgus assessment: Report of research committee of American Orthopaedic Foot and Ankle Society. Foot Ankle 1984; 2: 92-103.

23 Vlatis G, Kitsos CP. Modelling weight-bearing patterns through anatomical parameters in feet with hallux valgus. (Abstract of scientific paper) J Bone Joint Surg 1989; 71B: 888.

24 Swanson AB, Lumsden RM, De Groot Swanson G. Silicone implant arthroplasty of the great toe. Clin Orthop 1979; 142: 30-43.

APPENDIX TO CHAPTER IV

Skeletal parameters (see Figs. IV.2-5)

1. **Hallux angle** (HA).[1,3,5,16-23] After a distal first metatarsal osteotomy, the head is shifted laterally. To compare geometry before and after surgery, the axis of the shaft is chosen. The effect of the lateral shift manifests itself in the change of forefoot width.
2. **Modified hallux angle** (MHA):[10] the angle between the longitudinal axis of the proximal phalanx of the hallux and the longitudinal axis of the second metatarsal.
3. **Intermetatarsal$_{1\text{-}2}$ angle** ($IMTA_{1\text{-}2}$).[1,3,5,10-13,16,17]
4. **Intermetatarsal$_{1\text{-}5}$ angle** ($IMTA_{1\text{-}5}$).[5,16]
5. **Tarso-metatarsal$_1$ angle** ($TMTA_1$):[5,20] the angle between the longitudinal axis of the medial cuneiform and the longitudinal axis of the first metatarsal.
6. **Tarso-metatarsal$_1$ obliquity.** This is defined as the angle between the line which is perpendicular to the longitudinal axis of the medial cuneiform and the line across the medial and lateral margins of the joint space of the first tarso-metatarsal joint (Fig. IV.4).
7. **Tarso-metatarsal$_1$ flattening**. To quantify the roundness or flattening of the joint surfaces, a scale with 10 different curves was composed (Fig. IV.3). Each different curve with grade n (n=1-10) has a different radius which is defined as $r_n = \sqrt{(2^{(n-1)}/\pi \times 1.5)}$. This results in a gradually increasing flattening which probably corresponds with the virtual appearing range.
8. **Metatarso-phalangeal$_1$ flattening**. Grading see "7." and Fig. IV.3.
9. **Lateral sesamoid position:** a measure of (sub)luxation and classified into seven positions according to Swanson et al. (Fig. IV.5).[22,24]
10. **Forefoot width** (mm). A definition is required to increase reproducibility of the measurements in this study. We propose: the maximal length of the line segment, that runs from the lateral contour of the fifth metatarsal head, through the center of the lateral sesamoid bone, to the medial contour of the first metatarsal head (Fig. IV.2).

Table IV.2. Pre- and postoperative averages (and ranges) of the angles between bones (in degrees), the degree of flattening of the first tarso-metatarsal and MTP joints (grade 1-10), lateral sesamoid position (grade 1-6) and forefoot width (mm).

	Hallux valgus Osteotomy (n=14-16)		**Hallux valgus Arthrodesis (n=21-22)**		**Hallux rigidus Arthrodesis (n=27-29)**	
	Before	**After**	**Before**	**After**	**Before**	**After**
HA	34 (24-43)	23 ‡ (14-35)	37 (20-54)	17 § (2-27)	21 (6-43)	12 § (0-23)
MHA	22 (13-31)	11 ‡ (0-20)	23 (11-39)	6 § (-4-16)	12 (-1-28)	3 § (-6- 9)
$IMTA_{1-2}$	11 (7-17)	12 (8-17)	12 (6-20)	10 * (6-20)	8 (0-13)	9 * (4-17)
$IMTA_{1-5}$	30 (23-39)	28 * (18-42)	30 (20-38)	26 ‡ (19-33)	23 (12-34)	22 (13-34)
$TMTA_1$	23 (16-29)	23 (16-29)	24 (18-36)	22 (13-28)	19 (8-28)	20 (10-31)
TMT_1 obliquity	26 (17-32)	26 (17-32)	26 (23-37)	24 (11-34)	22 (13-32)	22 (12-30)
TMT_1 flattening	4.4 (3- 8)	-	4.2 (3-10)	-	4.0 (2- 6)	-
MTP_1 flattening	2.7 (2- 3)	-	3.1 (2- 4)	-	3.6 (2- 5)	-
Sesamoid position	4.1 (3- 6)	3.7 (2- 5)	6.0 (3- 7)	5.3 * (3- 7)	3.7 (1- 6)	4.4 ‡ (3- 7)
Forefoot width	87 (81-93)	82 ‡ (74-91)	90 (75-98)	85 † (73-95)	85 (78-98)	84 (72-99)

Difference compared with the preoperative value: * $P<0.05$, ‡ $P<0.01$, † $P<0.001$, § $P<0.0001$

Table IV.3. Investigated relationships between the preoperative radiographic parameters: Spearman's rank correlation coefficients (r_s) and P-values.

	MHA	$IMTA_{1\text{-}2}$	$IMTA_{1\text{-}5}$	$TMTA_1$	TMT_1 obl.	TMT_1 flat.	MTP_1 flat.	Ses. pos.
Group I								
HA	0.9 †	#	#	#	#	#	#	#
MHA		#	#	#	#	#	#	#
$IMTA_{1\text{-}2}$			#	#	#	#		0.6 *
$TMTA_1$			#		#	#		
MTP_1 flat.					0.7 ‡	0.6 *		#
Group II								
HA	0.9 §	#	#	#	#	#	#	0.6 *
MHA		#	#	#	#	#	#	#
$IMTA_{1\text{-}2}$			0.5 *	0.6 *	#	#		0.6 ‡
$TMTA_1$			#		0.6 *	#		
MTP_1 flat.					#	#		#
Group III								
HA	0.9 §	0.7 †	0.7 †	#	0.6 ‡	#	#	0.6 ‡
MHA		0.5 ‡	0.6 ‡	#	-0.6‡	#	#	0.5 *
$IMTA_{1\text{-}2}$			0.5 *	#	0.5 *	#		0.8 †
$TMTA_1$			0.5 *		#	#		
MTP_1 flat.					#	#		#

TMT_1 obl. = tarso-metatarsal$_1$ obliquity
MTP_1 flat. = metatarso-phalangeal$_1$ flattening
Ses. pos. = lateral sesamoid position
P-values: * $P<0.05$, ‡ $P<0.01$, † $P<0.001$, § $P<0.0001$
= $r_s<0.5$ and/or $P\geq0.05$

Table IV.4. Investigated relationships between the radiographic parameters in the postoperative period: Spearman's rank correlation coefficients (r_s) and P-values.

	MHA	$_{\Delta}$MHA	IMTA$_{1\text{-}2}$	$_{\Delta}$IMTA$_{1\text{-}2}$	IMTA$_{1\text{-}5}$	$_{\Delta}$FFW	TMTA$_1$	Ses. pos.
Group I								
HA	0.9 †				#			
$_{\Delta}$HA		0.8 ‡		#		#		
MHA			#					#
IMTA$_{1\text{-}2}$					#		0.6 *	0.7 *
$_{\Delta}$IMTA$_{1\text{-}2}$		-0.6*				0.6 *		
TMTA$_1$			0.6 *		#			
$_{\Delta}$Ses.pos		-0.6*		0.7 *		#		
Group II								
HA	0.6 ‡				0.5 *			
$_{\Delta}$HA		0.9 †		0.7 ‡		#		
MHA			-0.5*					-0.5*
IMTA$_{1\text{-}2}$					#		#	#
$_{\Delta}$IMTA$_{1\text{-}2}$		0.6 *				#		
TMTA$_1$			#		#			
$_{\Delta}$Ses.pos		#		#		#		
Group III								
HA	0.5 ‡				0.5 ‡			
$_{\Delta}$HA		0.8 †		#		0.6 ‡		
MHA			#					#
IMTA$_{1\text{-}2}$					0.6 ‡		#	0.6 ‡
$_{\Delta}$IMTA$_{1\text{-}2}$		#				#		
TMTA$_1$			#		0.6 ‡			
$_{\Delta}$Ses.pos		#		0.7 ‡		0.5 *		

$_{\Delta}$ = reduction by surgery = pre- minus the postoperative value
FFW = forefoot width
Ses.pos. = lateral sesamoid position
P-values: * $P<0.05$, ‡ $P<0.01$, † $P<0.001$, § $P<0.0001$
= $r_s<0.5$ and/or $P\geq0.05$

Chapter V

Effects of surgical treatment of hallux valgus and hallux rigidus on biomechanics and daily living

SUMMARY

This study aims at assessment of the effects of surgery on patients' daily functioning, and at the establishment of preoperative (risk) factors that could lead to non-optimal surgical results. A modified Hohmann osteotomy was performed in 18 hallux valgus patients. Twenty-two patients with hallux valgus and 31 patients with hallux rigidus underwent an arthrodesis of MTP_1. At follow-up (mean 7 years), clinical features were assessed by means of a questionnaire, visual analog scales, physical examination and dynamic footprints. X-rays were taken preoperatively and two months after surgery. Several relationships were established between the assessed impairments and disabilities. The preoperative first tarso-metatarsal angle, the obliquity of the first tarso-metatarsal joint and the (sub)luxation of the sesamoids constitute risk factors for disappointing surgical outcomes. After osteotomy there were clinical recurrences in 22% of the patient group. Osteotomy is preferred in younger patients with moderate preoperative hallux angles and a distinct oblique setting of the first tarso-metatarsal joints. Arthrodesis is dissuaded when there is a distinct oblique setting of the first tarso-metatarsal joint. The fusion is preferred in case of a large hallux valgus angle and can give good functional results. Problems are found in the postoperative development of a painful IP joint, which is associated with a lateral gait pattern and a feeling of unsteadiness in the foot.

INTRODUCTION

From a biomechanical study on hallux valgus it was concluded that arthrodesis, from a mechanical point of view, is the treatment of first choice (see Chapter III). In medical practice, however, additional criteria have to be taken into consideration. What also matters is the patient's opinion about the therapy and its effects at different levels of health experience. The present study investigates the effects of a modified Hohmann osteotomy of the first metatarsal[1] and arthrodesis of the first MTP joint[2-9], which are two routinely used surgical methods in the treatment of hallux valgus (Fig. IV.1). Arthrodesis is also indicated for patients with hallux rigidus.[10-13]

One of the aims of surgeons is to give the patient a betterlooking foot with a straighter great toe and a narrower forefoot, which should result in relief of bunion pain. The elimination of pain inside MTP_1 is sought. Further, it is hoped that the mechanics of the foot will improve with a more evenly distributed plantar pressure, which could lead to relief of pain in or under the ball of the foot. If this is achieved during the period of follow-up, without complications (such as: infection, non-union, avascular necrosis, recurrence of great valgus angles and development of degenerative changes with decrease of range of motion of the MTP_1 joint), the surgeon is satisfied with the effect of treatment.

For patients, other standards concerning the effects of surgery may play a role. Patients compare the intensity of preoperative pain with that of postoperative pain. They judge the external form of the foot and want to know if they can walk the distance they want, and wear the shoes they choose. Social and economic consequences are related to a possible re-operation, and to the time needed to resume normal daily activities and hobbies. The quality of communication between patient and physician also influences the overall perception of patient satisfaction.

Summarizing, the objective parameters are examined more closely by surgeons and researchers, whereas subjective aspects, mainly related to function and appearance, are more the concern of the patient.

In the field of rehabilitation medicine, the International Classification of Impairments, Disabilities, and Handicaps (ICIDH) is often used to describe the consequences of disease.[14] This approach is followed in the present retrospective study in which five methods are used to make an inventory of the pre- and postoperative structure of the foot, and functioning of the patient at different levels of health experience. These methods are: file-study; radiographs; physical examination; footprinting mat; and questionnaire. The choice of these methods is partly due to practical reasons and partly related to the level of health (experience) in the ICIDH.

An attempt is made to demonstrate the relationships between the results obtained by these methods. Some preoperative (risk) factors related to poor results after osteotomy or arthrodesis may become apparent as well.

MATERIAL AND METHODS

Study design

At follow-up at 3 - 10 years (mean: 7 years) after surgery, clinical features were assessed by the author (APS) by means of a file-study, a questionnaire, visual analog scales, physical examination and dynamic footprints. The visual analog scales were applicable to the preoperative period, as well as at follow-up. X-rays were taken preoperatively and two months after surgery.

Patients

Seventy-one patients with idiopathic hallux valgus/rigidus were operated between 1983-1987 at the Orthopedic Department of the University Hospital Rotterdam, Dijkzigt, and investigated in this study (see Chapter IV). These patients were retrospectively divided in three groups: 18 patients with hallux valgus who underwent a subcapital wedge osteotomy of the first metatarsal

(Group I); 22 patients with hallux valgus who underwent an arthrodesis of MTP_1 (Group II); and 31 patients with hallux rigidus (with or without hallux valgus) who underwent an arthrodesis of MTP_1 (Group III). The characteristics of the MTP_1 joints of the three groups are listed in Table IV.1. A more detailed description of the patients population is given in Chapter IV.

Surgical methods

The modified Hohmann osteotomy is a medial closing wedge osteotomy through the metatarsal neck with a limited lateral shift of the head which is fixed with two Vicryl sutures. At the same time, a re-insertion of the distal tendon of the abductor hallucis to the dorso-medial aspect of the proximal phalanx is performed (Fig. IV.1). Great care is taken to prevent dorsal migration of the osteotomized head.

The fusion of MTP_1 is combined with a resection of the bunion (Fig. IV.1). Fixation is attained with the help of a Rush pin (44 patients), two K-wires (7 patients), one K-wire (1 patient), or a combination of one K-wire with a Rush pin (1 patient). In 6 patients with an arthrodesis a correction of a hammered second toe (4x), a resection of a tailor's bunion (1x), or a dorsal angulation osteotomy of the third metatarsal (1x) were performed in the same session.

Features of the postoperative care are described in Chapter IV.

File study

All medical records of the patients in the three groups were traced. In the present retrospective study design, the choice of usable parameters was restricted due to inconsequential or incomplete medical records and, in some cases, illegible handwriting. Further, reported facts were sometimes different from the information required for research purposes. Finally, only the following variables were related to the aims of this study and statistically analysed: gender, age, use of analgesics, insoles, orthopedic footwear, or shoe adaptations.

Radiography

The non weight-bearing AP and lateral X-rays taken preoperatively, and taken two months after surgery were used. Twelve X-rays were missing or demonstrated an insufficient view of the structures to be investigated. The number of patients in whom the different parameters could be measured varied from 14 to 16 in Group I; 21 to 22 in Group II, and 27 to 29 in Group III. The skeletal parameters were measured on the X-rays and regarded angles, curvatures, lengths and positions of bones. In Chapter IV these parameters are listed in the Appendix and shown in Figs. IV.2-5. The results are presented in Table IV.2.

The shortening of the first metatarsal (in mm) is defined as the preoperative length of MT_1 minus the postoperative length of MT_1 multiplied by the ratio preoperative length of MT_2 divided by the postoperative length of MT_2 (as a correction for the difference in magnification), or in formula:

$$MT_1\, shortening = length\ MT_{1,pre} - length\ MT_{1,post}\left(\frac{length\ MT_{2,pre}}{length\ MT_{2,post}}\right)$$

The presence of degenerative changes in the MTP_1 joint and/or the interphalangeal joint of the hallux was determined using the classification of Grace et al.[15] and concerned in particular: osteophytes, irregularity, flattening, sclerosis, cysts and joint narrowing.

Physical examination

At follow-up, the range of passive motion of MTP_1 in the sagittal plane (i.e. the angle between the longitudinal axis of the hallux and the plantar contact surface of the foot) was estimated on sight. Furthermore, the feet were examined for the presence of: (1) hyperkeratosis under the metatarsal heads, (2) under the medial aspect of the hallux, or (3) under the inter-phalangeal (IP) joint of the hallux, and (4) bunions, (5) hammer, claw or mallet toes, and (6) pain during passive sagittal motion of MTP_1 or the first IP joint.

Footprinting mat

At follow-up, static and dynamic recordings of the plantar pressure were made with the help of a modified version of a Harris footprinting mat (Berkemann).[16-18] To measure a dynamic situation, the patient walked on the mat starting one step length in front of the mat.[19,20] The ink footprints were examined for the presence of weight-bearing of the hallux, and markedly increased plantar pressure under the individual metatarsal heads, under the medial aspect of the hallux, or under the IP joint of the hallux.

From the literature, a list of geometric foot parameters which might have clinical significance was obtained. This included 4 form parameters (dynamic print): (1) the print hallux angle,[21] (2) the orientation of the heel oval (adapted from Rose et al.[17]), (3) the forefoot angle,[22] and (4) the Chippaux-Smirak index (= midfoot/forefoot ratio).[22] The latter three variables are presumed to quantify differences in position of the calcaneus and "arch" height (Fig. V.1).

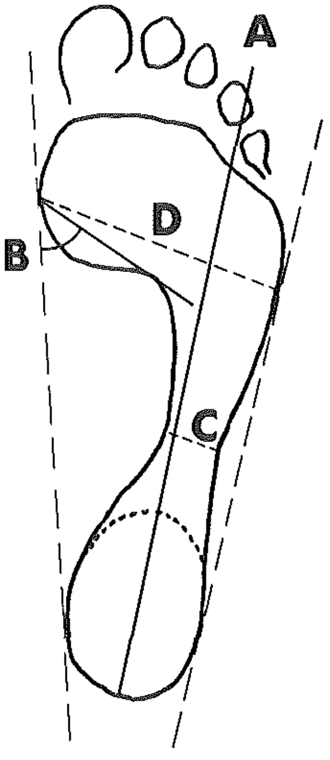

Fig. V.1. Footprint parameters: A, orientation of the longitudinal axis of the heel oval, recorded in relation to the toes (score 4 in this example); B, the forefoot angle; C and D, the Chippaux-Smirak index = C/D x 100 [%].

Questionnaire

At follow-up, the patients completed the questionnaires assisted by the author (APS). The questions concerned both the preoperative period and the situation at follow-up.

The degree of burden of pain, impediment during daily activity, and the degree of patient satisfaction were assessed using a visual analog scale.

These scales range from "no burden/impediment" to "unbearable burden/impediment", or "completely discontented" to "very satisfied". In data processing, the position of the mark of the patient was converted to a numerical score, ranging from 0-100. The choice of the parameter "degree of burden of pain" instead of "degree of pain" is based on experiences from a preceding study on the effect of a sub-diaphysar silicone orthosis.[23] It appeared that this parameter was easier to quantify by scoring one number per day (or longer period) in a diary. This is particularly meaningful for those patients who experience varying degrees of pain during the day.

In an attempt to further quantify the effect of surgery, the complaints at follow-up were expressed as a percentage of the preoperative complaints: "If you regard your complaints before surgery as 100%, what percentage of the complaints remain at this moment? Circle your answer. 0%, 10%, 20%, ..., 200%."[24]

After interviews with the patients, the types of footwear were classified. The classification chosen includes eight elements. This classification enables distinction in the range of choice and thus the tolerance for specific types of footwear, expressing the level of foot functioning. According to our estimation this grading (from high to low heeled shoes) (Fig. V.4) reflects a decreasing order of foot function. Of course, other individual motives will also play an important part.

Statistical analysis

After the formulation of hypotheses, correlations between the assessed individual parameters were estimated and tested. Spearman rank correlation coefficients (r_s) were used for testing monotonic relationships between ordinal scaled variables, and visually checked on reliability with the help of graphs. To adjust the correlations for the possibly confounding effect of the variable "time since surgery", partial rank correlations were estimated and tested. Relationships between dichotomous parameters were tested using Fisher's exact test (two-tailed). The Mann-Whitney U-test was used for between groups comparison of ordinal scaled variables and the McNemar's test for comparison of paired dichotomous variables. Only one foot side per patient was measured and analysed, namely the one with the greater preoperative hallux angle. The reason is that the patients, and not their feet, are the mutually independent observational units.

RESULTS

Incentives of the patients

The questionnaire asked for the main incentive to present for surgery. Allthough some patients had more than one reason, patients in Groups I (n=18), II (n=22), and III (n=31) noted the following answers, respectively:

1. bunion pain at the side of the big toe joint (13, 19, 7)
2. pain inside the big toe joint (0, 0, 22)
3. bunion pain and pain inside the big toe joint (2, 0, 1)
4. bunion pain and poor functioning of the foot during walking, standing or other activities (1, 0, 0)
5. bunion pain and difficulties with finding comfortable footwear (0, 1, 1)
6. bunion pain, shoe-fitting problems and an ugly foot shape, namely an oblique big toe (1, 0, 0)
7. bunion pain and pain in or under the ball of the foot (0, 1, 0)
8. pain in or under the second and third MTP joints (0, 1, 0)
9. prevention of symptoms (1, 0, 0)

Age of the study population

The patients in Group I were on average younger than the patients in Groups II and III ($P<0.0001$). The average age for Group I was 29 years range 15-65 years, Group II 53 years range 23-73, and Group III 49 years range 25-72.

Preoperatively, the older patients in Group I had smaller hallux angles ($r_s=-0.7$, $P<0.05$) and experienced a greater burden of pain in or under MTP_1 at follow-up ($r_s=0.6$, $P<0.05$).

In Group II it was found that the older the patient the more flattening of the MTP_1 joint was seen on the preoperative X-ray ($r_s=0.6$, $P<0.05$). Postoperatively, the older patients showed greater $intermetatarsal_{1\text{-}2}$ angles ($r_s=0.5$, $P<0.05$) and more (sub)luxation of the sesamoids ($r_s=0.5$, $P<0.05$).

In the following sections the pre- and postoperative anatomical and functional abnormalities of the patients are classified according to 3 different levels of health experience: impairments (abnormalities of structure or function); disabilities (limitations of activities), and handicaps (limitations in the fulfilment of individual roles).[14]

Impairments

FOOT FORM

The postoperative X-rays of Group I showed that of the 15 patients undergoing osteotomy and documented sufficiently with X-rays, two months after surgery, 5 patients (33%) showed a hallux angle > 25° (range: 28-35°).

At follow-up, the average and range of the degree of satisfaction with the change of foot form was 68 (0-100) in Group I, 72 (0-100) in Group II and 84 (7-100) in Group III. After arthrodesis on hallux valgus patients, the level of satisfaction concerning the alteration of foot form decreased as the length of the first metatarsal decreased (r_s=0.6, $P<0.05$). The average shortening of the first metatarsal in Groups I, II and III was 5 mm (range: 2 to 10), 4 mm (range: 0 to 13) and 4 mm (range: 0 to 12), respectively.

Clear degenerative changes in the MTP_1 joint were not present in any of the patients of Group I (pre- and postoperative), in 24% of Group II and in 78% of Group III. Pre- and postoperative X-rays showed clear degenerative changes in the IP joint in 7% of Group I, 18% of Group II and in none of Group III.

The percentage of patients with hyperkeratosis at specific sites of the forefoot is shown in Fig. V.2.

PAIN

The percentage of patients who experienced a burden of pain at specific sites of the forefoot before surgery or at follow-up, is shown in Fig. V.2.

The use of analgesics for pain in the forefoot was restricted to 11 patients. Four patients (1 in Group I, and 3 in Group III) used analgesics almost daily in the period before surgery; at follow-up this need had disappeared. Of the hallux rigidus patients, 7 used analgesics on occasion only preoperatively.

1. Bunion pain

See text Chapter IV.

2. Pain in or under the MTP joints

The number of patients with pain in or under the MTP joints, before and after surgery, is given in Table IV.5. Percentages are shown in Fig. V.2. Only Group III showed a significant decrease in the number of patients with pain in or under one of the MTP joints ($P<0.0001$); namely, MTP_1. (See Chapter IV).

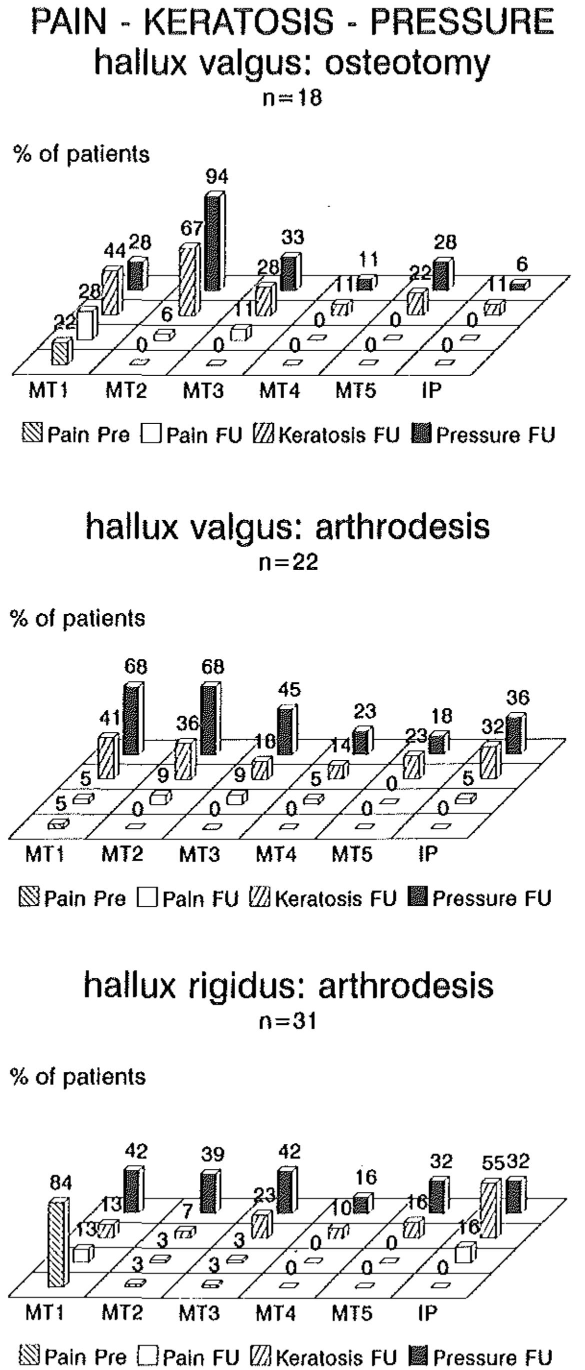

Fig. V.2. Percentage of patients with burden of pain during daily living (preoperative (Pre) and at follow-up (FU)), hyperkeratosis or high plantar pressure under the metatarsal heads (MT1-MT5) or inter-phalangeal joint (IP). Hallux valgus - osteotomy (Group I); hallux valgus - arthrodesis (Group II); and hallux rigidus - arthrodesis (Group III). The only significant change was found in the hallux rigidus group: namely, pain under MT_1 ($P<0.0001$).

3. Painful IP joint

Some patients reported pain during daily activity in the IP joint of the hallux, which had developed postoperatively: 1 patient (5%) in Group II and 5 patients (16%) in Group III (Fig. V.2).

Of the patients in Groups I, II and III 6%, 23% and 35% experienced pain during passive motion of the IP joint at follow-up, respectively.

At follow-up it was established that patients who had undergone an arthrodesis and complained of pain in the IP joint during passive motion, compared with the patients without this symptom, more frequently had:

- pain in the IP joint during daily activity ($P<0.01$);
- hyperkeratosis under the IP joint ($P<0.05$) and under the third to fifth metatarsal heads ($P<0.05$) and
- disturbed balance of the foot during walking ($P<0.05$).

Patients with an arthrodesis showing hyperkeratosis on the medial aspect of the plantar side of the hallux, had more chance of producing a dynamic foot print with a high pressure mark at the same location ($P<0.01$).

At follow-up, no significant correlations were found between pain in the IP joint during passive motion and: (1) high pressure areas at the dynamic foot print or (2) rigidity of MTP_1 during walking. Also no significant correlations were found between pain in the IP joint during daily activity and postoperative radiographic parameters, or the print hallux angle.

RANGE OF MOTION OF MTP_1

In the patients who underwent osteotomy the mean passive maximal plantar flexion was 41° (range: 10-70°, painful in: 28%). Passive maximal dorsiflexion was 46° (range: 15-80°, painful in: 17%). For patients who underwent an osteotomy it was established that the greater the preoperative tarso-metatarsal$_1$ angle (r_s=-0.7, $P<0.05$) or the luxation of the sesamoids (r_s=-0.6, $P<0.05$), the smaller the remaining passive range of motion of MTP_1 at follow-up. No significant correlation was found between the range of motion and the flattening (in the horizontal plane) of MTP_1.

GAIT PATTERN

In 17%, 27% and 6% of the patients of Groups I, II and III respectively, there was awareness of a diminished range of motion of MTP_1 whilst walking. Six percent of Group I, 41% of Group II and 26% of Group III had a feeling of unsteadiness or the feeling of falling side-, for-, or backwards while standing or walking, after the operation. Patients in Group III with the heel oval orientated to the third toe, or even more laterally, experienced a feeling of unsteadiness more frequently after the operation ($P<0.05$).

Great forefoot angles correlated with small Chippaux-Smirak indices (= small midfoot/forefoot ratio) (Group I: r_s=-0.5, $P<0.05$, Group II: r_s=-0.6, $P<0.01$, Group III: r_s=-0.6, $P<0.01$).

Group I:
At follow-up, it was found that:
- the greater the postoperative hallux angle (r_s=0.7, $P<0.05$) or the shortening of the first metatarsal (r_s=0.7, $P<0.05$), the greater the forefoot angle of the dynamic foot print.
- the greater the forefoot angle, the greater the impediment to daily activity (r_s=0.6, $P<0.05$).
- the greater the reduction of the hallux angle, the more the heel oval was orientated medially at follow-up (r_s=-0.6, $P<0.05$).

Group II:
In these patients it was found that:
- the greater the experienced bunion pain at follow-up, the more laterally directed were the heel ovals at the dynamic foot prints (r_s=0.5, $P<0.05$).
- the greater the reduction of the forefoot width, the more the heel oval was orientated medially (r_s=-0.6, $P<0.05$).
- the greater the reduction of the hallux angle (r_s=-0.5, $P<0.05$) or the reduction of the tarso-metatarsal$_1$ angle (r_s=-0.5, $P<0.05$), the smaller was the forefoot angle.

Group III:
The patients demonstrated that:
- the heel ovals were more laterally directed when the patients experienced a greater degree of pain in the inter-phalangeal joint in daily living (r_s=0.5, $P<0.01$).
- when the shortening of the first metatarsal was more distinct, the forefoot angle appeared to be smaller at follow-up (r_s=-0.5, $P<0.05$).
- the greater the postoperative radiographic hallux angle, the greater the hallux angle obtained with the help of a dynamic foot print at follow-up (r_s=0.7, $P<0.001$).

In patients who underwent an arthrodesis, no significant correlation was found between the static and the dynamic assessments of the presence of weight-bearing of the hallux. If the static foot print showed a non weight-bearing hallux after arthrodesis it was more frequently found that hyperkeratosis existed under the second metatarsal head ($P<0.05$). Using static and dynamic footprints, no correlation could be established between the presence of a non weight-bearing hallux and hyperkeratosis under the first, or the third to fifth metatarsal heads, nor increased plantar pressure under the ball of the foot.

The percentage of patients with high plantar pressures at specific sites of the forefoot is given in Fig. V.2.

Disabilities (limitations of activities)

WALKING DISTANCE

One functional limitation of a basic sensomotoric skill is expressed in the walking distance and presented in Table V.1 and Fig. V.3 (modification of a classification used by Rijnberg[25]).

Table V.1. Number and percentage of patients with (un)changed walking distance.

	Group I (n=18): Hallux valgus Osteotomy	**Group II (n=22): Hallux valgus Arthrodesis**	**Group III (n=31): Hallux rigidus Arthrodesis**
Lengtened	5 (28%)	13 (59%)	23 (74%)
Unchanged	12 (67%)	8 (36%)	7 (23%)
Shortened	1 (6%)	1 (5%)	1 (3%)

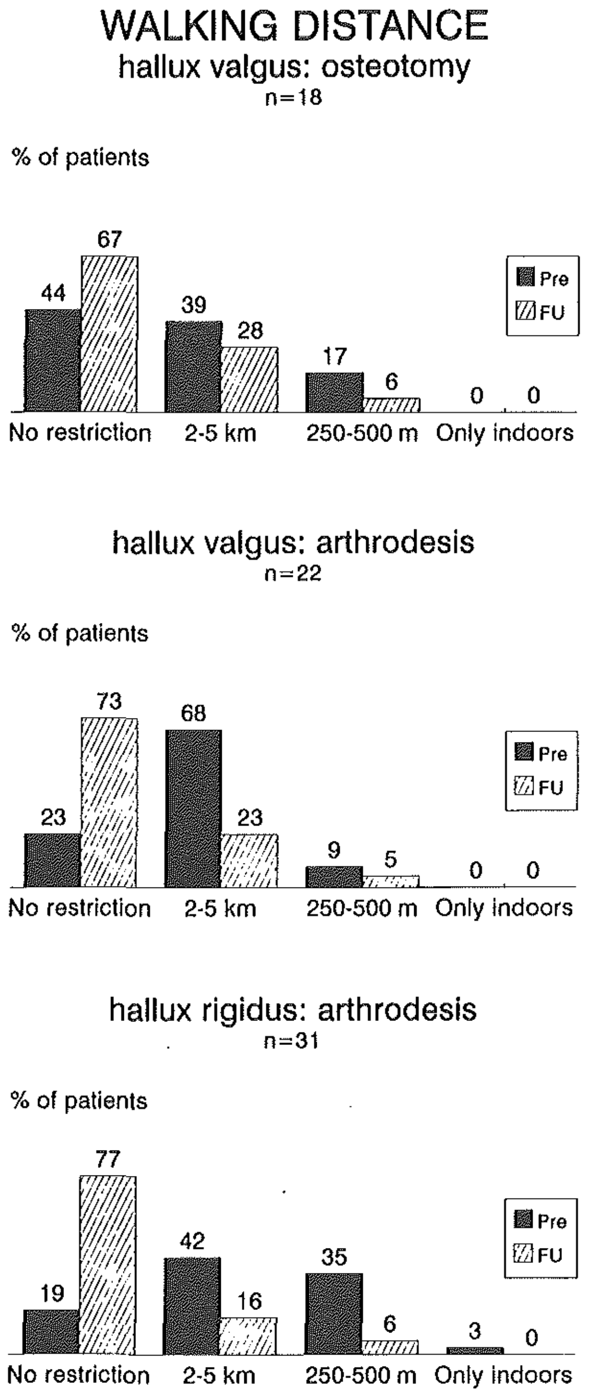

Fig. V.3. Walking distance: preoperative (Pre) and at follow-up (FU). Hallux valgus - osteotomy (Group I); hallux valgus - arthrodesis (Group II); and hallux rigidus - arthrodesis (Group III).

FOOTWEAR

The (change of the) types of outdoor footwear used by the patients is shown in Table V.2 and Fig. V.4.

Table V.2. Number and percentage of patients with (un)changed range of choice of footwear.

	Group I (n=18): Hallux valgus Osteotomy	**Group II (n=22): Hallux valgus Arthrodesis**	**Group III (n=31): Hallux rigidus Arthrodesis**
Increased	4 (22%)	4 (18%)	5 (16%)
Unchanged	12 (67%)	11 (50%)	17 (55%)
Decreased	2 (11%)	7 (32%)	9 (29%)

Compared to the preoperative situation, the number of patients who experienced problems finding comfortable footwear for outdoor daily use was decreased at follow-up: from 14 (78%) to 4 (22%) in Group I ($P<0.01$); 17 (77%) to 8 (36%) in Group II ($P<0.05$); and from 11 (77%) to 5 (16%) in Group III ($P>0.05$). For 3 patients (1 in Group I, and 2 in Group III) the problems started after the fusion of the big toe joint, with pressure on the dorsal aspect of the fused hallux.

After arthrodesis, 3 patients started to use an insole, 3 a rocker sole and 1 a metatarsal bar on the outer sole, to obtain some pain relief under the metatarsal heads; this was successful in 1, 3 and 0 patients, respectively. For the same reason, but without success, 3 of the patients who underwent an osteotomy used insoles only after the operation.

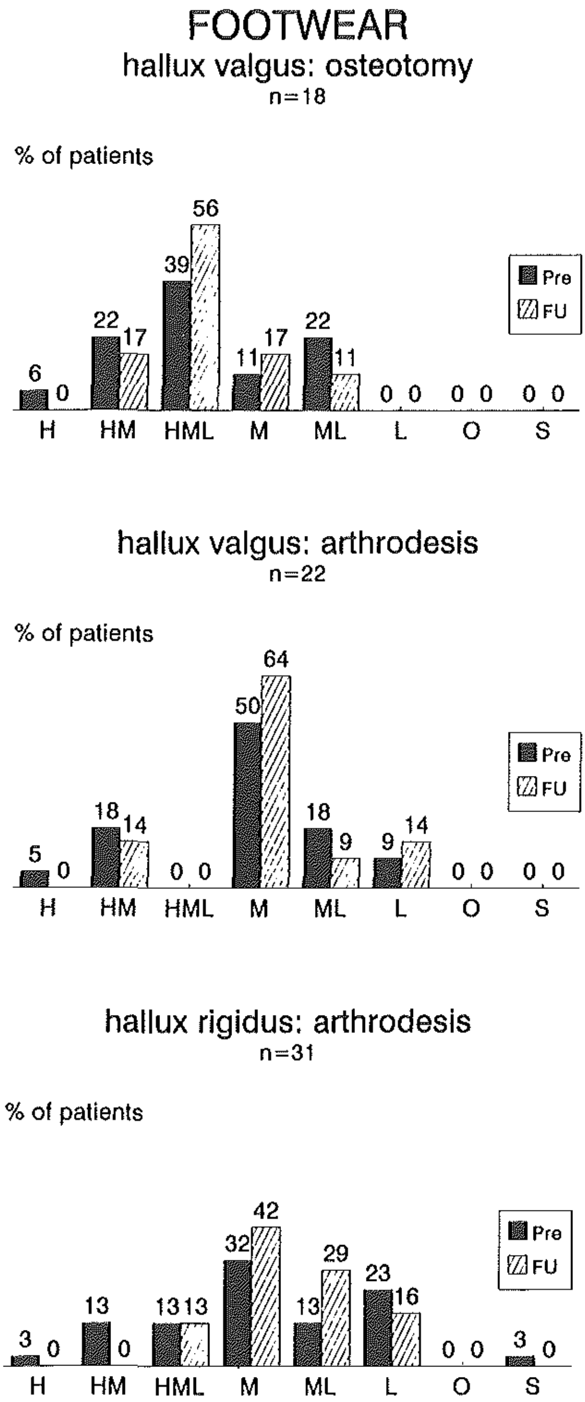

Fig. V.4. Type of footwear for outdoor daily use: preoperative (Pre) and at follow-up (FU). Hallux valgus - osteotomy; hallux valgus - arthrodesis; and hallux rigidus - arthrodesis. H = high heels, HM = high and medium, HML = high, medium and low, O = orthopedic footwear, and S = socks only.

DAILY ACTIVITIES

1. Convalescence

After osteotomy the average convalescent period, with no or minimal normal daily activities, was 70 days (range 6-120 days). After arthrodesis for the hallux valgus patients it was 98 days (range 14-730 days) and for the hallux rigidus patients 138 days (range 14-1460 days) (one outlier with 2555 days due to general complications of surgery was excluded from calculation of the average).

In both osteotomy and arthrodesis patients it was found that the greater the preoperative (sub)luxations of the sesamoids, the longer the convalescent period to resume normal activities (r_s=0.5, $P<0.05$).

Group I:
The shorter the recovery time after osteotomy, the worse the bunion pain (r_s=-0.6, $P<0.05$), the pain in the MTP_1 joint (r_s=-0.5, $P<0.05$) and the impediment to daily activity at follow-up (r_s=-0.5, $P<0.05$).

Groups II + III:
The greater the valgus angle of the fused hallux, as recorded with the footprint, the shorter the convalescent period to resume normal daily activities (r_s=-0.6, $P<0.05$).

Group III:
The longer the convalescent period needed by the patients to recover normal daily functioning, the greater the burden of pain in MTP_1 (r_s=0.5, $P<0.01$) and the impediment to daily activity (r_s=0.6, $P<0.01$) at follow-up.

2. Patient satisfaction after surgery

The level of patient satisfaction some months after surgery was scored on a scale ranging from 0-100. Group I scored an average of 80 (range 0-100), Group II, 72 (range 0-100) and Group III, 86 (range 4-100).

Group I:
It was found that the greater the postoperative hallux angle (r_s=-0.5, $P<0.05$), the reduction of the radiographic width of the forefoot (r_s=-0.6, $P<0.05$), the burden of bunion pain (r_s=-0.6, $P<0.01$), of pain in MTP_1 (r_s=-0.5, $P<0.05$) or the impediment to daily activity (r_s=-0.6, $P<0.05$) at follow-up, the lower was the level of satisfaction with the effect of the operation some months after surgery.

Group II:
For these patients it was found that a small degree of early patient satisfaction correlated with a larger percentage of complaints at follow-up (r_s=-0.5, P<0.05).

Group III:
Less patient satisfaction some months after arthrodesis correlated with a smaller preoperative intermetatarsal$_{1-5}$ angle (r_s=0.5, P<0.05) and with a larger percentage of complaints (r_s=-0.5, P<.05) at follow-up.

3. Remainder of complaints

At follow-up, the remainder of the forefoot complaints related to the 100% preoperative situation were on average 23% (range 0-120) in Group I; 25% (range 0-120) in Group II; and 16% (range 0-50) in Group III patients.

Group I:
The percentages of the remainder of complaints at follow-up were greater if preoperatively less obliquity of the first tarso-metatarsal joint (r_s=-0.6, P<0.05) or small tarso-metatarsal$_1$ angles (r_s=-0.6, P<0.05) existed, or if the patients experienced at follow-up a greater degree of pain in the first MTP joint (r_s=0.6, P<0.05) or greater impediment in daily activities (r_s=0.6, P<0.05).

At follow-up 4 of the 18 patients (22%) who had undergone osteotomy showed obvious clinical recurrence of the valgus position of the halluces with distinct bunions. Three patients (17%) experienced pain in or under one or more of the metatarsal heads only after the operation. One patient complained at follow-up of hypesthesia of the hallux associated with hypertrophic scar tissue.

Group II:
The greater the obliquity of the first tarso-metatarsal joint (r_s=0.7, P<0.01) or the smaller the reduction of the (sub)luxation of the sesamoids (r_s=-0.5, P<0.05), the larger the percentage of the remainder of complaints at follow-up.

Group III:
At follow-up, the percentage of the remainder of complaints correlated positively with the degree of burden of bunion pain (r_s=0.6, P<0.01), of pain in the MTP$_1$ joint (r_s=0.6, P<0.01) and with the degree of impediment to daily activity (r_s=0.8, P<0.001).

In patients undergoing arthrodesis, the following undesired effects were reported at follow-up:

- painful inter-phalangeal joint, experienced in daily life by 6 patients (11%) and during passive motion in 16 patients (30%);
- pain in or under one or more metatarsal heads in 3 patients (6%);
- cosmetic and shoe-fitting problems as a result of a fusion in too much dorsiflexion (3 patients);
- hypesthesia of the hallux (1 patient);
- pain during external pressure on the Rush pin (1 patient);
- re-arthrodesis due to a false position of the Rush pin through the metatarsal cortex (1 patient) and
- a painless pseudarthrosis (2 patients).

4. Impediments to daily activity

The degree of impediment to daily activity due to forefoot complaints, which was scored using a scale ranging from 0-100, changed after surgery. The average value of the osteotomy group decreased significantly from 55 preoperatively to 17 after surgery ($P<0.01$). For hallux valgus patients the average decreased from 53 preoperatively to 11 after arthrodesis ($P<0.01$), and for hallux rigidus patients the values were 60 and 10 ($P<0.00001$), respectively.

The hallux valgus patients reported the following preoperative forefoot complaints which were associated with specific activities: bunion pain when a blanket was pressed against the bunion (4 patients), or after standing for a long period (1 patient), and a spontaneously painful MTP_1 joint (1 patient). The hallux rigidus patients reported the following preoperative complaints: pressure of the blanket with bunion pain (3 patients), or pain in MTP_1 (1 patient), a painful MTP_1 joint during dancing (2 patients), while walking in the swimming-pool (1 patient) or after stubbing a toe (2 patients). After osteotomy these specific activities no longer caused complaints. After arthrodesis, pain in the inter-phalangeal joint of the hallux occurred whilst dancing (2 patients), while walking on a rough sub-soil (1 patient), or at the moment of push-off when running (1 patient).

Group I:
It was found that the impediment to daily activity at follow-up was greater when bunion pain was worse at follow-up ($r_s=0.8$, $P<0.01$) or the postoperative radiographic width of the forefoot ($r_s=0.5$, $P<0.05$) had increased.

Group II:
The smaller the preoperative hallux angle, the greater the impediment to daily activity at follow-up (r_s=-0.6, $P<0.01$).

Group III:
Preoperatively, it was found that the impediment to daily activity was greater when bunion pain was severe (r_s=0.5, $P<0.05$). At follow-up, impediment was greater if the bunion pain (r_s=0.7, $P<0.001$) or the pain in the MTP_1 joint (r_s=0.5, $P<0.01$) was greater.

The (alteration of the) degree of burden of the forefoot complaints during the practice of specific sports or (physical) hobbies was assessed using visual analog scales, and is shown in the Appendix to Chapter V (Table V.3; page 100).

Handicaps (limitations in the fulfilment of individual roles)

Before osteotomy, 7 patients (39%) found it unpleasant if other people could see their bare feet; at follow-up, 4 patients (22%) still experienced this. Before arthrodesis, 6 hallux valgus patients (27%) and 5 hallux rigidus patients (16%) had the same experience; postoperatively 1 (5%) and 0 patients, respectively, still felt uncomfortable about being in company, without shoes. These changes of frequences are not statistically significant.

Before surgery, groups I, II and III included 6 (33%), 3 (14%) and 2 (6%) patients respectively, who had restricted social activities if these involved taking shoes off. At follow-up, in respectively 5, 2 and 2 of these patients, the situation was drastically improved. These changes are not statistically significant.

In 5 patients postoperative foot complaints were (partly) the reason to change their occupation. Walking (Group I a model, Group III a beautician), standing, kneeling (Group II a saleswoman in a shoe-shop, Group III a clerk in a record-office) and climbing stairs (Group III a ship's supplier) gave problems.

Communication and overall judgement

The patients judged the preoperative communication with the orthopedic surgeon about the foot complaints as "insufficient" in 1 (Group I), 2 (II) and 1 (III) cases. The postoperative communication was rated as "insufficient" by 4 (22% of Group I), 6 (27% of Group II) and 5 (16% of Group III) patients and as "very bad" by 1 patient in Group III. One reason for not giving a "good" judgement was insufficient information about the operation, and about the fusion position of the big toe. Another complaint was that too little attention was given to postoperative complaints.

At follow-up, 2 of the 18 osteotomy patients (11%) stated they would not choose for the same operation again, because the performed operation did not have a narrowing effect on their forefoot. Seven patients (13%) with an arthrodesis stated they would not choose to undergo the same operation again. The reasons were: "the high expectations, based on the results of a former operation, turned out differently with the development of pain in the IP joint" (Group II), "shoe-fitting problems, irritating feeling in the foot, not satisfied with the foot shape, and pain at different sides" (Group II), "prefers an operation for the bunion only and possibly afterwards, if impediment of degenerative changes starts, a fusion of the joint" (Group II), "too much setback (painful IP joint) with last operation" (Group III), "ugly shape of the great toe and cramp in footsole" (Group III), "the rigidity of the big toe joint" (Group III) and "insufficient pain relief" (Group III).

DISCUSSION

The presentation of three groups of patients and two surgical methods allows to make inter-group comparisons. But, as the surgical methods were not randomly assigned, and the age ranges of the study groups are different, inter-group comparisons have to be interpreted with great caution.

The first aim of the present study was to establish preoperative (risk) factors that could lead to non-optimal surgical results. Within this scope, and especially considering anatomy, the following relationships were found. When the first tarso-metatarsal joint was positioned less obliquely, or the tarso-metatarsal$_1$ angle was small (thus little varus deviation of the first metatarsal) before an osteotomy, then a larger percentage of complaints persisted at follow-up. On the other hand, in these patients a large preoperative tarso-metatarsal$_1$ angle or a distinct luxation of the sesamoids, was associated with a limited postoperative range of motion of MTP$_1$. Osteotomy is less successful in older patients, who, at follow-up, experienced a greater burden of pain in or under MTP$_1$ than the younger patients. In the hallux valgus patients with an arthrodesis, a distinct oblique setting of the first tarso-metatarsal joint or a small reduction in the luxation of the sesamoids correlated with a larger percentage of complaints persisting at follow-up. Small preoperative hallux angles resulted in a high level of impediment to daily activity at follow-up.

Further, hallux valgus patients who underwent an arthrodesis showed more satisfaction with the form of their feet when the length of the first metatarsal was well conserved.

The second aim of this study was to assess the effects of surgery on patients' daily functioning. We found that the greater the degree of luxation of the sesamoids before surgery, the longer the postoperative period to resume normal functioning. The convalescent period after osteotomy (in a younger patient group) was on average shorter than after arthrodesis. In the osteotomy group, short recovery periods were correlated with more bunion pain, more pain in the MTP_1 joints, and more impediment to daily activity, at follow-up. If these correlations are causal, then a short convalescent period (with no or minimal normal daily activities) after osteotomy should be avoided. Greater (printed) valgus angles of the fused halluces were related to a shorter recovery period.

These findings indicate that the greater the deformation of the foot, the worse results of treatment can be expected. Special attention is directed to the luxation of the sesamoids and to large first tarso-metatarsal angles. The impediments after arthrodesis in patients with small preoperative hallux angles may indicate that this treatment is especially appropriate for major deformities. These conclusions correspond with the advocated clinical practice.[26]

In this study the walking distance lengthened after arthrodesis in 59% of the hallux valgus patients and in 74% of the hallux rigidus patients. Ivory and Gregg[11] reported an almost 50% improvement in a group of patients with walking problems after arthrodesis. Using parameters obtained from the dynamic footprints we established that specific anatomy or complaints were related to specific gait patterns. Stokes et al.,[27] and Hutton and Dhanendran[28] found that hallux valgus is associated with a significant reduction in the loading imposed on the toes and the medial side of the forefoot in walking, compared with healthy feet. We assumed that a laterally orientated heel oval or a great forefoot angle, which correlates with a small Chippaux-Smirak index, is characteristic for a supinated foot with a hollow appearance and a more laterally directed pressure pattern. In the osteotomy patients we found that greater postoperative hallux angles, less reduction of the valgus position or a more distinct shortening of the first metatarsal resulted in more laterally positioned pressure patterns. Even more important are the correlations found between this gait pattern and distinct impediments in daily activity (after the osteotomy) and the feeling of unsteadiness in the foot (after arthrodesis). Further, when the length of the first metatarsal was well conserved, or the forefeet were still wide and accompanied by bunion pain, then the lateral gait pattern was produced, after arthrodesis. Thus, a laterally directed gait pattern can also serve as a measure for level of functioning, and is possibly antalgic of origin.

The complaint most frequently reported after an arthrodesis was pain in the IP joint. This was experienced in daily life by 11% of the operated patients, or during passive motion in 30%. According to the findings of Moynihan[8] these painful IP joints do not always show clear degenerative changes on radiographs. Further, we found that patients who complained of pain during passive motion of their IP joints after fusion of MTP_1, more frequently demonstrated hyperkeratosis under these IP joints and also under the lateral metatarsal heads. Ivory and Gregg[11] established that 79% of those patients whose arthrodesis united and 45% of those which did not unite, had callosities on the medial aspect of the IP joint. Others have reported that the fusion position may influence the postoperative result.[4-6,8-10,12,26] Moynihan[8] could not establish a relationship between the existence of a painful IP joint and the degree of dorsiflexion of the fused MTP_1 joint. Nevertheless, a dorsal tilt of a non weight-bearing hallux, which is associated with hyperkeratosis under the second metatarsal head and may give shoe-fitting problems, should be avoided. Fitzgerald[4] found that fusion at less than 20° of valgus increases the incidence of degenerative changes in the IP joint. This was not confirmed in our study. In the hallux rigidus patients it was demonstrated that postoperative pain in the IP joints during daily living moderately correlated with lateral (antalgic) gait patterns. These same patients more frequently experienced a disturbance of the "balance" of their foot. They had the feeling of falling side-, for- or backwards whilst standing or walking. The presence of a stiff and/or painful IP joint may form a contra-indication for arthrodesis.[8]

The reason why more loading of the lateral plantar aspect occurs during walking remains obscure. Possible explanations include the presence of pain when loading the medial side, loss of flexion force[27,29] and compensation for restricted range of motion of the MTP_1 joint.[28] Many think that the rigidity of a fused MTP_1 joint will automatically exclude normal walking capacity. Our questionnaire revealed that 27% of the hallux valgus patients and 6% of the hallux rigidus patients were aware of a diminished range of motion of their fused great toe during walking. However, athletic activities after arthrodesis are reported in the literature.[10,26] In the present study the inventory of sports and (physical) hobbies shows that a number of patients with fused MTP_1 joints can perform a variety of sports without particular impediment.

In the osteotomy patients there was little satisfaction after convalescence when the hallux angle was still large, or when they had bunion pain or pain in the MTP_1 joint; 33% of these patients had hallux angles greater than 25° postoperatively. After an average of 7 postoperative years, 22% showed obvious clinical recurrences of the valgus position of the halluces with distinct bunions.

Comparison between the preoperative situation and at follow-up regarding the type of footwear showed no striking differences. Before and after surgery the patients who were selected for an arthrodesis, compared with the osteotomy group, were less free in their choice of footwear. In particular, patients with a fused MTP_1 joint seldom wore high-heeled shoes. Ivory and Gregg[11] found that the percentage of patients with problems in footwear decreased significantly from 91-40% following arthrodesis. We established that the preoperative shoe-fitting problems were solved after surgery in more than 63% of the patients with hallux valgus or rigidus.

The number of patients who experienced an unpleasant feeling if other persons saw their bare feet decreased after arthrodesis. The osteotomy group, being younger patients in our case, more frequently experienced this feeling before surgery. As a result of recurrences, this changed less than in the patients with fused joints. In particular, the osteotomy group had a more restricted participation in social activities when these involved unshod moments (33%). Both types of surgical procedure diminished this handicap. However, marked negative effects related to occupation were seen in 5 patients.

Of the entire study population, 23% of the patients were not satisfied with the communication with the surgeon. In their opinion better preoperative information about the procedures and consequences of surgery (such as a great toe in some degree of dorsiflexion) and more attention to the postoperative complaints, would improve patient satisfaction.

The analysis of postoperative parameters and questionnaires gives the overall impression that a poor preoperative condition reduces the chance for successful effects of surgery. Osteotomy is preferred in younger patients who have a moderate preoperative hallux angle and a distinct oblique setting of the first tarso-metatarsal joint. Arthrodesis is dissuaded when there is a distinct oblique setting of the first tarso-metatarsal joint. The fusion is preferred in case of a large hallux valgus angle, excludes recurrences and can give good functional results. The degree of success of an arthrodesis can be influenced by attempting the optimal fusion position, including preoperative examination of the first tarso-metatarsal and IP joints, and informing the patients about possible postoperative disabilities.

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REFERENCES

1 Kelikian H. Osteotomy. In: Hallux valgus, allied deformities of the forefoot and metatarsalgia. Philadelphia, London, W.B. Saunders Company, 1965: 166-170.

2 Bonney G, Macnab I. Hallux valgus and hallux rigidus. A critical survey of operative results. J Bone Joint Surg 1952; 34B: 366-385.

3 Coughlin MJ, Mann RA. Arthrodesis of the first metatarsophalangeal joint as salvage for the failed Keller procedure. J Bone Joint Surg 1987; 69A: 68-75.

4 Fitzgerald JAW. A review of long-term results of arthrodesis of the first metatarso-phalangeal joint. J Bone Joint Surg 1969; 51B: 488-493.

5 Fitzgerald JAW, Wilkinson JM. Arthrodesis of the metatarsophalangeal joint of the great toe. Clin Orthop 1981; 157: 70-77.

6 Henry APJ, Waugh W. The use of footprints in assessing the results of operations for hallux valgus. J Bone Joint Surg 1975; 57B: 478-481.

7 Johnson KA. Bunion of the great toe. In: Surgery of the foot and ankle. New York, Raven Press, 1989: 17-20.

8 Moynihan FJ. Arthrodesis of the metatarso-phalangeal joint of the great toe. J Bone Joint Surg 1967; 49B: 544-551.

9 Salis-Soglio G von, Thomas W. Arthrodesis of the metatarsophalangeal joint of the great toe. Arch Orthop Traumat Surg 1979; 95: 7-12.

10 Harrison MHM, Harvey FJ. Arthrodesis of the first metatarsophalangeal joint for hallux valgus and rigidus. J Bone Joint Surg 1963; 45A: 471-480.

11 Ivory JP, Gregg PJ. The management of the painful first metatarsophalangeal joint in the older patient: a 5-year review. The Foot 1992; 2: 162-165.

12 Lipscomb PR. Arthrodesis of the first metatarsophalangeal joint for severe bunions and hallux rigidus. Clin Orthop 1979; 142: 48-54.

13 O'Doherty DP, Lowrie IG, Magnussen PA, Gregg PJ. The management of the painful first metatarsophalangeal joint in the older patient. J Bone Joint Surg 1990; 72B: 839-842.

14 World Health Organization. International Classification of Impairments, Disabilities, and Handicaps. A manual of classification relating to the consequences of disease. (Published for trial purposes in accordance with resolution WHA29.35 of the Twenty-ninth World Health Assembly) May 1976. Geneva, WHO, 1980.

15 Grace DL, Clark P, Klenerman L. A comparison of Wilson and Hohmann osteotomies in the treatment of hallux valgus. J Bone Joint Surg 1988; 70B: 236-241.

16 Hughes J, Kriss S, Klenerman L. A clinician's view of foot pressure: a comparison of three different methods of measurement. Foot Ankle 1987; 7: 277-284.

17 Rose GK, Welton EA, Marshall T. The diagnosis of flat foot in the child. J Bone Joint Surg 1985; 67B: 71-78.

18 Silvino N, Evanski PM, Waugh TR. The Harris and Beath footprinting mat: Diagnostic validity and clinical use. Clin Orthop 1980; 151: 265-269.

19 Cavanagh PR, Ulbrecht JS. Biomechanics of the diabetic foot: A quantitative approach to the assessment of neuropathy, deformity, and plantar pressure. In: Jahss MH, editor. Disorders of the foot and ankle. Philadelphia, London, Toronto, Mexico City, Rio de Janeiro, Sydney, Tokyo, W.B. Saunders Company, 1991: 1884-1890.

20 Sanders AP, Snijders CJ, HJ Stam. A method for dynamic measuring with pressure or force platforms. J Rehabil Sciences 1993; 6: 114-123.

21 Sanders AP, Snijders CJ, Van Linge B. Medial deviation of the first metatarsal head as a result of flexion forces in hallux valgus. Foot Ankle 1992; 13: 515-522.

22 Forriol F, Pascual J. Footprint analysis between three and seventeen years of age. Foot Ankle 1990; 11: 101-104.

23 Sanders AP, Van Lith R, Snijders CJ, Mulder PGH. Morton's neuralgie: Een gerandomiseerde therapie-effectstudie bij de Podotherapie. Project nr. 89-47, CRO-208397 of the Ministry of Welfare, Public Health and Culture, The Netherlands, 1992.

24 Linssen ACG, Spinhoven P. Pijnmeting in de klinische praktijk. Ned Tijdschr Geneeskd 1991; 135: 557-560.

25 Rijnberg WJ. Reconstructie van de tibiaschacht door een centrale spongiosaplastiek. Thesis, Rotterdam, The Netherlands, 1990.

26 Mann RA. The great toe. Orthop Clin North Amer 1989; 20: 519-533.

27 Stokes IAF, Hutton WC, Stott JRR, Lowe LW. Forces under the hallux valgus foot before and after surgery. Clin Orthop 1979; 142: 64-72.

28 Hutton WC, Dhanendran M. The mechanics of normal and hallux valgus feet - A quantitative study. Clin Orthop 1981; 157: 7-13.

29 Mann RA, Poppen NK, O'Konski M. Amputation of the great toe. A clinical and biomechanical study. Clin Orthop 1988; 226: 192-205.

APPENDIX TO CHAPTER V

Table V.3. The alteration of the impediment of the forefoot complaints during specific sports or (physical) hobbies. The impediment was assessed using a visual analog scale (0-100), related to the situation before surgery (first value) and at follow-up (second value). An asterix indicates when a patient does not practice a specific activity (anymore).

	Hallux valgus Osteotomy (n=18)	**Hallux valgus Arthrodesis (n=22)**	**Hallux rigidus Arthrodesis (n=31)**
Walking	78-35, 0-0	83-4, 56-3, 80-12, 13-30	77-10, 85-0, 97-0, 99-0, 38-3, 69-2, 44-24, 87-0, 41-16, 0-0
Walking during fishing	-	-	82-2
Walking in swimming-pool	3-0	85-4, 0-0, 0-0, 86-80, 0-0, 0-0	32-2, 3-*, 2-22
Golf	-	-	30-4, 94-*, 86-12
Hunting	-	-	86-12
Gardening	-	-	*-14
Running	75-0, 50-0, 51-0, 97-0	85-0	56-*, 80-31, 93-0, 64-*
Marathon running	69-0	-	-
Bowling	-	12-0	-
Dancing	0-0	14-74	97-55, *-35, 79-22
Yoga	-	-	79-22
Fitness, aerobics	6-10, 52-0, *-0	0-*	*-6, *-0, *-4, *-4, 99-*, 99-*, 53-25, 63-26
Gymnastics	88-*	-	-
High and long jumping	75-*	-	-
Squash	8-0	-	75-*
Table tennis	-	-	91-1
Badminton	50-0, 100-*	49-*	-
Tennis	65-12, 48-0	-	43-*, 96-*, 48-*, 75-32, 87-*
Volleyball	-	-	87-*
Soccer	52-0	73-0	79-31, 97-0
Field hockey	53-0	-	-
Asian fight sports	-	80-0	-
Horse-riding	3-*	-	-
Cycling	*-0	0-0, 0-0, 0-0, *-0, 36-25	0-0, 0-0, 0-0, *-0, 1-1, 10-9, 13-11, 13-1, 54-19

Chapter VI

General discussion and summary

GENERAL DISCUSSION AND SUMMARY

The hallux valgus complex is a disorder of the foot which can be attributed to different causes. In many patients the cause of the abberation is unclear and they have a so-called idiopathic hallux valgus complex. With regard to the etiology of hallux valgus a number of theories with a biomechanical basis exist, such as hyperlaxity of connective tissue,[1] subtalar hyperpronation in gait,[2] anatomical characteristics of the first tarso-metatarsal and first metatarso-phalangeal joints,[3,4] and, last but not least, narrow footwear.[4-8] Although biomechanical aspects in the etiology of the hallux valgus complex deserve attention in view of prevention and therapy, these are beyond the scope of this thesis. In the present study mechanical features are investigated independent of the causes of hallux valgus. A starting-point is that deviated positions of the tendons of the hallux flexors lead to an increase of the valgus angle of the hallux and the varus angle of the first metatarsal. This has particular significance in splayfoot. This phenomenon was described in a biomechanical model by Snijders et al.[9] The aim of the present study is to determine how far this theoretical model is applicable to in vivo situations and, in particular, to patients in the pre- and postoperative situation. With that objective in mind, a number of sub-studies were performed.

Chapter II - Medial deviation of the first metatarsal head as a result of flexion forces in hallux valgus

The aim of this study is to explain how bunions and pain under the metatarsal heads develop. We started with the biomechanical model of Snijders et al.,[9] which states that contraction of the hallux flexors causes an increase of both the valgus deviation of the hallux and the varus angle of the first metatarsal. The present study was designed to validate the model in patients. Whilst pressing the hallux downward, simultaneously the force under the toe and the medial deviation of the first metatarsal head were measured. We measured 8 subjects with straight great toes, 10 subjects with hallux valgus but without complaints and 17 patients with clinical hallux valgus who received corrective surgery the following day. We demonstrated that (1) when subjects with hallux valgus pushed the great toe on the ground, the first metatarsal head moved in medial direction; in other words the foot widened. In the controls the foot generally became narrower. (2) The greater the valgus deviation of the hallux, the greater was the effect of the toe flexors. (3) The maximal applicable flexion force on the hallux is significantly smaller in the symptomatic group compared with subjects without deformity, and asymptomatic subjects with valgus deviation of the hallux. The implications of these findings for both conservative and surgical therapy are discussed. Recurrence of deformity after first metatarsal osteotomy is explained by the action of the hallux flexors.

The stable result of arthrodesis of the first metatarso-phalangeal joint is expected to be accompanied by narrowing of the foot due to contraction of the flexor muscles.

Chapter III - Biomechanical analysis of the effects of osteotomy and arthrodesis for hallux valgus and metatarsus primus varus

According to the biomechanical model the effects of a first metatarsal osteotomy and an arthrodesis of the first MTP joint are predicted to be essentially different. Before and after surgery we measured flexion forces on the hallux and simultaneous displacement of the first metatarsal head. We concluded that (1) flexion forces exerted by the preoperative hallux result in widening of the forefoot. (2) After a modified Hohmann osteotomy (8 patients) a widening effect was still measured, which might explain the development of recurrences of deformity and complaints. (3) After arthrodesis (10 patients), flexion forces can lead to a narrowing effect on the forefoot. (4) Postoperatively, both the osteotomy and arthrodesis groups showed a slight, but statistically non-significant decrease (from 37-25 N and from 36-31 N, respectively) of the isometrically determined average maximal applicable flexion force. These small hallux loads may cause, or result from, a deviation in gait pattern.

Chapter IV - The influence of osteotomy or arthrodesis on the geometry of hallux valgus and hallux rigidus

The effects of first ray surgery on different elements of the hallux valgus complex were studied. In order to find (causal) relationships we used a number of parameters. These were obtained from X-rays, visual analog scales, physical examination, and dynamic footprints of 71 patients and concerned the pre- and postoperative situations. Use of the concept of the "hallux valgus complex" was supported by the assessment of significant positive correlations between several (newly introduced) forefoot parameters: (modified) hallux angle; (sub)luxation of the sesamoids; intermetatarsal$_{1\text{-}2}$ angle; intermetatarsal$_{1\text{-}5}$ angle; tarso-metatarsal$_1$ angle; obliquity of the tarso-metatarsal$_1$ joint; flattening of the tarso-metatarsal$_1$ and MTP$_1$ joint and forefoot width. We found that the obliquity of the first tarso-metatarsal joint correlates with the degree of metatarsus primus varus and with a measure of degenerative flattening of the first metatarsal head. The question whether the obliquity of the tarso-metatarsal$_1$ joint is an etiologic factor of metatarsus primus varus, or results from remodelling of the first tarso-metatarsal joint, was not addressed. Realignment of the first ray after the osteotomy diminishes the (sub)luxation of the sesamoids. The reduction of the hallux (valgus) angle, by means of an arthrodesis, results in a narrowing effect on the forefoot. Furthermore, relationships between toe deformities, increased plantar pressure and hyperkeratosis under the metatarsals were quantified, emphasizing the importance of the toes in foot functioning.

Chapter V - Effects of surgical treatment of hallux valgus and hallux rigidus on biomechanics and daily living

Using the medical reports, radiographs, physical examination, a footprinting mat and a questionnaire we obtained data from the same patients described in Chapter IV. We established pre-operative (risk) factors for disappointing surgical outcomes. Special attention is given to a great first tarso-metatarsal angle, an oblique setting of this joint, the (sub)luxation of the sesamoids, and to poor communication with the physician associated with insufficient medical information.

The modified Hohmann osteotomy gave the best results in younger patients, if the preoperative metatarsus primus varus was greater, or when the postoperative convalescent period was longer. On the other hand, greater preoperative deviations of the first metatarsal or sesamoids resulted in restricted range of motion of MTP_1 at follow-up. At follow-up (mean 7 years), 22% of the patients had clinical recurrences.

After osteotomy, less reduction of the valgus position or a more distinct shortening of the first metatarsal resulted in more laterally positioned pressure patterns.

A lateral gait pattern was associated with distinct impediments to daily activities (after osteotomy) and a feeling of unsteadiness in the foot (after arthrodesis).

The success of arthrodesis of MTP_1 was greater if performed in patients with larger preoperative valgus deviations of the great toe, or less oblique settings of the first tarso-metatarsal joint. A dorsal tilt of the hallux was associated with hyperkeratosis under the second metatarsal head and with shoe-fitting problems. Fusion in small valgus angles resulted in longer convalescent periods. An inventory of the sports and hobbies showed that a number of patients with fused MTP_1 joints could perform physical sports without problems.

In conclusion

We were able to measure the toe pressure of the hallux and the change in forefoot width, simultaneously and reproducibly, in patients. The degree of difficulty was not the severity of the foot deformity, but taking up a motionless position of the foot whilst executing forces on the toe in an erect posture.

Fixation with the help of tape, clamps or points of support resulted in counter-effects because these allowed the subject to introduce disturbing reaction forces.

The biomechanical model, which describes the relationship between deviations of the first ray alignment and flexor forces on the hallux, proved to be applicable to the patients. The model increases knowledge on the pathogenesis and the required therapeutic interventions.

- If a valgus deviation of the hallux existed, the forefoot width increased during contraction of the flexors of the great toe. The action of the flexors is repeated during each step. The deformity enhances itself.
- This phenomenon still presented after a modified Hohmann osteotomy. This can explain the development of recurrences of radiographic hallux angles greater than 25° and clinical hallux valgus that were found in, respectively, 33% and 22% of the patients studied.
- After an arthrodesis of the first metatarso-phalangeal joint, during contraction of the hallux flexors, the forefoot became narrower in 60% of the patients.

This study was restricted to biomechanics of a modified Hohmann osteotomy and arthrodesis of MTP_1. However, with reference to the biomechanical model of Snijders et al.[9] it can be expected that the conclusions above also hold for other types of first metatarsal osteotomies.

In a number of patients with hallux valgus and/or rigidus the choice between osteotomy or an arthrodesis (or other methods) is obvious. In borderline cases selection criteria are necessary. Our findings demonstrated that (1) osteotomies were especially successful in younger patients, or in patients with a great first tarso-metatarsal angle, or an oblique setting of this joint. (2) Arthrodeses scored well if this joint was less obliquely positioned, or if the hallux had a large preoperative hallux angle.

In daily functioning a number of differences were found between the two studied surgical methods. The choice of the technique has to be strongly related to the individual and requires further research. Surgeons can be advised not to avoid the use of an arthrodesis in younger patients who have severe deformities. This opinion is based on biomechanical findings and answers of the patients.

The present biomechanical study made use of static and dynamic footprints. In a previous study[10] several patients experienced difficulty in hitting a pressure or force platform whilst maintaining a "natural" gait. Therefore, in the present study, another method was chosen: namely, first step data collection. With the help of a footprinting mat, a significant relationship was demonstrated between the valgus angle of the hallux, determined with a static footprint, and the valgus angle of the weight-bearing X-ray. This relationship is relevant for disciplines that do not have X-ray facilities at their direct disposal. A significant correlation between a footprint parameter (forefoot angle) and functioning in daily life was found. These relationships emphasize the usefulness of a simple footprinting mat. Furthermore, correlations between the presence of deformities of the toes (claw, hammer, mallet toe) and high pressure areas and hyperkeratosis under the metatarsal heads were determined. These findings emphasize the need to consider the functioning of the toes in both conservative (e.g., silicone orthoses,[11] toe crests in insoles) and in surgical treatment. The results demonstrate that several parts of the forefoot are functionally linked and support the choice to use the term hallux valgus complex.

REFERENCES

1 Carl A, Ross S, Evanski P, Waugh T. Hypermobility in hallux valgus. Foot Ankle 1988; 8: 264-270.

2 Kalen V, Brecher A. Relationship between adolescent bunions and flatfeet. Foot Ankle 1988; 8: 331-336.

3 Mann RA, Coughlin MJ. Hallux valgus - Etiology, anatomy, treatment and surgical considerations. Clin Orthop 1981; 157: 31-41.

4 Scranton PE, Rutkowski R. Anatomic variations in the first ray: Part I. Anatomic aspects related to bunion surgery. Clin Orthop 1980; 151: 244-255.

5 Barnicot NA, Hardy RH. The position of the hallux in West Africans. J Anatomy 1955; 89: 355-361.

6 Heylings DJA. Hallux valgus and abductor hallucis; personal thoughts on their connection. Chiropodist 1990; August: 162-164.

7 Kato T, Watanabe S. The etiology of hallux valgus in Japan. Clin Orthop 1981; 157: 78-81.

8 Sim-Fook L, Hodgson AR. A comparison of foot forms among the non-shoe and shoe-wearing Chinese population. J Bone Joint Surg 1958; 40A: 1058-1062.

9 Snijders CJ, Snijder JG, Philippens MM. Biomechanics of hallux valgus and spreadfoot. Foot Ankle 1986; 5: 327-332.

10 Sanders AP, Snijders CJ, Stam HJ. A method for dynamic measuring with pressure or force platforms. J Rehabil Sciences 1993; 6: 114-123.

11 Sanders AP, Van Lith R, Snijders CJ, Mulder PGH. Morton's neuralgie: Een gerandomiseerde therapie-effectstudie bij de Podotherapie. Project nr. 89-47, CRO-208397 of the Ministry of Welfare, Public Health and Culture, The Netherlands, 1992.

Diskussie en samenvatting

DISKUSSIE EN SAMENVATTING

Het hallux valgus complex is een aandoening van de voet die verschillende oorzaken kan hebben. Bij een groot aantal patiënten is de oorzaak van de afwijking onduidelijk. Zij hebben het zogenaamde idiopathische hallux valgus complex. Met betrekking tot de etiologie van hallux valgus bestaat er een aantal theorieën met een biomechanische basis, zoals hyperlaxiteit van bindweefsel,[1] subtalaire hyperpronatie tijdens lopen,[2] anatomische kenmerken van het eerste tarso-metatarsale en het eerste metatarso-phalangeale gewricht,[3,4] en nauw schoeisel.[4-8] Hoewel biomechanische aspecten in de etiologie van het hallux valgus complex aandacht verdienen met het oog op preventie en behandeling, behoren deze niet tot de strekking van dit proefschrift. In de huidige studie worden mechanische kenmerken onafhankelijk van de oorzaken van hallux valgus bestudeerd. Uitgangspunt is dat de afwijkende ligging van de pezen van de hallux flexoren een toename van de valgushoek van de hallux en de varushoek van het eerste metatarsale doet ontstaan. Dit is met name van belang met betrekking tot spreidvoet. Dit fenomeen was beschreven in een biomechanisch model van Snijders et al.[9] Het doel van de huidige studie is te bepalen in hoeverre dit theoretische model toepasbaar is op in vivo situaties. Met dit doel werd een aantal sub-studies uitgevoerd.

Hoofdstuk II - Mediale deviatie van het eerste metatarsaalkopje ten gevolge van flexiekrachten bij hallux valgus

Het doel van deze studie is te verklaren hoe knokken (hallux valgus) en pijn onder de metatarsaalkopjes ontstaan. We startten met het biomechanisch model van Snijders et al.,[9] dat aangeeft dat aanspanning van de hallux flexoren een toename geeft van de valgusdeviatie van de hallux en de varushoek van het eerste metatarsale. Deze studie werd verricht om het model bij patiënten te valideren. Tijdens het neerwaarts drukken van de hallux werden de flexiekracht van de hallux en de verplaatsing, in mediale richting, van het eerste metatarsaalkopje gemeten. We bestudeerden 8 personen met rechte tenen, 10 personen met hallux valgus maar zonder voetklachten en 17 patiënten met klinische hallux valgus, die een dag later een korrigerende operatie ondergingen. We konden aantonen dat (1) wanneer de personen met hallux valgus hun grote teen op de ondergrond drukten, het eerste metatarsaalkopje in mediale richting bewoog; met andere woorden, de voet werd breder. In de kontrolegroep werd de voet gemiddeld smaller. (2) Des te groter de valgusafwijking van de hallux, des te groter was het effekt van de teenflexoren. (3) De maximale flexiekracht van de hallux was significant kleiner in de symptomatische groep in vergelijking met personen zonder voetafwijkingen en asymptomatische personen met hallux valgus. De implicaties van de bevindingen voor zowel konservatieve als chirurgische therapie worden bediskussieerd. Het optreden van recidieven na een osteotomie van het eerste metatarsale wordt verklaard door de werking van de hallux flexoren. Tevens wordt verwacht dat het stabiele resultaat van een arthrodese van het eerste metatarso-phalangeaal gewricht samengaat met het smaller worden van de voet ten gevolge van kontraktie van de hallux flexoren.

Hoofdstuk III - Biomechanische analyse van de effekten van osteotomie en arthrodese voor hallux valgus en metatarsus primus varus

Volgens het biomechanisch model zijn de effekten van een osteotomie van het eerste metatarsale en een arthrodese van het eerste metatarso-phalangeaal gewricht essentieel verschillend. Voor en na operatie maten we de flexiekracht van de hallux en de verplaatsing van het eerste metatarsaalkopje simultaan. We konkludeerden dat (1) bij flexiekrachten van de pre-operatieve hallux een verbreding van de voorvoet optrad. (2) Na een gemodificeerde Hohmann osteotomie (8 patiënten) maten we nog steeds een verbredend effekt, dat het ontstaan van recidieven van deformiteit en klachten kan verklaren. (3) Na arthrodese (10 patiënten) kunnen flexiekrachten in een versmallend effekt op de voorvoet resulteren. Zowel in de osteotomie groep als in de arthrodese groep werd postoperatief een kleine maar statistisch niet significante vermindering (respectievelijk van 37-25 N en van 36-31 N) van de isometrisch bepaalde gemiddelde maximale flexiekracht vastgesteld. Deze lage belastingen van de hallux kunnen zowel een oorzaak als een gevolg van een afwijkend gangpatroon zijn.

Hoofdstuk IV - De invloed van osteotomie of arthrodese op de geometrie van hallux valgus en hallux rigidus

De effekten van chirurgie van de eerste straal op verschillende elementen van het hallux valgus complex werden bestudeerd. Teneinde (kausale) relaties te vinden maakten we van een aantal parameters gebruik. Deze werden verkregen van röntgenfoto's, dynamische blauwdrukken en visueel analoge schalen van 71 patiënten en betroffen de pre- en postoperatieve situaties. Het gebruik van het koncept van het hallux valgus complex werd onderbouwd door middel van de vaststelling van signifikante positieve korrelaties tussen verschillende parameters: (gemodificeerde) hallux hoek; (sub)luxatie van de sesambotjes; intermetatarsale$_{1\text{-}2}$ hoek; intermetatarsale$_{1\text{-}5}$ hoek; tarso-metatarsale$_1$ hoek; positionering van het eerste tarso-metatarsale gewricht; afplatting van het eerste tarso-metatarsale en eerste metatarso-phalangeale gewricht en voorvoet breedte. De vraag of de schuine positionering van het eerste tarso-metatarsale gewricht een etiologische faktor is van metatarsus primus varus of een resultaat is van het remodelleren van het eerste tarso-metatarsale gewricht, werd niet beantwoord. Korrektie van de standsafwijking van de eerste straal na een osteotomie resulteert in een vermindering van de (sub)luxatie van de sesambotjes. De reduktie van de hallux (valgus) hoek door middel van een arthrodese heeft een versmalling van de voorvoet tot gevolg. Verder werden er relaties tussen teenafwijkingen, verhoogde plantaire druk en hyperkeratose onder de metatarsaalkopjes gekwantificeerd. Deze benadrukken de belangrijke rol van de tenen met betrekking tot het funktioneren van de voet.

Hoofdstuk V - Effekten van chirurgische behandeling van hallux valgus en hallux rigidus op de biomechanika en het dagelijks leven

Met behulp van een status-onderzoek, röntgenfoto's, lichamelijk onderzoek, een blauwdrukmat en een enquête verkregen we aanvullende gegevens van de patiënten die reeds in hoofdstuk IV werden beschreven. We stelden pre-operatieve risicofaktoren voor teleurstellende operatieresultaten vast. De aandacht gaat hierbij speciaal uit naar een grote tarso-metatarsale$_1$ hoek, een schuine positie van dat gewricht, de (sub)luxatie van de sesambotjes en een slechte kommunikatie met onvoldoende informatie.

De gemodificeerde Hohmann osteotomie gaf het beste resultaat bij jonge patiënten, indien er pre-operatief een duidelijke metatarsus primus varus was, of bij een lange postoperatieve herstelperiode. Daar stond tegenover dat grotere pre-operatieve deviaties van het eerste metatarsale in een verminderde beweeglijkheid van het eerste metatarso-phalangeale gewricht resulteerden, ten tijde van het na-onderzoek. Na een "follow-up" van gemiddeld zeven jaar bleek bij 22% van de patiënten de vormafwijkingen en klachten te recidiveren.

Na een osteotomie gaf een beperkte reduktie van de valgusstand, of een duidelijke verkorting van het eerste metatarsale, een meer via lateraal verlopend drukpatroon onder de voetzool.

Een lateraal looppatroon ging samen met klachten die het dagelijks leven beïnvloedden (na de osteotomie) en met een gevoel de balans in de voet kwijt te zijn (na de arthrodese).

Het resultaat van een arthrodese van het eerste metatarso-phalangeaal gewricht was beter indien deze was verricht bij patiënten met pre-operatief grote valgusdeviaties van de hallux, met een minder schuine stand van het eerste tarso-metatarsaal gewricht of als de verkorting van het eerste metatarsale beperkt was gebleven. Een dorsaalflexie stand van de hallux ging samen met overmatige eeltvorming onder het tweede metatarsaalkopje en met problemen bij het dragen van schoeisel. Een fusie in een kleine valgushoek resulteerde in een langere herstelperiode. Een inventaris van sporten en hobbies gaf aan dat een aantal patiënten met gefuseerde eerste metatarso-phalangeaal gewrichten konden hardlopen (marathon), voetballen, hockeyen of tennissen zonder dat zij duidelijke beperkingen ervaarden.

Konklusies

We waren in staat om de teendruk van de hallux en de verandering in voorvoetbreedte simultaan en reproduceerbaar bij patiënten te meten. De moeilijkheidsgraad bleek niet te liggen in de ernst van de deformiteit van de voet, maar in het bewegingloos positioneren van de voet terwijl er in een staande houding krachten worden uitgeoefend op de teen. Fixatie met behulp van tape, klemmen of steunpunten resulteerde in tegengestelde effekten omdat deze de patiënt de mogelijkheid bood om reaktiekrachten te introduceren.

Het biomechanisch model dat de relatie tussen deviaties van de eerste straal en flexiekrachten op de hallux beschrijft was toepasbaar op patiënten. Het model vergroot de kennis met betrekking tot de pathogenese en de vereiste therapeutische interventies.

- Indien er een valgusdeviatie van de hallux bestond, dan nam de breedte van de voorvoet toe tijdens aanspannen van de flexoren van de grote teen. De aktiviteit van de flexoren vindt gedurende elke stap plaats. De deformiteit versterkt zichzelf.
- Na een gemodificeerde Hohmann osteotomie was dit fenomeen nog steeds aanwezig. Dat kan een verklaring vormen voor de ontwikkeling van recidieven van radiografische halluxhoeken >25° en klinische hallux valgus die gevonden werden in, respectievelijk, 33% en 22% van de onderzochte patiënten.
- Na een arthrodese van het eerste metatarso-phalangeaal gewricht werd de voorvoet in 60% van de patiënten smaller tijdens aanspannen van de hallux flexoren.

Deze studie was beperkt tot de biomechanika van een gemodificeerde Hohmann osteotomie en arthrodese van MTP_1. Echter, verwijzend naar het biomechanische model van Snijders e.a.[9] kan verwacht worden dat de bovenstaande konklusies ook voor andere typen osteotomieën van het eerste metatarsale gelden.

In een aantal patiënten met hallux valgus en/of rigidus is de keuze tussen een osteotomie of een arthrodese (of andere methoden) duidelijk. In het grensgebied van deze keuzes zijn selektiecriteria nodig. Onze bevindingen laten zien dat (1) osteotomieën met name succesvol zijn in jonge patënten of in patiënten met een grote eerste tarso-metatarsale hoek, of met een schuine positie van dit gewricht. (2) Arthrodeses scoorden goed als dat gewricht minder schuin gepositioneerd was of als de hallux pre-operatief een grote valgushoek vertoonde.

Met betrekking tot de dagelijkse aktiviteiten werd een aantal verschillen tussen de twee bestudeerde chirurgische methoden gevonden. De keuze van de techniek moet sterk worden gekoppeld aan het individu. Hiervoor is verder toekomstig onderzoek benodigd. Aan chirurgen kan geadviseerd worden om niet terug te deinzen voor het toepassen van een arthrodese in jongere patiënten met ernstige deformiteiten. Deze mening is gebaseerd op biomechanische bevindingen en antwoorden van patiënten.

Deze biomechanische studie maakte gebruik van statische en dynamische blauwdrukken. In een voorafgaande studie ervaarden verschillende patiënten moeilijkheden bij het met de voet raken van een druk- of krachtenmeetplatform met behoud van een "natuurlijk" gangpatroon. Daarom werd in de huidige studie voor een andere methode gekozen: eerste-stap dataverzameling. Met behulp van een blauwdrukmat werd een signifikante relatie vastgesteld tussen de valgushoek van de hallux, bepaald met een statische voetprint, en de valgushoek van de belaste röntgenfoto. Deze relatie is belangrijk voor disciplines die niet direkt de beschikking hebben over röntgenfoto's. Er werd een signifikante korrelatie gevonden tussen een blauwdrukparameter (voorvoethoek) en het funktioneren in het dagelijks leven. Deze relaties benadrukken de bruikbaarheid van een eenvoudige blauwdrukmat. Verder werden er korrelaties bepaald tussen de aanwezigheid van teenafwijkingen (klauw-, hamerteen, "mallet toe"), verhoogde plantaire druk en hyperkeratosis onder de metatarsaalkopjes. Deze bevindingen vormen argumenten om bij konservatieve (b.v. een sub-diafysair element in een inlegzool of siliconen orthesen[10]) en chirurgische behandelingen aandacht te schenken aan het funktioneren van de tenen. De resultaten tonen aan dat verschillende delen van de voorvoet funktioneel aan elkaar verbonden zijn en onderbouwen de keuze van het gebruik van de naam hallux valgus complex.

REFERENTIES

1 Carl A, Ross S, Evanski P, Waugh T. Hypermobility in hallux valgus. Foot Ankle 1988; 5: 264-270.

2 Kalen V, Brecher A. Relationship between adolescent bunions and flatfeet. Foot Ankle 1988; 6: 331-336.

3 Mann RA, Coughlin MJ. Hallux valgus - Etiology, anatomy, treatment and surgical considerations. Clin Orthop 1981; 157: 31-41.

4 Scranton PE, Rutkowski R. Anatomic variations in the first ray: Part I. Anatomic aspects related to bunion surgery. Clin Orthop 1980; 151: 244-255.

5 Barnicot NA, Hardy RH. The position of the hallux in West Africans. J Anatomy 1955; 89: 355-361.

6 Heylings DJA. Hallux valgus and abductor hallucis; personal thoughts on their connection. Chiropodist 1990; August: 162-164.

7 Kato T, Watanabe S. The etiology of hallux valgus in Japan. Clin Orthop 1981; 157: 78-81.

8 Sim-Fook L, Hodgson AR. A comparison of foot forms among the non-shoe and shoe-wearing Chinese population. J Bone Joint Surg 1958; 40A: 1058-1062.

9 Snijders CJ, Snijder JG, Philippens MM. Biomechanics of hallux valgus and spreadfoot. Foot Ankle 1986; 5 (6): 327-332.

10 Sanders AP, Snijders CJ, Stam HJ. A method for dynamic measuring with pressure or force platforms. J Rehabil Sciences 1993; 6: 114-123.

11 Sanders AP, Van Lith R, Snijders CJ, Mulder PGH. Morton's neuralgie: Een gerandomiseerde therapie-effectstudie bij de Podotherapie. Project nr. 89-47, CRO-208397 of the Ministry of Welfare, Public Health and Culture, The Netherlands, 1992.

Appendix

Reliability of measurements of radiographs

RADIOGRAPHY OF FOOT DEFORMITIES

Clinical investigation of foot deformities generally involves radiography of the feet. According to the literature, most radiographs are made in antero-posterior (AP) and/or lateral directions, with the foot in a loaded (weight-bearing)[1-5] or in an unloaded (non weight-bearing) situation.[1,3,4]

In medical practice, particularly for scientific studies in which intra- or inter-individual comparisons are made, radiographs produced with reproducible methods are desired. In addition, measurements of the radiographs should be made using standardized methods.

Venning and Hardy[4] reported 3 sources of errors from unintended variations: (1) errors arising in the marking and measuring of any given radiograph i.e., errors due to limitations of the investigator; (2) errors due to variations in the mutual relationships between the source of X-rays, the object and the film; and (3) errors arising from variations within the foot in an individual subject e.g., due to a change in weight distribution.

The following section discusses and comments on these errors in measurement.

1. First source of errors:

Venning and Hardy noted that errors due to linear measurements were very small, or absent. Errors in the measurement of angles were slightly greater, but generally not greater than SD = 1.5°. This was concluded after 2 observers made 4 measurements of the intermetatarsal$_{1\text{-}2}$ angle of 1 unloaded AP X-ray.[4]

Kilmartin et al. studied inter- and intra-observer measurement errors using 10 different radiographs.[2] They made measurements 3 times on the same day, and also once a day for 3 consecutive days. Measurements made by one observer on the same day showed the least variation. In the measurements made on consecutive days it was found that, with regard to the hallux angle and the intermetatarsal$_{1\text{-}2}$ angle, the difference between the observations on the first and second day was on average $\leq 0.85°$ (SD $\leq 1.0°$).[2]

2. Second source of errors:

Changes in mutual relationships between the source of X-rays, foot and the film can be a source of large errors in measurement.[4] Hence, this mutual orientation has to be controlled (with the help of a protocol).

The projection on the film is dependent on the direction of entry of the X-rays in the bones. A radiograph of 2 feet simultaneously (see Fig. App.1: center of the X-rays in the middle between both feet; "B") can result in a different AP projection than that in radiographs made of each foot separately (Fig. App.1: center of the X-rays on the base of the third metatarsal; "A").

Theoretically, the effect of a horizontal shift, in the frontal plane, of the X-ray tube on a specific parameter is greater if the 2 bones, that contribute to the parameter, differ with regard to their distance from the film cassette, i.e. in case of the angle between the approximately horizontal axis of the proximal phalanx of the hallux and the inclined axis of the first metatarsal (hallux angle), or the position of the lateral sesamoid in relation to the first metatarsal.

In order to estimate the effect of the above-mentioned horizontal shift of the X-ray tube on the direction by which the region of interest is X-rayed, the following calculation example is presented (see Fig. App.1):

- In the horizontal plane the distance between the 2 loci on which the beam is centered is approximately 6 cm (rough estimate);
- the distance between the X-ray tube and the film is normally 1 m.[4,6,7]

Geometrically a difference of 3.4° (in the frontal plane) between the directions by which the first ray is X-rayed can be calculated: $\tan \alpha = 0.03 \Rightarrow \alpha = 1.7°$ and $\beta = 2\alpha = 3.4°$

A numerical estimation of the effect of the (estimated) 3.4° difference on the values of specific radiographic parameters can be made after estimation of the possible inter-individual variation in bony structure; but this would be inaccurate and therefore unrealistic.

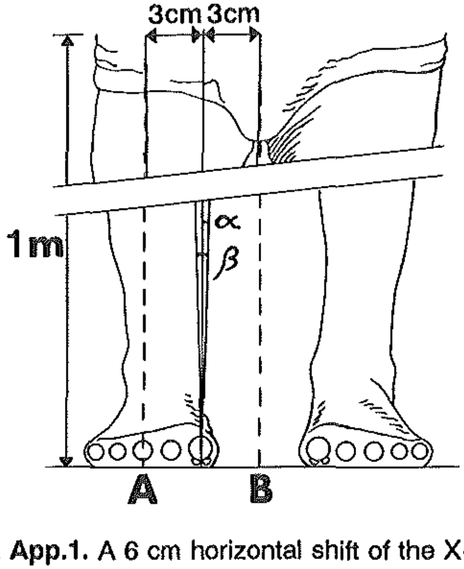

Fig. App.1. A 6 cm horizontal shift of the X-ray tube, which is centered at a distance of 1 m on the base of the third metatarsal (A) or in the middle between both feet (B), results in a change of the direction by which the first ray is X-rayed of 3.4° (angle $\beta = 2\alpha$) (see text).

Another unintended variation can be found if the beam is centered in different directions, in the sagittal plane (Fig. App.2). Theoretically, the effect on the value of a studied parameter is greater if an X-rayed bone, which contributes to the parameter, is more inclined in relation to the horizontally placed film cassette.

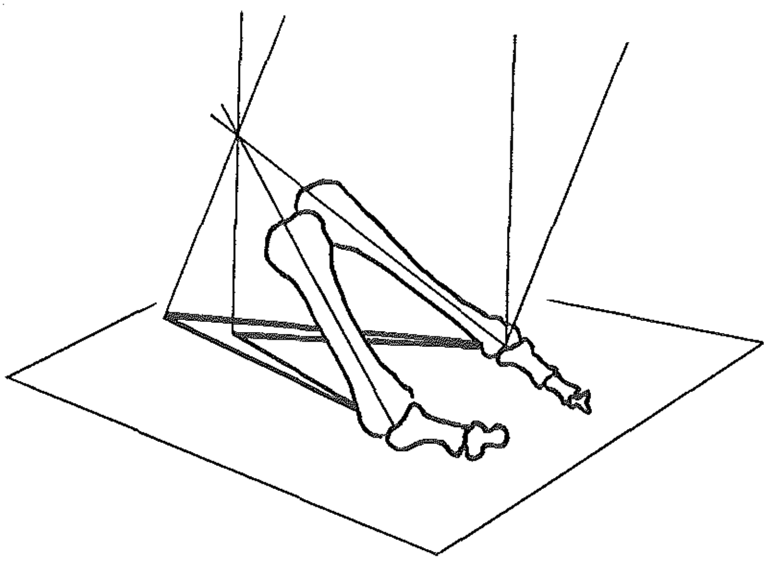

Fig. App.2. An illustration of the effects on the projections of 2 metatarsal bones in case of directions of the X-rays which are in the sagittal plane and perpendicular or inclined on the film. To elucidate the phenomenon the linear and angular dimensions of the 2 metatarsals are greatly exaggerated.

3. Third source of errors:

Internal deformation of the foot is encountered if an unloaded situation (sitting or recumbent posture) is changed into a loaded situation (standing posture), or due to pro- or supination movements of the foot. Shereff et al. studied the effect of weight-bearing on a series of parameters measured on AP radiographs. Different angles, such as metatarso-phalangeal and intermetatarsal angles appeared to change in an inconsistent way. Linear measurements, such as forefoot width and length of the metatarsals and phalanges, were more consistent. In most cases the forefoot width and the assessed lengths were increased in the loaded radiographs.[6]

In the literature, use of weight-bearing radiographs is generally preferred to non weight-bearing radiographs.[1-5,8] Radiographs taken of the weight-bearing foot demonstrate the foot skeleton in a more functional situation and may provide insight (hypothetically) into the relationship between the soft tissues, the bones and the joints under physiological loads.[8] Measurements on loaded radiographs may show more reproducible results than unloaded radiographs.

With the unloaded radiographs, an unintended variation may arise when the thigh and knee are deviated laterally and the shin is obliquely positioned. This effect has been reported by Venning and Hardy.[4] In this posture a patient can: (1) tilt over his foot as a whole, by which the medial aspect of the footsole comes off the film cassette (mainly a second category error); or (2) keep contact with the film cassette, as a result of a pronation of the forefoot (third category error) (Fig. App.3). In both instances, the changed position of the shin will influence the "AP" projection of the foot skeleton. Jahss observed a decreased inter-metatarsal$_{1\text{-}2}$ angle.[1] Thus, the position of the shin and the contact between the footsole and the film cassette should also be controlled.

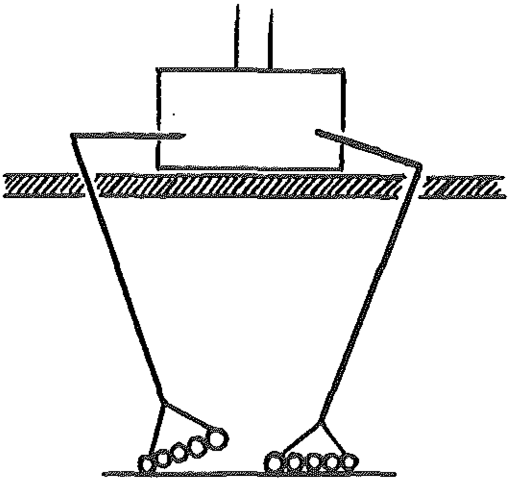

Fig. App.3. Model of a sitting subject during non weight-bearing radiography. The projections are influenced by the oblique positions of the shins. Right leg: the foot as a whole is tilted. Left leg: the footsole contact is retained by pronation of the forefoot.

RADIOGRAPHY IN THE PRESENT STUDY

This thesis describes research using AP radiographs of the feet. All the radiographs were examined by a single observer (APS). Two studies (Chapters II and III) have a prospective design, in which weight-bearing radiographs were used. The other studies (Chapters IV and V) are partly retrospective, therefore routinely produced radiographs were used. The patients who participated in the study were attending the Orthopedic Department of the University Hospital Rotterdam, Dijkzigt. In this department, a non weight-bearing radiograph is requested if an AP radiograph is indicated (Figs. App.4 and 5). For specific questions the unloaded radiograph will be replaced by a weight-bearing radiograph. The protocol used by the Department of Diagnostic Radiology of Dijkzigt for a non weight-bearing AP radiograph of the foot has the following features:

Technique;	manual adjustment with 1 m distance between X-ray tube and film cassette;
Positioning;	patient is sitting or lying recumbent on the table with the knees flexed to approximately 90° and both feet resting flat on the film cassette;
Beam direction;	the X-ray source is tilted 15° and centered on the base of the third metatarsal;
Additional criteria;	the tarso-metatarsal, the talo-navicular and the calcaneo-cuboid joints have to be reasonably "open".

The protocol for a weight-bearing radiograph deviates from the above-mentioned with regard to:

Positioning;	patient stands with both feet on the film cassette, with the weight distributed as evenly as possible over both feet.

The question remains as to what extent measurement errors are involved in the assessment of radiographic parameters. This concerns: (1) unknown (occasional) deviations of the protocol; (2) a limited reproducibility of the used radiographic method or (3) the measurements of the radiographs (all performed by a single observer).

An estimation of the extent to which different radiographs correspond with regard to the direction of the X-rays on the bones of the foot was made (subjectively) by the author. During the measurements, the radiographs were compared to each other with regard to the mutual orientation of different bones, the extent to which a number of joints could be booked "open", and the measure of overprojection of the bones of the foot. Only in 2 radiographs was deviation of the direction of the X-ray beam obvious and these 2 radiographs were excluded from the measurements.

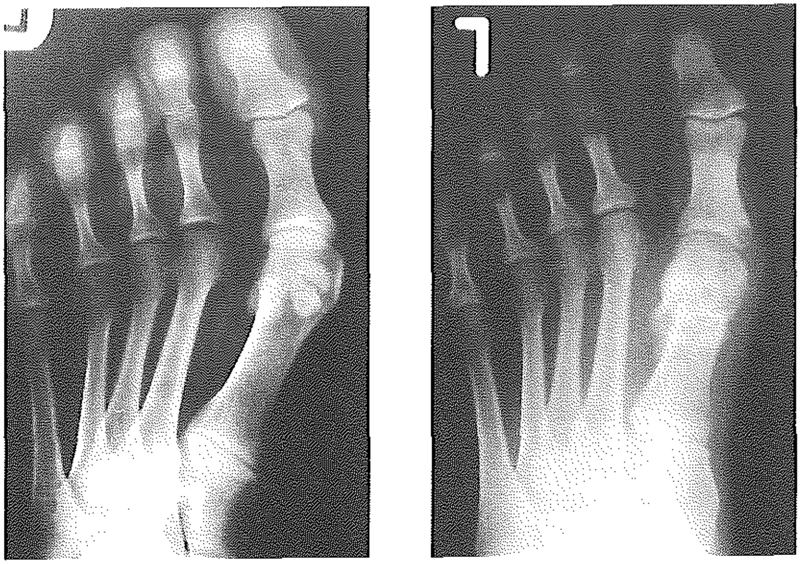

Fig. App.4. Examples of non weight-bearing AP radiographs made before (left) and after a modified Hohmann osteotomy (right).

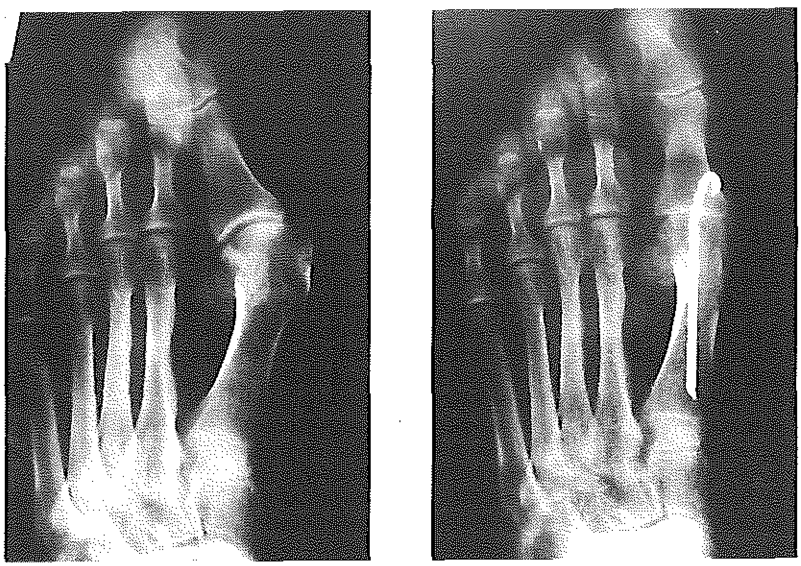

Fig. App.5. Examples of non weight-bearing AP radiographs made before (left) and after arthrodesis of MTP_1 (right).

In order to estimate the reproducibility of the X-rays quantitatively, the pre- and postoperative unloaded AP X-rays of 5 patients who underwent a modified Hohmann osteotomy and 5 patients with an arthrodesis, were re-investigated. On these X-rays the inter-metatarsal$_{2\text{-}4}$ angle (IMTA$_{2\text{-}4}$) was measured. This is the angle between the axes of the second and fourth metatarsals. In the literature, no evidence was found that the IMTA$_{2\text{-}4}$ is influenced significantly by increasing age, a Hohmann osteotomy, or an arthrodesis of MTP$_1$. Therefore, the measurement values of the IMTA$_{2\text{-}4}$ are used to estimate reproducibility of the measurements of the X-rays. The mean pre- and postoperative IMTA$_{2\text{-}4}$ of the 10 patients are 7.3° and 6.8°, respectively, and correlate significantly ($r=0.86$, $P=0.007$). The reproducibility is assessed by calculating the 95% limits of agreement as follows.[9] The mean difference (pre- minus postoperative IMTA$_{2\text{-}4}$) is 0.5° and the SD of the differences is 1.35°. Of the differences, 95% are expected to lie between the mean difference ± 2 SD.[9] For the IMTA$_{2\text{-}4}$ data these limits of agreement are -2.2° and 3.2°. Despite the high correlation between the pre- and postoperative measurements ($r=0.86$), differences within an individual patient may be substantial from a clinical point of view. The assessed reproducibility may be the sum of several sources of variation: structure and position of the foot, radiographic and measurement techniques. To what extent each source of variation contributed to the total is not known.

Furthermore, in one of the 10 re-investigated patients, 6 X-rays of the right foot made over a 6-year period were available for investigation. On 5 X-rays the IMTA$_{2\text{-}4}$ was 6°, on 1 X-ray it was 7°.

For estimation of the reproducibility of the measurements of the radiographs used, the following observation may be valuable. In the studies presented in this thesis, several relationships with a number of radiographic parameters were established. If one states that the used radiographs have a limited reproducibility, then the level of significant correlations found represents a sort of lower limit, because in case of a greater reproducibility of the measurements the result (r_s) would have been greater.

CONCLUSIONS

When routinely performed radiographs are used, a degree of uncertainty will exist concerning the reproducibility of the produced projections. During the studies described in this thesis the reproducibility was not controlled completely. Nevertheless, the reproducibility appears to be of a sufficiently high level to demonstrate a number of relationships with different radiographic parameters.

REFERENCES

1 Jahss MH, Troy AI, Kummer F. Roentgenographic and mathematical analysis of first metatarsal osteotomies for metatarsus primus varus: a comparative study. Foot Ankle 1985; 5; 280-321.

2 Kilmartin TE, Barrington RL, Wallace WA. The X-ray measurement of hallux valgus: an inter- and intra-observer error study. The Foot 1992; 2: 7-11.

3 Romash MM, Fugate D, Yanklowit B. Passive motion of the first metatarsal cuneiform joint: preoperative assessment. Foot Ankle 1990; 6: 293-298.

4 Venning P, Hardy RH. Sources of error in the production and measurement of standard radiographs of the foot. Br J Radiol 1951; 24: 18-26.

5 Mann RA. The great toe. Orthop Clin North Amer 1989; 20: 519-533.

6 Shereff MJ, DiGiovanni L, Bejjani FJ, Hersh A, Kummer FJ. A comparison of nonweight-bearing and weight-bearing radiographs of the foot. Foot Ankle 1990; 10: 306-311.

7 Smith RW, Reynolds JC, Stewart MJ. Hallux valgus assesment: Report of research committee of American Orthopaedic Foot and Ankle Society. Foot Ankle 1984; 2: 92-103.

8 Shereff MJ. Radiographic analysis of the foot and ankle. In: Jahss MH, editor. Disorders of the foot and ankle. Philadelphia, London, Toronto, Mexico City, Rio de Janeiro, Sydney, Tokyo, W.B. Saunders Company, 1991: 91-108.

9 Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986; Feb 8: 307-310.

List of references

REFERENCES

Barnicot NA, Hardy RH. The position of the hallux in West Africans. J Anatomy 1955; 89: 355-361.

Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986; Feb 8: 307-310.

Bonney G, Macnab I. Hallux valgus and hallux rigidus. A critical survey of operative results. J Bone Joint Surg 1952; 34B: 366-385.

Camper P. Dissertation on the best form of shoe. Clin Orthop 1975; 110: 2-5.

Carl A, Ross S, Evanski P, Waugh T. Hypermobility in hallux valgus. Foot Ankle 1988; 5: 264-270.

Cavanagh PR, Ulbrecht JS. Biomechanics of the diabetic foot: A quantitative approach to the assessment of neuropathy, deformity, and plantar pressure. In: Jahss MH, editor. Disorders of the foot and ankle. Philadelphia, London, Toronto, Mexico City, Rio de Janeiro, Sydney, Tokyo, W.B. Saunders Company, 1991: 1884-1890.

Coates IS. Silicone orthodigita and shielding. Supplement in: J Amer Podiatr Assoc 1976; 66.

Coughlin MJ, Mann RA. Arthrodesis of the first metatarsophalangeal joint as salvage for the failed Keller procedure. J Bone Joint Surg 1987; 69A: 68-75.

Debrunner HU. Ätiologie und Pathogenese des Hallux valgus. In: Blauth W, editor. Der Hallux valgus. Berlin, Heidelberg, New York, Tokyo, Springer-Verlag, 1986: 38-43.

Edgar MA. Hallux valgus and associated conditions. In: Klenerman L, editor. The foot and its disorders, Oxford, London, Edinburgh, Melbourne, Blackwell Scientific Publications, 1976: 83-129.

Feldkamp M. Der Hallux valgus bei Zerebralparese. In: Blauth W, editor. Der Hallux valgus. Berlin, Heidelberg, New York, Tokyo, Springer-Verlag, 1986: 79-82.

Fitzgerald JAW. A review of long-term results of arthrodesis of the first metatarso-phalangeal joint. J Bone Joint Surg 1969; 51B: 488-493.

Fitzgerald JAW, Wilkinson JM. Arthrodesis of the metatarsophalangeal joint of the great toe. Clin Orthop 1981; 157: 70-77.

Foot and Footwear Foundation. [Stichting Voet en Schoeisel] Bejaardenenquête. Waalwijk, The Netherlands, 1978.

Forriol F, Pascual J. Footprint analysis between three and seventeen years of age. Foot Ankle 1990; 11: 101-104.

Goldner JL. Hallux valgus and flexus associated with cerebral palsy: Analysis and treatment. Clin Orthop 1981; 157: 98-104.

Grace DL, Hughes J, Klenerman L. A comparison of Wilson and Hohmann osteotomies in the treatment of hallux valgus. J Bone Joint Surg 1988; 70B: 236-241.

Gregory JI, Childers JL, Higgins KR, Krych SM, Harkless LB. Arthrodesis of the first metatarsophalangeal joint: a review of the literature and long-term retrospective analysis. J Foot Surg 1990; 29: 369-374.

Grieve DW, Rashdi T. Pressures under normal feet in standing and walking as measured by foil pedobarography. Ann Rheumatic Diseases 1984; 43: 816-818.

Haeff PAJ van. De operatieve behandeling van de hallux valgus. Thesis, Nijmegen, The Netherlands, 1958.

Harrison MHM, Harvey FJ. Arthrodesis of the first metatarsophalangeal joint for hallux valgus and rigidus. J Bone Joint Surg 1963; 45A: 471-480.

Hattrup SJ, Johnson KA. Chevron osteotomy: analysis of factors in patients dissatisfaction. Foot Ankle 1985; 5: 327-332.

Helal B. Surgery for adolescent hallux valgus. Clin Orthop 1981; 157: 50-63.

Henry APJ, Waugh W. The use of footprints in assessing the results of operations for hallux valgus. A comparison of Keller's operation and arthrodesis. J Bone Joint Surg 1975; 57B: 478-481.

Herschel H, Meel PJ van. Metatarsalgie. Ned Tijdschr Geneeskd 1982; 45: 2056-2061.

Heylings DJA. Hallux valgus and abductor hallucis; personal thoughts on their connection. Chiropodist 1990; August: 162-164.

Hohmann G. Hallux valgus und Spreizfuß. In: Fuß und Bein; ihre Erkrankungen und deren Behandlung. München, Verlag von J.F. Bergmann, 1948: 156-158.

Hughes J, Kriss S, Klenerman L. A clinician's view of foot pressure: a comparison of three different methods of measurement. Foot Ankle 1987; 7: 277-284.

Hughes J, Clark P, Klenerman L. The importance of the toes in walking. J Bone Joint Surg 1990; 72B: 245-251.

Hung LK, Ho YF, Leung PC. Survey of foot deformities among 166 geriatric inpatients. Foot Ankle 1985; 5; 156-164.

Hutton WC, Dhanendran M. The mechanics of normal and hallux valgus feet - a quantitative study. Clin Orthop 1981; 157: 7-13.

Imhoff A, Baumgartner R, Blauth W, Büsch HG, Lamprecht E. Fehlschläge nach Hallux-valgus-Operationen und ihre Behandlung. In: Blauth W, editor. Der Hallux valgus. Berlin, Heidelberg, New York, Tokyo, Springer-Verlag, 1986: 105-117.

Ivory JP, Gregg PJ. The management of the painful first metatarsophalangeal joint in the older patient: a 5-year review. The Foot 1992; 2: 162-165.

Jahss MH. Disorders of the foot. Philadelphia, W.B. Saunders Company, 1982.

Jahss MH, Troy AI, Kummer F. Roentgenographic and mathematical analysis of first metatarsal osteotomies for metatarsus primus varus: a comparative study. Foot Ankle 1985; 5; 280-321.

Jahss MH. Disorders of the hallux and the first ray. In: Jahss MH, editor. Disorders of the foot and ankle. Philadelphia, London, Toronto, Mexico City, Rio de Janeiro, Sydney, Tokyo, W.B. Saunders Company, 1991: 943-1174.

Johnson KA. Bunion of the great toe. In: Surgery of the foot and ankle, New York, Raven Press, 1989: 1-34.

Kalen V, Brecher A. Relationship between adolescent bunions and flatfeet. Foot Ankle 1988; 6: 331-336.

Kato T, Watanabe S. The etiology of hallux valgus in Japan. Clin Orthop 1981; 157: 78-81.

Kelikian H. Introduction In: Hallux valgus, allied deformities of the forefoot and metatarsalgia. Philadelphia, London, W.B. Saunders Company, 1965: 1-5.

Kelikian H. Causal relations. In: Hallux valgus, allied deformities of the forefoot and metatarsalgia. Philadelphia, W.B. Saunders Co., 1965: 54-68.

Kelikian H. So-called conservative operations. In: Hallux valgus, allied deformities of the forefoot and metatarsalgia. Philadelphia, London, W.B. Saunders Company, 1965: 136-162.

Kelikian H. Osteotomy. In: Hallux valgus, allied deformities of the forefoot and metatarsalgia. Philadelphia, London, W.B. Saunders Company, 1965: 166-170.

Kelikian H. Arthrodesing operations. In: Hallux valgus, allied deformities of the forefoot and metatarsalgia. Philadelphia, London, W.B. Saunders Company, 1965: 236-248.

Kilmartin TE, Barrington RL, Wallace WA. The X-ray measurement of hallux valgus: an inter- and intra-observer error study. The Foot 1992; 2: 7-11.

Lake NC. The foot. London, Baillière, Tindall and Cox, 1943.

Linssen ACG, Spinhoven P. Pijnmeting in de klinische praktijk. Ned Tijdschr Geneeskd 1991; 135: 557-560.

Lipscomb PR. Arthrodesis of the first metatarsophalangeal joint for severe bunions and hallux rigidus. Clin Orthop 1979; 142: 48-54.

Lundberg BJ, Sulja T. Skeletal parameters in the hallux foot. Acta Orthop Scand 1972; 43: 576-582.

Luthje P. Long-term results of proximal metatarsal osteotomy in hallux valgus. J Amer Podiatr Med Assoc 1990; 80: 304-306.

Mann RA, Coughlin MJ. Hallux valgus - Etiology, anatomy, treatment and surgical considerations. Clin Orthop 1981; 157: 31-41.

Mann RA. The great toe. Orthop Clin North Amer 1989; 20: 519-533.

Mann RA, Poppen NK, O'Konski M. Amputation of the great toe. A clinical and biomechanical study. Clin Orthop 1988; 226: 192-205.

McBride ED. The McBride bunion hallux valgus operation. J Bone Joint Surg 1967; 49A: 1675-1683.

McRae R. Clinical orthopaedic examination. 3rd edn. Churchill Livingstone, Edinburgh, London, Melbourne, New York, 1990: 261.

Meier PJ, Kenzora JE. The risks and benefits of distal first metatarsal osteotomies. Foot Ankle 1985; 6: 7-17.

Merkel KD, Katoh Y, Johnson EW, Chao EYS. Mitchell osteotomy for hallux valgus: Long-term follow-up and gait analysis. Foot Ankle 1983; 3: 189-196.

Milgram JE. Office measures for relief of the painful foot. J Bone Joint Surg 1964; 46A: 1095-1116.

Moynihan FJ. Arthrodesis of the metatarso-phalangeal joint of the great toe. J Bone Joint Surg 1967: 49B: 544-551.

Myerson M. Metatarsocuneiform arthrodesis for treatment of hallux valgus and metatarsus primus varus. Orthopedics 1990; 13: 1025-1031.

O'Doherty DP, Lowrie IG, Magnussen PA, Gregg PJ. The management of the painful first metatarsophalangeal joint in the older patient. J Bone Joint Surg 1990; 72B: 839-842.

Piggott H. The natural history of hallux valgus in adolescence and early adult life. J Bone Joint Surg 1960; 42B: 749-760.

Raymakers R, Waugh W. The treatment of metatarsalgia with hallux valgus. J Bone Joint Surg 1971; 53B: 684-687.

Rijnberg WJ. Reconstructie van de tibiaschacht door een centrale spongiosaplastiek. Thesis, Rotterdam, The Netherlands, 1990.

Romash MM, Fugate D, Yanklowit B. Passive motion of the first metatarsal cuneiform joint: preoperative assessment. Foot Ankle 1990; 6: 293-298.

Rose GK, Welton EA, Marshall T. The diagnosis of flat foot in the child. J Bone Joint Surg 1985; 67B: 71-78.

Salis-Soglio G von, Thomas W. Arthrodesis of the metatarsophalangeal joint of the great toe. Arch Orthop Traumat Surg 1979; 95: 7-12.

Sanders AP, Van Lith R, Snijders CJ, Mulder PGH. Morton's neuralgie: Een gerandomiseerde therapie-effectstudie bij de Podotherapie. Project nr. 89-47, CRO-208397 of the Ministry of Welfare, Public Health and Culture, The Netherlands, 1992.

Sanders AP, Snijders CJ, Van Linge B. Biomechanical analysis of the effects of osteotomy and arthrodesis for hallux valgus and metatarsus primus varus. Presented at the Symposium on Problems of the First Ray; held at the Royal Society of Medicine, London, May 9th, 1992.

Sanders AP, Snijders CJ, Van Linge B. Medial deviation of the first metatarsal head as a result of flexion forces in hallux valgus. Foot Ankle 1992; 13: 515-522.

Sanders AP, Snijders CJ, Stam HJ. A method for dynamic measuring with pressure or force platforms. J Rehabil Sciences 1993; 6: 114-123.

Sanders AP, Snijders CJ, V. Linge B. Potential for recurrence of hallux valgus after a modified Hohmann osteotomy: A biomechanical analysis. Foot Ankle Int 1995; 16: 351-356.

Scranton PE. Metatarsalgia: diagnosis and treatment. J Bone Joint Surg 1980; 62A: 723-732.

Scranton PE, Rutkowski R. Anatomic variations in the first ray: Part I. Anatomic aspects related to bunion surgery. Clin Orthop 1980; 151: 244-255.

Shereff MJ, DiGiovanni L, Bejjani FJ, Hersh A, Kummer FJ. A comparison of nonweight-bearing and weight-bearing radiographs of the foot. Foot Ankle 1990; 10: 306-311.

Shereff MJ. Radiographic analysis of the foot and ankle. In: Jahss MH, editor. Disorders of the foot and ankle. Philadelphia, London, Toronto, Mexico City, Rio de Janeiro, Sydney, Tokyo, W.B. Saunders Company, 1991: 91-108.

Silvino N, Evanski PM, Waugh TR. The Harris and Beath footprinting mat: Diagnostic validity and clinical use. Clin Orthop 1980; 151: 265-269.

Sim-Fook L, Hodgson AR. A comparison of foot forms among the non-shoe and shoe-wearing Chinese population. J Bone Joint Surg 1958; 40A: 1058-1062.

Smith RW, Reynolds JC, Stewart MJ. Hallux valgus assesment: Report of research committee of American Orthopaedic Foot and Ankle Society. Foot Ankle 1984; 2: 92-103.

Snijders CJ. Statica. In: Frankel VH, Nordin M, Snijders CJ, editors. Biomechanica van het skeletsysteem. Lochem, Gent, Uitgeversmij. De tijdstroom, ISBN 90-6087-526-5, 1984: 389-404.

Snijders CJ, Snijder JGN, Philippens MM. Biomechanics of hallux valgus and spreadfoot. Foot Ankle 1986; 5: 327-332.

Stewart JDM. Traction and orthopaedic appliances. Edinburgh, London, New York, Churchill Livingstone, 1975.

Stokes IAF, Hutton WC, Evans MJ. The effects of hallux valgus and Keller's operation on the load-bearing function of the foot during walking. Acta Orthop Belg 1975; 41: 695-704.

Stokes IAF, Hutton WC, Stott JRR, Lowe LW. Forces under the hallux valgus foot before and after surgery. Clin Orthop 1979; 142: 64-72.

Swanson AB, Lumsden RM, De Groot Swanson G. Silicone implant arthroplasty of the great toe. Clin Orthop 1979; 142: 30-43.

Turnbull T, Grange W. A comparison of Keller's arthroplasty and distal metatarsal osteotomy in the treatment of adult hallux valgus. J Bone Joint Surg 1986; 68B: 132-137.

Venning P, Hardy RH. Sources of error in the production and measurement of standard radiographs of the foot. Br J Radiol 1951; 24: 18-26.

Vlatis G, Kitsos CP. Modelling weight-bearing patterns through anatomical parameters in feet with hallux valgus. (Abstract of scientific paper) J Bone Joint Surg 1989; 71B: 888.

World Health Organization. International Classification of Impairments, Disabilities, and Handicaps. A manual of classification relating to the consequences of disease. (Published for trial purposes in accordance with resolution WHA29.35 of the Twenty-ninth World Health Assembly) May 1976. Geneva, WHO, 1980.

Yale I. Podiatric medicine. Baltimore, The Williams & Wilkins Company, 1974: 244-246.

CURRICULUM VITAE

In 1974, twelve fundamental years after my birth on 20 June in Amsterdam, I started high school (Atheneum-B) at the "Waterlant College". In my youth, I studied the human locomotory system in different sports and from 1980-1982 at "Jan van Essen", Academy for Physiotherapy in Amsterdam.

In 1990, I passed my final medical exams at the University of Amsterdam. However, before this time I had already carried out some research work at the Erasmus University Rotterdam. My first project was a randomised clinical effect study. From 1998 this was supported by grants from the Ministry of Welfare, Public Health and Culture. I also commenced employment as a Scientific Researcher at the department of Biomedical Physics and Technology at the Erasmus University Rotterdam where I prepared the present thesis. Various study projects were also organised in co-operation with the Department of Podiatry of the "Hogeschool Eindhoven", the institute for Leather and Footwear of "TNO" and the Departments of Orthopaedic Surgery, Physical Medicine and Rehabilitation, Radiodiagnostics, Neurology and Neurophysiology of the University Hospital Rotterdam, "Dijkzigt". The results were presented at national and international congresses.

Between times, I taught basic medical sciences, worked as a medical journalist and also created video productions.

I also undertook various administrative duties as a committee member of the Department of Biomedical Physics and Technology, the Foot and Footwear Foundation, the Foundation for Examination of Chiropodists "SEPVO" (Chairman) and the attending commission of the Department of Podiatry of the "Hogeschool Eindhoven" (Chairman).

In July 1993, I started as Resident at the University Hospital Maastricht in the Rehabilitation Department.

In January 1994 I commenced my training for the position of Doctor in Physical Medicine and Rehabilitation. This involves attending the rehabilitation centers "Groot Klimmendaal" in Arnhem and "Het Roessingh" in Enschede, as well as two hospitals in Zwolle namely, "Stichting Sophia" and "De Weezenlanden".

CURRICULUM VITAE

Vanaf 1974, twaalf fundamentele jaren na mijn geboorte op 20 juni te Amsterdam, doorliep ik het Atheneum-B op het Waterlant College. In mijn jeugd bestudeerde ik het menselijk bewegingsapparaat in verschillende takken van sport en van 1980-1982 bij "Jan van Essen", Akademie voor Fysiotherapie te Amsterdam.

Hierna volgde de studie Geneeskunde aan de Universiteit van Amsterdam. Voordat ik in 1990 het basisartsexamen behaalde, had ik in het kader van het "vrijekeuze-onderwijs" en in de wachttijd voor de co-assistentschappen reeds een start gemaakt met wetenschappelijk onderzoek aan de Erasmus Universiteit Rotterdam.

Het eerste projekt dat ik opzette was een gerandomiseerd klinisch vergelijkend onderzoek dat vanaf 1989 door het ministerie van WVC werd ondersteund. Daarmee startte een aanstelling als wetenschappelijk onderzoeker op de afdeling Biomedische Natuurkunde en Technologie (BNT) van de Erasmus Universiteit Rotterdam, alwaar dit proefschrift werd bewerkt. In samenwerking met de Studierichting Podotherapie van de Hogeschool Eindhoven, het Instituut voor Leder en Schoeisel van TNO en de afdelingen Orthopedie, Revalidatiegeneeskunde, Radiodiagnostiek, Neurologie en Neurofysiologie van het Academisch Ziekenhuis Rotterdam, Dijkzigt, werden verschillende onderzoeksprojekten georganiseerd. De opgedane kennis werd in binnen- en buitenland voorgedragen.

Tussentijds doceerde ik medische basisvakken, fungeerde als medisch journalist en creëerde videoprodukties. Via de vakgroep BNT, de Stichting Voet en Schoeisel, de Stichting Examens en Proeven voor het Voetverzorgingsbedrijf (voorzitter) en de begeleidingscommissie van de Studierichting Podotherapie van de Hogeschool Eindhoven (voorzitter) ontstonden aktiviteiten op het bestuurlijke vlak.

Vanaf juli 1993 deed ik in het Academisch Ziekenhuis Maastricht ervaring op als arts-assistent Revalidatie. De opleiding tot revalidatie-arts in het circuit van revalidatiecentra Groot Klimmendaal (Arnhem) en Het Roessingh (Enschede), alsmede de ziekenhuizen Stichting Sophia en De Weezenlanden (Zwolle), begon op 1 januari 1994: een nieuwe fase.

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