Reliability of the radiographic measurement of the hallux interphalangeal angle

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A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of

Master of Medicine

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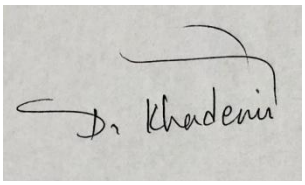
DECLARATION

I, Mohammadali Khademi, declare that this research report is my own work.

It is being submitted for the degree of Master of Medicine in the branch of Orthopaedic Surgery in the University of the Witwatersrand, Johannesburg.

It has not been submitted before for any degree or examination at this or any other University.

_08_th___ day of _June____2018



Dedication

I dedicate this thesis to my wife “Maryam” and my son “Daniel”, without whom none of my success would be possible. A special feeling of gratitude to my loving parents, “Morteza” and “Fatemeh” whose words of encouragement inspired me, all the way, to give it all it takes to complete my studies.

I will always appreciate the support of my father and mother in law throughout the process.

Abstract

Introduction: The hallux valgus interphalangeus (HVI) deformity has a common association with hallux valgus and hallux rigidus.

The radiographic measurement of the hallux valgus interphalangeus is formed by the angle between the long axes of the proximal and distal phalanges. The normal value for this angular deformity in the coronal plane is less than 10 degrees.

The reliability of measuring the hallux interphalangeal angle has not been verified as yet .The purpose of this study is to analyse the intra- and inter-observer reliability of measurements of the interphalangeal angle by orthopaedic surgeons. This study is going to be the first study to evaluate the reliability and reproducibility of the hallux valgus interphalangeal angle.

Methods: Twenty one X-ray prints (images) of the weight bearing foot constituted a set. Three such sets were sent to each evaluator at four week intervals. Sixteen qualified orthopaedic surgeons were asked to measure the hallux interphalangeal angle of all twenty one X-ray images at three different occasions. After all three sets were measured, data was retrieved and statistically analysed to determine the incidence of inter- and intra-observer variability and reliability in the measurement of the hallux interphalangeal angle.

Results: Reproducibility of the hallux interphalangeal angle measurement was assessed using three categories which included the ability to measure the same angle three times and achieve: three degrees or less, five degrees or less, more than five degrees.

The intra-observer reliability was found to be 5 degrees and less in 75.2% of participants and for the inter-observer reliability was 61.2%.

The researcher did not find significant correlation between the surgeons' level of experience with respect to the reliability of measurement of the hallux interphalangeal angle.

Conclusion: The reliability and reproducibility of measurement of the hallux interphalangeal angle is low. The level of experience of the surgeon does not improve this reliability.

Acknowledgements

I would like to express the deepest appreciation to Professor NP Saragas, Dr A.Strydom and Dr Z.Mayet, who continually supported me. Without their guidance and persistent help this dissertation would not have been possible.

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Nomenclature

AP: Antero-posterior

DMAA: Distal metatarsal articular angle

HV: Hallux valgus

HVA: Hallux valgus angle

HVI: Hallux valgus interphalangeus

IMA: Intermetatarsal angle

IPA: Interphalangeal angle

IPJ: Interphalangeal joint

PACS: Picture archiving and communication system

SD: Standard deviation

CHAPTER 1

1 Introduction and literature review

1.1 Background

Historically, the confusing term bunion was used to describe disorders of the first metatarsophalangeal (MTP) joint.

In 1871, Carl Hueter proposed the term hallux valgus to describe the angular deformity of the first metatarsophalangeal (MTP) joint. [1, 2]

The first surgical treatment for hallux valgus was probably introduced by Keller.[2]

1.2 Definitions

1.2.1 Hallux valgus

Carl Heuter defined hallux valgus as lateral deviation of the great toe and medial deviation of the first metatarsal. This deformity is the commonest deformity of the big toe.[1, 2]

1.2.2 Hallux valgus interphalangeus

In 1935 Daw described the outward deformity of the interphalangeal joint (IP) of the big toe and called it “hallux valgus interphalangeus”. Later in 1957, Burry introduced the method of measurement of this valgus angulation at the interphalangeal joint (IP) between the longitudinal axes of the proximal and distal phalanges of the hallux.[1-4]

1.3 Epidemiology of hallux valgus

Hallux valgus and hallux rigidus are the most common disorders of the hallux. Hallux valgus causes functional disability due to pain and gait abnormality especially in the elderly population leading massive impact on the health system costs .[2, 4-6]

There is no consistency and agreement regarding prevalence of hallux valgus in the literatures. The American national health reported the prevalence of hallux valgus 0.9% for all age groups. Roddy et al. reported a prevalence of 28.4% in adults in the United Kingdom. This problem can be as high as 74% in elderly population.[1-6]

1.3.1 Demographics

1.3.1.1 Age of onset

The age of onset highly depends on the patient's understanding of the deformity. In some studies peak of symptoms were reported in the third to fifth decades of life but there are some studies that found the peak of this disorders in the juvenile and adolescent population. The early onset of hallux valgus (less than 10 years old) was found to have a higher distal metatarsal articular angle (DMAA) by Coughlin.[1, 3, 7-9]

1.3.1.2 Gender

The predilection of hallux valgus in the female has been investigated in many studies. This preponderance varied between 2:1 and 15:1.[1]

Nerry et al. reported more severe deformity in the male population and at a much younger age .[1, 9]

1.3.1.3 Bilaterality

A prospective study by Mann et al. showed 84% of patients presenting with bilateral hallux valgus. The bilaterality has been shown to be as high as 97%. It should be mentioned that despite bilateral deformity, most patients request surgery on one side only.[1, 3.7,8]

1.3.1.4 Handedness

The correlation between handedness and foot deformity is not proven in the current literature .[1]

1.4 Epidemiology of hallux valgus interphalangeus

The epidemiologic aspects of hallux valgus interphalangeus are not investigated in the current literature.

1.5 Local study on hallux valgus demographic

In 1980, Gottschalk et al. conducted a study and found hallux valgus deformity is more common in Caucasians than Africans. They also found this deformity has similar prevalence between rural and urban African population.[11]

1.6 Aetiology

1.6.1 Extrinsic Causes

1.6.1.1 Footwear

Hallux valgus is a disease of people who wear shoes and only occasionally occurs in unshod people. In the Japanese population who wear tabi sandal, the prevalence of hallux valgus reported to be very rare. [1, 7]

In shoe wearing people the progression of hallux valgus is to be expected. However, in unshod people only in the person with a hereditary background, the deformity will progress to symptomatic hallux valgus.[1,7,12]

1.6.1.2 Occupation

Current studies show that only 17% of symptomatic patients believe that their job is a risk factor for their hallux valgus deformity. There is no correlation though between severities of deformity and occupation.[1, 7]

1.6.1.3 Trauma

Damage and weakening of the medial joint capsule due to trauma can lead to acute or chronic hallux valgus deformity. Entrapment neuropathy of the medial plantar nerve, has been shown to be a risk factor for hallux valgus.[1, 7, 12, 13]

1.6.2 Intrinsic Causes

1.6.2.1 Heredity

Various studies showed 58 − 88% of individuals with hallux valgus deformity have a positive family history. Johnston proposed that hallux valgus deformity inherited with an autosomal dominant with incomplete penetrance pattern.[1,7,13]

There are many articles confirming family history as a risk factor for early onset hallux valgus deformity.[1, 7, 12, 13]

X-linked dominant or polygenic transmission has been postulated in the hallux valgus deformity.[1, 13]

1.6.2.2 Pes Planus

Pes planus is a risk factor for hallux valgus only in patients with neuromuscular disorders.[1]

1.6.2.3 Hypermobility of the first tarsometatarsal joint

According to current studies isolated instability in the sagittal plane is not a causative factor for hallux valgus deformity. Not a single study has proven that first ray hypermobility is a pathologic entity on its own. It has been shown that treatment of hallux valgus without arthrodesis of the metatarsocuneiform joint will reduce the sagittal movement of this joint.[1, 13, 14]

In 2000, Myerson and Badekas stated that a hypermobile first ray should be treated with the Lapidus procedure and fusion of first tarsometatarsal joint is mandatory.[15]

1.6.2.4 Ligamentous Laxity

Hallux valgus in patients with generalized ligamentous laxity such as Marfan syndrome, Ehlers-Danlos syndrome, and rheumatoid arthritis is more common. High rate of recurrence of the deformity after surgical treatment has been confirmed and nonsurgical treatment in these groups of patients is recommended.[1.13, 14]

1.6.2.5 Achilles Contracture

The correlation between hallux valgus and tight Achilles is very uncommon .[1, 13]

1.6.2.6 Miscellaneous Factors

Obesity, second toe amputation, space occupying mass in the first intermetatarsal space are also considered to be risk factors in the development of hallux valgus deformity.[1, 13-20]

1.6.3 Risk factors for hallux valgus interphalangeus

Currently, there is not a single article about risk factor for hallux valgus interphalangeus either as isolated deformity or in conjunction with hallux valgus.

Strydom et al. found that the interphalangeal angle correlates inversely with the other angular measurements in the foot. They also found that hallux valgus interphalangeus deformity is more common in the feet without hallux valgus deformity.[1,20]

1.7 Anatomy of the Hallux

1.7.1 Anatomy of the First Metatarsophalangeal Joint

Presence of two sesamoid bones make the anatomy of the first metatarsophalangeal joint more specialised and differs from the other metatarsophalangeal joints.

The metatarsal head is bigger than the proximal phalanx. Collateral ligaments arise from the epicondyles and stabilise the joint. The crista will divide the two grooves for sesamoid articulation. The sesamoid bones are contained within the flexor hallucis brevis. The sesamoids attach to the base of the proximal phalanx with the plantar plate. The two sesamoids attach to each other by the intersesamoidal ligament (see Figure 1.1).[1]

Four groups of tendons are around the first metatarsophalangeal joint:

a) The dorsal group : the long and short extensor tendons
b) The plantar group: the long and short flexor tendons
c) The medial group: the abductor hallucis
d) The lateral group : The adductor hallucis

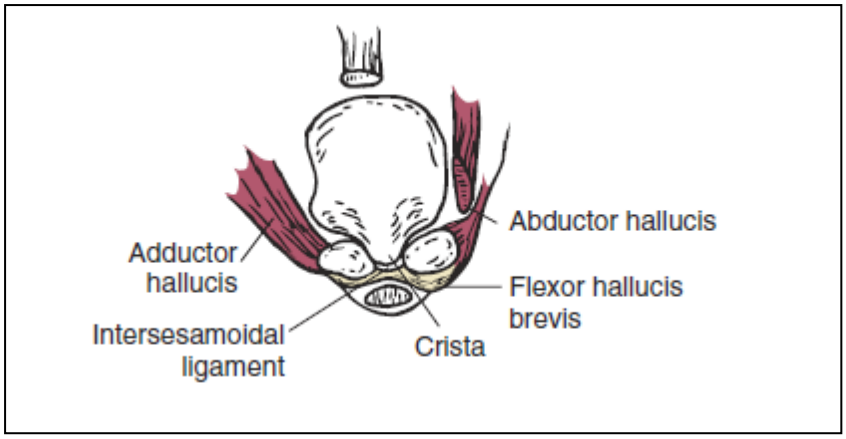

Figure 1.1: Cross section anatomy of the first metatarsophalangeal joint [1]

The joint capsule of the hallux metatarsophalangeal joint is thicker in the plantar aspect comparing to the dorsal capsule and consists of the hood ligaments and collateral ligaments.[1] The dorsal and plantar digital arteries supply the first ray. The branches of the superficial peroneal nerve on the foot are very variable. However, the dorsomedial cutaneous nerve - a terminal branch of the superficial peroneal nerve - usually supplies the sensation on the dorsal and medial aspects of the hallux. Surgeons should be aware of these anatomical variations and avoid any iatrogenic injury to this nerve (see Figure 1.2).[1, 16]

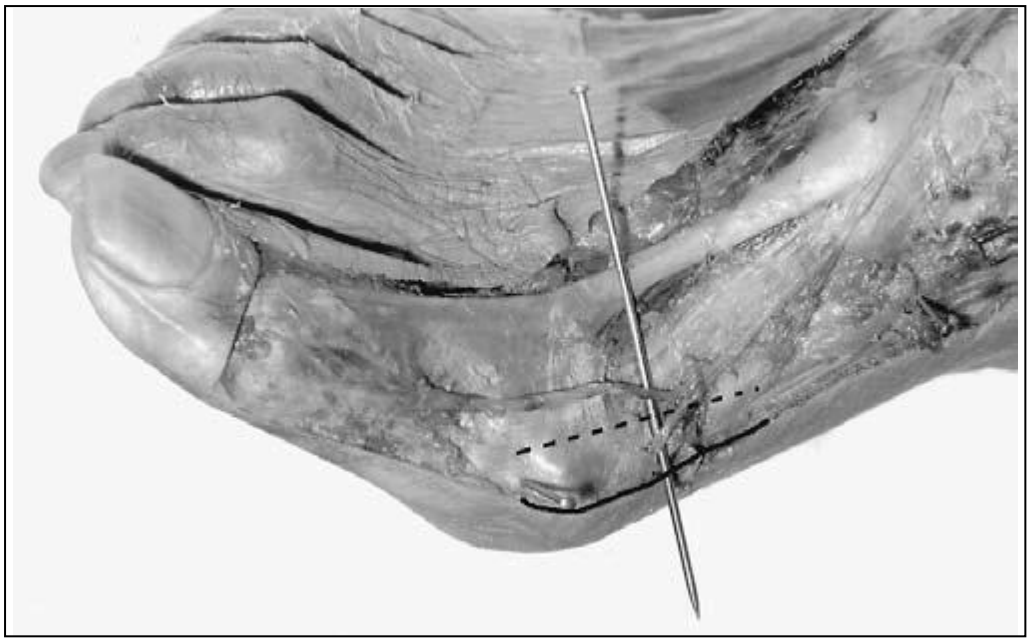

Figure 1.2: Dorsomedial cutaneous nerve to the hallux[16]

1.7.2 Anatomy of the hallux interphalangeus Joint

This simple hinge joint allows sagittal plane movement. The strong collateral ligaments make this joint very stable. This stability is more pronounced in the transverse plane relative to the sagittal plane. The joint capsule is thicker in the plantar aspect and encircles the entire joint. Dynamic stabilisers of the hallux interphalangeus include: the extensor hallucis longus tendon and flexor hallucis longus tendon. The condylar shape of the joint, the collateral ligaments and joint capsule form the static stabilisers of the joint.

Trolle and Dyre in 1986 found the hallux interphalangeal sesamoids in only 56% of embryologic specimens. The size, position and composition of these sesamoid bones are variable. They can be completely bony, cartilaginous or fibrocartilaginous. The size of these structures varies from 0.05 cm to 1.00 cm .They can be plantar medial, plantar lateral, or located directly in the plantar aspect.

Symptomatic hyperkeratotic lesions in the plantar aspect of the hallux interphalangeus joint, makes these sesamoids clinically significant.

Only the anterior facet of the proximal phalanx of the big toe articulates with the distal phalanx. This facet is a part of the dorsal intra-articular cartilage that has been divided by a transverse crest.

The anatomy of the plantar surface is still controversial in the current literature. McCarthy et al. found an accessory tendon in the plantar aspect of the interphalangeal joint and named it: flexor hallucis capsularis interphalangeal tendon.[1, 3, 17]

1.8 Pathoanatomy of the hallux valgus

The medial supporting structures of the metatarsophalangeal joint consist of the medial sesamoid and joint capsule.

According to Wilson, the ‘‘early and essential lesion” is the failure of these medial structure. Deformity begins with medial subluxation of the first metatarsal and valgus position of the proximal phalanx. The tendons around the metatarsophalangeal joint start drifting laterally.
In the normal foot without hallux valgus deformity, these tendons stabilise the joint but with change in the axis of pull, they become deforming forces (see Figure 1.3).[13]

Progression of the deformity will diminish the stabilising effect of the plantar aponeurosis as well as the windlass mechanism.
As the deformity progresses the following anatomical changes will happen:

- The distal lateral soft tissues of the metatarsophalangeal joint contract
- The distal medial soft tissues of the metatarsophalangeal joint attenuate
- Progressive uncoverage of the sesamoids
- Erosion of the articular cartilage in the plantar aspect; especially crista
- Transfer metatarsalgia and lesser toe deformities due to abnormal weight loading [1,2,11,13,18]

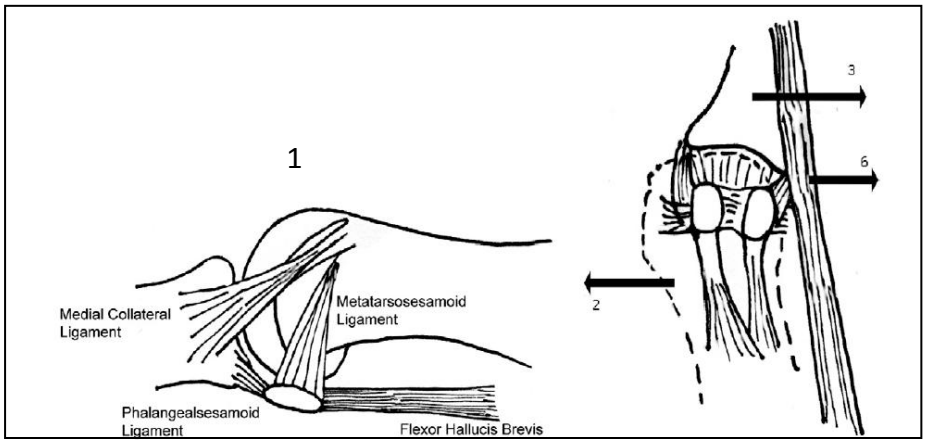

Figure 1.3: Pathoanatomy of hallux valgus: 1- failure of medial structures; 2- shifting metatarsal head medially; 3 - drifting proximal phalanx laterally;6:distorted biomechanics of the adductor hallucis and extensor hallucis longus tendons[13]

1.9 Pathophysiology of the hallux valgus

The shape of the metatarsophalangeal articular surface has great contribution to the stability of this joint. First metatarsal head shape classified as: (see Figure 1.4)[1, 13, 19]

- Round
- Square or flat
- Chevron.

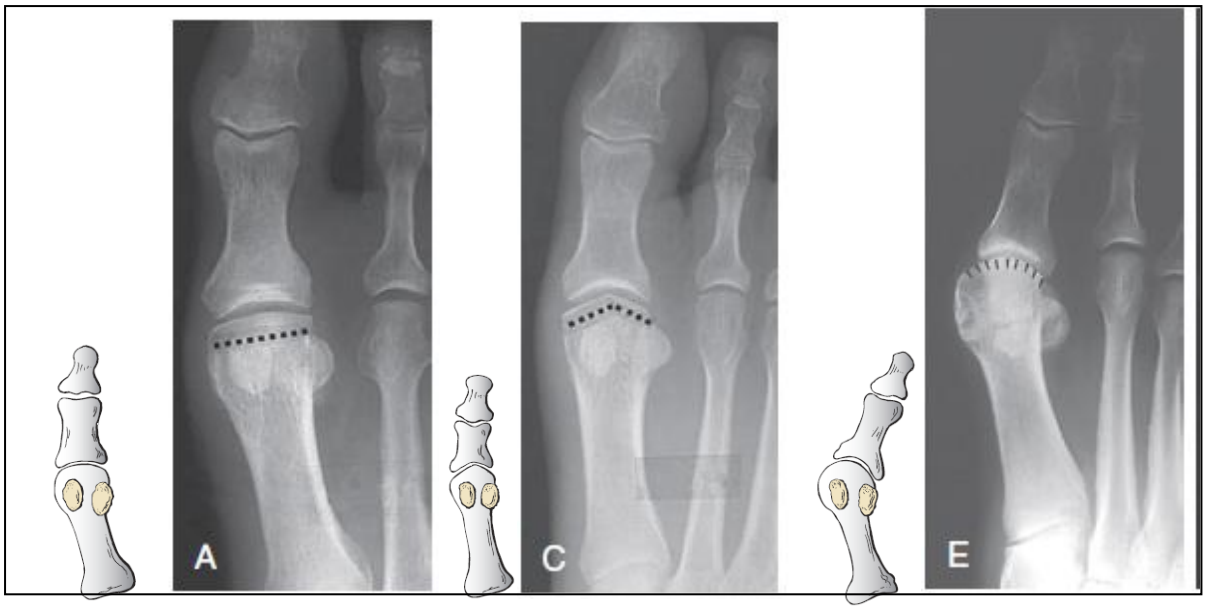

Figure 1.4: Shapes of the first metatarsal head (A: Flat, B: Chevron, C: Round) [1]

Current studies show a correlation between a round shape of the first metatarsal head and hallux valgus deformity.[1, 13, 19]

Okuda et al. introduced a classification system for the shape of the lateral edge of the first metatarsal head into three types:

- Type A: angular
- Type R: round
- Type I: intermediate

They concluded that type R is associated with hallux valgus deformity and could be a risk factor for recurrence of hallux valgus after surgical treatment (see Figure 1.5). [19]

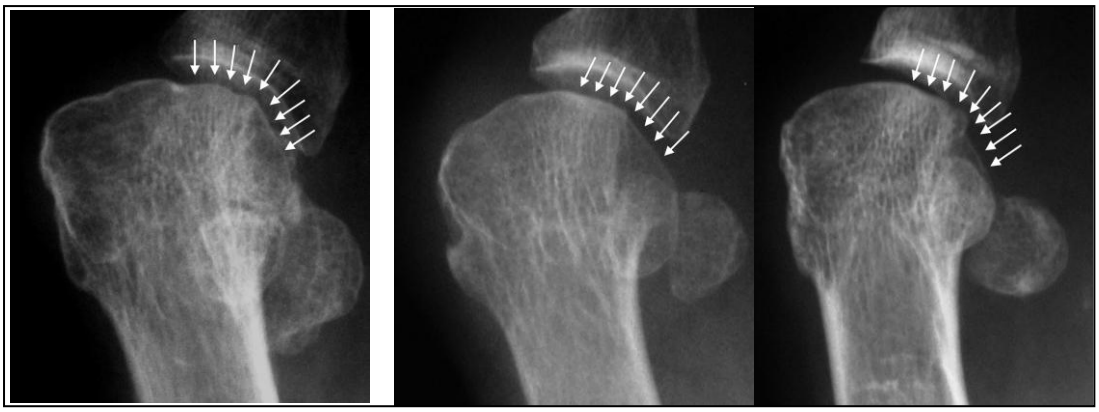

Figure 1.5: Okuda classification (From right to left: Type A, Type R, Type I) [19]

Articular surface deviation of more than 10 to 15 degrees of the distal metatarsal will cause symptomatic hallux valgus deformity. This angle has been discussed in the radiographic evaluation section.[1, 13]

A hallux valgus interphalangeus deformity can exist on its own and give the impression of hallux valgus deformity, although, it usually has a significant contribution to total deformity of the hallux.[1, 13, 20] Intermetatarsal angle will increase as the deformity increases according to the steps of the pathoanatomical changes described earlier.[1, 13]

With chronic pressure of the metatarsal head medially the weakest part of the joint capsule will fail. This part is the immediate part of the joint capsule above the tendon of abductor hallucis muscle. The axis of pull of the abductor hallucis tendon will change and the metatarsal head slips over the sesamoid complex and cause atrophy of the crista. [1, 13]

At this stage intrinsic muscles will exaggerate the deformity and the abductor hallucis tendon will pull and rotate the proximal phalanx. This explains the valgus deformity and pronation of the proximal phalanx clearly.[1, 13] In the severe hallux valgus deformity even the extensor hallucis longus tendon will shift laterally and instead of dorsiflexion can cause adduction of the big toe. Another dynamic deforming force is the flexor hallucis brevis tendon that is still attached to the laterally positioned sesamoid complex related to the metatarsal head (see Figure 1.6). [1]

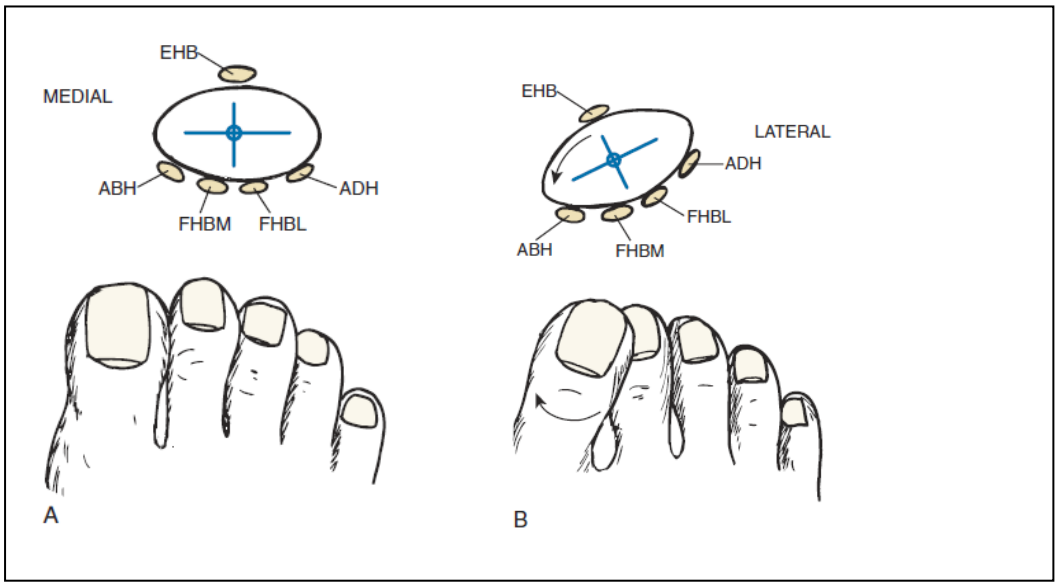

Figure 1.6: Cross-sectional anatomy of the hallux metatarso phalangeal joint: A, Normal Joint. B, with hallux valgus deformity. ABH, abductor hallucis; ADH, adductor hallucis; EHB, extensor hallucis brevis; FHBL, flexor halluces brevis lateral head; FHBM, flexor hallucis brevis medial head. [1]

1.10 Pathophysiology of the hallux valgus interphalangeus

Sorto and Balding conducted a study in 1992 and found that the cause is probably phalangeal condyle hypoplasia. There is no other study to support this theory .[21]

1.11 Radiographic consideration of the hallux valgus deformity

The basic radiographic evaluation of the patient with hallux valgus deformity consists of weight bearing antero-posterior, lateral, and oblique views of both feet. For a standard antero-posterior view, tube-to-film distance should be 1 metre and the X-ray tube should be centred on the midfoot and angled 15 degrees cephalad. The following angles should be measured: [1, 22]

- 1 – 2 Intermetatarsal angle (IMA)
- Hallux valgus angle (HVA)
- Distal metatarsal articular angle (DMAA)
- Interphalangeal angle (IPA)

1.11.1 1–2 Intermetatarsal angle (IMA) [1]

This angle is created by the intersection of the long axes of the first and second metatarsals on the antero-posterior X-ray. Normal value is 9 degree or less.

1.11.2 Hallux valgus angle (HVA) [1]

This angle is defined as the angle between the long axes of the first metatarsal and the proximal phalanx of the big toe. The normal value is less than 15 degrees.

1.11.3 Distal metatarsal articular angle (DMAA) [1]

This angle is created by the intersection of the longitudinal axis of the first metatarsal and articular surface of the first metatarsal head. The normal value is 6 degrees or less.

1.11.4 Interphalangeal angle (IPA) [1]

The intersection of the axis of the proximal phalanx of the hallux and distal phalanx of the hallux creates the hallux interphalangeal angle. The normal value is 10 degrees or less.

1.11.5 Method of measurement of angles

In 2002, the Ad Hoc Committee of the American Orthopaedic Foot and Ankle Society conducted a study on how to measure the above mentioned angles and they suggested using specific reference points. These reference points are on the longitudinal axis of the bone and equidistant from the medial and lateral cortices. The reference points for the first and second metatarsal were suggested by the committee to be 1 – 2 cm proximal and distal to the respective articular surfaces. For the proximal phalanx the reference points are 0.5 – 1.0 cm from the articular surface.

The radiographic measurement of HVI is formed by the angle between the long axes of the proximal and distal phalanges. The normal angulation in the axial plane between these two bones is less than 10 degrees.

The IPA is used to assess the severity of the HVI deformity and the magnitude of correction required is based on the angular measurements on the standing X-rays (see Figure 1.7 – 1.10).[1,20,23,24]

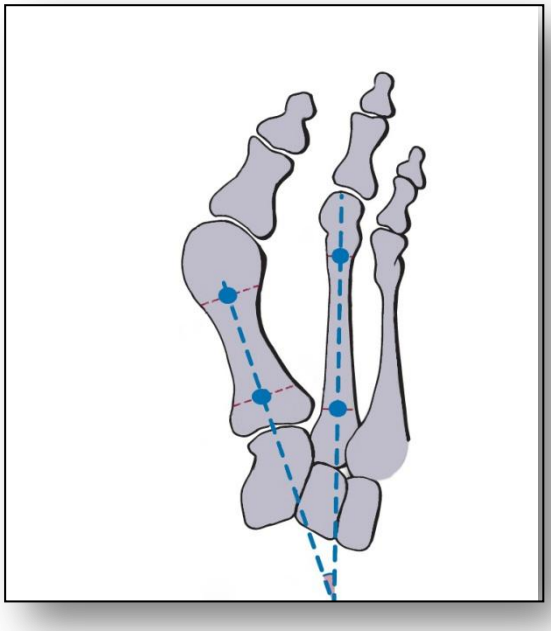

Figure 1.7: Reference points and measurement method for IMA

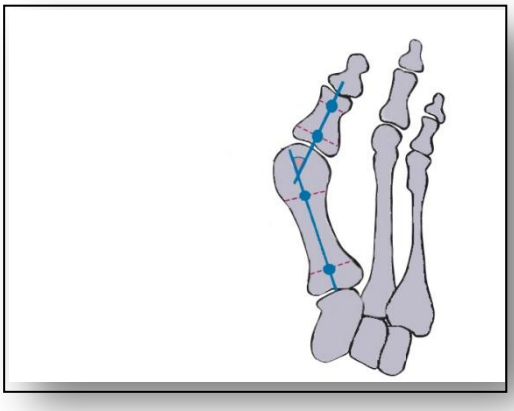

Figure 1.8: Reference points and measurement method for HVA

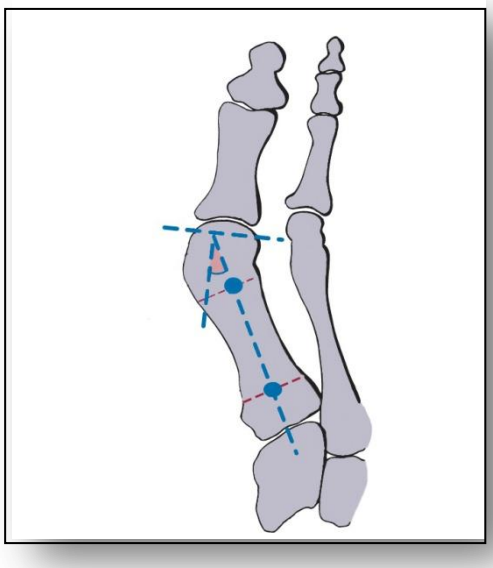

Figure 1.9: Reference points and measurement method for DMAA

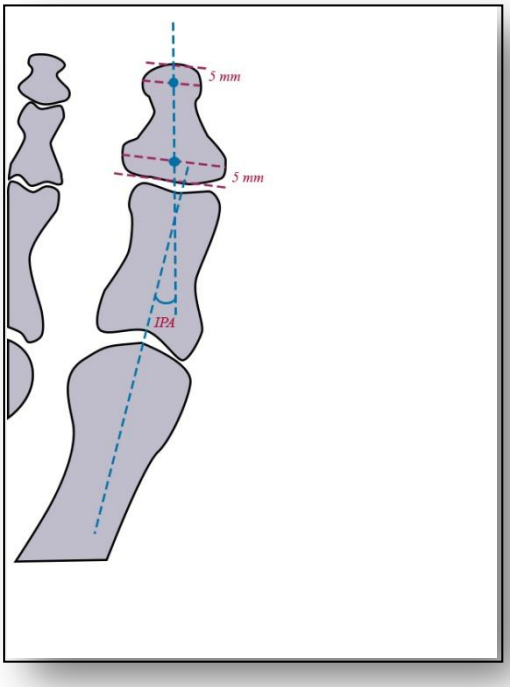

Figure 1.10: Reference points and measurement method for IPA

1.11.6 Other radiographic measurers of the hallux valgus

1.11.6.1 Medial Eminence

The size of the medial eminence should be evaluated in a patient with hallux valgus deformity. It is the perpendicular distance of the widest part of the medial eminence from the medial diaphysis of the first metatarsal (see Figure 1.11).[1]

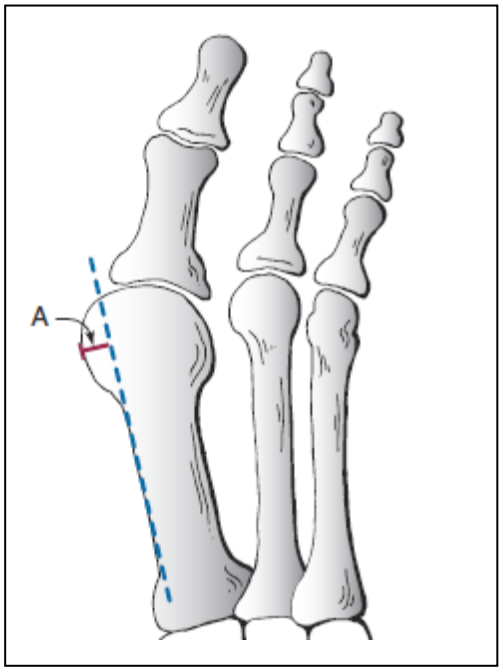

Figure 1.11: Method of measurement of medial eminence

1.11.6.2 Metatarsophalangeal joint congruency

Reference points should be placed on the most medial and lateral edges of the proximal phalanx and metatarsal head articulation surfaces. In the congruent or non-subluxated joints these reference points of the proximal phalanx and the metatarsal head are matching. If these reference points do not match then it is incongruent (see Figure 1.12).[1]

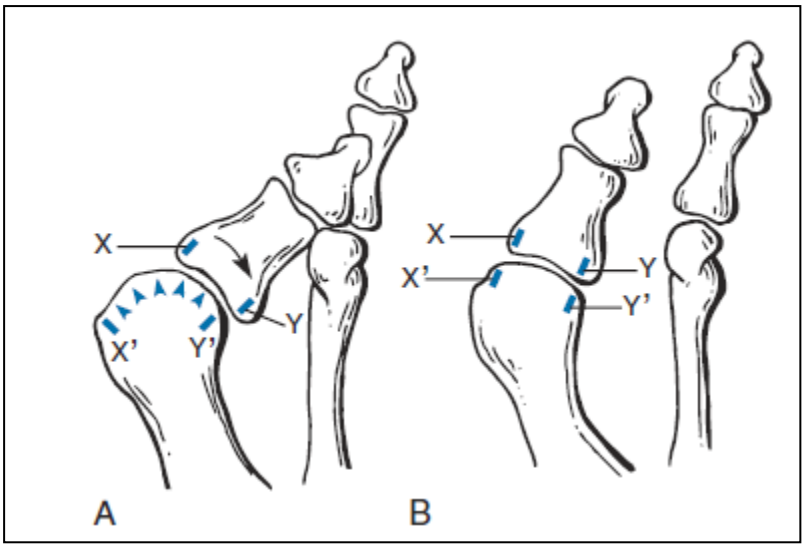

Figure 1.12: A, Incongruent B, congruent hallux valgus[1]

1.11.6.3 Tibial Sesamoid Position

Hardy and Clapham in 2015 classified the position of the tibial sesamoid in to seven positions in an anteroposterior view .This classification can guide the surgeon pre-operatively as well as intra-operatively to achieve appropriate correction of the 1 – 2 intermetatarsal angle (see Figure 1.13).[25]

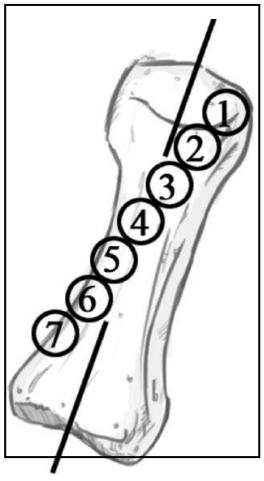

Figure 1.13: Tibial Sesamoid Position classification [25]

1.12 Classification of hallux valgus

The classification of the severity of the hallux valgus will guide the surgeon in the decision making. This classification divides the hallux valgus deformity into mild, moderate and severe types (see Table 1.1).

Table 1.1: Classification of hallux valgus

Severity	HVA	IMA
Mild	< 20°*	≤ 11°
Moderate	20 – 40°	11 – 16°
Severe	> 40°	> 16°

*° = degree

1.13 Patient's evaluation

Assessment of the patient with hallux valgus starts with thorough history taking. Pain over the medial eminence is reported to be the most common complaint. Plantar hyperkeratosis, difficulty with shoe wear and cosmesis are also reported main complaints.[1, 2, 7]

Level of recreational activity, family history of hallux valgus, patient's occupation, patient's expectation are additional aspects that should be probed by the surgeon.

Physical examination should be started by assessing the medical condition of the patient for any comorbidity and generalised hyper laxity. The patient's gait, severity of deformity, associated lesser toe deformities should be carefully evaluated by the surgeon. The amount of hallux pronation, hallux valgus interphalangeus and hypermobility of the first ray must be recorded. Range of motion of the ankle joint, hindfoot, hallux metatarsophalangeal joint must be examined. The gastrocnemius-soleus tightness must also be checked. Sesamoid pathology must be ruled out. [1, 2, 7]

Hypo-aesthesia in the distribution of the dorsomedial cutaneous nerve must be documented.[1] A complete neurologic and vascular examination should be conducted by the surgeon. [1, 2, 7]

1.14 Management

1.14.1 Conservative management

Ellington et al. believe that conservative treatment is adequate and can completely help with the patient's pain. [27] A mild hallux valgus deformity must be followed up with a clinical examination as well as radiographic assessment. Using roomy shoes, night splints, bunion pads shown to have effect on pain relief in patients with symptomatic hallux valgus.[1, 27]

Botulinum toxin A has also been used as non-surgical treatment of hallux valgus deformity. Radovic et al. found injection of the botulinum toxin A not only can correct the deformity but also can alleviate the pain. [28]

Comfortable shoes are the most important non-surgical treatment. Shoes should have low-heel, soft upper fabricate and wide toe box.[1, 26, 27]

With regard to orthotics, these devices are not comfortable and cannot prevent the progress of the hallux valgus deformity (see Figure 1.14).[1, 2, 27]

If conservative treatment fails with pain relief or deformity progresses, surgical treatment should be considered.[1, 2, 27, 28] Difficulty with shoe wear is an important indication for surgical intervention in patients with hallux valgus deformity. Purely cosmesis as an indication for surgical management is controversial. [1, 29, 30]

Figure 1.14: Some of the available devices for conservative management of hallux valgus [1]

1.14.2 Surgical management

More than a hundred of surgical procedures have been described for treating the hallux valgus. No single procedure though, can be used to treat all hallux valgus deformities. Long-term patient satisfaction can be achieved if anatomical realignment of the metatarsophalangeal joint is achieved.[1, 29, 30]

Discussion related to indications, contraindications, pros and cons of each surgical procedure is beyond the scope of this research. This section will categorise the surgical options for hallux valgus operative management.

1.14.2.1 Distal soft tissue procedure

This procedure should be always considered in conjunction with the other corrective osseous procedures. Silver's technique includes: medial capsulorrhaphy, medial exostectomy, and lateral capsular and adductor release .[1, 29, 31]

McBride technique includes: lateral sesamoid excision and transfer of the conjoined adductor- tendon to the first metatarsal head. Mann and Coughlin in 1997 recommended not excising the lateral sesamoid because of high risk of hallux varus complication. [1, 29, 31]

The whole purpose of this procedure is to release the contracted soft tissue laterally and placation of the medial capsule after bunionectomy.[1, 31]

1.14.2.2 Distal metatarsal osteotomy

Many osteotomies have been described for the distal first metatarsal in order to correct the malalignment of the first ray. The chevron osteotomy is commonly used.

With these types of osteotomies, the surgeon can decrease the intermetatarsal angle and translate the metatarsal head to achieve correction of the hallux valgus deformity. These osteotomies can be combined with other types of osteotomies or tarsometatarsal fusion for more accurate deformity correction. These osteotomies are not powerful enough to correct the severe deformities or first ray instability on their own.[1, 29-32]

1.14.2.3 Shaft / Proximal metatarsal osteotomy

Many shaft and proximal osteotomies have been described. These osteotomies are more powerful to correct more severe deformities. Proximal osteotomies can be combined with distal osteotomies. These osteotomies are more technically demanding and often require a distal lateral soft tissue release.

The scarf and Ludloff osteotomies are two types of shaft osteotomy, whereas the proximal opening wedge osteotomy is performed at the base of the first metatarsal. [1, 29-32]

1.14.2.4 First tarsometatarsal arthrodesis

Arthrodesis of the first metatarsocuneiform joint with modified McBride technique was popularised by Lapidus. Since the correction with the Lapidus procedure is at the apex of the deformity, it significantly improves the 1 – 2 intermetatarsal angle. The Lapidus procedure can be combined with the distal osteotomies. Distal soft tissue release should always be

performed in conjunction with the Lapidus procedure. Hypermobile first ray, severe hallux valgus and revision surgery are main indications for the Lapidus procedure. [1, 29-32]

1.14.2.5 Keller Bunionectomy

Keller procedure is resection of the base of the proximal phalanx. This procedure makes the metatarsophalangeal joint of the hallux unstable and should be reserved for the inactive geriatric patients with painful joint due to arthritis. [1, 29-32]

1.14.2.5 Metatarsophalangeal joint arthrodesis

Severe hallux valgus, arthritis of the hallux metatarsophalangeal joint, failed hallux valgus surgery, rheumatoid arthritis are some of accepted indications of this procedure. It is often used for iatrogenic hallux varus. [1, 33]

1.14.2.6 Implant Arthroplasty

The use of metatarsophalangeal implant in the primary hallux valgus setting is rarely indicated. This should be reserved for a patient with severe arthritis of the hallux metatarsophalangeal joint and a mild deformity refusing an arthrodesis.[1,32]

1.14.2.7 Proximal Akin Osteotomy

The Akin osteotomy is primarily indicated for correction of hallux valgus interphalangeus deformity. The Akin osteotomy is not effective in isolation to correct hallux valgus and should be performed in conjunction with other osteotomies and distal soft tissue release. [1, 34-37]

Akin described this osteotomy in 1925. The osteotomy starts 5 mm distal to metatarsophalangeal joint of the hallux and is a medially based closing wedge osteotomy.
In conjunction with the other osteotomies it can assist with a further 10 degrees of deformity correction. Shannak and Sehat in 2011 found in their study that for 10 degrees of correction a 3 mm base osteotomy will be needed. [1, 34-37]

Plattner et al. in their study showed that the Akin osteotomy can make the metatarsophalangeal joint unstable and should not be performed as a single procedure in cases with metatarsus primus varus deformity .[37]

By using the Akin osteotomy, we can achieve correction of the pronation deformity as well as hallux valgus intephalangeus deformity. Various methods of fixation have been described (suture, screw, staple). [1, 34-37]

1.14.2.8 Distal Akin osteotomy

This technique was described by Vander Griend in 2016. The principle basis of this modification from the conventional Akin osteotomy is based on the fact that the centre of rotation is at the interphalangeal joint. [38]

1.14.2.9 Miscellaneous

Mini tight-rope has been used to reduce the intermetatarsal angle and correction of the hallux valgus.[34]

1.15 Decision making for treatment

Neither all hallux valgus deformities have equal severity nor can a single procedure be contemplated for all patients. Many algorithms have been proposed in the literature to simplify the decision making for the surgeon. The first step is to recognise the presence of arthritis and congruency of the hallux metatarsophalangeal joint (see Figure 1.15). [1]

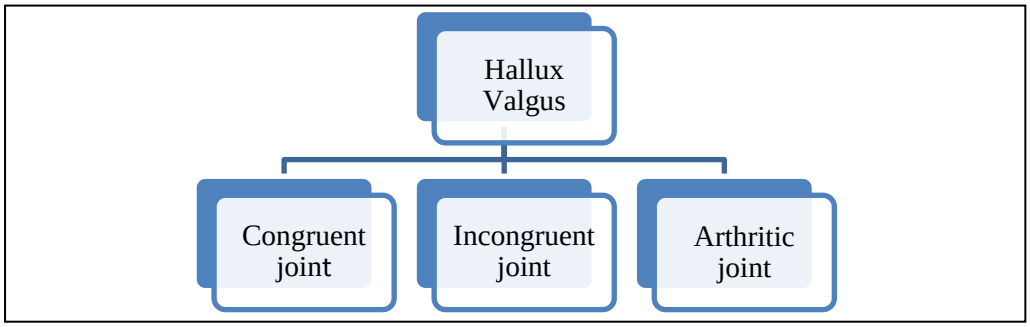

Figure 1.15: First step in decision making of treatment of hallux valgus[1]

Two surgical methods for the arthritic joints are arthrodesis or arthroplasty (see Figure 1.16). [1]

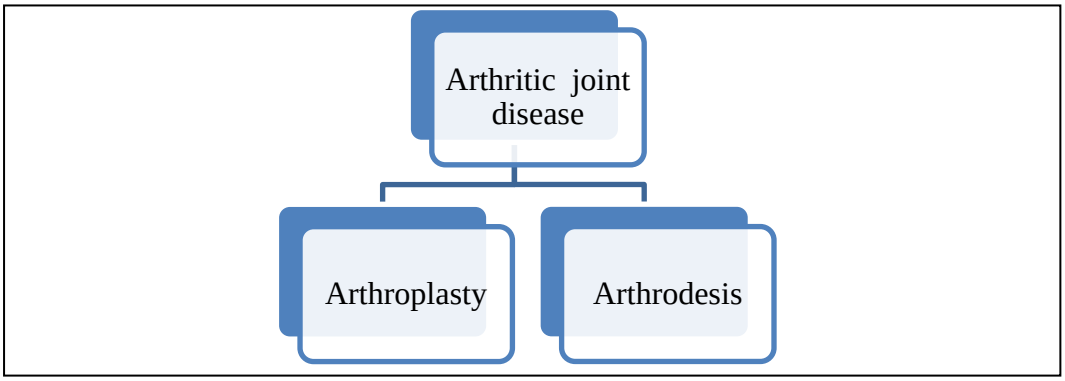

Figure 1.16: Algorithm for management of hallux valgus deformity and presence of arthritis of hallux metatarsophalangeal joint. [1]

As mentioned earlier many osteotomies have been described for the treatment of hallux valgus deformity. The following algorithms provide guide lines for the treatment of congruent (see Figure 1.17) and incongruent hallux valgus deformity (see Figure 1.18)**.**[1]

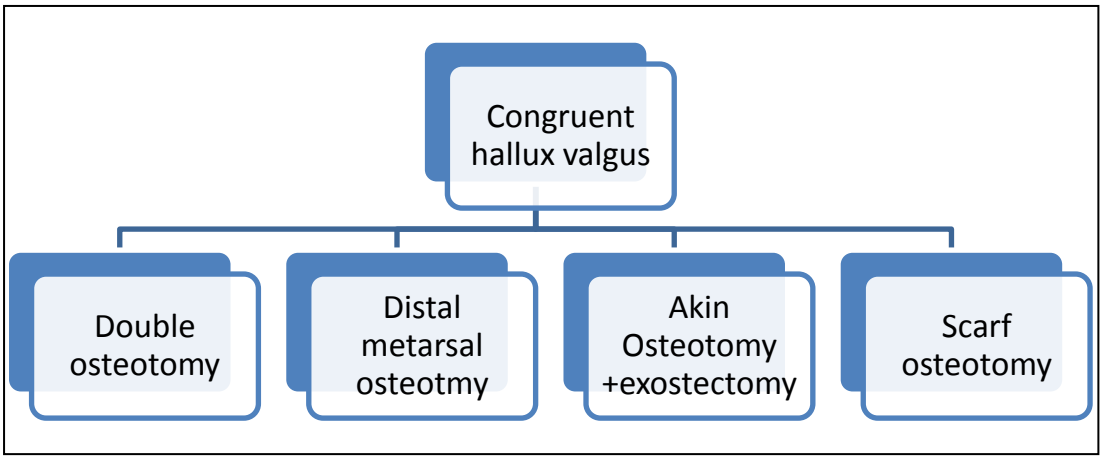

Figure 1.17: Algorithm for management of the congruent hallux valgus deformity[1]

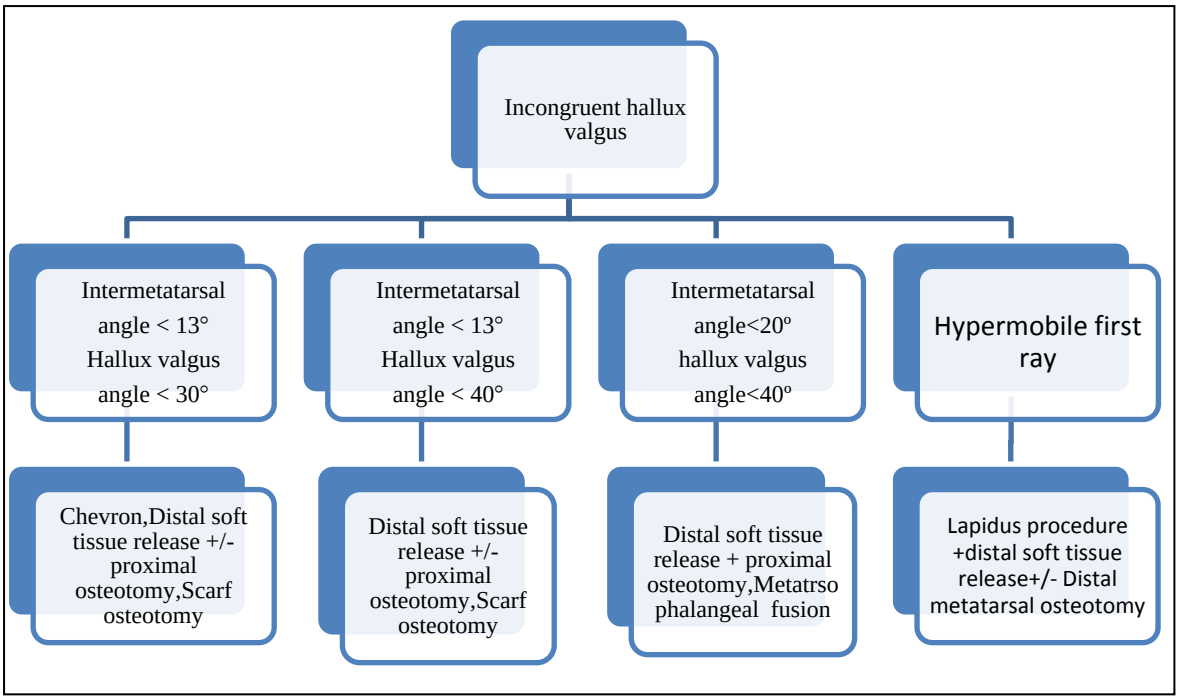

Figure 1.18: Algorithm for management of the incongruent hallux valgus deformity[1]

It is important to consider the Akin osteotomy for hallux valgus interphalangeus deformity with or without pronation of the big toe.[1]

1.16 Reliability

The consistency and repeatability of a finding refers to the reliability of a measurement. Obtaining the same results in repeated observed measurements refers to the reliability of the test or method.

The standard deviation is used to measure variability of the data. To measure the reliability of a test, the standard deviation of the subject's true value and of the measurement errors needs to be calculated.

Higher reliability shows smaller measurement errors of a test, i.e. the test is less prone to error. Reliability values range between zero and one. A reliability value of one shows zero measurement error and vice versa.[43]

The intra and inter-observer reliability of this radiographic measurement is important as it is commonly used by the orthopaedic surgeon during surgical planning. Quantitative method of the hallux interphalangeal measurements should be reproducible and provide a constant value. [1, 45]

1.16.1 Reliability of the radiographic measurement of the hallux valgus interphalangeal angle

The principle purpose of this research study is to determine the reliability and reproducibility of radiographic measurement of the hallux valgus interphalangeus using current methods of measurement. Many studies have been conducted to evaluate intra-observer and inter-observer reliability of measurement of intermetatarsal, hallux valgus and distal metatarsal articular angles. One of these studies showed inter-observer and intra-observer in the measurement of the intermetatarsal angle to be very high but this consistency is slightly lower for the measurement of the hallux valgus angle. The consistency was found to be less reliable with regards to the distal metatarsal articular angle measurement and is hypothesised by the authors to be due to the difficulty of taking the measurement as the articular line can be difficult to find on X-rays.[39]

Another study showed high intra-observer and inter-observer reliability for the measurement of intermetatarsal angle however the authors concluded that reliability can be improved using careful technique and repeating the measurements at least twice.[40,41,]

The reliability of a non-invasive clinical evaluation of hallux valgus using “The Manchester scale” was investigated. The result showed that the intermetatarsal angle and hallux valgus angle highly correlate while interphalangeal angle negatively correlates with this technique .[42]

The level of experience of the observer was shown to be effective in terms of increasing the reliability with more difficult angular measurement such as distal metatarsal articular angle, however there was no difference with the intermetatarsal angle measurement.[39, 40]

Smart phones and computerized methods called Autocad® software have been used to evaluate the reliability of most of the angular measurements mentioned earlier.[41, 44]

With the exception of the interphalangeal angle, the reliability of angular measurements including hallux valgus angle, intermetatarsal angle and distal metatarsal articular angle have been verified in other studies.[39] The purpose of this study is to analyse the intra and inter-observer reliability of measurements of the interphalangeal angle by orthopaedic surgeons.

To our knowledge no intra-observer or inter-observer accuracy studies have been performed with regards to radiological measurements of the interphalangeal angle. This study will be the first to determine the reliability of the IPA measurement.

CHAPTER 2

2 Methodology

2.1 Hypothesis

The measurement of the hallux interphalangeal angle is reliable and reproducible.

2.2 Aim of the study

The aim of this study is to find out inter and inter observer reliability of the hallux valgus interphalangeal angle.

2.3 Objective

To measure the hallux valgus interphalangeal angle on the X-ray print out images.

2.4 Research Design

This study is a comparative study.

2.5 Materials and Methods

The methodology that was used for this study was based on the methodology of Coughlin et al. study.[39]

In this study twenty one preoperative weight bearing antero-posterior (AP) radiographs of feet with hallux valgus deformities were selected. The radiographs were obtained from the collection of a private orthopaedic practice at the Netcare Linksfield Hospital.

All radiographs that included in the study were taken according to an international standardised protocol of weight bearing radiographs with the X-ray beam one meter from the cassette centred on the midfoot with a 15 degrees inclination cephalad.[1]

X-rays of mild, moderate and severe hallux valgus with associated hallux valgus interphalangeus were included to widen the range of deformity. Each individual radiograph was scanned and three clear copies were chosen to produce on ordinary paper. The twenty one clear images constituted a set.

A code number, known only to the primary investigator was attached to the back of each image. A second number was attached to the front of the image and it did not correlate with the code attached to the back. Each evaluator was supplied with a goniometer, HB lead pencil (Staedtler), eraser, sharpener and a standardised instruction method to measure the interphalangeal angle.

Three sets of images were sent to each evaluator at four week intervals.

Each set was randomly shuffled and the evaluator recorded the measurement for each image according to the number designated on the front of the image.

The interphalangeal angle once measured, was recorded by the evaluator on a label attached to the front of the image.

Upon completion of the measurements the set of images was returned to the primary investigator. At four and eight weeks following the first measurement, the second and third sets were respectively posted to each evaluator.

Once all three sets were measured, they were sorted and ordered according to the code number on the back of the image. Recorded data was statistically analysed to determine the

incidence of inter- and intra-observer variability and reliability in the measurement of the hallux interphalangeal angle. Sixteen qualified orthopaedic surgeons were included on a voluntary basis. Each evaluator was assigned an individual letter, which was placed at the back of each photograph. The following additional data was requested from each evaluator: years since qualifying as an orthopaedic surgeon and any previous work experience (in months) in a foot and ankle unit at a postgraduate level.

2.6 Sample size calculation[46]

To calculate the optimal sample size or number of physicians required to determine the reliability of measurements the sample size calculation for kappa analysis below was used:

$$n = \frac{n^\star}{1 + n^\star/N}, \text{ where } n^\star = \frac{1}{r^2(p_a - p_e)^2},$$

Where:

n = sample size

N = total population (for the present study *N* = 7 which is the total number of orthopaedic surgeons/physicians at the Netcare Linksfield hospital)

r = error margin (for the present study 5% was used)

$p_a - p_e$ = the difference between the overall agreement probability p_a and the chance-agreement probability p_e (for the present study, the best case scenario was assumed to be: p_e = 0 and p_a = 50%)

The total sample size for the present study was calculated to be 6.9 i.e. seven orthopaedic surgeons, however 16 orthopaedic surgeons voluntarily participated in the study.

2.7 Data Collection

An excel spreadsheet with the following fields was used to collect the data:

- Code Number
- Evaluator number
- Work experience
- Hallux interphalangeus angle (IPA) Measurement 1
- Hallux interphalangeus angle (IPA) Measurement 2
- Hallux interphalangeus angle (IPA) Measurement 3

2.8 Data processing

The data for the study was entered into an Excel spreadsheet prior to entering it into STATA version 14 for analysis. To process the data in preparation for analysis, the data was checked for errors in recording, duplicates and missing values. Sixteen qualified orthopaedic surgeons completed the measurements thrice within the time frame that was defined for the study. Those who measured only one or two sets of X-rays were excluded from the study.

2.9 Data analysis

The inter- and intra-observer reliability was assessed using three categories which included the ability to measure the same angle three times and achieve: [39]

- Three degrees or less range for all three measures, this was considered strong accuracy/ reliability
- Five degrees or less range for all three measures, this was considered optimum accuracy/ reliability
- Above five degrees, this was considered poor accuracy/ reliability
- For each physician frequency tables were computed to count the number of photographs within each degree range, then the total number was averaged across all 16 physicians to determine the average number of photographs physicians re-measured at each specific range.

To assess inter-observer reliability (whether different physicians can measure the same angle on X-ray photograph and arrive at the same measurement), frequency tables were computed to count the number of physicians that re-measured the photograph of the angle within the specified degrees for each photograph. Consistency was present when the number in any of the categories was close to twenty one (the total number of photographs)

To determine the association between years of experience and intra-physician reliability, a "Spearman's correlation coefficient" calculation was conducted. The Spearman's correlation test is a non-parametric measure of the statistical dependence between the rankings of two variables and it was used in this case to determine the statistical dependence (rank correlation) between years of experience and intra-physician reliability.[48]

The amount of observations could not allow for a regression analysis. An intra-observer reliability score was calculated by counting the number of photographs each physician measured within a five degree angle and this number was converted to a percentage of the total number of photographs given to each physician (n = 21). [39] Tables and graphs were used to present the findings of the study. All statistical analysis was conducted at the 5% significance level (p = 0.05).

CHAPTER 3

3 Results

3.1 The intra-observer reliability

Table 3.1 below shows the results of the intra-observer reliability in reproducibility of three measurements of an image of the same angle. The table shows an intra- observer reliability to be 5 degrees and less for successive measurements in 75.2% of the images. Only 3 physicians had a range greater than 5 degrees for the measurement of a single image set. Figures 3.1 and 3.2 show the number of photographs measured within a 3 degree and 5 degree range respectively for each physician. Out of the 16 physicians 10 (63%) were able to measure more than half of the images with strong accuracy (within 3-degree range) and all the physicians were able to measure more than half of the images with optimum accuracy (within 5-degree range).

Table 3.1: Hallux interphalangeus angle intra-physician reliability range average

	3 degrees or less	**4 or 5 degrees**	**more than 5 degrees**
Count	12.6	5.3	3.0
Percentage	60.0%	25.2%	14.3%
Count Average = number of radiographs measured within range/number of physicians (16) x number of radiograph sets (21)			

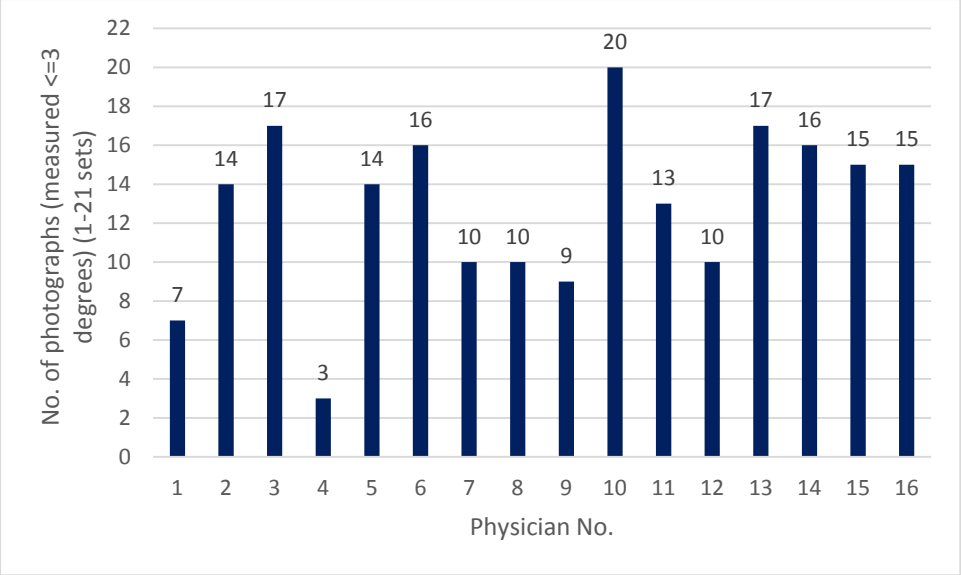

Figure 3.1: Hallux interphalangeus angle measurement (intra-observer reliability) (<=3 degrees)

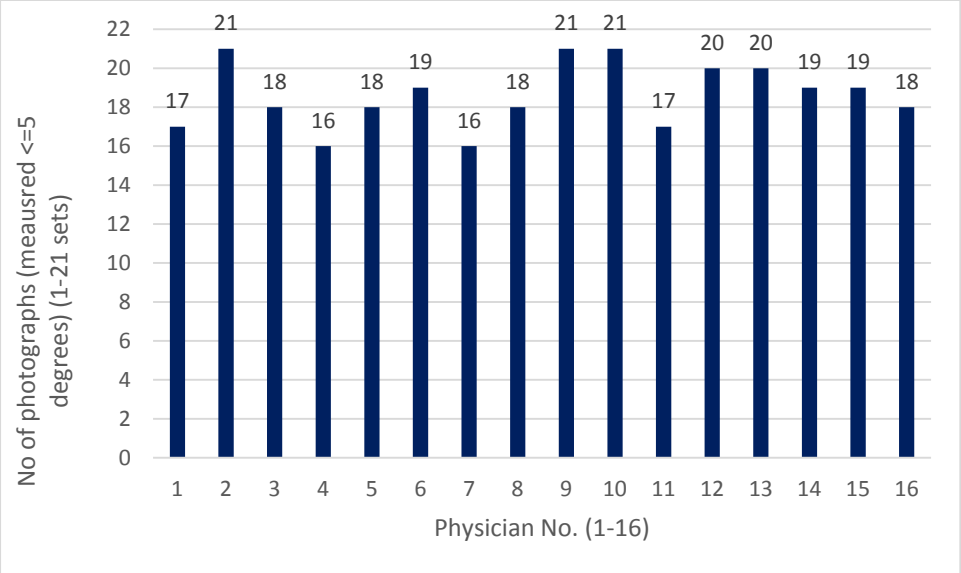

Figure 3.2: Hallux interphalangeus angle measurement (intra-observer reliability) (<=5 degrees)

3.2 The inter-observer reliability

Table 3.2 below shows the results of the inter-observer reliability in reproducibility of three measurements of an image of the same angle. The table shows that on average 11 physicians measured within a range of 3 degrees or less, 12 measured within 5 degrees and less and 4 of the physicians measured above 5 degrees. The same pattern is shown in figure 3.3.

Table 3.2: Hallux interphalangeus angle inter-observer reliability range average

	3 degrees or less	**4 or 5 degrees**	**more than 5 degrees**
Count	11.4	1.4	4
Percentage	54.5%	6.7%	19.0%
Count Average = number of radiographs measured within range/number of physicians (16) x number of radiograph sets (21)			

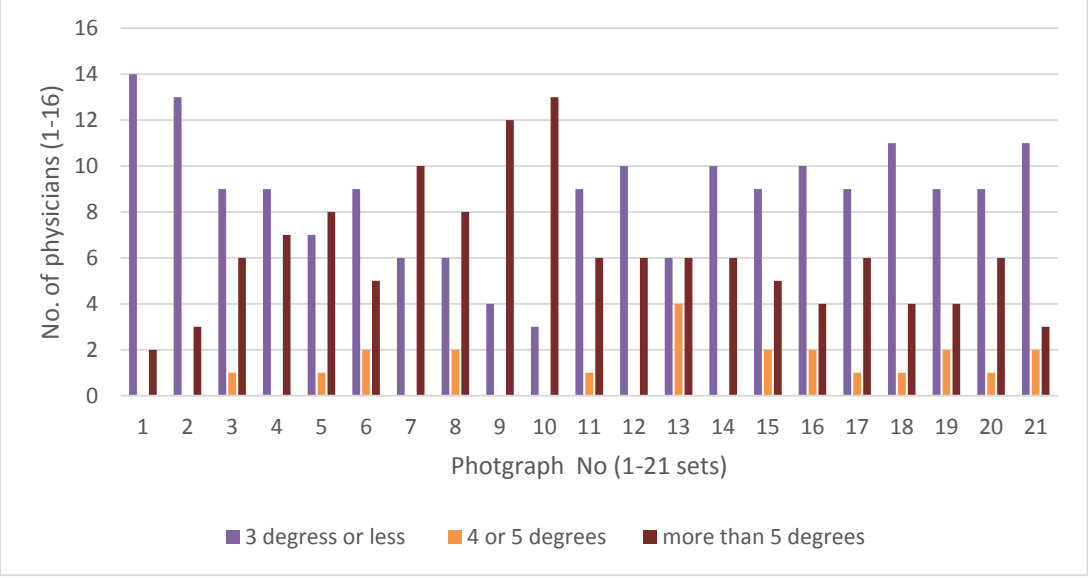

Figure 3.3: Hallux interphalangeus angle measurement (inter- observer reliability) (degree ranges: <=3 degrees; 4 or 5 degrees; more than 5 degrees)

3.3 Association between years of experience and measurement reliability

Figure 3.4 below shows the association between numbers of years of experience as an orthopaedic surgeon and intra-observer reliability score. The figure shows that as year of experience increased, the intra-observer reliability score decreased however there was no statistical significance to this finding as shown by the Spearman's correlation test which shows no significant correlation between years of experience and intra-reliability score.

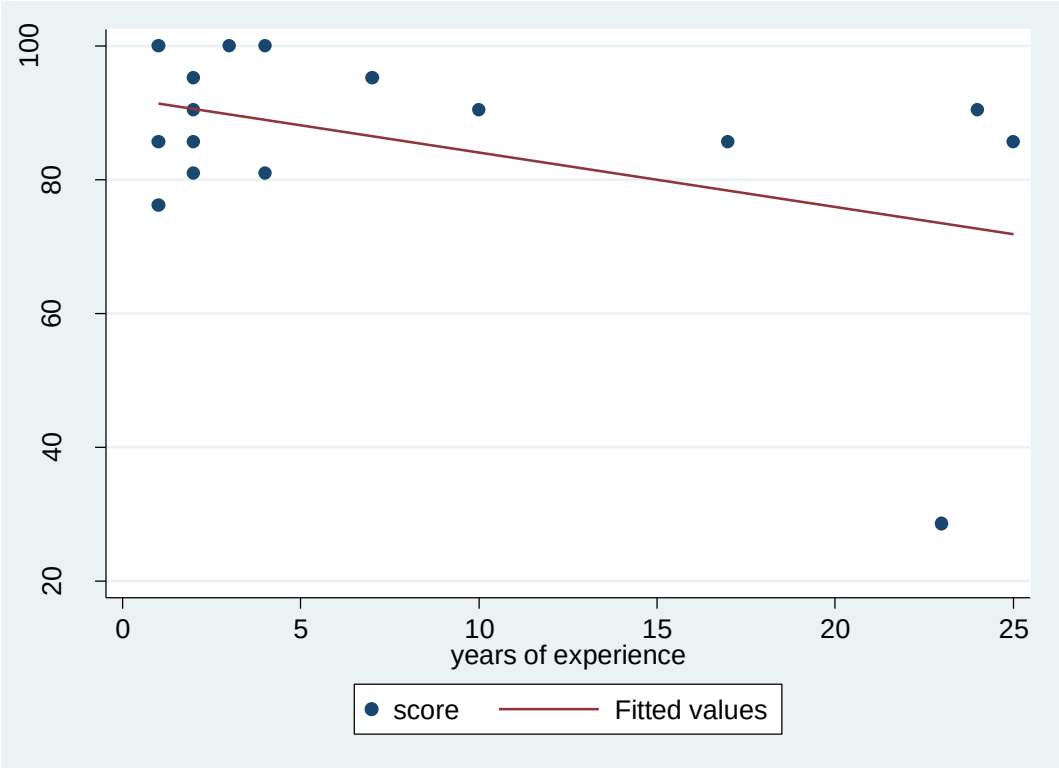

Figure 3.4: Scatter plot with fitted line showing relationship between years of experience and intra-physician reliability score (Correlation coefficient = − 0.07; p = 0.7854)

CHAPTER 4

4 Discussion

4.1 The importance of the hallux valgus interphalangeus assessment

The hallux valgus interphalangeus is a three dimensional deformity (pronation and valgus deformities). In some studies, the flexor halucis longus tendon has been blamed to cause hallux valgus interphalangeus deformity. This tendon will eccentrically pull the distal phalanx and causes rotation of the hallux. By pronation of the hallux the magnitude of the valgus deformity can be masked and radiographic measurement may lead to a false lower value. The hypoplasia of the lateral condyle of the distal phalanx secondary to abnormal pressure during gait was also postulated. [1, 20, 36,47]

The exact prevalence of this deformity is not investigated as yet. Strydom et al. found a very high prevalence of the hallux valgus interphalangeus when they evaluated X-rays of patients who had hallux valgus deformity. According to this study the prevalence of hallux valgus interphalangeus was 62.1%. They have concluded that the contribution of the interphalangeal angle is 37.9%. [1, 20, 36]

The negative linear relationship between interphalangeal angle and hallux valgus angle has been confirmed in many studies. This means that hallux valgus angle increases without increasing in the interphalangeal angle. [20,47]

It is crucial to consider correction of the hallux valgus interphalangeus as a part of the hallux valgus deformity correction. Park JY et al. showed that by correcting the pronation of the hallux, the hallux valgus interphalangeus deformity will be more conspicuous and necessitates correction.

Surgical correction of the hallux valgus deformity will unmask the magnitude of deformity of the hallux valgus interphalangeus. Ignoring correction of the hallux valgus interphalangeus following correction of the hallux valgus negatively will affect patient satisfaction due to sub optimal treatment .[36, 45]

Treatment of the hallux valgus deformity is based on the physical and radiological examination. Various radiographic angles have been described for surgical planning. These angles need to be reproducible and accurate to aid in the surgical planning.[23]

4.2 The reliability and reproducibility of the hallux valgus interphalangeal angle

The Ad Hoc Committee of the American Orthopaedic Foot and Ankle Society introduced reference points on the first metatarsal and proximal phalanx of the hallux to standardise the measurement techniques in measuring the most commonly used angular measurements.[23] However, they did not introduce a reference point for the distal phalanx of the hallux to have more standardized measurement of the hallux interphalangeal angle.

Coughlin et al. showed that measurement of 1 − 2 intermetatarsal angle and the hallux valgus angle is reliable and reproducible. They also concluded that the distal metatarsal articular angle is not as reliable.[39]

The inter- and intra-observer reliability of these angular measurements might improve by using computerised software techniques. No specific soft-ware has been designed for these angular measurements. [22]

Strydom et al. suggested reference points for the distal phalanx of the hallux (see **Chapter 1**) to standardise a method of measurement of the hallux interphalangeal angle.

In this study the investigator found the intra-observer reliability of this technique to be only 75.2% with the hallux interphalangeal angle 5 degrees and less. The investigator also found the inter-observer reliability of this technique with the hallux interphalangeal angle measuring 5 degrees and less to be 62.1%

Furthermore, the investigators did not find statistical significant correlation between the level of experience of the surgeons and consistency of measurements of the hallux interphalangeal angle.

4.3 Recommendations

Despite requesting all the surgeons who have taken part in this research study, to use the standardised techniques, some errors could have led to lower reliability values. Some of these possibilities are as follow:

1- The surgeons had not used the prescribed method of measurement
2- Despite using the prescribed method of measurement , some surgeons had problems finding the reference points leading to different measurement values in each set of images

The investigator has included sixteen orthopaedic surgeons with various level of expertise to conduct this study. Results could have been more accurate by increasing the number of participating surgeons.

The investigator also recommends doing the same study by using current software available from the PACS radiology system and comparing manual *versus* computerised techniques.

CHAPTER 5

5 Conclusion

Hallux valgus interphalangeus is a three dimensional Deformity .This deformity should be sought when surgical treatment of the hallux valgus is being planned. This is the first study performed to assess the inter- and intra-observer reliability of the hallux valgus interphalangeal angle.

By using references points for measurement of the hallux valgus angle and 1 – 2 intermetatarsal angle, the inter- and intra-observer reliability of measurements increase while this study showed this is not applicable for the hallux valgus interphalangeal angle.

The measurement of the hallux interphalangeal angle as recommended by Strydom et al. – using reference points for distal phalanx of the big toe is not highly reproducible and reliable.

Although the previous studies confirmed the level of experience of the surgeons can increase the reliability of measurement of the hallux valgus angle and 1 – 2 intermetatarsal angle, this study showed the level of experience of the surgeon has no effect in hallux valgus interphalangeal angular measurement reproducibility.

CHAPTER 6

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CHAPTER 7

7 Appendices

7.1 Data collection sheet

Evaluator Name:	Evaluator Code:	Evaluator experience:	
	Measurement 1	Measurement 2	Measurement 3
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7.2 Ethics Approval

R14/49 Dr Mohammadali Khademi

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M170279

NAME: (Principal Investigator)	Dr Mohammadali Khademi
DEPARTMENT:	Orthopaedic Surgery Netcare Linksfield Hospital - The Orthopaedic Foot and Ankle Unit
PROJECT TITLE:	Reliability of the Radiographic Measurement of the Hallux Interphalangeal Angle
DATE CONSIDERED:	24/02/2017
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Dr A. Strydom, Dr Z. Mayet and Prof N. Saragas
APPROVED BY:	Professor P Cleaton-Jones, Chairperson, HREC (Medical)
DATE OF APPROVAL:	31/03/2017

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

DECLARATION OF INVESTIGATORS

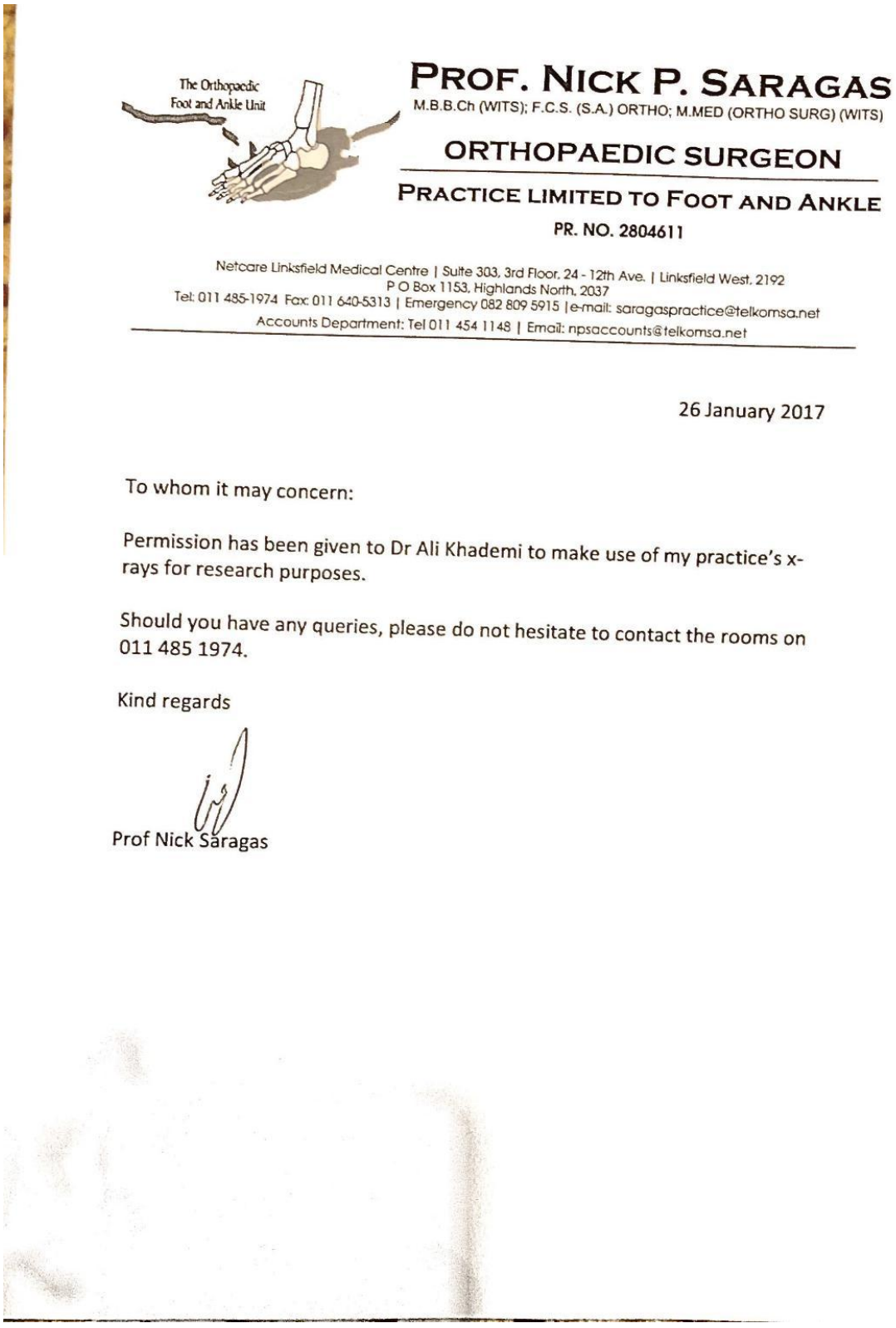
To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary in Room 301, Third Floor, Faculty of Health Sciences, Phillip Tobias Building, 29 Princess of Wales Terrace, Parktown, 2193. University of the Witwatersrand. I/we fully understand the conditions under which I am/we are authorized 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 the application 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 reviewed in 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 28/02/2017

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

7.3 Permission to use X-rays



The Orthopaedic Foot and Ankle Unit

PROF. NICK P. SARAGAS

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26 January 2017

To whom it may concern:

Permission has been given to Dr Ali Khademi to make use of my practice's x-rays for research purposes.

Should you have any queries, please do not hesitate to contact the rooms on 011 485 1974.

Kind regards

Prof Nick Saragas