MORPHOLOGY OF THE FIRST METATARSAL HEAD AS A RISK FACTOR FOR HALLUX VALGUS INTERPHALANGEUS

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Declaration

I, Stephanus Johannes van Deventer declare that this Research Report is my own, unaided work. It is being submitted in the 'submissible format of a paper' for the Degree of Master of Medicine in the branch of Orthopaedic Surgery at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

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Abstract

Introduction:

Hallux valgus interphalangeus (HVI) has a poorly understood aetiology. First metatarsophalangeal joint stability, influenced by first metatarsal head shape, may be linked to HVI. We hypothesised that first metatarsal head shape is a risk factor for HVI. No published article could be found in the literature investigating this hypothesis.

Methods:

127 standardised foot radiographs were analysed retrospectively. The hallux valgus angle (HVA) and interphalangeus angle (IPA) were measured. The first metatarsal head shape was divided into chevron, round and flat groups. Statistical analysis was then performed to investigate the relationship between first metatarsal head shape and the occurrence of HVI.

Results: There was no statistically significant relationship between first metatarsal head shape and the occurrence of HVI. There was however a negative relationship between HVA and HVI.

Conclusion:

The morphology of the first metatarsal head does not seem to be a risk factor for HVI. A known negative relationship between HVA and IPA is reinforced.

Acknowledgements

Thanks to my lovely wife for all her support while producing this article.

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RESEARCH REPORT

1. Introduction

Hallux valgus (HV) is a common foot deformity [1]. Multiple studies have reported a multifactorial and complex aetiology. One risk factor is a round first metatarsal head [2]. There are three described shapes of the first metatarsal head articular surface: round, flat and chevron shaped [3]. These shapes are illustrated below in Figure 1. There is however no definition or clear description distinguishing between these three shapes.

Fig. 1 Anteroposterior radiographs showing different first metatarsal head shapes

(A- Round B- Flat C-Chevron)

1.1 Literature review

Sagittal as well as transverse plane motion occurs at the first metatarsophalangeal joint (MPJ) [4]. A round head is most common and more prone to subluxation of the first MPJ in the transverse plane, possibly due to its inherent instability [3, 5, 6]. The more stable flat or chevron-shaped head tends to resist subluxation [3, 7, 8]. There have been numerous reports regarding the incidence of HV and metatarsal head shape.

Hallux valgus interphalangeus (HVI) is defined as an abnormal valgus angulation between the longitudinal bisections of the proximal and distal phalanges of the hallux, which is normally less than ten degrees [9]. HVI is a common deformity and is important to consider in the management of HV [10]. However, not much has been written about the aetiology of HVI. Known associations include shoe wear, congenital or traumatic deformity of the proximal phalanx, lateral physeal arrest due to enchondroma and congenital chromosomal abnormalities [8, 11-14].

The pathophysiology of HVI is poorly understood although a few theories exist [9]. One theory suggests that constant medial sided shoe pressure may result in hypoplasia of the lateral part of the interphalangeal joint (IPJ). This leads to relative lengthening of the medial epiphyses with subsequent valgus angulation at the IPJ. Eccentric pull of the flexor hallucis longus tendon on the distal phalanx has been proposed as a possible contributor to HVI development [10].

Increased transverse plane stability of the first MPJ may be a risk factor for HVI [9, 15]. The proposed hypothesis is that if the first MPJ is stable, then lateralising forces to the hallux will encounter greater resistance at the MPJ. This force will be transferred distally, resulting in progressive valgus IPJ deviation with a subsequent increase in IPA. However, with an unstable MPJ these forces will produce the valgus deviation in the MPJ leading to HV instead. This is illustrated in figure 2 on page 3.

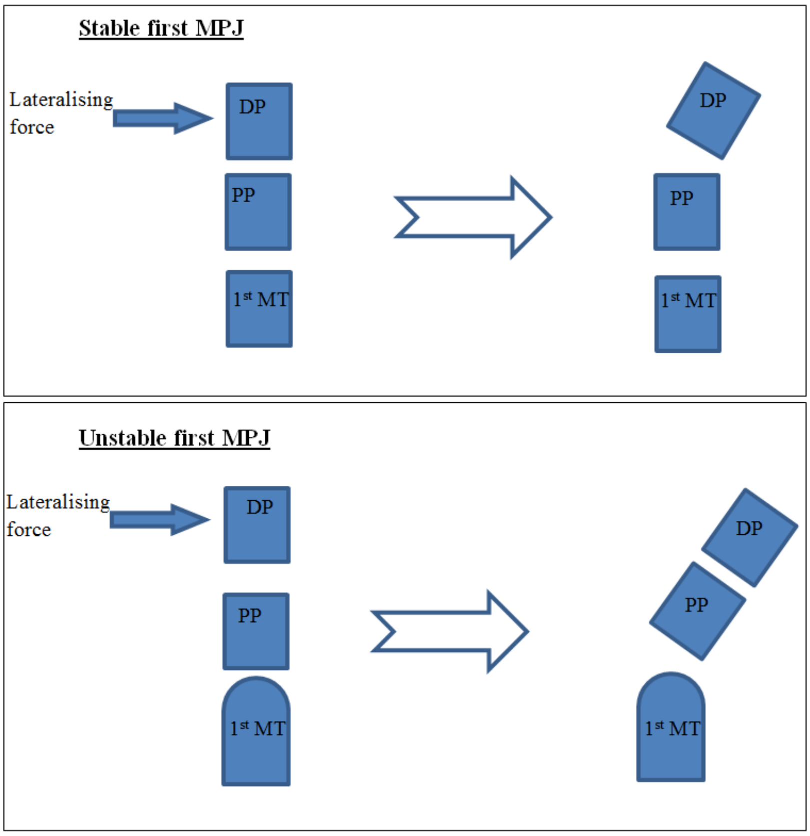

Fig. 2 First metatarsophalangeal joint (MPJ) stability as a risk factor for HVI.

(MT= metatarsal, PP = proximal phalanx, DP = distal phalanx)

Transverse plane instability of the first MPJ may be a buffer to the effect of lateralising forces on the lateral part of the distal phalanx epiphysis [9, 15]. This is supported by decreased incidence of HVI in cases of HV [16]. However the IPA does not decrease as the HVA increases; the HVA increases without a corresponding increase in IPA [10].

Conversely, increased transverse plane stability of the first MPJ may lead to increased pressure on the lateral part of the distal phalanx epiphysis [9]. This is supported by an increased incidence of HVI in association with a decreased HV angle.

1.2 Hypothesis

We hypothesised that a more stable first metatarsal head shape would result in an increased frequency of HVI.

1.3 Aims

The primary aim of this study was to radiographically assess the relationship between first metatarsal head shape and hallux valgus interphalangeus. The secondary aim was to radiographically assess the relationship between first metatarsal head shape and the frequency of hallux valgus interphalangeus in patients with and without hallux valgus.

2. Patients and methods

2.1 Patients

Radiographs of patients suffering from HV and without HV were studied retrospectively once approval was obtained from our institutional review board. One hundred and twenty seven weight bearing anteroposterior radiographs from 87 patients were used. Every radiograph was taken from January 2006 until December 2014 and encompassed patients with varying foot and ankle symptoms. Criteria for study inclusion were age above 18 years, weightbearing films and no previous foot surgery.

2.2 Methods

An international standard protocol for obtaining foot radiographs was followed [17, 18].

Each angular measurement was performed once, by the article author using a goniometer. The American Orthopaedic Foot and Ankle Society's measurement technique was used for determining the hallux valgus angle (HVA) [19]. Measurement of the interphalangeal angle (IPA) was performed using a technique utilising the mid-diaphyseal reference points for the long axis of the distal and proximal phalanx measured 5 mm from the articular surfaces and the tip of the distal phalanx [10].

Distinguishing between a round or flat first metatarsal head shape on a horizontal plane was achieved by determining the radius of the curvature (RC) of the first metatarsal articular surface [20]. The larger the radius of the curvature, the flatter the head shape is (illustrated in figure 3).

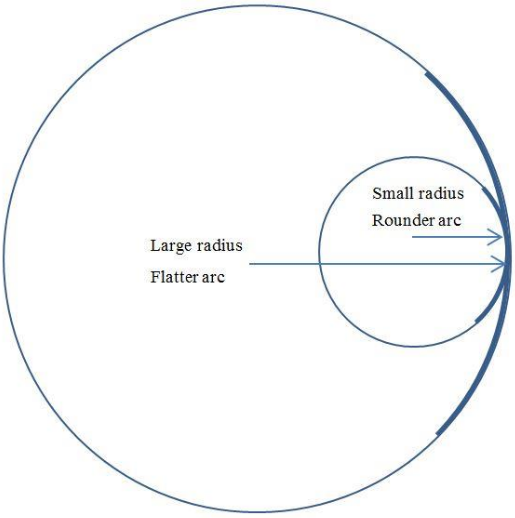

Fig. 3 Comparison of radii of an arc: Showing small radius with round arc and large radius with a flat arc

To determine the first metatarsal articular surface radius of the arc, all necessary distance measurements were performed once, manually by a single researcher using a digital calliper (made by GRIP tools, with a 0.01 mm resolution). Figure 4 shows reference points and lines used.

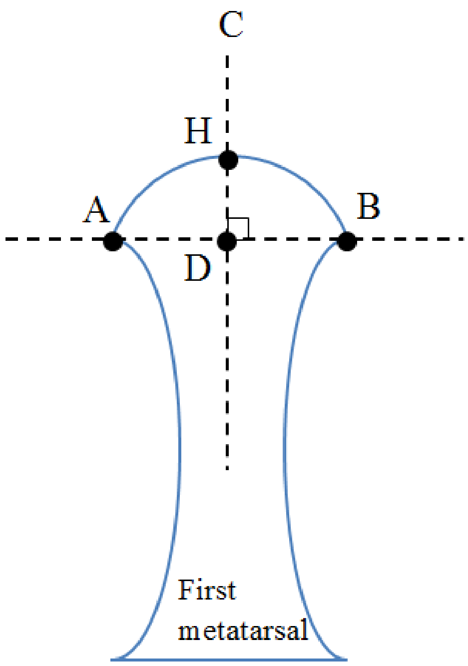

Fig. 4 Radius of curvature determination**.** Points A and B represent the medial and lateral extent of the effective articular surface of the first metatarsal head. Line AB is a line connecting points A and B. Point H is the highest point of the effective articular surface of the first metatarsal head from line AB. Line CD is a line perpendicular to line AB drawn from point H. Line AB represents the width of the curvature and line HD the height of the curvature. $\textbf{Radius of curvature} = \frac{\textbf{HD}}{\textbf{2}} + \frac{(\textbf{AB})^{\textbf{2}}}{\textbf{8HD}}$

A numerical identifier was assigned to each patient which ensured confidentiality. General demographics (age, race and sex), which foot was imaged (left or right), IPA, HVA, width and height measurements of the first metatarsal head were recorded. HV was defined as HVA ≥ 15° [3]. HVI was defined as an IPA > 10°. A chevron-shaped head was a subjective determinant.

The midpoint of the range for RC (14.3mm in our study group) was taken as the cut off value distinguishing between round and flat first metatarsal articular surfaces.

An RC $\geq$ 14.3 mm was classified as a flat first metatarsal articular surface, while an RC < 14.3 mm was categorised as a round first metatarsal articular surface.

2.3 Conclusion

Standardised foot radiographs obtained according to international standard protocol from a single centre were used. Using the radius of the arc of the first metatarsal head provides the first objective distinction between a round and a flat shaped first metatarsal head.

3. Statistical methodology

The variables utilised included the following:

I. Patient age
II. Sex of the patient
III. The race of the patient
IV. Side (left or right foot imaged)
V. HV angle (HVA)
VI. Presence/absence of HV
VII. Interphalangeal angle (IPA)
VIII. Presence or absence of HVI
IX. Radius of curvature (RC), calculated from:
    i. Length of base of arc (W)
    ii. Height of base of arc (H)
X. First metatarsal morphology:
    a. Chevron / Round / Flat

Logistic regression was used to investigate the relationship between first metatarsal head shape and the presence/absence of HVI (with HVI as the dependent variable and morphology as the independent variable). This required a sample size of 30 according to Peduzzi's rule of thumb [21].

Regression analysis was used to assess the relationship between the first metatarsal head RC and IPA (with IPA as the dependent variable and RC or chevron shape as the independent variables). This required a sample size of 77 for detecting a medium effect size (should it exist, with 80% power, at the 5% significance level). This was calculated using G*Power [22].

The effect of HV and the HVA on above mentioned relationships was determined by adding these variables (in turn) as well as their interaction term with morphology to the regression models defined above.

Data analysis was carried out using SAS. The 5% significance level was used throughout.

4. Source of funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

5. Results

Mean patient age was 55.3 years (SD=14.7y; range 20-80 y) with 73 (83.9%) being female. Eighty-one (93.2%) patients were Caucasian, 5 (5.7%) African and 1 (1.1%) Asian. Sixty-four (50.4%) of the X-rays were of the right foot.

Eighty-seven (68.5%) of the feet had HV and 72 (56.7%) had HVI with a median IPA of 12° (Interquartile range (IQR) 6-15°; range 0-28°).

Forty-one heads (32.3%) were flat, 77 (60.6%) were round and 9 (7.1%) were chevron shaped. The median RC was 12.8 mm (IQR 11.2-15.1mm; range 7.3-21.4mm).

No statistically significant relationship was found between first metatarsal head shape and the presence or absence of HVI. For chevron versus round head shape the odds ratio (OR) for HVI was 1.85 (95% CI: 0.43-7.94), while for flat versus round head shape the OR was 1.60 (95% CI: 0.74-3.49).

There was also no statistically significant relationship between HVI status and first metatarsal head shapes when controlling for the HVA, or the presence of HV. HVA and presence of HV were controlled for in order to unmask possible hidden associations between morphologies and HVI.

The effect of HVA on HVI status was however statistically significant; for a given morphology, the odds of HVI decreased by an estimated 6% for each 1° increase in HVA.

No statistically significant relationship between IPA and chevron/ non-chevron (round and flat) groups was found ($p=0.081$). When controlling for the presence of HV or HVA there was still no significant relationship between IPA and chevron and non-chevron groups ($p=0.24$ and 0.34 respectively).

HV status and HVA had a marginally significant ($p=0.057$) and significant ($p<0.0001$) effect on IPA respectively. Within a given morphology, patients with HV had an IPA on average 2.3° lower than those without HV. IPA decreased by an estimated 0.2° for each 1° increase in HVA.

No significant relationship between IPA and RC was found either ($p=0.088$). Controlling for HV status or HVA confirmed this finding ($p=0.23$ and 0.80). When morphology was treated as a continuous variable within the non-chevron group the effect of the HVA on the IPA was significant ($p=0.0001$); at a given RC, the IPA decreased by an estimated 0.2° for each 1°

increase in HVA. This is the same relationship we saw in the chevron and non-chevron group, but here morphology was treated as a continuous variable within the non-chevron group.

6. Discussion

Transverse plane stability of the first metatarsophalangeal joint may be related to the shape of the first metatarsal head shape. We hypothesized that this stability continuum may affect the prevalence of HVI. This has been found with round metatarsal head shape correlating with an increased incidence of HV [3, 5, 6].

The relationship between the three described shapes (chevron, round and flat) and the frequency of HVI was investigated in this study and no significant relationship was found. When controlling for HV there was still no significant relationship between first metatarsal head shape and IPA or HVI.

The effect of the HVA on the IPA was significant (p=0.0001) with each 1° increase in HVA the IPA decreased by an estimated 0.2°. This does not mean that as the HVA increases the IPA becomes normal. This study exhibits a negative relationship of IPA to HVA which reinforces similar findings of other studies [10, 23-25]. Our hypothesis that a stable first MPJ is more prone to HVI is supported by this finding. However first MPJ stability is not only dependent on first metatarsal head shape, but on muscles, ligaments, joint capsule and sesamoids [8, 26].

6.1 Metatarsal head shapes

This is the only study in which round and flat first metatarsal head shapes were objectively defined. As well as being the first study investigating first metatarsal head shape in Africa.

The study population was 83.9 % female with 93.2% being Caucasian. This is however not of concern as sex and race is not related to first metatarsal head shape according to a 2006 study looking at 478 first metatarsal bones [27].

Round heads were most common (60.6%) and chevron the least common (7.1%), which is in keeping with literature [3, 8, 27]. The percentage of chevron morphologies is lower than a reported 25% [27]. This could indicate a local demographic difference or more asymptomatic individuals with chevron morphology.

Validation of morphological typing of the first metatarsal head using the RC will have to be investigated, along with establishment of reference values before its use can be advocated.

6.2 Measurement difficulties

Accurate measurement of the small linear distances required for calculating the RC as well as the small IPA is challenging. This is a possible source of inaccuracy in this study and a shortcoming of this technique for distinguishing between round and flat metatarsal head shapes. Measurement reliability of linear distances and IPA can be improved by utilising computer software [28, 29]. However ,a standard deviation of 0.5 mm when measuring short distances has been reported [30]. This standard deviation, although small, would have a large effect on the RC.

Computer-assisted and manual goniometer measurements of HVA have been compared. And no significant differences between interobserver and intraobserver reliability using either technique were found [28, 31].

Weightbearing computed tomography is a promising imaging modality that eliminates radiographic imaging errors such as magnification and beam orientation [32].

In conclusion, HVI is a common deformity with a largely unknown aetiology. First metatarsal head shape was investigated as a risk factor for HVI. A novel technique for objectively determining the first metatarsal head shape utilising the RC was used.

An association between first metatarsal head shape and HVI could not be found and therefore: first metatarsal head shape alone was not a risk factor for HVI.

The Hallux metatarsal-phalangeal joint stability is dependent on multiple factors, which may need to be investigated to elucidate the role instability plays in the development of HVI.

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APPENDIX A: RESEARCH PROTOCOL

Post Graduate Research Protocol: MMED Orthopaedic Surgery

TITLE: Morphology of the first metatarsal head as a risk factor for hallux valgus interphalangeus

COURSE: Master of Medicine: Orthopaedic Surgery

COURSE CODE: MC000

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Contents

Literature Review

1.1 Hallux Valgus

Hallux valgus (HV) is possibly the most common of all foot deformities.[1] The term HV was introduced by Carl Hueter to define a subluxation of the first metatarsophalangeal joint characterized by lateral deviation of the great toe and medial deviation of the first metatarsal.[8]

In the nineteenth century, hallux valgus was thought to be due to an enlargement of the metatarsophalangeal joint of the great toe.[9] The most well-known association with hallux valgus is with shoe wearing. In the 1950s, Sim-Fook and Hodgson compared shod vs. un-shod feet and showed an increase in the prevalence of hallux valgus among the shoe-wearing group. [33] However many unshod feet have hallux valgus and many shoe wearing people have no hallux valgus.[34]

Multiple studies have investigated the aetiology of hallux valgus and found it to be multifactorial and complex.[2]

Generally accepted risk factors for hallux valgus include:

- Ill-fitting, narrow toe-box, high heel shoes [1, 2, 8]
- Genetics – hereditary / spontaneous mutations [1, 8]
- Advancing age [2]
- Foot deformities: pes planus [2], metatarsus primus varus
- Metatarsal morphology: [2]
    - long first metatarsal
    - round metatarsal head
- Foot biomechanics: dorsal hypermobility of the first ray [2], tight Achilles tendon [8]
- Female gender [2, 8]
- Any inflammatory arthritis including rheumatoid arthritis [1]

A systematic review of literature up to December 2010 showed that factors associated with the development of hallux valgus (HV) are multifactorial and remain unclear. [2]

Risk factors for HV were:

- Round first metatarsal head
- Greater first intermetatarsal angle
- Greater first metatarsal protrusion distance i.e. long first metatarsal (measured on dorsoplantar radiographs).
- Increased mobility at the first metatarsocuneiform (MTC) joint
- Inadequate footwear width.

1.1.1 Anatomy

The head of the first metatarsal is spherical and articulates with the concave base of the proximal phalanx. The specialized articulation of the first metatarsophalangeal joint of the great toe differs from that of the lesser toes in that it has a sesamoid mechanism. [8]

1.1.2 Pathoanatomy

The metatarsal heard is vulnerable to extrinsic forces as no muscles insert on it. These external forces cause the metatarsal to drift medially resulting in a prominent first metatarsal head. [8]

The metatarsal head is pushed in a medial direction by the lateral deviation of the proximal phalanx, thereby progressively exposing the sesamoids laterally. The proximal phalanx drifts laterally into valgus as it is tethered at its base to the sesamoids and is subjected to the deforming force of the adductor hallucis muscle.[8, 34]

1.1.3 Pathophysiology

The dynamics of the hallux valgus deformity can best be understood by first examining the articulation where the deformity occurs, that is, the MTP and MTC joints.

The tarsometatarsal articulation is quite stable in the central portion because of interlocking of the central metatarsals and cuneiforms. The first and fifth tarsometatarsal articulation may be less stable. [8]

There may be substantial variation in the shape of the distal articular surface of the first metatarsal. The three described shapes of the distal articular surface are round, flat and chevron shaped. [3] No definition or clear description distinguishing between these three distal articular surface shapes could be found during the literature review.

<u>Figure 1.1</u> Anteroposterior radiographs demonstrating varying shapes of the metatarsophalangeal (MTP) articular surface. A, Flat MTP joint surface. B and C Chevron shaped MTP articular surface. D,E and F rounded MTP articular surface with subluxation, reproduced from Coughlin MJ, Saltzman CL, Anderson RB. Mann's surgery of the foot and ankle. 2014

A rounded distal articular surface is most common, and is more prone to subluxation with the development of a progressive hallux valgus deformity, possibly due to its inherent instability. [5, 6] A flattened or chevron-shaped metatarsophalangeal articulation is more stable and tends to resist subluxation. [3, 7, 8] Coughlin and Jones noted this in 71% of patients in a large series of cases of hallux valgus they examined.[24] Okuda et al also observed an increased incidence of a rounded first metatarsal head associated with hallux valgus.[7] Heden and Sorto observed that a round first metatarsal head is common in hallux valgus (occurring in 90% of 100 affected subjects compared with 20% of 210 control subjects).[35]

1.2 Hallux Valgus Interphalangeus (HVI)

In 1935 Daw established the term hallux valgus interphalangeus (HVI), to describe an outward deflection of the great toe at the interphalangeal joint.[13] HVI can be defined as an abnormal valgus angulation between the longitudinal bisections of the proximal and distal phalanges of the big toe.[9] In some circumstances, alignment of the first MTP joint is normal but a valgus deformity is present due to HVI arising from a deformed proximal phalanx or interphalangeal joint. These deformities may be congenital or less commonly due to trauma resulting in malunited fractures of the first proximal phalanx. [8]

Not much has been written about the aetiology of HVI. Barnett and Wilkinson independently demonstrated HVI in human foetuses but not in any other primates.[36, 37] Barnett concluded that HVI was a distinctly human feature characteristic of bipedal gait.

Shoe wear may contribute to HVI due to medial aspect pressure on the big toe.[15] The mean HVI angle in an unshod population of New Guinea natives was 9.0 degrees which is significantly lower than that of a shod population. The mean HVI angle was determined to be 13.4 degrees in a series of 100 feet exhibiting no clinical or radiographic abnormalities among a shoe wearing population.[36]

HVI has been documented in certain congenital chromosomal abnormalities such as hand-foot-genital syndrome. [14]

The pathophysiology of HVI is poorly understood but a few theories exist. [9] One theory suggests that constant medial sided shoe pressure may result in hypoplasia of the lateral epiphysis of the base of the distal phalanx and distal epiphysis of the proximal phalanx. This leads to relative lengthening of the medial epiphyses with subsequent valgus angulation at the interphalangeal joint.

Decreased transverse plane mobility of the first metatarsophalangeal joint may be a risk factor for HVI. [9, 15] The proposed explanation for this is that if the first metatarsophalangeal joint is stable in the transverse plane, the lateral forces that tend to divert the hallux (e.g. shoe pressure, muscle action) will encounter greater resistance to lateral deviation in the metatarsophalangeal joint, resulting in interphalangeal joint involvement in the deviation, with an increase in IPA. If, however, the metatarsophalangeal joint is unstable in the transverse plane, these forces will be at a mechanical advantage to produce the deviation in this joint instead leading to hallux valgus.

Transverse plane instability of the first metatarsophalangeal joint may be a buffer to the effect of medial sided pressure on the distal phalanx lateral proximal epiphysis. This is supported by a decreased HVI in cases of increased HV. Conversely decreased transverse plane mobility of the first metatarsophalangeal joint may lead to increased pressure on the lateral proximal epiphysis of the distal phalanx. This is supported by an increase incidence of HVI in association with decreased HV angle. [9]

1.3 Radiographic measurement of HV and HVI angles

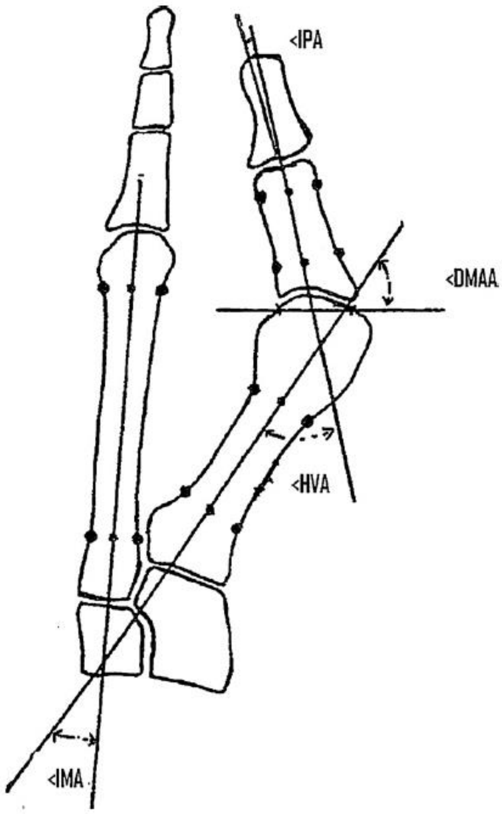
Radiographic angles are crucial in decision making for orthopaedic surgeons treating patient with hallux valgus. [17] Smith et al. described the various radiographic measurements used in hallux valgus.

These measurements help the surgeons in all aspects of management including:

- Classifying the deformity
- Follow the progression of deformity
- Operative decision making
- Assessing the results of surgical treatment

The commonly used angular measurements for hallux valgus in clinical practice are:

- Hallux valgus angle (HVA) – angle between first metatarsal axis and the hallux proximal phalanx axis.
- Intermetatarsal angle (IMA) – angle between first and second metatarsal axis.
- Interphalangeal angle (IPA) – angle between the halluceal proximal and distal phalanx axis.
- Distal metatarsal angle (DMAA) – angle between first metatarsal axis and distal articular surface of the first metatarsal.



<u>Figure 1.2</u>. Diagram showing the radiographic angles measured in hallux valgus, reproduced from Srivastava S, Chockalingam N, El Fakhri T. Radiographic measurements of hallux angles: a review of current techniques. Foot (Edinburgh, Scotland). 2010;20(1):27-31.

The focus of this study will be on the interphalangeal angle (IPA) and its relationship to the first metatarsal articular morphology.

These angles have traditionally been measured using a manual technique. There are many studies that have shown poor inter- and intraobserver reliability with manual measurements of radiographic angles especially measurements carried out after surgery. [17]
Such errors can be minimised in a clinical situation by using standardised technique of weight-bearing dorsoplantar radiographs and standardising the technique of angular measurements. Guidelines for standardised techniques have been published. [17]

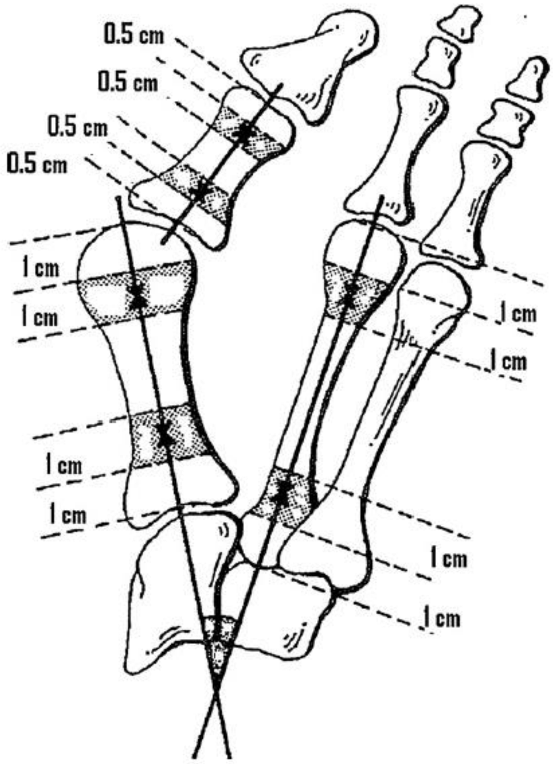
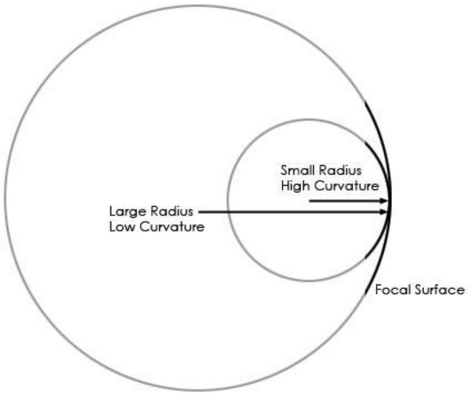


Figure 1.3. The location of reference points for first metatarsal, second metatarsal and proximal phalanx as described by Coughlin et al. modified from Srivastava S, Chockalingam N, El Fakhri T. Radiographic measurements of hallux angles: a review of current techniques. Foot (Edinburgh, Scotland). 2010;20(1):27-31.

1.4 Determining first metatarsal articular morphology

Variations in the shape of the first metatarsal head have been described in the literature and have been classified subjectively into three types: round, square and chevron (square with a central ridge). [34, 38] Unfortunately there is still no consistent or accurate method of describing metatarsal head shape or of taking into account the concept of traveling distance of the head. [39]

There is no standardised method to describe metatarsal head shape; however a method used by Brahm to distinguish between a round or flat first metatarsal articular surface on a horizontal plane is to determine the radius of the arc of the first metatarsal articular surface.[20]. The larger the radius of the arc, the flatter the articular surface is.



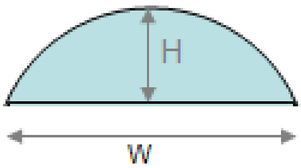
<u>Figure 1.4</u>. Comparison of Radii of Curvature showing small radius with high curvature vs large radius with low curvature, reproduced from South N. Radius of curvature 2009 [accessed 2016 January 31]. Available from: http://www.monolithic.org/blogs/engineering/radius-of-curvature. [40]

To determine the radius of the curvature the following formula is used when the width and height is known of a segment of the arc/circle. [41]

$$Radius = \frac{H}{2} + \frac{W^2}{8H}$$

Where:

W is the length of the base of the arc
H is the height measured at the midpoint of the arc's base



<u>Figure 1.5.</u> Diagram of an arc to show the base of the arc (W) and the height of the arc (H), reproduced from Math open reference. Radius of an arc or segment 2009 [accessed 2016 31 January]. Available from: http://www.mathopenref.com/arcradius.html

Determining whether the first metarsal articular surface is chevron shaped appears to be subjective. [42] No definition or objective measurement technique to determine that the first metatarsal distal articular surface is chevron shaped could be found during this review. Judging whether the first metatarsal distal articular surface is chevron shaped will therefore be done subjectively.

1.5 My Question

This study is an expansion of a study by Dr A Strydom which investigated the contribution of HVI to the total deformity present in HV. [10] In this study it was found that HVI contributed significantly to the total valgus deformity of the hallux (TVDH). The aetiology of HVI was found to be unclear.

First Metatarsal articular morphology has been associated with hallux valgus deformity but no association between first metatarsal articular morphology and hallux valgus interphalangeus (HVI) has been investigated in any literature.

In order to investigate this statement an online literature search was done using the following terms:

1) "hallux valgus" AND "hallux valgus interphalangeus" AND "hallux interphalangeus" AND "interphalangeus"

2) "hallux valgus" AND "metatarsal anatomy" AND "hallux valgus interphalangeus" AND "hallux interphalangeus" AND "interphalangeus"

3) "first metatarsal anatomy" AND "hallux valgus"

Across PubMed, Medline on Medscape and Google scholar search engines.

The reference lists of each article were manually searched for articles on first metatarsal anatomy, hallux valgus and interphalangeal valgus which may relate to the search criteria.

Summary of search results:

No study dedicated to the first metatarsal articular morphology and hallux valgus interphalangeus was identified. A round first metatarsal articular morphology is associated with the development of HV. [3, 7, 8]

It is the belief of some researchers that the HVI deformity in isolation or in conjunction with HV is rare. [3, 43] However in a study conducted in Korea, HVI was present in 20% of patients with HV compared to 82% in patients without HV. [16]

In a study conducted in Johannesburg (the only local study of its kind on the epidemiology of HVI) [10] it was found that HVI is common, and appears to be more prevalent in feet without HV or with mild HV deformity. It was postulated that it may be the eccentric pull of FHL which causes HVI. Further study is needed to determine why HVI occurs.

A study done by Coughlin and Shurnas found that a flat or chevron-shaped first metatarsal articular morphology is associated with hallux rigidus. [25] HVI was also more common in patients with hallux rigidus.

The question then arises if the increased transverse plane stability at the first metatarsophalangeal joint conferred by a flat or chevron-shaped first metatarsal articular morphology predisposes patients to developing HVI. And does the decreased transverse plane stability at the first metatarsophalangeal joint conferred by a round first metatarsal articular morphology prevent patients from developing HVI.

The literature leads to the following questions:

1) Is there a relationship between HVI and first metatarsal articular morphology?

Research protocol

1. Study Objectives

Primary Objective

To radiographically assess the relationship between 1st metatarsal articular morphology and hallux valgus interphalangeus.

Secondary Objective

To radiographically assess the relationship between 1st metatarsal articular morphology and the frequency of hallux valgus interphalangeus in patients with and without hallux valgus

2. Hypothesis

There is a relationship between first metatarsal articular morphology and hallux valgus interphalangeus.

3. Study design

This study will be a retrospective study.

4. Materials and Methods

This study will utilize AP X-rays of the foot to perform a radiographic analysis of the first metatarsal articular morphology and the hallux interphalangeus angle.

The study population will comprise a minimum of 100 X-rays from an existing database of X-rays at Netcare Linksfield and department of Orthopaedic Surgery University of the Witwatersrand. These X-rays were performed between January 2010 and December 2014 for a variety of foot and ankle related complaints. This collection has been utilized in a previous study by Dr A Strydom. [10]

The X-rays included in the study were obtained according to the international standardised protocol of full weight-bearing AP views with the beam 1 meter from the cassette, directed 15 degrees cephalad and centered on the mid-foot.

These foot X-rays will be measured for hallux IPA, first metatarsal articular morphology and hallux valgus angles as described above. The data will also be sub-analyzed to determine any significant differences between the population groups.

The longitudinal axes of 3 foot bones will be determined as follows:

1. 1^{st} metatarsals – mid-points of diaphysis measured between 1-2cm from base and tip of the head are joined
2. Proximal phalanx of the hallux – mid-points of diaphysis measured between 0.5 -1.0cm from base and tip of the head are joined
3. Distal phalanx of the hallux – mid points of diaphysis measured 0.5cm from base and tip of the head are joined

The angles required for measurement are formed by the intersections of these 3 axes and are measured utilising a standard goniometer.

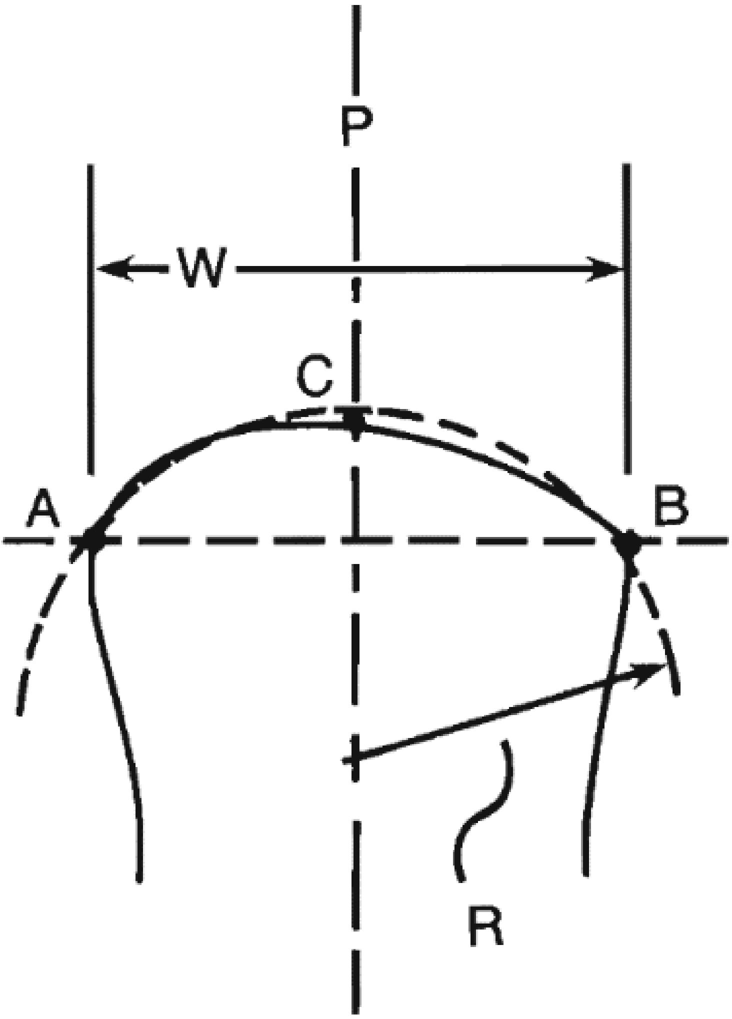
This technique for determining the long axes of the foot bones and thus the angular measurements is the technique advocated by the American Foot and Ankle Society and is 96.7% reproducible within a 5 degree range. All angular measurements will be made by the researcher in all foot x-rays.

The radius of curvature will be determined by plotting the points of effective articulation medially and laterally (points A and B). This distance between point A and B will be the length (W) of the base of the arc.[20] Distance measurements will be done with a digital calliper.

The highest point of the articular surface will be plotted (point C). The height of the arc (H) will then be determined by dropping a perpendicular line from point C to the base of the arc (line AB). A similar technique has been described by Brahm.

Using the values obtained through these measurements the radius of curvature will be determined as described above.

To eliminate magnification effects that may be produced by varying X-ray technique the metatarsal head width (W) to radius of curvature ratio will be determined by dividing the metatarsal head width (W) by the radius of curvature in millimeters. This technique has been described by Brahm in the Journal of the American Podiatric Medical Association.



<u>Figure 5.1</u>. **Metatarsal head silhouette and radius of curvature determination. Points A and B represent the medial and lateral estimation of the effective articular surface of the metatarsal head. Line W is the distance between points A and B. Line P is the bisection of the line AB. Point C is the intersection of the articular dome and line P. Line R is the radius of the arc which best connects points ABC**. Reproduced from Brahm SM. Shape of the first metatarsal head in hallux rigidus and hallux valgus. Journal of the American Podiatric Medical Association. 1988;78(6):300-4.

5.1 Inclusion criteria:

- 18 years and older
- Foot or ankle complaint necessitating foot x-rays
- X-rays obtained utilizing accepted standards as described

5.2 Exclusion criteria:

- Previous foot or ankle surgery
- Foot or ankle fractures
- Non-weight bearing X-ray

5.3 Data collection

Each foot X-ray will be assigned a number as an identifier and will have two angles (hallux valgus angle (HVA) and interphalangeal angle (IPA)) measured as described above.

The 2 angular measurements (HVA and IPA), width of the first metatarsal articular surface arc (W), height of the arc (H), radius of curvature (RC) and width:radius will be collected onto an excel spread sheet along with basic demographic data as follows:

1. Number
2. Side (right or left)
3. Age
4. Sex
5. Race
6. Hallux valgus angle (HVA)
7. Hallux interphalangeus angle (IPA)
8. First metatarsal articular surface shape (round, flat or chevron)
9. Length of base of arc (W)
10. Height of the arc (H)
11. Radius of curvature (RC)
12. Length of base of arc to radius of curvature ratio (W:RC)

5.4 Bias & Confounding Variables

To eliminate magnification effects that may be produced by varying X-ray technique the metatarsal head width (W) to radius of curvature ratio will be determined.

The measurements are being made by a single observer, eliminating inter-observer reproducibility, but relying on the precision and accuracy of a single measurement for each foot.

5. Data Interpretation & Statistical Analysis

A statistician will be consulted regarding which tests will be appropriate to my research question.

6. Ethics

Ethics approval has been from the Human Research Ethics Committee, ethics number M160233.

7. Costs

No additional costs will be incurred to any department.

All paper, stationery and measuring equipment will be self-funded

The services of a bio-statistician have been obtained through the post-graduate free consultations and any costs incurred in final analysis will be self-funded if necessary.

8. <u>Timeline</u>

	February	March	April	May	June	July
Ethics Submission	X					
Postgraduate Submission	X					
Data Collection				X	X	
Dissertation					X	
Examination						X

9. References:

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APPENDIX B: ETHICS CLEARANCE

R14/49 Dr Stephanus Johannes van De Venter

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M160233

NAME: (Principal Investigator)	Dr Stephanus Johannes van De Venter
DEPARTMENT:	Orthopaedics Chris Hani Baragwanath Academic Hospital Netcare Linkfield Hospital
PROJECT TITLE:	Morphology of the First Metatarsal Head as a Risk Factor for Hallux Valgus Interphalangeus
DATE CONSIDERED:	26/02/2016
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Andrew Strydom
APPROVED BY:	Professor P. Cleaton-Jones, Chairperson, HREC (Medical)
DATE OF APPROVAL:	03/05/2017

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary in Room 10004,10th floor, Senate House/3rd floor, Phillip Tobias Building, Parktown, University of the Witwatersrand. I/We fully understand the the conditions under which I am/we are authorised to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated,from the research protocol as approved, I/we undertake to resubmit to the Committee. **I agree to submit a yearly progress report**. The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. in this case, the study was initially review February and will therefore be due in the month of February each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature   Date 04/05/2017

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

APPENDIX C: CEO LETTER

GAUTENG PROVINCE
HEALTH
REPUBLIC OF SOUTH AFRICA

MEDICAL ADVISORY COMMITTEE
CHRIS HANI BARAGWANATH ACADEMIC HOSPITAL

PERMISSION TO CONDUCT RESEARCH

Date: 26 May 2016

TITLE OF PROJECT: Morphology of the first metatarsal head as a risk factor for hallux valgus interphalangeus

UNIVERSITY: Witwatersrand

Principal Investigator: SJ van Deventer

Department: Orthopaedics

Supervisor (If relevant): NP Saragas

Permission Head Department (where research conducted): Yes

Date of start of proposed study: May 2016
Date of completion of data collection: Dec 2018

The Medical Advisory Committee recommends that the said research be conducted at Chris Hani Baragwanath Hospital. The CEO /management of Chris Hani Baragwanath Hospital is accordingly informed and the study is subject to:-

- Permission having been granted by the Human Research Ethics Committee of the University of the Witwatersrand.
- the Hospital will not incur extra costs as a result of the research being conducted on its patients within the hospital
- the MAC will be informed of any serious adverse events as soon as they occur
- permission is granted for the duration of the Ethics Committee approval.

....
Recommended
(On behalf of the MAC)
Date: 26 May 2016

....
Approved/Not Approved
Hospital Management
Date: 30/05/16