"RADIOLOGICAL AND MORPHOMETRIC STUDY OF HUMAN METATARSALS AND PHALANGES"

By

Dr. PATIL SHRISH

Dissertation submitted to the
KLE University, Belgaum, Karnataka

In Partial Fulfillment
of the requirements for the degree of

M. D. (ANATOMY)

Under the Guidance of

Dr. S. P. DESAI. MS
Professor

DEPARTMENT OF ANATOMY,
JAWAHARLAL NEHRU MEDICAL COLLEGE,
NEHRU NAGAR, BELGAUM – 590 010, KARNATAKA

APRIL - 2010

KLE UNIVERSITY, BELGAUM, KARNATAKA

DECLARATION

I hereby declare that this dissertation entitled **"RADIOLOGICAL AND MORPHOMETRIC STUDY OF HUMAN METATARSALS AND PHALANGES"** is a bonafide and genuine research work carried out by me under the guidance of **Dr. S. P. DESAI** **MS** Professor, Department of Anatomy, Jawaharlal Nehru Medical College, Nehru Nagar, Belgaum – 590 010.

Date: (Dr. Patil Shrish)

Place: Belgaum

KLE UNIVERSITY, BELGAUM, KARNATAKA

CERTIFICATE BY THE GUIDE

This is to certify that the dissertation entitled **"RADIOLOGICAL AND MORPHOMETRIC STUDY OF HUMAN METATARSALS AND PHALANGES"** is a bonafide research work done by **Dr. Patil Shrish** in partial fulfillment of the requirement for the degree of **M. D. (ANATOMY).**

Date:
Place: Belgaum

Dr. S. P. DESAI. MS
Professor,
Department of Anatomy,
J. N. Medical College,
Nehru Nagar,
Belgaum – 10

KLE UNIVERSITY, BELGAUM, KARNATAKA

ENDORSEMENT

This is to certify that the dissertation entitled **"RADIOLOGICAL AND MORPHOMETRIC STUDY OF HUMAN METATARSALS AND PHALANGES"** is a bonafide research work done by **Dr. Patil Shrish** under the guidance of **Dr. S. P. Desai.** MS, Professor, Department of Anatomy, J. N. Medical College, Nehru Nagar, Belgaum – 10.

Dr. V. S. SHIROL MS
Professor and Head,
Department of Anatomy,
J. N. Medical College,
Nehru Nagar, Belgaum – 10

Date:

Place: Belgaum

Dr. V. D. Patil MD,DCH
Principal,
J. N. Medical College,
Nehru Nagar, Belgaum – 10

Date:

Place: Belgaum

KLE UNIVERSITY, BELGAUM, KARNATAKA

COPYRIGHT

DECLARATION BY THE CANDIDATE

I hereby declare that the KLE University, Belgaum, Karnataka shall have the rights to preserve, use and disseminate this dissertation in print or electronic format for academic / research purpose.

Date :

(Dr. Patil Shrish)

Place : Belgaum

ACKNOWLEDGEMENT

It is my privilege to express my heartfelt gratitude to **Dr. S. P. Desai** MS, Professor, Department of Anatomy, J. N. Medical College, Belgaum, for being a source of encouragement and inspiration throughout the period of the study. His constant efforts in guiding me, with his suggestions, constructive criticism and kind help are gratefully acknowledged.

I thank **Dr. V. S. Shirol** MS, Professor and Head of Department and **Dr. P. S. Jevoor** MS, Professor, Department of Anatomy, J. N. Medical College, Belgaum, for all the help rendered me during the study. I thank all staff and my colleagues in the Department of Anatomy, J. N. Medical College, Belgaum, for their encouragement and help.

I thank **Dr. R. V. Mali** MD, Professor and Head of Department, and the staff, especially **Mr. A. R. Yadur**, Sr.Technician, Department of Radiology, J. N. Medical College, Belgaum for the support and technical help given to me.

I thank **Mr. M. D. Mallapur** M. Sc, Lecturer in Statistics, J. N. Medical College, Belgaum for his time and help in the statistical analysis of the data.

I thank **Dr. V. D. Patil** MD, DCH, Principal, J. N. Medical College, Belgaum for permitting me to carry out this study.

I thank all my family members and friends who gave their time undemanding without complaints and for being the reason of the timely completion of my study. I have no words to acknowledge adequately the sacrifices they have made, just so that I can complete my work on time.

Finally, my everlasting gratitude to God for his blessings.

Date: Dr. Patil Shrish

Place: Belgaum

LIST OF ABBREVIATIONS USED

AP-	Anteroposterior
AO/ASIF-	Arbeitsgemeinschaft fuer Osteosynthesefragen, Association for the Study of Internal Fixation
cm-	Centimeter
mm-	Millimeter
MT-	Metatarsal
PP-	Proximal phalanx
MP-	Middle phalanx
DP-	Distal phalanx
CTEV-	Congenital Talipes Equino Varus
3-D -	Three dimensional
SD -	Standard deviation
SEE -	Standard Error of Estimate

ABSTRACT

Background and objectives -

The feet have a major role in human evolution and continue to play a significant role in present day human endeavours. Consequently, alterations, deformities and disorders of the feet have a significant bearing on an individual's capacity to live life fully and successfully. The functional and aesthetic harmony of the feet may be grossly affected even if there is a small disturbance in the proportions and the relations of the bones of the feet. A fixed correlation between the metatarsals amongst themselves and phalanges amongst themselves can be used to assess, analyze and treat disharmonious metatarsals and phalanges. Orthopaedicians and podiatrists will have a tool for a more accurate prediction of outcome of surgeries. Standardized radiographs of the feet provide a cheap, reliable and non-invasive technique for length and breadth measurements of metatarsals and phalanges.

Methods -

Plain AP radiographs of the feet were obtained by a standardized technique, in sixty volunteers above the age of twenty two years and screened for readability. Lengths and breadths (mid-shaft thickness) of the metatarsals and lengths of phalanges were measured using calibrated vernier calipers. The data were tabulated. A fixed correlation was arrived at, with respect to dimensions of the bones amongst their own group. Formulae for stature estimation were calculated using simple regression methodology. Best fit multiple regression equations were also calculated.

Results -

The longest metatarsal in both the sexes was the second metatarsal (67.61mm ± 3.49 in males and 62.46mm ± 3.45 in females). The shortest metatarsal was the first metatarsal (56.42mm ± 4.41 in males and 50.09mm ± 3.06 in females). The widest metatarsal was first metatarsal (13.7mm ± 1.00 in males and 11.7mm ± 0.91in females) and the least thickness

was that of third metatarsal (6.8mm ± 0.65 in males and 5.9mm ± 0.57 in females). The best multiple regression equation for stature estimation was 81.139 + 1.608 MT4 + 0.261 MT5 in males and 88.978 + 0.014 MT4 + 1.112 MT5 in females. Fixed correlation was found between the lengths, and also between the thicknesses of bones of the feet amongst their own group.

Conclusions and interpretation -

Morphometry of metatarsals and phalanges using radiographs of the feet is a simple and reliable tool for arriving at a fixed correlation amongst the bones of the feet and in estimating stature of individuals.

Key words -

Metatarsals; Toe phalanges; Metatarsalgia; Forensic anthropology; Stature; Regression analysis; Radiography; Foot

CONTENTS

LIST OF TABLES

LIST OF GRAPHS

LIST OF FIGURES

INTRODUCTION

The human foot is a marvel of engineering and mechanics, as much as, if not more than any other body structure. Dr. Fredrick Wood Jones (1949), a noted anthropologist and anatomist, states - "Man's foot is all his own, unlike the hand which is built on the basal plan prevailing in the manus of a tortoise. The human foot on the other hand is unlike any other foot. It is a human specialization and whether he be proud of it or not, it is his hallmark and so long as Man has been Man and so long as he remains Man it is by his feet that he will be known from all other members of the animal kingdom".[1]

"While upright posture and the ability to run and walk on two feet is not in itself regarded as a rubicon, it should, nevertheless, probably be looked upon as the critical pre-adaptation responsible for the origin of man".[2]

The foot, having evolved from a relatively unspecialized hand-like member[3], is specialized for two basic actions. One is of bearing weight while standing upright and another is of locomotion. The line of gravity after passing in front of the ankle is resolved into radiating components. All the metatarsal heads bear weight. The first metatarsal bears double the weight of each of the remaining four.[4] The weight is distributed in the ratio of 2:1:1:1:1.[3]

Any disturbance in the distribution of this load because of alterations in the linear structure of the forefoot may lead to functional disorders. While standing erect at one place, the body swings to and fro on the feet. This leads to a continuous shifting of line of gravity in front of the ankle joint, over a small range. To keep the body upright, during the continuous shifting of line of gravity, the strain is distributed over the forefoot consisting of metatarsals and phalanges. During the gait cycle, weight from the hindfoot is transmitted forward via three bony columns of the fore and midfoot.

Alterations in the various structures of the foot have a causal relationship with alterations in lower extremity kinematics that may predispose an individual to characteristic musculoskeletal injuries.[5] These structural variations may be isolated only to the feet as in Congenital Talipes Equino Varus (CTEV), or may be part of complex congenital syndromes

affecting various organ systems, such as Laurence- Moon- Biedel- Bardett syndrome, Grebe syndrome, Gorlin - Sedano syndrome, F- Syndrome etc.

Any disturbance in the relative lengths and widths of the bony components of the forefoot may lead to pain in the feet, gait disturbances and subsequent inability to perform ones duties optimally.

Comparative anatomy studies of the forefoot bones have provided clues about evolution of man. The shape and orientation of the metatarsal heads and orientation of the proximal phalanges have been analyzed for anthropological studies to explain the mechanical changes that accompanied the transition to terrestrial bipedality.[6] Differences between the relative lengths of the metatarsals have been used to explain evolutionary changes.

The small bones of the feet are more resistant to postmortem changes than other bones, and are more often found intact.[7] This property has been used in identification of unclaimed bodies for medico-legal purposes and in forensic anthropology in sexing of bones and stature estimation.

With the advent of industrialization, grievous musculoskeletal injuries, especially of the feet, are on the rise. Several surgical procedures are in practice to reconstruct the foot to achieve correct biomechanical results. Many surgical procedures involving implants, especially of the first metatarso-phalangeal joint, are available for relief of severe symptoms and disabilities.

Thus, a wide range of studies, from evolution and anthropology, forensic anthropology, surgeries for trauma, reconstructive and plastic surgeries, implantology, diagnosis of genetic syndromes, to kinesiology and biomechanics require morphometric data of metatarsals and phalanges. Very few such studies have been published world over and data on Indian population is scarce.

The present study has been done to provide the basic data for further studies, to find if a correlation with respect to lengths and widths of metatarsals amongst themselves and lengths of phalanges amongst themselves exists, and if a mathematical relation can be found between the lengths of metatarsals and stature, in Indians.

OBJECTIVES

1. The aim of this study is to measure the lengths and widths of metatarsals, and lengths of phalanges of the feet, on radiographs, in Indians.

2. To determine the possible correlation between the metatarsals amongst themselves, and phalanges amongst themselves.

3. To determine the regression equation of stature on metatarsals.

REVIEW OF LITERATURE

Historical review of studies on the human forefoot-

Problems of the feet, diseases affecting them and various corrective procedures have interested researchers and surgeons since centuries. Mention is made of Reverdin having devised a surgery for hallux valgus in the year 1881 by several authors.[8] Mayo (1908) practiced resection of head of the first metatarsal for the relief of bunion, operating on sixty five cases since the year 1900.[9] Frieberg in 1914 was the first to present six cases of infraction of head of second metatarsal and attributed it to excess lengths of metatarsals causing increased stress on them.[10]

Meisenbach (1916) had proposed raising the anterior arch to relieve pain in the region.[11] Boorstein (1916) reported a case of short metacarpals and short metatarsal in an individual with history of similar anomaly in nine other members of her family.[12] Hohmann (1923) was the first to report an osteotomy operation devised for the correction of hallux valgus.[8]

Morton (1924) had recognized disorders of the feet as the second most common and most widely spread form of physical impairment among civilized peoples of those days.[13] Peabody (1931) reported a bunionectomy first employed by him in 1922. Internal fixation was a significant modification over Hohmann's procedure.[14] Engle and Morton (1931) noted, in the natives of Africa, congenital deformities of the toes, especially the fourth digit and attributed it to retardation of growth of the metatarsal bone.[15] Fischer and Vandemart (1945) reported a rare case of bilateral symmetrical shortening of metacarpals and metatarsals.[16]

Over the years researchers have reported that surgical shortening of first metatarsal may lead to a secondary metatarsalgia.[8] Researchers in 1949 had contested the theory that surgical shortening of first metatarsal is the only cause of foot disability.[17] This was opposed by other researchers who attributed the shortening of first metatarsal in forcing the other metatarsals to bear weight previously borne by it and thus increasing the compression stress on the adjacent metatarsal heads leading to their fracture.[18] Mckeever(1952) was the first to

propose a surgery for treatment of plantar keratosis by shortening the first metatarsal. Giannestras (1958) modified the technique further.[19] Wilson (1963) devised a new surgery for treatment of adolescent hallux valgus.[20] For correction of adolescent hallux valgus, Kellikian lists at least 130 surgical approaches.[21, 22]

Studies by Viladot (1973) attribute metatarsalgia due to non-local causes, mainly to alteration of the fine biomechanics of the fore-foot. Toes have been grouped based on their lengths of the metatarsals.[4] Helal (1975) proposed an oblique osteotomy in the distal half of the metatarsal.[23] In 1983, Gudas et al described the Z bunionectomy for hallux valgus correction.[21] Chiappara(1985) described surgical shortening of first proximal phalanx combined with shortening of proximal ends of the middle three metatarsals and lengthening of medial cuneiform.[24]

Sherref (1990) conducted radiographic studies on weight bearing and non-weight bearing feet.[25] Various authors such as Takakura (1997), Masada (1999), Kucukkaya (2002) and Lamm (2006) have described procedures on metatarsals for lengthening and shortening.[26, 27, 28]

Anatomy of the metatarsals and phalanges -

The human foot has twenty six bones, which may be classified into three sections- hindfoot, midfoot and forefoot. The forefoot represents one half of the overall length of the foot. It is made up of miniature long bones: the five metatarsals and fourteen phalanges. Weight distribution occurs through three conceptual bony columns. The lateral column is made up of the calcaneus, the cuboid, the fourth and fifth metatarsals and their six phalanges. The medial column comprises the calcaneus, talus, navicular, medial and middle cuneiforms, first and second metatarsals and phalanges of first and second digits. Between these two columns lies an intermediate column made of lateral cuneiform, the third metatarsal and phalanges of the third digit. The lateral column being more flexible allows for easy conformity to the uneven surfaces during walking on irregular ground. The medial column is more rigid than the lateral column to allow weight bearing and has more mass in its component bones.[29] Except for the first; the metatarsals are long and slender with heavy

proximal bases and small laterally compressed heads. This is in contrast with metacarpals which have large rounded heads and smaller bases. The metatarsals narrow down distally.

The metatarsals-

The metatarsals have some common characteristics - the body is prismatic in form, narrows down gradually, proximo-distally and is curved longitudinally with concavity downwards. The base articulates with the tarsal bones, and with the contiguous metatarsal bones. The dorsal and plantar surfaces are rough for the attachment of ligaments. The head has a convex articular surface, oblong from above downward and extending farther below than above. The sides are flattened, and on each is a depression, and a tubercle. The plantar surface is grooved antero-posteriorly for the passage of the flexor tendons, and marked on either side by an articular eminence continuous with the terminal articular surface.

The first metatarsal bone is the thickest and the shortest of the metatarsals. The base, as a rule has no articular facets on its sides but occasionally it articulates with the second metatarsal by an oval facet. Its proximal articular surface is large and kidney-shaped. The head is large and on its plantar surface are two grooved facets separated by a smooth elevation. The sesamoid bones glide on these facets.

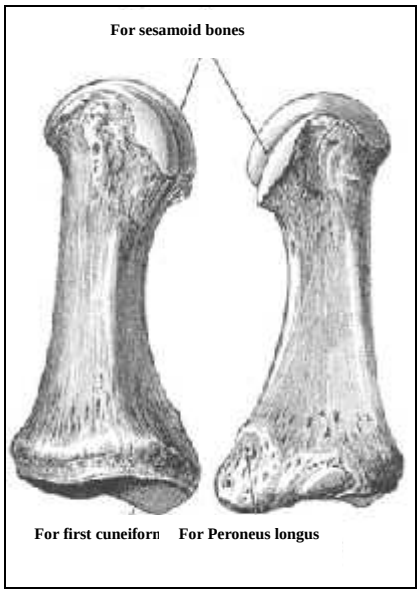


Figure 1 – First metatarsal

The second metatarsal is the longest of the metatarsal bones. It extends into the hollow formed by the three cuneiforms. Its base is broad above, narrow and rough below. It has four articular surfaces for articulation with the three cuneiforms, the third metatarsal and occasionally an additional oval facet for the first metatarsal.

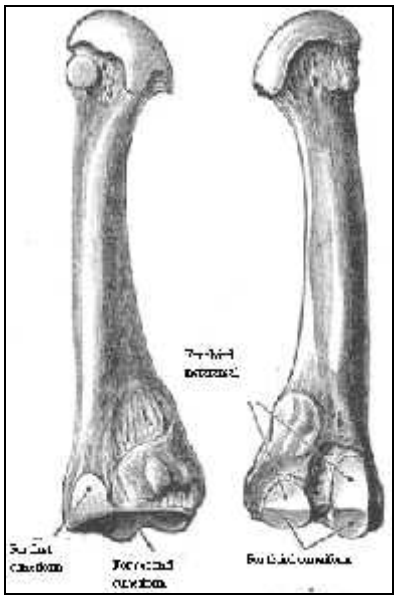


Figure 2 – Second metatarsal

The third metatarsal bone articulates with the lateral cuneiform, the second metatarsal and the fourth metatarsal. The fourth metatarsal bone is smaller than the third. The base articulates with the cuboid, the third and the fifth metatarsals and the lateral cuneiform. The fifth metatarsal bone can be recognized by the presence of a tuberosity (Styloid process). The metaphyseal-diaphyseal junction of the fifth metatarsal base is prone to traumatic or stress fracture and these have a tendency to delayed or non-union. The base articulates with the cuboid and the fourth metatarsal.

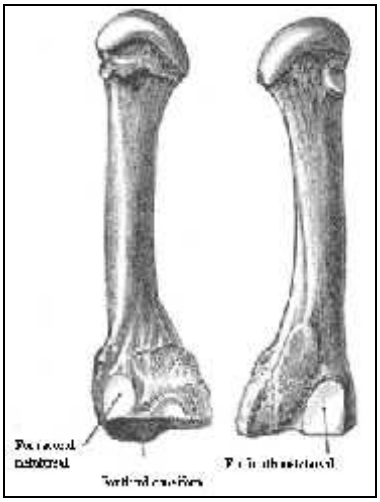


Figure 3 – Third metatarsal

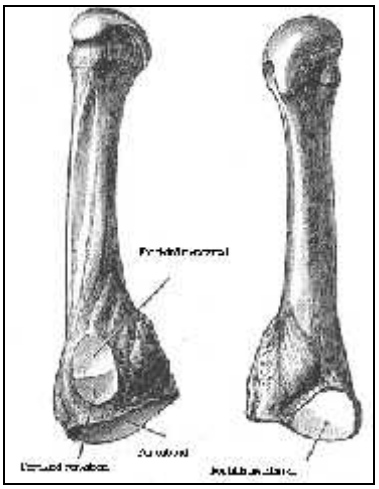


Figure 4 – Fourth metatarsal

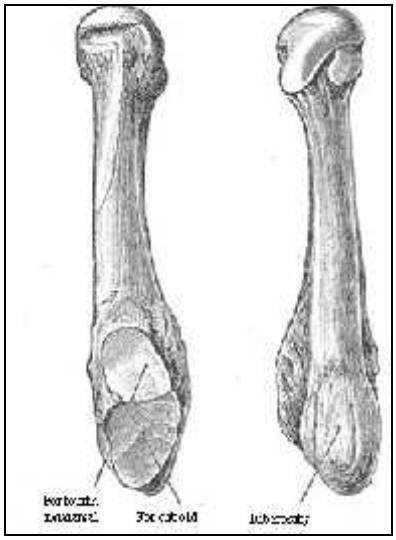


Figure 5 – Fifth metatarsal

Articulations of the metatarsals are shown in Figure 6.

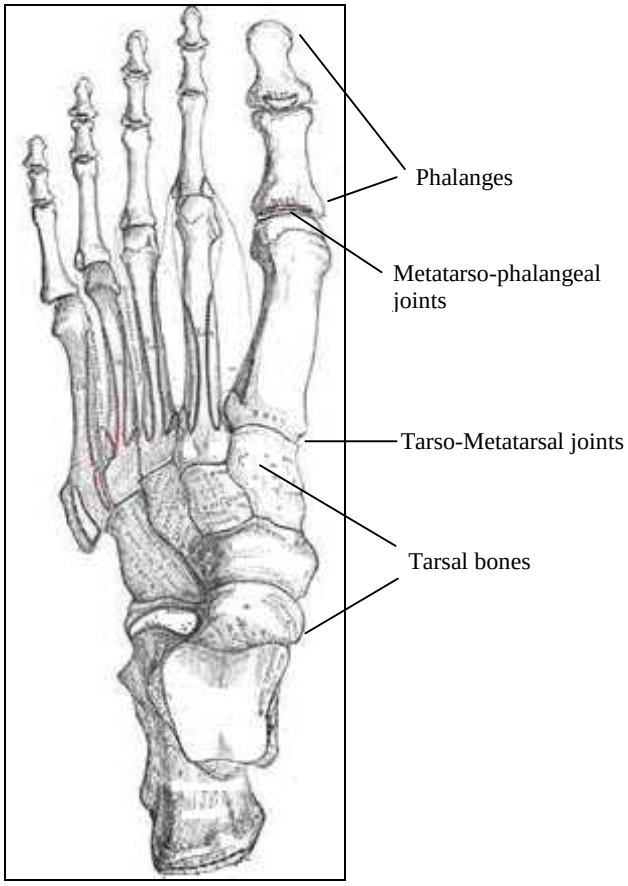


Figure 6- Articulations of the foot

The Phalanges of the Foot -

The number and general arrangement of phalanges of the foot correspond, with those of the hand. There are two in the great toe, and three in each of the other toes. They differ from them; however, in their size, the bodies being much reduced in length, and are laterally compressed, especially in the proximal row. Proximal phalanges - The body of each is compressed from side to side, convex above, concave below. The base is concave and the head presents a trochlear surface for articulation with the second phalanx. Middle phalanges - The phalanges of the second row are remarkably small and short, but rather broader than those of the first row. Distal phalanges resemble those of the fingers but are smaller and flattened from above downward; each presents a broad base for articulation with the

corresponding bone of the second row, and an expanded distal extremity for the support of the nail and end of the toe.

Ossification of the bones of the forefoot- The metatarsal bones are each ossified from two centers (except for the fifth metatarsal which has three centers) one for the body, and one for the head, of the second to fifth metatarsals; one for the body, and one for the base, of the first metatarsal. Ossification commences in the center of the body about the ninth to tenth week. The center for the base of the first metatarsal appears about the third year. The centers for the heads of the other bones appear between the third and fourth years. They fuse with the bodies between the seventeenth and twentieth years. The fifth metatarsal has an additional center for the tuberosity (an apophysis).

The phalanges are each ossified from two centers: one for the body, and one for the base. The center for the body appears between the second and the fourth years and, that for the base between the fourth and tenth years. It joins the body about the eighteenth year. Considerable variations are seen in the ossification patterns of the phalanges.

Blood supply of metatarsals and phalanges- Dorsal and plantar metatarsal arteries supply all the metatarsals. The first metatarsal has an additional superficial branch of medial plantar artery supplying it and the fifth metatarsal has an inconsistent fibular marginal artery supplying it. The proximal phalanges receive blood from dorsal digital arteries, middle phalanges from plantar and dorsal digital arteries and the distal phalanges from plantar digital arteries. Venous drainage is through dorsal digital and dorsal metatarsal veins.

Nerve supply- The first and the second metatarsals receive branches from deep peroneal nerve and medial plantar nerve. The third and the fourth metatarsals receive branches from deep peroneal and lateral plantar nerves. The fifth metatarsal receives branches from sural, superficial peroneal and lateral plantar nerves. The phalanges are innervated by plantar and dorsal digital nerves.[30]

Evolution of the human foot.

The greatest advance in locomotion was initiated when vertebrates emerged from water to land, and levers in the form of legs came upon the scene. The human foot is practically at right angles to the body – a change necessitated by erect posture. Man is plantigrade i.e. the phalanges, the metatarsals and even some tarsals touch the ground. Birds, cats and dogs are digitigrades - ankle is lifted off the ground. Horses and cattle are unguligrade- terminating in hooves. Man has a long road to travel before he reaches the extreme stage of pedal evolution attained by the horse.[31]

It has been proved beyond doubt that man has evolved from apes. One of the most important adaptations Man had to incorporate was total bipedality. For this, the foot had to evolve from being an organ of prehension to be an organ with an ability to sustain static weight of the body over long periods of standing and also adapt to the highly irregular surfaces over which he had to walk, run and jump. Though most of these changes occurred in the joints[32] some changes occurred in the individual bones too. An understanding of the evolutionary development of the human foot is of definite value in providing a fuller comprehension of its weaknesses and may possibly indicate newer methods of prevention and treatment[13] of diseases of the foot.

Although the gorilla resembles Man more closely than does the chimpanzee in relative shortness of the lateral digits, it shows no indication of the more fundamental changes essential for the development of the human condition. The fundamental similarity in architecture of the feet of the chimpanzee and man leaves no doubt as to the evolution of the human foot from that of an ape. In the chimpanzees, when the heel is lifted off the ground, pressure is transferred not to the region of metatarsal heads but to the toes unlike in man. It is unquestioned that the distal portions of the metatarsals have undergone changes in which the bases have not participated.[32]

Apart from torsion of heads of the metatarsals with respect to their bases, another important difference between man and chimpanzees is the shorter lateral four metatarsals and their phalanges in man. Of the bones of the toes, the second phalanges have undergone actual

reduction in length.[32] Definite structural changes, such as metatarsal lengthening and loss of some divergence of the hallux occurred during the course of evolution when the foot was no longer necessary for a firm grasp of tree branches.[13] The digits and metatarsals of the gorilla have become shorter and the strong development of the first and second metatarsals over that of the three other metatarsals clearly shows that they are used in a distinct leverage function.

The general increase in size of the foot led to a basic alteration in the line of leverage of the foot. It changed from being along the line of third metatarsal to the present day form i.e. along the line of second metatarsal which extends more distally than other metatarsals.[13] In the process of adapting to the terrestrial mode of life no part of the pre-human frame would be so greatly or intensively influenced as would the feet. The first metatarsal has undergone considerable evolutionary changes, to attain its human characters. It has grown in length and thickness and adducted itself to lie parallel to others.

In the modern human foot, conditions have been acquired, which by their complete conformation to engineering principles, are ideally adapted for support and also for propulsive leverage in the horizontal plane, as well as in the vertical plane.[13] In terms of human evolution in the broader context, it is now generally considered that the development of obligate bipedal locomotion was one of the most significant adaptations to occur within the hominin lineage. The foot is particularly specialized in both its anatomy and its function. This makes perfect sense, because in developing bipedal locomotion, the foot becomes the only structure that directly interfaces with the ground, and subsequently is under strong pressure to deal with both balance and propulsion in a highly efficient way.[33]

An understanding of the evolutionary development of the human foot would be of definite value in comprehending fully the weaknesses of the foot. It is the foot, rather than the hand, which separates the human from the sub-human.[34]

Embryology of the human foot-

The first visible hint of the developing lower extremity is a swelling on the ventrolateral surface of the 4-week-old embryo, a few days after the appearance of the upper limb bud. The lower limb bud is located opposite the five lumbar and first sacral somites.

Over the next few days, the bud develops a distinctive morphology with a flattened ventral surface and a rounded dorsum. By end of the fourth week an apical ectodermal ridge appears. This transient structure is critical in maintaining limb outgrowth.[35] Toes are formed when cell death in apical ectodermal ridge separates it into five parts.

In the sixth week, a flat, rounded foot disk develops, oriented in a transverse plane. Also at this time mesenchymal condensation occurs. The footplate soon begins to rotate inward, clockwise on the right and counterclockwise on the left. This results in the flexor surface obliquely facing the median sagittal plane of the embryo. The foot is more or less continuous with the leg, showing no dorsal angulation. Morphologically, the foot is divided into two regions (i) cranial (preaxial) and (ii) caudal (postaxial) linked with the tibia and fibula. The preaxial region comprises the second ray and the talus, navicular, and cuneiforms. The postaxial region comprises the third ray, cuboid, and calcaneus. In the seventh and eighth week, the foot will continue to develop so that the 5 rays evolve into a more fanlike structure.

Endochondral ossification begins first within the central metatarsals. The most apical (third) toe is the longest, and footpads develop on the plantar surface. In the seventh week, both feet are nearly sagittal in orientation. There is as yet no dorsal angulation at the ankle, and the whole leg is, in essence, in external rotation. Medial rotation of the bud causes the great toe to lie on medial side. The toes and metatarsals are divergent. The stage of ossification now proceeds. First to ossify are the distal phalanges and metatarsal shafts (week 9-10) followed by the proximal and middle phalanges.[35] Bohm (1929) described the development of the foot in four stages based on the degree of equinus, adduction and pronation.[36] At birth the feet are usually inverted with a greater degree of dorsiflexion.[30]

Several processes interfere with the normal development of feet. Common developmental defects of the first metatarsal are - (i) Metatarsus atavicus: considerably short metatarsal, (ii) Metatarsus primus varus: the first metatarsal remains abducted, causing the axis of the foot to shift to lateral side and shifting of weight of the body largely onto second and third metatarsals, and (iii) Hypermobile first metatarsal: strain is again transferred to

lesser metatarsals. These three errors are usually compensated for by increased strength and thickness of the second and third metatarsals and by the activity of muscles of the foot.

Congenital short fourth metatarsal is of unknown aetiology. It has been proposed to be due to premature closure of the epiphysis although no explanation as to why early closure should occur, is provided.[38] A rare ossification defect of the tubular bones of hands and feet called the 'Longitudinal epiphyseal bracket' or 'Delta phalanx' leads to a progressive shortening and angulation deformities of involved bones. The deformity contains an abnormal secondary ossification centre.[27]

Radiographic analysis of the feet, utility and validity of radiographic measurements-

Radiography is often the only investigative procedure required for evaluation of the feet. It is a cheap and rapid procedure with minimal side effects on the subject / patient and offers an easily retrievable medium of investigation. Assessment of the 'metatarsal parabola' and 'metatarsal parabola angle' is used to identify an abnormal length metatarsal. The metatarsal parabola is constructed on an AP radiograph of the foot by connecting the distal ends of the first, second and the fifth metatarsals. The metatarsal parabola angle is the angle between a line joining the distal ends of the first and second metatarsals and a line joining the distal ends of the second and the fifth metatarsals. Normal value of metatarsal parabola angle is 142.50^0. Bilateral radiographs are useful, in assessing patients with multiple short metatarsals. With an AP radiograph and measurement of metatarsal parabola the amount of lengthening can be determined. It has been noted that on a radiographic examination, a short metatarsal is typically deviated as compared to adjacent normal metatarsals.[28]

Weight bearing antero-posterior, lateral, medial oblique foot and ankle radiographs allow for accurate surgical planning and assessment of metatarsal deformities. Obtaining bilateral foot films can also be very helpful for surgical planning. Radiographic assessment of the short metatarsals on AP and lateral views is very important for formulating a pre-operative plan and in placement of the external fixator and the osteotomy level.[28] Pre-operative AP radiographs of both feet have been used in assessing the immediate and long-term outcome of

surgeries for hallux valgus. Comparison of lengths of metatarsals on radiographs of contralateral and ipsilateral feet has helped in assessment of osteotomies done bilaterally and unilaterally.[39] Pre-operative evaluation of radiographs, including the length measurements of metatarsals along with other parameters is important to ensure use of the most efficacious surgical procedure for correction of hallux valgus, in each patient.[40] Radiographic measurements of the first metatarsal and its phalanges compared between normal controls and patients with incipient hallux valgus limitus have revealed significant differences in relative first metatarsal protrusion, lengths and widths of first metatarsals, lengths of first and distal phalanges and total length of hallux.[41]

In the evaluation of surgical techniques for correction of hallux valgus, pre and post-operative radiographs have been used by other researchers. Apart from angular measurements, length changes were also measured. Studies using radiographs of the feet have been used to propose newer theories and also to refute older theories of, cause of second metatarsal hypertrophy.[42] Newer surgical techniques and concepts have been devised utilizing radiographic assessments of procedures. Baek and Chung earlier had viewed favorably, lengthening of metatarsal by using iliac bone graft. Later along with Kim, utilizing pre-operative radiographic measurements and planning they could achieve the same surgical outcome by combined lengthening and shortening procedures without going in for bone graft harvest from a second site.[43, 44]

Conversion factors, to quantify the amount of magnification imparted on a radiograph have been calculated using radiographic and direct measurements on preserved bone specimens. These factors are of value in the pre-operative assessment of patients.[45]

Opposition to use radiographic measurements as the sole criterion for formulating treatment plans has been advanced by a few surgeons.[2] Some researchers prefer basing surgical corrections on intra-operative assessments rather than radiographic measurements. But, for assessing the outcomes of surgeries they have relied on radiographic measurements in addition to clinical scoring systems.[46]

The utility of using radiographic assessment of the feet in diagnosis and treatment of foot pathologies thus cannot be denied.

Diseases of the foot-

The human foot, though a marvelous feat of engineering by nature, has numerous afflictions affecting it. An individual is estimated to take ten to fifteen thousand steps in a typical day.[47] Disabilities of the feet may range from being minor irritants in daily life to severe conditions that limit normal activities. Cosmesis is also seen to be assuming a larger role than previously, especially in the fairer sex. The foot has matched up quite admirably with the responsibility of carrying the weight of the body in static conditions and propelling it during locomotion over a wide variety of surfaces. Trauma is assuming much importance in the modern industrialized world. Reconstructive surgeries to put a man back on his feet, literally, are being practiced more frequently with much success in such a scenario.

Some of the disabilities/ diseases of the hind foot are- flat foot, club foot, talo-calcaneal bar, congenital ligament laxity etc. These disorders also affect the fore foot, though indirectly. Affections of the bones and joints of the metatarsus mentioned under developmental anomalies, lead to clinical conditions such as hallux valgus, hallux varus, hallux rigidus, hallux extensus, hallux flexus, metatarsalgia, march foot / fracture, Frieberg's infraction (Kohler's disease) of the metatarsal head, etc.[37] The diseases of the foot may be limited to the foot itself or may be part of a much more extensive syndrome affecting other parts and organs of the body. They may be congenital or acquired or may be iatrogenic. Congenital metatarsal and metacarpal abnormalities may raise the possibility of various syndromes such as Laurence-Moon-Bardett-Biedel syndrome, Grebe syndrome, Gorlin-Sedano syndrome and Rett syndrome to name a few.[48] Shortness of first metatarsal may be associated with Tibial aplasia[48] or with hamartomatous syndrome.

Synostoses of fourth and fifth metatarsals have been described as part of multiple congenital anomaly patterns in different syndromes. Absence of metatarsals has been described along with absence of tarsals and both tibia. Lesser toe abnormalities are among the most common of all foot and ankle disorders. Eg- Hammer toe, Claw toe, Mallet toe, Curly

toe, etc.[47] Incidence of industrial injuries to the metatarsals, excluding toe avulsion injuries is most common in first and second metatarsals.[49]

Some of the diseases of the feet with relevance to the lengths of metatarsals and phalanges are reviewed.

Abnormalities of the hallux-

Hallux valgus (Bunion)- Lateral deviation of the great toe; is not a single disorder as the name implies, but is a complex deformity of the first ray that frequently is accompanied by deformity and symptoms in the lesser toes. Controversy still continues over which deformity is the essential lesion in hallux valgus: metatarsus primus varus or lateral deviation of great toe. Hallux valgus may be familial, especially when it occurs in the adolescents. Abnormally long first ray is also implicated in the aetiology. The hallux valgus condition may lead to varus of the first metatarsal, valgus of the great toe, bunion formation, arthritis of first metatarso-phalangeal joint, hammer toe of one or more toes, corns, calluses or metatarsalgia.[50]

Juvenile hallux valgus in adolescents should be considered separately from the adults with the disability for several reasons. One of the important reasons is that osteotomy of the first metatarsal is almost always a necessity. Hallux varus and intrinsic minus hallux is a complication of hallux valgus surgery first described in the year 1935. Hallux rigidus- refers to limitation of motion of first metatarso-phalangeal joint of the great toe. The term was coined by Cotterill in 1888. Davies- Connelly called it hallux flexus in 1887 and had reported the resection of base of proximal phalanx for this disorder. Even today the exact pathogenesis is not explained. One of the causes suggested is an abnormally long first metatarsal.[50]

Lesser toe abnormalities-[51]

Metatarsophalangeal joint instability- Deformity of lesser toes, particularly of second toe, sometimes is related to instability of the metatarso-phalangeal joint. It is a well recognized problem, common in women wearing high heeled shoes and in athletes with chronic overuse and hyperextension of toes. Common to both groups is the prevalence of a long second metatarsal, which in a study was reported in 90% of patients and averaged

4 millimeters in excessive length. Claw and hammer toes- Claw toe is abnormal flexion deformity of the proximal interphalangeal joint with extension deformity of metatarso-phalangeal joint. Flexion at distal interphalangeal joint may be present. Hammer toe is abnormal flexion deformity of the proximal interphalangeal joint without flexion at distal interphalangeal joint with or without extension deformity of metatarso-phalangeal joint. Hammer toe is usually limited to a single toe while claw toe may affect several toes at the same time. Of the several factors responsible for claw and hammer toes, anatomical factors include a long second ray which may result in buckling of the toe and hallux valgus, causing pressure against the second toe. Long term use of poorly fitting shoes is thought to be responsible for development of hammer toe deformity. Mallet toe is flexion deformity of distal interphalangeal joint. It may be an isolated entity or may exist in conjunction with hammer toe. Its cause is uncertain, but it commonly occurs in the second toe which is the longest toe.

Corns (Melomata and Clavi) are hyperkeratotic lesions. They may be hard or soft type. The soft corns on base of shorter toe, head of proximal phalanx of longer toe and the base of the web space of the fourth toe are associated with an abnormally short fifth metatarsal. Intractable plantar keratosis (Plantar corn) may be associated with an abnormally long metatarsal.[51]

Frieberg infraction (Kohler's disease) is probably an avascular necrosis of sub-chondral cancellous bone followed by a reparative process. Exact cause is uncertain. It usually affects the second metatarsal which is usually the longest and least mobile of all metatarsals.[51] There is no doubt, however, that the condition is associated with developmental anomalies which overload the middle group of metatarsals.[37]

March foot / March fracture- is a sequel to the developmental anomalies of the forefoot. It is a stress fracture. The primary factor is a developmental anomaly leading to a mechanical insufficiency of the first metatarsal as in Metatarsus primus varus or congenital short first metatarsal. The load is shifted to other metatarsals; such a load in a weak foot may lead to fractures. [37]

Metatarsalgia is defined as pain localized to the forepart of the foot. Although so defined in simple terms, it describes only a symptom. The cause may be as a result of biomechanical imbalances or local foot pathology or may be due to systemic diseases.[52] Several classifications of metatarsalgia have been recommended by various authors such as Helal, Regnauld and Viladot.[4]

Metatarsalgia may occur months after a fracture of a lesser metatarsal when pain appears in the other weight bearing metatarsals. This can occur with a shortening of a metatarsal as less as 2-4 millimeters.[53] Transfer metatarsalgia may occur if the shortening of the first ray disrupts the normal weight transfer as in surgery for hallux valgus.[54] Transfer metatarsalgia is a complication of surgeries on the hallux. Transfer of loads to the lateral metatarsals result when the normal weight bearing beneath the first metatarsal is reduced. The load is transferred most commonly to the second metatarsal head but may transfer to more than one of the lesser metatarsals.[55]

Keller resection arthroplasty is most commonly complicated by post-operative transfer metatarsalgia due to excessive shortening of proximal phalanx.[55] Most cases of static metatarsalgia are related to the great toe, but in some cases isolated metatarsal disharmony without hallux valgus may be seen. [56]

Brachymetatarsia and brachymetapody - Brachymetatarsia is a condition in which one of the metatarsals is abnormally short, resulting in a shortened toe. It usually affects a single metatarsal[26,41,57,58] and the fourth toe is most commonly affected. This condition may be hereditary and is usually bilateral, but may occur unilaterally too. It is usually idiopathic. If it affects more than one toe, the condition is called brachymetapody. Usually, not evident at birth, the condition may gradually develop with time, becoming evident between ages four and fifteen.[59]

Congenital brachymetatarsia is defined as an abnormal shortening of a metatarsal bone caused by premature closure of epiphysis. Incidence varies greatly, but there is a strong predominance towards the female gender. Female to male ratio is 98:4 [44,59] The causes may be classified as (i) Systemic syndromes- Apert syndrome, Down's syndrome, Grebe

syndrome,Turner's syndrome,etc., (ii) Dysplasias- Achondroplasia, Acromesomelic dysplasia, Thanatophoric dysplasia etc. and (iii) Endocrinopathies- Albright's hereditary dystrophy, Pseudohypoparathyroidism, Pseudopseudohypoparathyroidism etc.[28,41]

Brachymetatarsia due to injury to the physis may occur in many conditions such as fracture, infection, tumour, irradiation and thermal injury, or may result from a surgical procedure in the vicinity of the physis, pin placement across the physis or osteotomy across the physis. It may be acquired type in juvenile rheumatoid arthritis, polio and sickle cell crisis.[28]

A retrospective study has revealed an incidence of 30% with respect to shortening of first metatarsal as a complication of metatarsal osteotomies, showing a clear correlation with the surgical technique that was employed.[39] In another study it was noted that the phalanges were normal or longer than normal in persons affected with shortness of metatarsals.[26] Metatarsal overload may lead to loss of sensitivity in the sole of the foot.[41] Stress fractures of the second metatarsal may occur either due to a short first metatarsal or due to its own excessive length. These causes should be ruled out while considering treatment of stress fractures of lesser metatarsals.[52]

There is a surprising lack of literature regarding foot problems in general and hallux valgus in particular, regarding incidence and management in the Indian subcontinent. Diseases of the feet, either congenital or acquired, though usually localized can have a telling effect on the general ability and health of an individual.

Surgeries on the forefoot with relevance to lengths of metatarsals and phalanges-

The human foot is an intricate mechanism that functions interdependently with other components of the locomotor system. Interference with functioning of a single part may be reflected in altered functions of the remaining parts. Yet the surgeon is constantly called upon to change the anatomic and structural components of the foot.[60] Osteotomies of the forefoot are some of the most common procedures performed by both orthopaedic surgeons and podiatrists. Hallux valgus surgery is the most frequent disorder for which these procedures are employed, with the treatment of metatarsalgia and dislocations of the lesser

metatarsophalangeal joints. The current recommendations are that distal procedures be used when the hallux valgus angle is less than 35^0 with an intermetatarsal angle less than 14^0. With larger deformities, a proximal osteotomy with distal soft tissue release is indicated. The most frequently used distal osteotomy is the Chevron as described by Austin. Distal procedures consist of the Mitchell, modified McBride, modified Chevron and Wu procedures. These procedures have become less popular because of technical difficulties and associated complications such as shortening of the first metatarsal.

The most common metatarsal surgery is performed on the first metatarsal for the correction of hallux valgus deformity. Surgery on the lesser metatarsal bones is performed infrequently and it is generally for the treatment of painful calluses on the forefoot or for the treatment of non-healing ulcerations. Patients with rheumatoid arthritis may require surgery of the metatarsals. Surgery of the metatarsals may be necessary also in instances of trauma of the foot where the metatarsal bones may have been fractured.

Of late, reconstructive surgeries on the foot are being increasingly resorted to for achieving accurate anatomical and physiological corrections, especially in treating congenital deformities and trauma. Metatarsals have been used as autogenous graft material for reconstruction of other body parts such as mandible and the thumb. Various types of bone substitutes have been used in surgeries as are a variety of biomaterials for construction of implants especially the first metatarso-phalangeal joint.

Surgeries for hallux valgus- Any procedure for treatment of hallux valgus should take into consideration the length of first metatarsal relative to other lesser metatarsals, along with other structural components. Apart from pure soft tissue procedures, combined soft tissue and bony procedures are practiced.[50] Kellikian(1965) lists at least 130 procedures for the treatment of adolescent hallux valgus. Surgeries for adult hallux valgus involving first metatarso-phalangeal joint as done in adults cannot be used for adolescents.[22]

Distal first metatarsal osteotomies have played a prominent role in the surgical management of the hallux valgus deformity. Reverdin, Roux (1920), Hohmann (1923),

Peabody (1931), Suppan (1974), Johnson and Smith (1974) are some of the major contributors.

Mitchell (1945 and 1958) described an osteotomy procedure that was used to correct metatarsus primus varus and hallux valgus. The osteotomy is displaced plantarly to accommodate for shortening of the metatarsal and to prevent metatarsalgia. Wilson (1963) described an oblique osteotomy for the advantages of simplicity and stability. There have been a number of other modifications to the Wilson osteotomy. Helal et al. (1974), Davis and Litman (1976), Allen et al.(1981), Pittman and Burns (1984). Klareskov et al. (1988) modified Wilson's osteotomy by plantar-flexing the first metatarsal head as it is shifted laterally. Peg-in-hole osteotomy and Austin osteotomy are other significant osteotomies. Distal metatarsal osteotomies perform four basic functions. They can decrease the intermetatarsal angle, realign structural abnormalities in the transverse plane such as abnormal proximal articular set angles and shorten or maintain the length of the metatarsal.[61] The most troublesome complication of the distal osteotomies was metatarsalgia, which was attributed to excessive shortening of the first metatarsal.[50] In cases of metatarsal disharmony, osteotomy of the base of metatarsals for the median rays is proposed by some authors, to avoid transfer metatarsalgia.[56]

Middiaphyseal osteotomies - The Ludloff osteotomy (1918) is a through-in-through, middiaphyseal osteotomy. Mau, in 1926, modified the Ludloff osteotomy by changing the direction of the cut. Increasing the length of the osteotomy can reduce a severe metatarsus varus deformity with minimal rotation of the distal capital fragment and adequate bone contact. One of the three main complications following proximal wedge resection osteotomies for the correction of metatarsus varus associated with hallux valgus was first metatarsal shortening.[62] In some cases surgical shortening of first metatarsal forces the lesser metatarsals to bear weight and this increases the compression stress on adjacent metatarsals causing metatarsalgia and in severe cases- stress fractures.[18] The Scarf or Z osteotomy is another procedure that has found its place in the correction of hallux valgus deformity with the advent

of AO/ASIF fixation techniques. In this osteotomy the angular correction is dependent on intermetatarsal correction which is limited by the width of the shaft of the metatarsal.[63]

Proximal osteotomies - Osteotomy at the base of the first metatarsal is necessary for correction of severe metatarsus primus adductus. There are numerous procedures and even more numerous variations available today for its correction. Most commonly used surgeries include the closing base wedge osteotomy, the opening base wedge osteotomy, the crescentic osteotomy, and the double osteotomy.[62]

Two types of osteotomies are performed at the base of the first metatarsal for correction of hallux valgus in children; the closing wedge osteotomy and the opening wedge osteotomy. The choice of procedure is made by the surgeon on the basis of careful evaluation of the length of the first metatarsal and the metatarsal protrusion measurement. The opening wedge increases the length of the first metatarsal relative to the second metatarsal. The closing wedge shortens the metatarsal and may therefore predispose to metatarsalgia.[64] The choice of an opening or closing wedge osteotomy is determined by the preoperative length of the first metatarsal relative to the second metatarsal. For planning of a surgical procedure preoperative radiological assessment may be used. It has been proposed that shortening can be compensated by adequate plantar displacement of the distal fragment in a modified Wilson's osteotomy.[65] If the amount of shortening can be assessed preoperatively, then the surgeon can decide about the amount of plantar displacement required. In such a case preoperative measurement of all metatarsals and correlation between metatarsal lengths can be utilized. Some authors have proposed not to shorten the first metatarsal by more than 3-4 mm in treating metatarsus primus varus.[66]

For preoperative planning the relative metatarsal protrusion is measured on the radiograph. A normal protrusion measurement demonstrates the second metatarsal as being longer than the first metatarsal, although a range of plus or minus 2 millimeters is considered within normal limits. If the first metatarsal is found to be equal in length to the second metatarsal or longer, then a closing base wedge osteotomy can be performed, as a slight

shortening of the first metatarsal will take place. Another method for determining relative metatarsal length is by measuring the metatarsal parabola angle.

Shortening of the first metatarsal along with hallux varus, caused by overzealous reduction in the intermetatarsal angle are common complications of any of the base procedures. Shortening of the first metatarsal can lead to many subsequent problems such as lesser metatarsalgia, transfer lesions, stress fractures of the lesser metatarsals, and decreased propulsive force in toe-off. Metatarsal protrusion measurements must be taken into consideration before choosing a procedure. If the first metatarsal is within 2 millimeters of the length of the second metatarsal, a closing base wedge osteotomy can be employed. If the first metatarsal is shorter than the second by more than 2 millimeters, an opening base wedge osteotomy, crescentic, or V-type base osteotomy is appropriate.[62]

Surgery for correction of hallux limitus / rigidus-

When planning surgical intervention for hallux limitus, two basic factors are addressed: deformity of the joint and deformity of the first ray. Both, joint preserving and joint destructive procedures can be used. Additional consideration is given to management of a long first metatarsal.

Phalangeal osteotomy with resection for shortening of the hallux may be useful in those cases of hallux rigidus associated with a long hallux. Shortening of an excessively long first metatarsal can be managed by distal osteotomy. Bicorrectional osteotomies can result in shortening (decompression) and plantar flexion.

Many of the osteotomies used in the management of hallux valgus have been adapted for hallux limitus. The Z osteotomy performed in the sagittal plane can also be used for metatarsal shortening and plantar flexion.[67]

Implant surgeries-

The recognition of importance of the first metatarso-phalangeal joint in foot function has led to researchers' interest in developing an artificial functional joint prosthesis in the past several decades. Endler (1925), Swanson (1952), Seeburger(1964), Joplin (1964) and Cutter (1971) are some of the researchers in the area of implants. Various biomaterials and various

designs have been used with varying degrees of success.[68] With the continued advances in tissue and material engineering, prosthetic and biologic interpositional arthroplasties hold a great promise for treatment of destructive metatarsophalangeal joint and interphalangeal joint diseases. In all of these modalities the restoration of length of the bones along with range of motion and strength are fundamental in attaining a good clinical outcome. Stress fractures in lateral metatarsals have been reported following implant arthroplasty of first metatarsophalangeal joint. Newer implants have been designed and further modifications may be expected, so as to avoid excessive shortening or modification of first metatarsal. The aim is to preserve and / or restore the natural metatarsal parabola.

Surgeries on lesser metatarsals are less frequently done than on the first metatarsal. Usually these are for correction of brachymetatarsia, for metatarsalgia, intractable corns and calluses, tumours etc. Lengthening of the short bone is the most logical treatment with the aim of restoring the normal length of the metatarsal according to the formula 1=2>3>4>5.[59] For bone lengthening of short fourth toe Jinnaka devised a technique by interposing a spindle shaped graft within the metatarsophalangeal joint. The advantage was ease of lengthening of two centimeters or more.[38]

Many surgical procedures for treating brachymetatarsia have been described. The most widely used is either one stage lengthening with intercalary bone graft or gradual lengthening by callus distraction. Newer surgical procedures have been described involving one stage combined shortening of normal metatarsals and lengthening of affected short metatarsal utilizing the excised metatarsal as bone graft. In this surgical procedure pre-operative assessment of lengths of metatarsals is critical in estimation of (i) length of osteotomy required for a normal metatarsal parabola and (ii) amount of shortening required.[44] Distraction lengthening of metatarsals has been done successfully. Various methods of distraction lengthening have been employed using Ilizarov's technique. Distraction lengthening without supplemental grafts for multiple short metatarsals in a single extremity has been achieved.

The use of an external fixator for gradual metatarsal elongation was first reported by Skirving and Newman (1983).[59] Assessment of final outcome of surgery was done by measuring the length achieved in absolute terms and as percentage of the original length. Lengthening of 15 millimeters to 40 millimeters in absolute terms and 24.1% to 65% of original has been achieved.[59] Lengthening of not more than 50% of the original length led to completely satisfactory clinical follow-up with no serious or severe complications.

Various techniques of lesser metatarsal bone lengthening have been compared for total gain in length and percentage of length gained, utilizing pre and post operative radiographs.[69] Recommendations for maximum amount of lengthening to be done in surgeries for short first metatarsal by distraction osteogenesis have been formulated using pre and post operative measurements. To avoid potential complications such as metatarso-phalangeal joint subluxation, cavus foot and hallux valgus, the postoperative first metatarsal length should not exceed 40% - 50 % of the original length.[57,70] Restoration of first metatarsal length using distraction osteogenesis is thought to restore normal foot anatomy more closely than osteotomies of lesser metatarsals for treatment of iatrogenic short first metatarsal. Lengthening of first metatarsal, by 16.7% when expressed as a percentage of length of ipsilateral second metatarsal, was achieved.[54]

Preoperative measurement of the lengths and widths of metatarsals and phalanges is important not only to assess the amount of lengthening / shortening to be done but also to decide upon a particular technique of correction to be utilized.[71] Pre and post operative measurements of dimensions of metatarsals have been used in assessing the outcome of shortening osteotomies for plantar callosities[40], for assessing effectiveness of osteotomies and for information of the patient regarding risk of post operative metatarsalgia in case a short metatarsal is already existing.[72]

The selection of method of lengthening for lesser metatarsals is based on a target length determined by tracing an AP foot radiograph and carrying out the several possible adjacent bone shortening procedures on this model. Method of using gradual lengthening by callotasis is chosen for patients in whom target length, even after adjacent bone shortening,

is 15 millimeters or more. Failure to achieve target length, as well as neurovascular problems in one- stage lengthening and insufficient formation of callus with axial deviation during gradual lengthening led researchers to combine lengthening and shortening procedures on metatarsals and phalanges. This technique minimized the amount of lengthening required of the affected metatarsal. Gradual lengthening may have attendant complications like joint stiffness, subluxation of metatarso-phalangeal joint, flexion deformities of a digit and a hallux valgus, which can occur when the increase in length achieved is more than 40%.[26,58]

Surgeries on phalanges-

Osseous procedures include partial resection of phalanges, total resections of phalanges, and digital amputations. All parts of the phalanx have at one time or another been removed, including condyles, the head, the base, and the diaphyseal shaft. The two most commonly performed fusion procedures include the end-to-end and peg-in-hole proximal inter phalangeal joint arthrodesis.[73]

Surgeries for Freiberg's Disease-

A shortening osteotomy of the metatarsal is performed after a trial of conservative treatment.[74] Metatarsal head resection was suggested as appropriate for severe disease.[19]

Surgeries for Tailor's bunion or bunionette range from simple lateral exostectomy, partial exostectomies, exostectomies combined with soft tissue procedures to fifth metatarsal head resection with a lateroplantar condylectomy of the proximal phalanx of the fifth toe and a Wilson-type displacement osteotomy. Shortening is noted to occur with this osteotomy.[75]

Stature estimation from metatarsals-

Anthropologic studies involving stature estimation are important forensic tools in building an antemortem profile of an individual from skeletal remains. For the purpose of stature estimation, commonly the long bones viz, femur, tibia, radius and ulna are used. These bones may be fragmented or incompletely recovered. In such cases stature estimation can be done using the small bones of the feet i.e. calcaneus, talus and the metatarsals.[76]

Apart from stature, sex determination is also an important part of the anthropological profile. Some researchers have found sex determination using length and width measurements

of all five metatarsals to be 93.3% to 100% accurate. It has been found that women in disparate populations have smaller feet proportionate to stature than do men.[77] Statistically significant sex differences exist between the sexes in relation to comparison of mean measurements of metatarsal lengths.[78] Hundred percent accuracy, in sex determination has been achieved using a function associating two measurements of the metatarsal bones (length and mid-shaft diameter).

Significant correlation coefficients (0.58 – 0.89) are shown between known stature and foot bone lengths.[79] To date only two large studies have been conducted for investigating the potential of using metatarsals in the estimation of stature for forensic purposes. These studies have used skeletons from anthropological collections and the measurements have been done on dry macerated bones using osteometric boards, etc.[78] No study has been published to evaluate the potential of using radiographs of metatarsals for estimation of stature. Wide variability exists between populations with respect to discriminant functions obtained between bones and stature. This stresses the need for study of populations to which it is to be applied.

The anthropometry of the foot and its relation to various body parts has intrigued researchers since nearly a century. Over the past few decades importance of ergonomics especially in an industrial setting has gained importance.

Hrdlička is considered a pioneer of physical anthropology and has conducted several studies on relation of foot length to stature. Several Indian studies have dwelled on the relation of foot length and width with stature. Due to non-availability of large collection of complete dry macerated skeletons, many studies have relied upon measurements on living persons. Very few studies are available on estimation of stature from radiographic measurements of metatarsals.

Biomechanics and kinesiology of the foot-

The foot functions as one link in a biomechanical kinetic chain, where movement at one joint influences movement at other joints in the chain. As the base of this chain, the foot is subject to the forces of ground contact with every step, cushioning the body on landing and

launching the frame forward immediately thereafter. This seemingly simple manoeuver is accomplished through a series of complex biomechanical motions within the foot.

Viladot has classified feet depending on the lengths of toes and metatarsals. Based on the lengths of toes (Digital formula) (i) Greek foot: big toe shorter than second toe (22%), (ii) Egyptian foot: big toe longer than second toe (69%) and (iii) Squared foot: big toe same length as the second toe (9%). Based on the lengths of the metatarsals (Metatarsal formula) (i) Index plus-minus type: First metatarsal equal to second (28%), (ii) Index minus type: First metatarsal shorter than second (56%), (iii) Index plus type: First metatarsal longer than second (16%).[4]

It has been noted that the index minus type predisposes to the development of hallux valgus and the index plus type predisposes to hallux rigidus in males and sesamoiditis in females. The ideal foot is said to be Index plus-minus type or Index plus type with the Greek foot.[4]

The toes are in contact with the ground for about 75% of the walking cycle. If this contact time is reduced by a deformity or absence due to amputation, the load has to be borne by the heads of the metatarsals.[52] This continuous excessive load on the metatarsal heads may lead to metatarsalgia, formation of painful callosities etc. The importance of toes is much greater during running, jumping etc., than in standing at one place or slow walking.

A brief review of the gait cycle is essential for understanding of foot problems caused by imbalance of the various structures in it. The gait cycle is divided into two phases, viz., Stance phase and Swing phase. The stance phase is 62% of the gait cycle, begins with heel strike and ends at toe-off. It is divided into three periods, Contact period (27%), Midstance period (40%) and Propulsive period (33%). During this phase, the foot goes from being a mobile adaptor to being a rigid lever. The swing phase occupies 38% of the total gait cycle. It begins at toe-off and ends at the next heel strike. This is the non-weight bearing period of the gait cycle. During the gait cycle, weight of the body shifts from the fifth metatarsal head towards the first by pronation of foot around its longitudinal axis.

Stance phase presents the greatest risk to musculoskeletal integrity, because the foot is subjected to dual forces: the ground shock of heel strike and the vertical stress of weight from above. The body's orderly response to ground contact and locomotion can be disrupted by alterations in foot biomechanics. The patient may not experience pain in the feet, but may complain of discomfort in the knees, hips or back and exhibit poor posture. The first metatarsal bears one third of the body's weight through the forefoot on two subjacent sesamoid bones. The second and third metatarsals often bear more weight than the fourth and the fifth.[53] Experimental analysis on simulated 3-D foot models reveal that forefoot function was affected primarily by deficit of the first three metatarsals.[80] The second and the third metatarsals are important because they are the keystone of the foot. This complex is stable and does not tolerate instability. Angulation can lead to abnormal pressure distribution in the metatarsal heads causing biomechanical disturbance in the forefoot.[49]

Methodology

Volunteers, above the age of twenty one years, were selected randomly for the study after obtaining Institutional ethical committee clearance. All participants read, filled up and signed a data sheet and an informed consent form.

Antero-posterior radiographs of both feet were taken one at a time with due care to avoid unnecessary exposure to radiation. Subject was seated, foot was placed flat on the cassette and x-ray beam was centered on the base of third metatarsal which was identified by palpation. Source- Image receiver distance was fixed at 100 centimeters. Exposure factors were 46 kV and 6.5 mAS.

The radiographic projection and positioning of the foot was strictly determined and adhered to, in order to minimize the influence of pronation and supination of the foot on the radiograph. Radiographic exposures of all the subjects were done by the same technician for uniformity.

Exclusion criteria include subjects with history of major and / or long term injuries to the feet, past surgeries on the feet. Subjects with long standing pain in the feet were also excluded. The radiographs were screened for readability.

Measurements were conducted on the radiographs using Vernier calipers (Mitutoyo, Japan, Least count - 0.01). Reference points for taking length and width measurements were fixed. Measurements for length were taken from the most distal point on the heads of metatarsals to the midpoint of the shadow of the articular surface on the bases. For the fifth metatarsal base the midpoint of the articular surface excluding the styloid process was considered (shown in Annexure-3). Measurements for lengths of phalanges were taken from the middle of the articular surfaces both proximally and distally. Measurements for widths of the bones were taken at mid-shaft level.

Statistical analysis-

The mean and standard deviations (SD) of different measurements were calculated. Correlation analysis was done to assess the association between different variables. Regression analysis was used to estimate the stature by using different variables (lengths of metatarsals). F test was used to assess the regression analysis and t-test was used to assess the significance of correlation. Significance level was kept at 0.05.

RESULTS

The readings of different dimensions of the metatarsals and phalanges are shown in the Master Chart (Annexure 1). The mean, standard deviations and the range were noted and tabulated for further analysis.

Table No. 1: Lengths of metatarsals

Metatarsal	Length (mm)		Range (in mm)			
	Male	Female	Male		Female	
	Mean ± SD	Mean ± SD	Max	Min	Max	Min
MT1	56.42 ± 4.41	50.09 ± 3.06	66.10	46.39	57.84	43.80
MT2	67.61 ± 3.49	62.46 ± 3.45	77.55	60.54	69.25	55.47
MT3	65.88 ± 4.41	60.92 ± 2.99	77.85	57.16	68.57	54.27
MT4	66.52 ± 3.98	60.78 ± 2.91	75.02	58.70	66.54	54.28
MT5	64.32 ± 3.57	58.34 ± 2.90	72.72	57.69	64.54	51.10

MT1, MT2, MT3, MT4 & MT5 – First, Second, Third, Fourth and Fifth metatarsals respectively.

Graph No. 1: Length pattern of metatarsals

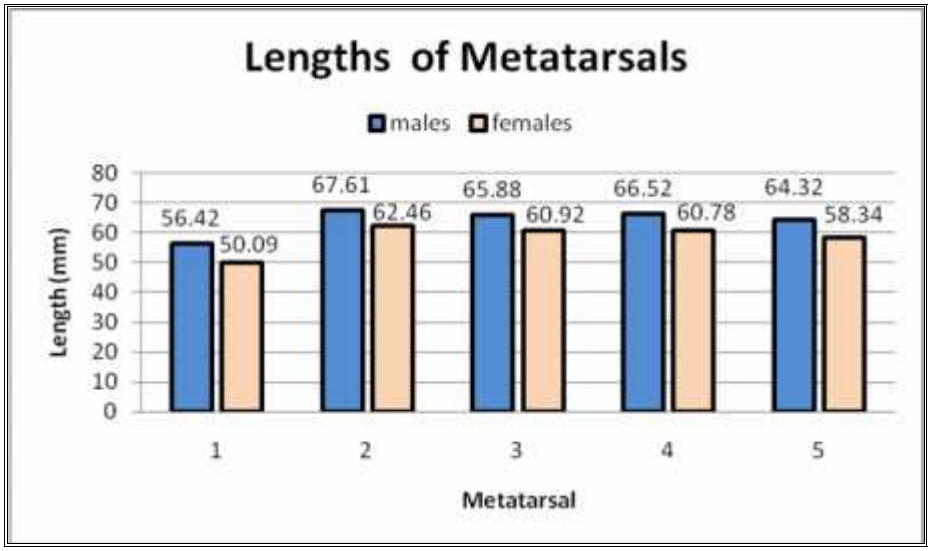


Table No. 2: Widths of metatarsals

Metatarsal	Width (mm)		Range (in mm)			
	Male	Female	Male		Female	
	Mean ± SD	Mean ± SD	Max	Min	Max	Min
MT1	13.7 ± 1.00	11.7 ± 0.91	16.54	11.62	14.01	9.03
MT2	7.6 ± 0.79	6.9 ± 0.72	9.74	6.54	8.94	5.57
MT3	6.8 ± 0.65	5.9 ± 0.57	6.36	5.58	7.60	4.81
MT4	7.1 ± 0.69	6.2 ± 0.38	9.53	5.83	7.25	5.23
MT5	8.1 ± 0.69	7.1 ± 0.67	9.69	6.93	8.52	5.72

MT1, MT2, MT3, MT4 & MT5 – First, Second, Third, Fourth and Fifth metatarsals respectively.

Graph No. 2: Width pattern of metatarsals

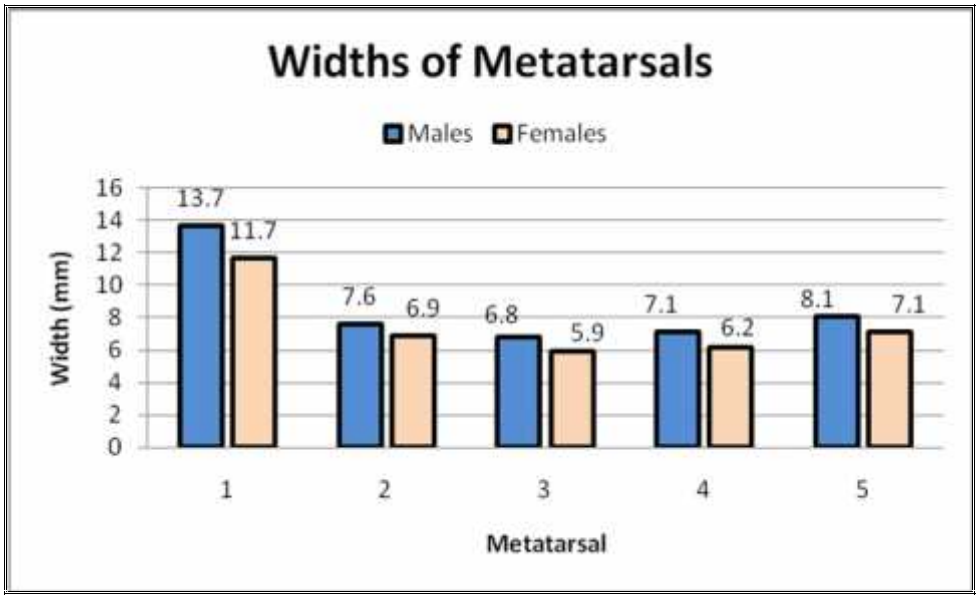
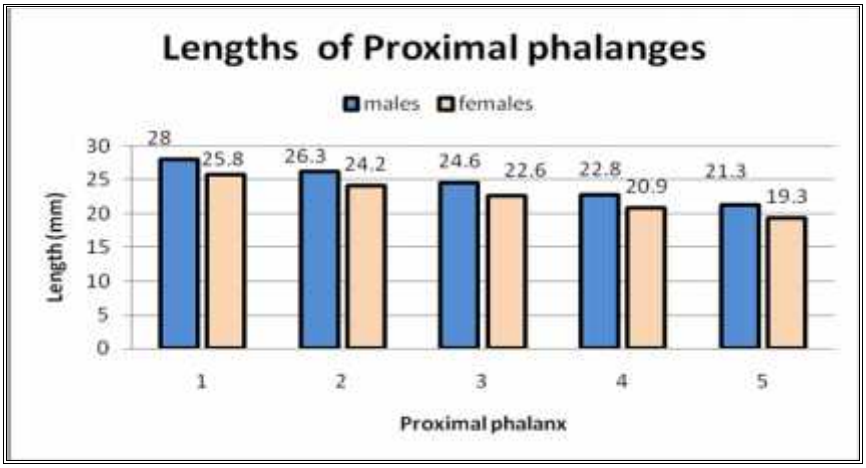


Table No. 3: Lengths of phalanges

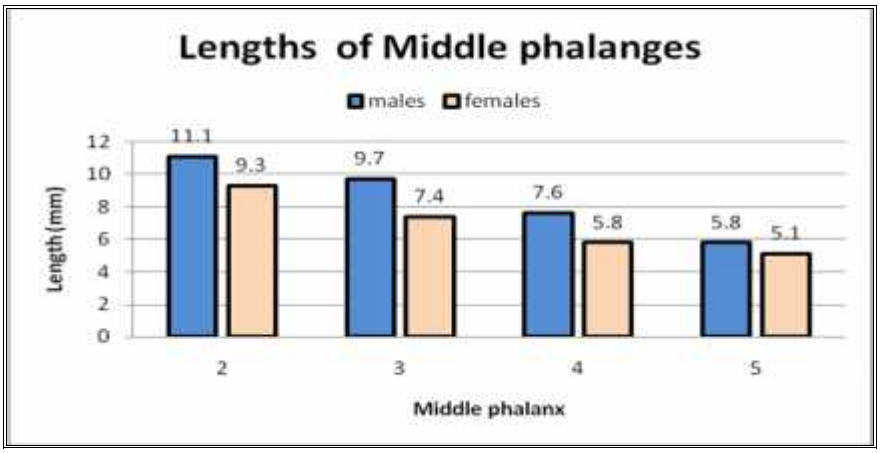
Phalanx	Length (mm)		Range (in mm)			
	Male	Female	Male		Female	
	Mean ± SD	Mean ± SD	Max	Min	Max	Min
PP 1	28.0 ± 2.40	25.8 ± 2.21	34.24	23.48	28.97	14.48
PP 2	26.3 ± 2.08	24.2 ± 1.62	30.34	21.99	27.44	20.25
PP 3	24.6 ± 1.77	22.6 ± 1.51	28.67	20.62	26.38	18.37
PP 4	22.8 ± 1.67	20.9 ± 1.44	26.32	18.99	24.58	17.02
PP 5	21.3 ± 1.54	19.3 ± 1.31	25.07	16.99	22.50	15.78
MP 2	11.1 ± 1.81	9.3 ± 2.06	15.02	5.47	13.05	5.27
MP 3	9.7 ± 2.07	7.4 ± 2.17	13.73	5.18	12.63	4.65
MP 4	7.6 ± 1.92	5.8 ± 1.44	12.15	4.12	10.78	3.75
MP 5	5.8 ± 0.97	5.1 ± 0.81	8.85	3.55	7.53	3.61
DP 1	22.5 ± 1.85	20.8 ± 1.90	27.59	18.66	24.94	17.22
DP 2	6.9 ± 1.41	6.9 ± 1.32	11.62	4.03	10.97	3.73
DP 3	6.3 ± 1.51	6.3 ± 1.25	10.60	3.92	10.03	3.85
DP 4	5.6 ± 1.44	5.3 ± 1.23	9.07	3.57	10.16	3.54
DP 5	5.2 ± 1.33	4.4 ± 1.03	9.53	2.82	7.54	2.65

PP – Proximal phalanx, MP – Middle phalanx, DP – Distal phalanx, SD – Standard deviation.

Graph No. 3: Length pattern of proximal phalanges



Graph No. 4: Length pattern of middle phalanges



Graph No. 5: Length pattern of distal phalanges

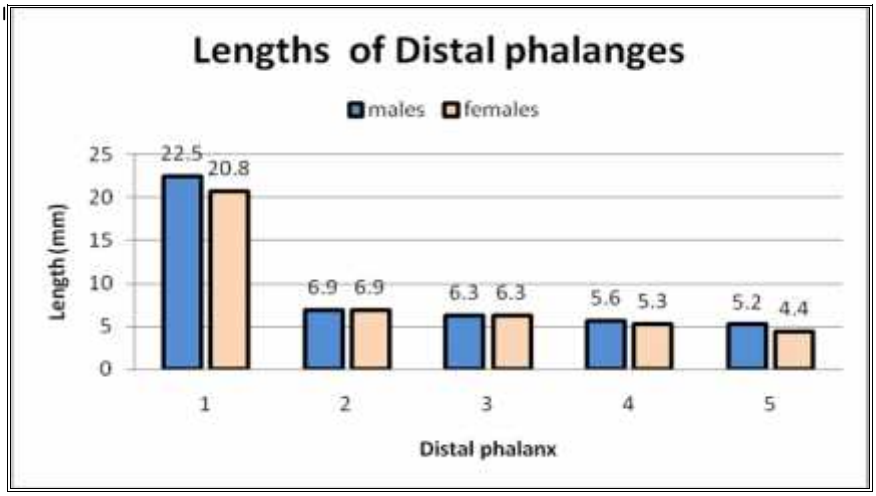


Table No. 4: Correlation matrices – Lengths of metatarsals

	MALE				FEMALE			
	MT2	MT3	MT4	MT5	MT2	MT3	MT4	MT5
MT1	0.631 (.000)	0.572 (.000)	0.600 (.000)	0.528 (.000)	0.739 (.000)	0.691 (.000)	0.665 (.000)	0.624 (.000)
MT2	-	0.850 (.000)	0.843 (.000)	0.742 (.000)	-	0.903 (.000)	0.877 (.000)	0.820 (.000)
MT3	-	-	0.856 (.000)	0.802 (.000)	-	-	0.872 (.000)	0.815 (.000)
MT4	-	-	-	0.834 (.000)	-	-	-	0.834 (.000)

MT1, MT2, MT3, MT4 & MT5 – First, Second, Third, Fourth and Fifth metatarsals respectively.
p Values are shown in parentheses.

Table No. 5: Correlation matrices – Widths of metatarsals

	MALE				FEMALE			
	MT2	MT3	MT4	MT5	MT2	MT3	MT4	MT5
MT1	-0.062 (.730)	0.445 (.011)	0.468 (.007)	0.041 (.842)	0.070 (.730)	0.053 (.292)	0.310 (.116)	0.187 (.300)
MT2	-	0.486 (.005)	0.313 (.081)	0.348 (.051)	-	0.688 (.000)	0.217 (.277)	0.226 (.256)
MT3	-	-	0.713 (.000)	0.230 (.205)	-	-	0.525 (.005)	0.267 (.178)
MT4	-	-	-	0.522 (.022)	-	-	-	0.504 (.007)

MT1, MT2, MT3, MT4 & MT5 – First, Second, Third, Fourth and Fifth metatarsals respectively.
p Values are shown in parentheses.

Table No. 6: Correlation matrices – Lengths of proximal phalanges

	MALE				FEMALE			
	PP2	PP3	PP4	PP5	PP2	PP3	PP4	PP5
PP1	0.851 (.000)	0.751 (.000)	0.776 (.000)	0.733 (.000)	0.772 (.000)	0.717 (.000)	0.678 (.000)	0.614 (.000)
PP2	-	0.916 (.000)	0.912 (.000)	0.801 (.000)	-	0.931 (.000)	0.798 (.000)	0.629 (.000)
PP3	-	-	0.934 (.000)	0.775 (.000)	-	-	0.918 (.000)	0.695 (.000)
PP4	-	-	-	0.821 (.000)	-	-	-	0.824 (.000)

PP1, PP2, PP3, PP4 & PP5 – First, Second, Third, Fourth and Fifth proximal phalanges respectively.
p Values are shown in parentheses.

Table No. 7: Correlation matrices – Lengths of middle phalanges

	MALE			FEMALE		
	MP3	MP4	MP5	MP3	MP4	MP5
MP2	0.784 (.000)	0.635 (.000)	0.390 (.000)	0.819 (.000)	0.746 (.000)	0.571 (.000)
MP3	-	0.806 (.000)	0.563 (.000)	-	0.778 (.000)	0.519 (.000)
MP4	-	-	0.634 (.000)	-	-	0.774 (.000)

M1, MP2, MP3, MP4 & MP5 – First, Second, Third, Fourth and Fifth middle phalanges respectively.
p Values are shown in parentheses.

Table No. 8: Correlation matrices – Lengths of distal phalanges

	MALE				FEMALE			
	DP2	DP3	DP4	DP5	DP2	DP3	DP4	DP5
DP1	0.480 (.005)	0.471 (.006)	0.433 (.012)	0.282 (.112)	0.465 (.015)	0.592 (.001)	0.460 (.016)	0.440 (.022)
DP2	-	0.929 (.000)	0.871 (.000)	0.711 (.000)	-	0.864 (.000)	0.712 (.000)	0.737 (.000)
DP3	-	-	0.871 (.000)	0.679 (.000)	-	-	0.885 (.000)	0.826 (.000)
DP4	-	-	-	0.822 (.000)	-	-	-	0.853 (.000)

DP1, DP2, DP3, DP4 & DP5 – First, Second, Third, Fourth and Fifth distal phalanges respectively.
p Values are shown in parentheses.

Table No. 9: Regression equations for stature estimation (in cm): Males

Metatarsal No.	Equation	R	R^2	F	p
MT1	131.102 + 0.671 MT1	0.387	0.150	5.468	.026
MT2	103.168 + 0.973 MT2	0.443	0.197	7.589	.010
MT3	117.744 + 0.778 MT3	0.448	0.175	7.799	.009
MT4	84.942 + 1.263 MT4	0.657	0.431	23.514	.000
MT5	88.288 + 1.255 MT5	0.585	0.321	16.113	.000
Multiple regression	81.139 + 1.608 MT4 + 0.261 MT5	0.660	0.398	11.591	.000

MT1, MT2, MT3, MT4 & MT5 – First, Second, Third, Fourth and Fifth metatarsals respectively.

Table No. 10: Regression equations for stature estimation (in cm): Females

Metatarsal No.	Equation	R	R^2	F	p
MT1	119.736 + 0.697 MT1	0.364	0.132	3.818	.062
MT2	109.961 + 0.720 MT2	0.424	0.180	5.473	.028
MT3	103.906 + 0.833 MT3	0.425	0.181	5.515	.027
MT4	97.583 + 0.939 MT4	0.465	0.217	6.910	.014
MT5	89.145 + 1.123 MT5	0.556	0.281	11.131	.003
Multiple regression	88.978 + 0.014 MT4 + 1.112 MT5	0.556	0.251	5.362	.012

MT1, MT2, MT3, MT4 & MT5 – First, Second, Third, Fourth and Fifth metatarsals respectively.

DISCUSSION

Morphometric studies of metatarsals and phalanges involve conducting measurements either directly on dry macerated bones[78, 79] or on radiographic films. Most radiographic studies have been mainly on angle measurements for formulating theories of hallux valgus development, and its pre-operative assessment[40], surgical techniques to be used[8, 9, 28] and assessment of results of surgeries.[22, 38, 44, 54, 58] Studies concerned with pure linear measurements are few. Only two studies are available on stature estimation by using metatarsals. No study has been conducted using lengths of metatarsals as measured on radiographs.

One of the arguments against using radiography for morphometry is that of loss of three-dimensional information. But in such a case the loss affects all the constituent bones of the forefoot equally and the ratios remain unaffected. Another factor to be considered in radiographic studies is the amount of magnification of the image. This is negligible if the correct technique is used, as is the case in the present study. The magnification is constant in all the radiographs since the same methodology has been used and hence will not affect ratios.

The measurement of lengths and widths and the mathematical correlation of the measurements amongst the bones of the same group are important for reconstructive surgeries on the foot, shortening or lengthening of metatarsals and digits.

In the present study the second and the first metatarsals were the longest and shortest metatarsals, respectively. The mean lengths of the metatarsals were; first - 56.42mm ± 4.41 & 50.09 mm ± 3.06, second - 67.61 mm ± 3.49 & 62.46 mm ± 3.45, third - 65.88 mm ± 4.41 & 60.92 mm ± 2.99, fourth - 66.52mm ± 3.98 & 60.78mm ± 2.91 and fifth - 64.32mm ± 3.57 & 58.34 mm ± 2.90 respectively, for males and females respectively.

This is not in agreement with another study by Dogan et al [48] in which it was found that the longest metatarsal was the fifth (72.10mm ± 5.55 and 68.56 ± 3.19 in males and

females respectively). But in this study the specific points of reference for measurements of length of the fifth metatarsals was not mentioned. It is important to specify the exact points of reference for measurements to be taken, especially the fifth metatarsal which has a styloid process / tuberosity. Measurements will vary if taken up to the tip of the styloid process and if taken up to the middle of the articular margin.

In another study by Moneim[76], the lengths of the metatarsals (in centimeters) in males and females respectively was, first - 6.4 ± 0.22 and 5.1 ± 0.12 , second - 7.0 ± 0.38 and 6.1 ± 0.12, third - 7.0 ± 0.12 and 6.4 ± 0.09, fourth - 6.9 ± 0.88 and 6.6 ± 0.13 & fifth - 7.5 ± 0.25 and 6.4 ± 0.10. In this study, the points of reference for measurement of lengths of each metatarsal bone were the highest and the lowest points.

In a study by Bidmos[78], the measurement of lengths of metatarsals was done separately in two population groups - Indigenous South Africans (ISA) and South Africans of European Descent (SAED). The length of the fifth metatarsal was measured by two different methods and named morphological length ($M5_P$) and functional length ($M5_F$). The measurements (in mm), in males and females respectively, for each metatarsal were as follows: ISA group – MT1- 63.14 ± 3.40 & 59.89 ±3.78, MT2- 75.56 ± 3.41 & 71.11 ± 4.30, MT3- 70.51 ± 3.65 & 68.00 ± 4.52, MT4- 71.26 ± 3.61 & 66.08 ± 4.42, MT5- 61.44 ± 3.35 & 58.53 ± 4.14 and $MT5_P$-72.13 ± 4.54 & 68.61 ± 5.35. SAED group - MT1- 62.94 ± 4.39 & 59.98 ± 3.78, MT2- 75.56 ± 3.41 & 66.08 ± 4.42, MT3- 70.51 ± 3.65 & 68.00 ± 4.52, MT4- 70.10 ± 4.64 & 65.90 ± 4.16, $MT5_F$- 62.30 ± 4.73 & 59.05 ± 3.92 and $MT5_P$-73.05 ± 502 & 68.50 ± 5.27. Males consistently had a higher mean value compared to females with regard to metatarsal lengths.

In the present study, the longest phalanges in both the sexes were first proximal phalanges (28.0mm ± 2.40 in males & 25.8mm ± 2.21in females). The fifth distal phalanges (5.2mm ± 1.33 in males & 4.4mm ± 1.03 in females) were the shortest. Again, males consistently had a higher mean value compared to females with regard to lengths of phalanges.

In another study by Dogan[48] the longest and shortest phalanges were first proximal phalanx (31.81 ± 2.76 in males & 28.29 ± 2.56 in females) and fifth middle phalanx (7.78 ± 1.46 in males & 6.59 ± 0.90 in females) respectively in both the sexes. Here the authors have failed to mention the exact landmarks used for measurements and it be would prudent to keep this in mind while comparing the values.

Widths of metatarsals were measured at the middle of the shaft. The widest metatarsals in the present study were first metatarsals (13.7mm ± 1.00 in males & 11.7mm ± 0.91 in females). The narrowest metatarsals in the present study were third metatarsals (6.8mm ± 0.65 in males & 5.9mm ± 0.57 in females). These values are in conformity with two other studies given below.

Dogan [48] found that the widest metatarsal was the first metatarsal (15.60mm ± 1.49 in males & 13.14mm ± 1.03 in females) and the narrowest was the third metatarsal (8.02mm ± 0.80 in males & 6.84mm ± 0.59 in females). In another study by Moneim[76], the widest were the first metatarsals in both the sexes (1.5cm ± 0.19 in males & 1.1cm ± 0.12 in females). The narrowest in males was the fifth metatarsal (0.89cm ± 0.1) and that in females was the second metatarsal (0.57 cm ± 0.08).[76]

For estimation of stature, calculations differ according to the sex, race and age of the individuals.[79] In the present study since all subjects were Indians by birth, regression formulae were computed only according to sex.

Standard errors in stature estimation using small bones of the feet, though not as small as those using long bones, are of the same magnitude as those using fragmentary bones.[79]

The simple regression formulae for stature estimation (in mm) using metatarsal bones in an earlier study[79] were 783+13.9(MT1), 791+11.5(MT2), 836+11.6 (MT3), 835+11.9(MT4), 953+11.3(MT5f) & 922+10.2(MT5) for females and 815+14.3(MT1), 873+11.1 (MT2), 909+11.2(MT3), 910+11.6(MT4), 989+11.8(MT5f) & 952+10.6(MT5) for males. In another study by Bidmos[78] the formulae arrived at (in cm) were 1.30MT1+64.97, 1.13MT2+61.99, 1.05MT3+71.04, 1.03MT4+74.50, 1.03$MT5_F$+82.43 &

0.69MT5$_P$+95.39 and 1.39MT1+63.57, 1.07MT2+69.98, 1.01MT3+78.78, 1.00MT4+81.00, 0.97MT5$_F$+89.89 & 0.74MT5$_P$+96.61 for females of two different racial groups. The corresponding values in males were 0.96MT1+92.67, 0.96MT2+80.62, 0.87MT3+91.75, 0.64MT4+107.42, 0.83MT5$_F$+102.31 & 0.68MT5$_P$+103.92 and 0.91MT1+100.49, 0.96MT2+84.00, 0.98MT3+87.41, 0.98MT4+88.65, 0.96MT5$_F$+97.73 & 0.83MT5$_P$+97.19. The two studies involved measurements on dry macerated bones and correction factors for age were considered in the former study.

In the present study the corresponding formulae (in mm) are 119.736 + 0.697 MT1, 109.691 + 0.720 MT2, 103.906 + 0.833 MT3, 97.583 + 0.939 MT4 & 89.145 + 1.123 MT5 in females and 131.102 + 0.671 MT1, 103.168 + 0.973 MT2, 117.744 + 0.778 MT3, 84.942 + 1.263 MT4 and 88.288 +1.255 MT5 in males.

The formulae in the present study were arrived at by using combined values of corresponding metatarsals of both the sides. Calculations were done by other authors using bones of right and left side separately or by using bones only of right side. No consensus has yet emerged on the method to be followed.[79]

In the present study the lowest SEE using combined male and female values was for the regression equation that used the fifth metatarsal length (SEE = 6.24, R = 0.782, R^2 = 0.611). The lowest SEE for the regression equation for females only, was for the fifth metatarsal (SEE = 4.97, R = 0.556, R^2 = 0.281) and the lowest SEE for the regression equation for males only, was for the fourth metatarsal (SEE = 5.87, R = 0.657, R^2 = 0.431).

The highest SEE using combined male and female metatarsal lengths was for the regression equation that used third metatarsal (SEE = 7.61, R = 0.650, R^2 = 0.413). The highest SEE using only female metatarsal length was for the regression equation that used first metatarsal (SEE = 5.57, R = 0.364, R^2 = 0.132). The highest SEE using only male metatarsal length was for the regression equation that used first metatarsal (SEE = 7.17, R = 0.387, R^2 = 0.150).

Equations with a high correlation coefficient and a low SEE are recommended while using regression method for estimation of stature.

Multivariate equations returned a higher correlation coefficient of 0.556 – 0.799 and SEE of 6.07 which indicates a higher degree of accuracy of regression equations derived from a combination of metatarsal measurements. The best multiple regression equation obtained, in the present study, for females was 88.978 + 0.014 MT4 + 1.112 MT5, R = 0.556, R^2 = 0.251, SEE = 5.07 and that for males was 81.139 + 1.068 MT4 + 0.261 MT5, R = 0.660, R^2 = 0.398, SEE = 5.94. The best multiple regression equation obtained using combined values in males and females, in the present study, was 48.726 + 0.843 MT4 + 0.972 MT5, R = 0.799, R^2 = 0.639, SEE = 6.07.

CONCLUSION

Morphometry of metatarsals and phalanges using radiographs of feet can help in arriving at a fixed correlation with respect to their lengths and breadths. This correlation can be used in pre-operative planning, in choosing one particular surgical technique over another, in assessing outcome of a surgery and in devising newer surgical techniques. They may be used to compare outcome of two different surgical techniques for the same indication.

The fixed proportions between the lengths or breadths of metatarsals among themselves and lengths of phalanges among themselves is a useful tool for a plastic and reconstructive surgeon, in arriving at the correct length to which the concerned bone should be lengthened or shortened, with the aim of achieving the correct metatarsal parabola.

Stature estimation using the lengths of metatarsals is possible by statistical methods. This has applications in situations where only the feet of a person are available for analysis and investigation or in situations such as fossil studies where the specimen cannot be destroyed by dissection for direct measurements of bones.

The limitation of the present study is its small size. Issues of loss of three-dimensional information on radiographs are yet to be conclusively settled. Stature is age, sex and race specific. Hence the present formulae can be applied only to the sex and race from which the sample has been drawn.

Future studies on larger samples may be able to further refine the results and reduce the errors of estimate and provide better formulae.

SUMMARY

Several diseases, congenital or otherwise, affect the lengths of metatarsals and phalanges, altering the biomechanics of the foot. Surgical correction of this imbalance, assessing the short and long term outcomes of a particular surgical correction done, devising and comparing new surgical techniques are all directed towards achieving patient satisfaction.

In forensic and anthropological applications, stature estimation is a useful tool in reconstructing the physical profile of an individual. Stature estimation using lengths of metatarsals will be useful in conditions wherein only metatarsals are available for study or along with fragmentary long bones.

Antero-posterior radiographs of sixty pairs of feet (total of 120 feet) of normal individuals above the age of twenty two years were analysed with respect to lengths and widths of metatarsals and lengths of phalanges. The results were tabulated and fixed proportions between bones of the same group were arrived at.

The longest metatarsal was the second metatarsal in both the sexes (67.61mm ± 3.49 in males and 62.46mm ± 3.45 in females). The shortest was the first metatarsal (56.42mm ± 4.41 in males and 50.09mm ± 3.06 in females).

The longest and shortest proximal phalanges were first and fifth respectively (28.0mm ± 2.40 in males and 25.8mm ± 2.21in females & 21.3mm ± 1.54 in males and 19.3mm ± 1.31in females).

The longest and shortest middle phalanges were second and fifth respectively (11.1mm ± 1.81in males and 9.3mm ± 2.06in females & 5.8mm ± 0.97 in males and 5.1mm ± 0.81in females).

The longest and shortest distal phalanges were first and fifth respectively (22.5mm ± 1.85in males and 20.8mm ± 1.90in females & 5.2mm ± 1.33 in males and 4.4mm ± 1.03 in

females). The widest metatarsal with respect to mid-shaft thickness was the first metatarsal in both sexes (13.7mm ± 1.00 in males and 11.7 ± 0.91 in females). The narrowest metatarsal with respect to mid-shaft thickness was the third metatarsal in both sexes (6.8mm ± 0.65 in males and 5.9 ± 0.57 in females).

Regression formulae for estimation of stature using lengths of metatarsals were calculated for males and females.

It is our hope that these data and formulae are helpful for surgical, anthropological and forensic applications.

BIBLIOGRAPHY

1. Wood Jones F. Introductory: Dealing With the Study of the Foot. Clin Orthop Relat Res. 2001 Oct; 391: 72-88.
2. Perry MD, Mont MA, Einhorn TA, Waller JD. The Validity of Measurements made on Standard Foot Orthoroentgenograms. Foot Ankle. 1992; 13(9): 502-7.
3. Specht EE. Minor Congenital Deformities and Anomalies of the Foot. In: Inman VT, editor. DuVries' Surgery of the Foot. 3rd ed: CV Mosby; 1973. p. 51-87.
4. Viladot A. Metatarsalgia Due to Biomechanical Alterations of the Forefoot. Orthop Clin North Am. 1973; 4: 165-78.
5. Nawoczenski DA, Saltzman CL, Cook TM. The Effect of Foot Structure on the Three-Dimensional Kinematic Coupling Behavior of the Leg and Rear Foot**.** Phys Ther. 1998; 78: 404-16.
6. Latimer B, Lovejoy CO. Metatarsophalangeal Joints of Australopithecus afarensis. Am J Phys Anthropol. 1990 Sep; 83(1): 13-23.
7. Hetherington VJ. Metatarsalgia and Lesser Metatarsal Surgery. In: Hetherington VJ, editor. Textbook of Hallux Valgus and Forefoot Surgery. New York: Churchill Livingstone; 1994. p. 429-51.
8. Hawkins FB, Mitchell CL, Hedrick DW. Correction of Hallux Valgus by Metatarsal Osteotomy. J Bone Joint Surg Am. 1945; 27: 387-94.
9. Mayo CH. The Surgical Treatment of Bunion. Ann Surg. 1908; 48(2): 300 - 2.
10. Freiberg AH. The So-Called Infraction of the Second Metatarsal Bone. J Bone Joint Surg Am.1926; 8: 257-61.
11. Meisenbach RO. Painful Anterior Arch Of The Foot: An Operation for its Relief by Means of Raising the Arch. J. Bone Joint Surg. Am. 1916; s2-14: 206 -11.
12. Boorstein SW. A Symmetrical Congenital Malformation of the Extremities with a Report of Two Cases. Ann Surg. 1916 Feb; 63(2): 192-7.
13. Morton DJ. Evolution of the Longitudinal Arch of the Human Foot. J Bone Joint Surg Am.1924; 6: 56-90.
14. Peabody CW. The Surgical Cure of Hallux Valgus. J Bone Joint Surg Am. 1931; 13: 273-82.
15. Engle ET, Morton DJ. Notes on Foot Disorders among Natives of the Belgian Congo. J Bone Joint Surg Am. 1931; 13: 311-8.
16. Fischer FJ, Vandemark RE. Bilateral Symmetrical Brachymetacarpalia and Brachymetatarsalia: Report of a Case. J Bone Joint Surg Am. 1945; 27: 145-8.

17. Harris RI, Beath T. The Short First Metatarsal: Its Incidence and Clinical Significance J Bone Joint Surg Am. 1949; 31: 553-65.
18. Kirkos JM, Kyrkos MJ, Kapetanos GA. Stress Fractures of the Lesser Metatarsals After a Wilson Osteotomy for Correction of Hallux Valgus Deformity. J Am Podiatr Med Assoc 2006; 96: 63-6.
19. Giannestras NJ. Plantar Keratosis, Treatment by Metatarsal Shortening: Operative Technique and End-Result Study. J Bone Joint Surg Am. 1966; 48: 72-6.
20. Wilson J N. Oblique Displacement Osteotomy for Hallux Valgus. J Bone Joint Surg Br. 1963; 45-B: 552-6.
21. Miller JM, Stuck R, Sartori M. The Inverted Z Bunionectomy: Quantitative Analysis of the Scarf and Inverted Scarf Bunionectomy Osteotomies in Fresh Cadaveric Matched Pair Specimens. J Foot Ankle Surg. 1994; 33(5): 455-62.
22. Sharrard WJW. Paediatric Orthopaedics and Fractures. 3rd ed. Blackwell Scientific Publication; 1993.
23. Helal B. Metatarsal Osteotomy for Metatarsalgia. J Bone Joint Surg Br. 1975; 57-B: 187-92.
24. Chiappara P. Treatment of Symptomatic First Metatarsal Shortened by Surgery. Foot Ankle. 1985; 6(1): 39-43.
25. Shereff MJ, DiGiovanni L, Bejjani FJ, Hersh A, Kummer FJ. A Comparison of Nonweight-Bearing and Weight-Bearing Radiographs of the Foot. Foot Ankle. 1990 Jun; 10(6):306-11.
26. Takakura Y, Tanaka Y, Fujii T, Tamai S. Lengthening of Short Great Toes by Callus Distraction. J Bone Joint Surg Br. 1997; 79-B: 955-8.
27. Kucukkaya M, Kabukcuoglu Y, Tezer M, Kuzgun U. Correcting and Lengthening of Metatarsal Deformity with Circular Fixator by Distraction Osteotomy: A Case of Longitudinal Epiphyseal Bracket. Foot Ankle Int. 2002 ;23(5):427-32.
28. Lamm BM. Metatarsal Lengthening. In: Rozbruch SR, Ilizarov S, editors. Limb Lengthening and Reconstruction Surgery: CRC Press; 2006. 291-301.
29. Fetto JF. Anatomy and Physical Examination. In: Nicholas JA, Hershman EB, editors. The Lower Extremity and Spine in Sports Medicine. 2nd ed: Mosby; 1995. p. 317-34.
30. Susan Standring, editor. Gray's Anatomy: The Anatomical Basis of Clinical Practice. 39th ed: Elsevier Churchill Livingstone; 2005.
31. Walter HE, Sayles LP. Biology of the Vertebrates: A Comparative Study of Man and His Allies. 3rd ed. New York: The Macmillan Company; 1961.
32. Elftman H, Manter J. The Evolution of the Human Foot, with Especial Reference to the Joints. J. Anat.1935; 70(pt1): 56-67.

33. Harcourt-Smith WEH, Aiello LC. Fossils, Feet and the Evolution of Human Bipedal Locomotion. J. Anat. 2004; 204: 403-16.
34. Peltier LF. The Classic 'Structure and Function As Seen in the Foot'. Clin Orthop Relat Res 2001(Oct); 391-3.
35. Mooney EK, Loh C. Lower Limb Embryology [monograph on the Internet]. 2009 Oct [cited 2009 Oct 01]. Available from http://emedicine.medscape.com/article/1291712-overview .
36. Böhm M. The Embryologic Origin of Club-Foot. J Bone Joint Surg Am. 1929; 11: 229-59.
37. Bentley G. Foot and Ankle. In: Duthei RB, Bentley G, editors. Mercer's Orthopaedic Surgery. 9th Ed: Arnold Jaypee Brothers; 2003. p. 1193-284.
38. Urano Y, Kobayashi A. Bone-Lengthening for Shortness of the Fourth Toe. J Bone Joint Surg Am1978; 60: 91-3.
39. Holden D, Siff S, Butler J, Cain T. Shortening of the First Metatarsal as a Complication of Metatarsal Osteotomies. J Bone Joint Surg Am 1984; 66: 582-87.
40. Karasick D, Wapner KL. Hallux Valgus Deformity: Preoperative Radiologic Assessment. AJR Am J Roentgenol. 1990; 155: 119-23.
41. Munuera Martinez PV, Sotillos GL, Maldonado GD, Macias JLS, Camuna LM. Morphofunctional Study of Brachymetatarsia of the Fourth Metatarsal. J Am Podiatr Med Assoc. 2004; 94: 347-52.
42. Grebing BR, Coughlin MJ. Evaluation of Morton's Theory of Second Metatarsal Hypertrophy. J Bone Joint Surg Am. 2004; 86: 1375-86.
43. Baek GH, Chung MS. The Treatment of Congenital Brachymetatarsia by One-Stage Lengthening. J Bone Joint Surg Br. 1998 Nov; 80(6): 1040 - 4.
44. Kim JS, Baek GH, Chung MS, Yoon PW. Multiple Congenital Brachymetatarsia: A One-Stage Combined Shortening and Lengthening Procedure without Iliac Bone Graft. J Bone Joint Surg Br. 2004; 86-B: 1013-15.
45. Camasta CA, Pontius J, Boyd RB. Quantifying Magnification in Pedal Radiographs. J Am Podiatr Med Asscn. 1991 Oct; 81(10): 545-8.
46. Kennedy JG, Deland JT. Resolution of Metatarsalgia Following Oblique Osteotomy Clin Orthop Relat Res. 2006; 453: 309-13.
47. Femino JE, Mueller K. Complications of Lesser Toe Surgery. Clin Orthop Relat Res. 2001; 391:72-88.
48. Dogan A, Uslu M, Aydinlioglu A, Harman M, Akpinar F. Morphometric Study of the Human Metatarsals and Phalanges. Clin. Anat. 2007; 20: 209-14.
49. Adelaar R S. Complications of Forefoot and Midfoot Fractures. Clin Orthop Relat Res. 2001; 391: 26-32.

50. Richardson EG, Donley BG. Rheumatoid Foot. In: Canale ST, editor. Campbell's Operative Orthopaedics. 10th ed: Mosby; 2003. p. 4085-110.
51. Murphy GA. Lesser Toe Abnormalities. In: Canale ST, editor. Campbell's Operative Orthopaedics. 10th ed: Mosby; 2003. p. 4047-84.
52. Hetherington VJ. Metatarsalgia and Lesser Metatarsal Surgery. In: Hetherington VJ, editor. Textbook of Hallux Valgus and Forefoot Surgery. New York: Churchill Livingstone; 1994. p. 429-51.
53. Hansen Jr ST. Foot Injuries. In: Browner BD, Jupiter JB, Levine Am, Trafton PG, editors. Skeletal Trauma. Fractures, Dislocations and Ligamentous Injuries. WB Saunders; 1992. p. 1959-91.
54. Hurst JM, Nunley JA 2nd. Distraction Osteogenesis for the Shortened Metatarsal after Hallux Valgus Surgery. Foot Ankle Int. 2007; 28(2): 194-8.
55. Sammarco GJ, Idusuyi OB. Complications after Surgery of the Hallux. Clin Orthop Relat Res. 2001Oct; 391: 59-71.
56. Valentin S, Galois L, Stiglitz Y, Wein F, Anne V, Mainard D. Disharmonious Metatarsals (Hallux Valgus Excepted). J Bone Joint Surg Br. 2008; 90-B SUPP 2: 245-a.
57. Rose R. Metatarsal Lengthening By Callus Distraction For Brachymetatarsia: Case Report and Review of the Literature . The Internet Journal of Third World Medicine. 2004 [cited 2009 Oct 01]; 1(2)[about 4 p.] Available from http://www.ispub.com/journal/the_internet_journal_of_third_world_medicine/volume_1_number_2_64/article/metatarsal_lengthening_by_callus_distraction_for_brachymetatarsia_case_report_and_review_of_the_literature.html .
58. Kim HT, Lee SH, Yoo CI, Kang JH, Suh JT. The Management of Brachymetatarsia. J Bone Joint Surg Br; 2003; 85-B: 683-90.
59. Magnan B, Bragantini A, Regis D, Bartolozzi P. Metatarsal Lengthening by Callotasis During the Growth Phase. J Bone Joint Surg.1995; 77-B: 602-7.
60. Coughlin MJ, Mann RJ editors. Surgery of the Foot and Ankle. 7th ed. St. Louis: Mosby; 1999.
61. Snyder AJ, Hetherington VJ. Overview of Distal First Metatarsal Osteotomies. In: Hetherington VJ, editor. Textbook of Hallux Valgus and Forefoot Surgery. New York: Churchill Livingstone; 1994. p. 163-7.
62. Mandracchia VJ, Mandracchia DM, Merrell TA. Proximal Osteotomy. In: Hetherington VJ, editor. Textbook of Hallux Valgus and Forefoot Surgery. New York: Churchill Livingstone; 1994. p. 227-66.

63. Patton GW, Zelichowski JE. Middiaphyseal Osteotomies. In: Hetherington VJ, editor. Textbook of Hallux Valgus and Forefoot Surgery. New York: Churchill Livingstone; 1994. p. 215-25.
64. Herring JA. Tachdjian's Pediatric Orthopaedics. 4th ed: Saunders Elsevier; 2008.
65. Keogh P, Jaishanker JS, O'Connell RJ, White M. The Modified Wilson Osteotomy for Hallux Valgus. Clin Orthop Relat Res. 1990; 255: 263-7.
66. Carr CR, Boyd BM. Correctional Osteotomy for Metatarsus Primus Varus and Hallux Valgus. J Bone Joint Surg Am. 1968; 50: 1353-67.
67. Muscarella V, Hetherington VJ. Hallux Limitus and Hallux Rigidus. In: Hetherington VJ, editor. Textbook of Hallux Valgus and Forefoot Surgery. New York: Churchill Livingstone; 1994. p. 313-25.
68. Hetherington VJ, Cwikla PS, Malone M. Review of First Metatarsophalangeal Joint Implants. In: Hetherington VJ, editor. Textbook of Hallux Valgus and Forefoot Surgery. New York: Churchill Livingstone; 1994. p. 347-58.
69. Minguella J, Cabrera M, Escola J. Techniques for Small Bone Lengthening in Congenital Anomalies of the Hand and Foot. J Pediatr Orthop B. 2001: 10; 355-9.
70. Oh CW, Satish BR, Lee ST, Song HR. Complications of Distraction Osteogenesis in Short First Metatarsals. J Pediatr Orthop. 2004; 24(6): 711-5.
71. Hanyu T, Yamazaki H, Murasawa A, Tohyama C. Arthroplasty for Rheumatoid Forefoot Deformities by a Shortening Oblique Osteotomy. Clin Orthop Relat Res. 1997; 338: 131-8.
72. Schemitsch E, Horne G. Wilson's Osteotomy for the Treatment of Hallux Valgus. Clin Orthop. 1989; 240: 221–5.
73. Nicklas BJ. Surgical Management of Digital Deformities. In: Hetherington VJ, editor. Textbook of Hallux Valgus and Forefoot Surgery. New York: Churchill Livingstone; 1994. p. 359-77.
74. Smith TWD, Kreibich DN. Frieberg's Disease. In: Hetherington VJ, editor. Textbook of Hallux Valgus and Forefoot Surgery. New York: Churchill Livingstone; 1994. p. 453-7.
75. Lehtinen JE. Tailor's Bunion Deformity. In: Hetherington VJ, editor. Textbook of Hallux Valgus and Forefoot Surgery. New York: Churchill Livingstone; 1994. p. 459-69.
76. Abdel Moneim WM, Abdel Hady RH, Abdel Maaboud RM, Fathy HM, Hamed AM. Identification of Sex Depending on Radiological Examination of Foot and Patella. Am J Forensic Med Pathol.2008; 29(2): 136- 40.
77. Fessler DMT, Haley KJ, Lal RD. Sexual Dimorphism in Foot Length Proportionate to Stature. Ann Hum Biol. 2005; 32(1): 44-59.

78. Bidmos MA. Metatarsals in the Estimation of Stature in South Africans. J Forensic Leg Med. 2008; 15(8): 505-9.
79. Byers S, Akoshima K, Curran B. Determination of adult stature from metatarsal length. Am J Phys Anthropol.1989 Jul; 79(3): 275-9.
80. Zhao-hui P, Ping-ping J, Jian-li W, Qing W, Yan-jun Z. Finite Element Analysis of Metatarsal Deficit and Reconstruction using Ilium, Fibula and Scapula. Commun Numer Methods Eng. 2006; 22(7): 799-808.

MASTER CHART FOR METATARSALS-1

S.NO.	SEX	HT (cm)	LENGTH OF METATARSALS (mm)										WIDTH OF METATARSALS (mm)									
			1		2		3		4		5		1		2		3		4		5	
			R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
1	M	175	56.08	56.04	69.69	70.59	63.81	61.45	69.14	69.29	66.26	63.03	15.36	15.37	6.84	7.29	6.93	7.16	7.37	7.28	8.94	8.69
2	F	160	50.59	51.05	64.30	62.54	64.90	60.80	66.13	65.90	63.11	61.28	11.83	11.87	7.31	7.41	5.56	5.26	6.35	6.08	6.91	6.94
3	F	150	47.36	48.78	61.96	62.69	60.16	59.31	60.89	61.54	58.86	58.80	12.27	11.77	7.98	7.92	6.61	6.71	6.34	6.26	8.30	8.52
4	M	163	61.96	62.58	68.03	67.14	69.90	64.74	66.57	65.67	61.99	62.55	11.62	12.38	9.49	9.32	6.90	6.53	6.12	6.52	9.25	9.69
5	M	172	56.11	56.66	66.02	65.36	67.34	64.92	66.14	68.50	64.08	65.18	13.51	13.96	8.23	7.99	7.79	7.73	7.45	6.90	7.82	7.49
6	M	165	61.53	55.48	65.10	65.71	64.49	60.98	66.42	61.98	62.68	59.93	12.64	12.30	7.57	6.79	6.88	6.92	7.09	6.92	8.74	8.49
7	M	172	58.08	57.54	66.18	67.83	68.92	69.89	67.34	68.19	63.71	63.69	14.53	13.97	8.82	8.98	6.81	6.65	6.61	7.23	7.65	7.33
8	M	160	54.59	54.16	64.48	62.53	62.16	57.16	63.10	63.78	60.64	57.69	12.67	12.40	6.64	7.46	6.16	6.20	6.98	7.15	9.39	9.23
9	M	181	59.85	66.10	70.91	70.04	68.37	68.52	71.15	71.18	65.95	66.26	13.11	13.92	7.79	8.06	6.47	6.90	7.50	7.39	8.71	9.41
10	M	163	62.54	60.46	69.38	68.78	66.80	64.12	67.41	64.12	63.95	61.30	14.42	13.14	7.21	7.03	6.93	6.48	6.59	6.86	6.94	7.22
11	M	165	61.94	61.94	70.72	69.31	63.77	66.40	66.13	68.16	62.18	61.68	12.82	12.77	8.47	8.32	8.23	7.94	7.87	7.42	7.41	7.90
12	M	176	54.92	56.04	64.25	64.86	62.85	64.86	66.88	68.49	65.70	63.52	12.89	14.54	7.71	7.88	6.66	7.32	6.66	7.50	8.27	8.20
13	M	180	60.60	59.04	71.39	72.41	67.86	70.11	70.12	70.75	67.07	64.84	13.69	13.69	8.70	8.73	7.38	8.02	7.21	9.53	8.85	8.59
14	M	163	48.95	52.05	63.62	65.10	63.55	62.28	65.10	63.05	62.26	63.12	16.09	15.80	6.87	7.48	8.02	7.86	8.28	8.55	8.52	8.13
15	M	170	56.31	54.76	70.89	71.43	72.66	72.05	70.28	70.87	71.57	70.97	12.58	12.58	8.08	8.07	6.14	6.26	6.35	6.10	8.74	7.97
16	M	176	52.97	53.08	66.01	64.95	64.60	62.62	65.91	65.77	63.24	62.82	12.12	13.15	7.53	7.10	6.23	6.37	7.17	6.93	8.08	8.05
17	M	160	54.88	58.13	64.60	61.91	67.82	62.69	63.40	61.49	64.28	64.25	12.68	12.92	7.40	7.50	6.65	6.51	7.06	7.12	8.37	7.67
18	M	167	54.14	52.93	68.47	69.84	70.46	69.58	67.62	68.40	63.05	63.14	12.80	13.01	6.73	7.32	6.96	7.11	7.16	6.72	8.06	8.16
19	M	168	65.31	63.30	70.29	70.23	70.76	67.57	69.55	68.53	67.82	67.58	14.13	14.20	6.76	7.15	6.12	6.82	7.51	7.47	7.80	8.18
20	M	168	61.87	56.10	68.37	66.92	68.16	65.05	66.59	65.87	66.36	65.37	15.47	15.31	8.21	6.61	7.55	7.87	8.03	8.18	8.77	8.60
21	M	182.5	58.19	53.87	69.54	68.84	73.31	72.63	75.02	73.15	69.63	67.43	13.50	13.15	7.85	9.53	7.30	8.04	6.97	6.95	7.94	7.83
22	M	168	57.20	59.29	70.46	68.39	67.77	68.01	70.27	69.52	67.58	66.91	13.76	12.87	6.65	6.98	5.80	5.58	5.83	5.95	6.94	7.01
23	M	176	57.61	57.07	66.87	68.41	63.27	63.87	61.14	63.15	66.22	62.40	13.69	13.87	6.93	6.84	6.79	6.76	6.71	6.44	8.24	8.07
24	M	178	64.61	63.15	72.09	70.09	67.40	71.12	71.15	70.23	72.71	71.51	16.35	16.54	8.01	8.26	7.82	8.36	8.20	8.73	9.29	9.22
25	F	155	54.75	54.13	64.94	62.68	61.27	62.25	62.09	64.21	62.16	61.63	13.26	12.42	7.26	7.31	5.17	5.32	6.0	5.77	7.88	7.36
26	F	155	52.82	51.82	66.34	66.13	63.23	62.97	62.19	63.27	61.21	59.97	10.63	11.74	7.81	8.42	6.81	7.46	6.69	6.58	7.11	7.17
27	F	143	46.39	46.04	55.66	55.47	59.66	59.31	56.58	57.45	53.26	52.84	11.21	10.47	6.32	6.78	5.68	5.54	5.71	5.52	5.95	5.72
28	F	150	51.51	50.80	69.25	69.18	64.49	66.10	63.67	65.97	62.66	63.15	12.82	12.12	7.21	7.91	6.28	6.38	6.24	6.34	5.87	5.96
29	M	172	58.44	60.93	72.93	74.22	73.41	72.52	73.35	72.09	72.41	72.72	13.34	13.42	8.01	7.45	7.03	6.15	8.25	6.91	8.12	7.70
30	F	160	52.59	52.86	62.67	65.00	61.91	61.90	60.30	60.22	59.91	60.23	11.36	11.16	6.04	6.12	5.39	5.23	6.29	5.48	7.21	6.85

MASTER CHART FOR METATARSALS-2

S.NO.	SEX	HT (cm)	LENGTH OF METATARSALS (mm)										WIDTH OF METATARSALS (mm)									
			1		2		3		4		5		1		2		3		4		5	
			R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
31	F	150	46.83	47.64	59.74	65.36	57.45	64.72	59.88	60.46	57.50	57.14	9.03	9.57	6.77	6.53	5.94	5.48	5.87	6.31	6.93	6.93
32	F	160	56.57	55.42	69.25	68.92	68.57	68.37	66.14	66.54	60.46	61.44	11.16	11.27	6.56	7.16	6.21	6.30	5.99	5.88	8.12	7.35
33	F	147	46.16	45.42	56.31	57.53	54.27	57.01	54.28	54.82	53.91	54.77	11.58	12.02	6.02	6.42	6.35	6.36	6.25	6.04	6.79	6.13
34	M	176	56.16	52.59	62.50	60.54	57.47	58.73	61.73	61.51	59.08	60.32	14.56	14.64	9.72	9.74	7.56	7.24	8.56	7.25	9.10	8.37
35	F	150	48.61	50.00	57.01	60.19	54.38	58.34	57.16	58.23	53.34	55.41	11.70	11.75	6.65	6.70	5.65	5.83	5.49	5.45	6.25	5.78
36	M	153	46.39	47.24	62.67	63.11	59.48	60.39	60.12	60.01	59.39	59.86	12.86	12.90	8.0	8.17	6.87	6.58	7.09	6.77	7.60	7.78
37	F	160	48.08	49.67	57.23	58.96	57.79	58.47	57.65	57.45	57.58	57.45	14.01	13.46	6.43	6.15	5.75	5.88	6.55	6.68	7.62	7.74
38	M	172	50.67	51.11	67.88	67.37	63.16	63.14	67.47	68.97	65.43	66.55	13.16	13.60	7.70	7.22	6.15	6.01	6.97	7.46	9.29	9.09
39	F	168	52.81	51.37	67.68	65.86	64.05	64.64	65.29	64.54	64.54	63.50	11.99	10.83	6.49	5.80	5.19	4.81	5.55	5.23	6.97	6.68
40	F	160	57.84	56.56	66.84	67.16	65.25	63.53	63.28	61.43	60.92	59.36	10.90	10.71	7.71	7.49	6.40	5.63	5.87	6.01	6.89	7.55
41	F	150	49.14	48.69	61.40	60.29	56.59	57.09	60.68	60.32	51.10	54.80	11.85	11.47	8.94	7.94	7.60	6.93	6.39	6.62	8.04	8.24
42	F	163	48.27	47.83	63.43	60.26	59.11	60.12	59.10	59.20	56.74	55.85	11.44	11.65	6.84	6.71	5.85	5.49	6.20	6.47	6.87	7.14
43	F	149	52.34	54.19	63.63	65.08	62.75	61.29	61.29	59.47	58.75	58.71	13.78	13.86	6.51	7.10	5.48	5.40	6.37	6.21	7.52	7.15
44	F	152	50.05	48.62	61.29	59.62	59.12	58.59	60.75	58.69	57.15	55.30	12.49	12.26	5.57	5.73	5.73	5.99	6.75	6.48	7.74	6.89
45	M	165	55.71	56.11	68.75	69.43	67.48	65.58	66.53	65.50	63.96	62.59	13.51	13.63	6.58	7.01	6.14	5.79	6.33	6.01	7.43	7.22
46	F	156	48.98	51.46	61.21	62.49	60.41	60.21	62.24	60.97	58.83	58.92	12.42	12.84	6.68	7.08	6.41	6.55	7.25	7.08	8.09	7.90
47	M	160	48.11	48.78	61.27	62.98	58.42	58.52	58.70	58.72	59.60	58.86	14.97	14.50	7.11	6.95	6.63	6.56	6.29	5.96	7.37	6.93
48	M	173	56.88	54.50	63.63	68.77	66.43	67.21	64.41	65.96	64.03	65.98	13.82	13.66	6.78	7.50	5.74	6.54	7.05	7.19	8.65	7.63
49	F	160	46.40	46.74	57.41	58.38	56.11	58.04	56.39	57.38	56.60	56.54	11.94	11.94	5.84	6.14	5.68	5.40	6.50	5.94	7.25	7.01
50	F	158	52.23	52.30	63.51	65.65	63.34	65.53	62.35	65.53	60.28	61.55	11.75	11.43	7.01	6.68	5.98	6.27	6.30	6.35	8.05	8.47
51	M	178	58.24	58.33	75.25	77.55	74.35	77.85	72.98	72.51	66.86	68.58	14.36	14.17	7.99	7.78	6.83	7.10	6.90	7.27	7.51	7.98
52	M	154	51.96	53.28	67.36	65.83	65.65	62.08	64.14	59.82	61.27	58.86	13.88	14.26	7.16	6.54	6.85	6.31	7.49	7.24	8.25	8.54
53	F	152	47.90	49.19	61.81	64.04	60.85	62.38	60.56	60.82	57.68	58.35	10.84	10.44	6.45	6.56	5.45	5.52	6.63	5.99	7.51	7.20
54	F	150	50.62	51.46	62.79	62.37	61.11	59.49	59.48	59.49	56.09	58.31	12.07	12.24	7.29	7.34	6.20	6.43	6.51	5.87	6.46	6.08
55	F	147	49.71	48.45	60.13	57.47	59.04	56.30	58.18	57.34	57.13	55.14	11.66	11.53	6.94	6.96	6.02	6.0	5.61	5.81	6.71	6.57
56	F	154	48.21	47.44	62.91	61.98	62.64	60.36	61.49	60.19	60.44	59.91	12.30	11.84	7.09	7.14	5.34	5.89	5.91	6.01	7.48	7.01
57	F	160	51.61	50.00	65.01	60.84	62.78	59.84	62.84	60.69	58.41	57.17	11.49	10.93	8.79	7.94	6.77	6.87	6.48	6.30	7.25	7.30
58	F	157	43.80	45.22	60.25	63.24	59.23	62.53	59.38	60.20	55.77	58.72	11.26	11.62	6.86	7.27	5.98	6.12	6.33	6.62	7.10	6.91
59	M	160	55.71	56.11	68.75	69.43	67.48	65.58	66.53	65.50	63.96	62.59	13.51	13.63	6.58	7.01	6.14	5.79	6.33	6.01	7.43	7.22
60	M	165	48.11	48.78	61.27	62.98	58.42	58.52	58.70	58.72	59.60	58.86	14.97	14.50	7.11	6.95	6.63	6.56	6.29	5.96	7.37	6.93

MASTER CHART FOR PHALANGES-1

S.No	LENGTH OF PHALANX (mm)																											
	PROXIMAL										MIDDLE								DISTAL									
	1		2		3		4		5		2		3		4		5		1		2		3		4		5	
	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
1	27.58	29.09	28.33	25.97	24.29	23.19	23.40	22.46	22.16	23.14	11.45	12.71	7.21	7.47	6.21	6.66	7.09	5.87	23.01	22.9	7.81	7.36	6.91	6.86	6.01	5.98	5.21	6.61
2	27.95	28.60	24.33	25.33	22.31	22.62	19.74	20.21	18.88	19.69	9.13	9.48	7.60	7.51	6.71	6.66	7.38	5.98	22.66	22.21	7.13	8.33	5.48	6.44	4.30	5.91	5.38	5.15
3	26.05	25.55	25.33	25.05	22.76	23.38	20.80	20.81	19.95	19.12	12.76	12.42	11.23	10.55	9.91	9.65	7.30	6.91	21.87	22.60	8.73	8.33	7.31	6.99	6.06	6.33	4.16	5.69
4	27.12	28.69	25.67	26.52	24.85	24.64	22.42	21.12	20.69	20.24	10.83	9.04	7.78	9.04	6.36	5.99	5.23	5.98	20.51	20.27	7.88	8.06	6.70	7.38	4.90	5.70	5.05	5.52
5	26.81	27.28	25.55	25.70	24.90	24.51	23.54	22.76	20.78	20.70	12.45	10.51	10.10	8.91	6.32	5.91	5.58	5.90	22.47	22.14	6.65	7.85	6.03	7.67	5.38	5.98	5.61	5.69
6	25.84	25.25	23.55	23.21	22.24	21.53	20.95	20.86	19.11	19.90	10.20	8.44	10.20	8.44	6.66	8.09	5.59	5.66	22.32	21.39	8.81	9.89	8.63	9.89	7.53	9.07	6.07	6.06
7	25.50	26.12	25.06	26.12	26.35	25.05	22.85	23.19	20.70	21.02	11.09	11.42	7.89	12.32	5.61	8.74	4.64	7.61	23.81	23.64	8.77	7.58	7.75	6.06	7.22	7.77	6.64	6.85
8	23.64	26.24	21.99	22.94	21.53	21.86	18.99	20.56	18.36	18.79	9.77	11.13	8.43	9.05	6.59	8.63	4.41	7.36	18.66	20.76	5.75	6.67	4.76	4.72	4.76	6.45	4.41	6.02
9	27.50	28.81	24.42	24.82	22.75	23.61	21.86	23.19	20.67	21.42	10.29	10.02	6.78	7.73	6.68	7.36	5.87	4.23	21.62	21.94	7.71	6.28	6.70	6.11	5.89	5.08	4.70	6.53
10	27.09	25.57	23.29	22.70	22.24	21.98	20.05	20.27	19.44	18.39	11.46	9.89	10.27	7.38	6.47	7.32	5.41	5.23	22.54	20.94	5.82	7.36	5.71	5.66	5.24	5.34	4.69	4.96
11	27.92	28.06	27.29	28.31	24.49	26.18	23.24	23.78	19.47	19.30	11.66	13.05	10.36	11.04	5.77	9.00	7.34	7.37	24.94	23.83	6.22	5.81	5.92	4.14	6.96	3.94	5.08	3.93
12	26.76	28.22	25.86	25.51	23.50	23.83	21.96	22.75	21.67	21.96	11.74	11.98	11.07	11.80	8.09	8.15	7.43	7.20	22.00	22.43	6.96	7.30	6.38	6.67	4.60	6.50	3.78	4.47
13	26.87	27.15	25.86	25.22	24.12	24.48	22.62	22.05	21.72	20.81	7.60	7.44	7.31	6.86	6.26	6.43	6.11	6.53	21.04	20.54	6.40	6.25	6.57	5.87	6.20	5.75	5.30	5.04
14	25.86	24.51	23.08	22.40	20.65	20.62	19.92	20.23	18.55	16.99	9.36	10.32	8.46	5.94	7.16	7.85	5.19	5.52	20.48	20.27	6.19	8.19	6.03	6.62	5.22	5.59	4.19	4.44
15	29.67	29.63	27.91	27.93	25.56	25.93	24.15	24.34	22.24	23.82	12.94	13.04	12.80	12.66	11.74	11.52	8.85	6.87	23.52	23.71	6.49	6.14	6.77	6.87	4.07	3.67	3.41	2.82
16	29.22	29.54	28.19	28.71	25.01	25.44	23.76	23.55	23.12	22.93	10.97	11.00	6.72	7.28	5.47	5.55	4.56	5.44	22.77	22.71	6.19	8.20	6.16	5.65	4.16	4.50	4.16	4.32
17	28.03	26.91	26.10	25.53	23.97	23.96	23.22	22.97	21.96	21.41	10.16	10.45	10.05	8.24	6.47	8.74	5.19	7.21	22.04	20.64	6.50	5.48	5.04	5.18	6.01	5.56	7.25	7.92
18	27.80	27.10	28.13	27.80	25.88	26.02	24.11	23.81	21.66	21.53	12.05	11.27	11.36	11.40	9.79	9.92	5.77	5.86	23.78	23.70	7.40	5.77	5.50	6.38	4.42	4.59	5.06	4.16
19	28.16	29.87	27.14	27.14	26.19	26.06	22.68	23.16	19.99	21.23	12.33	11.94	6.66	6.83	5.50	5.78	4.40	4.41	22.11	22.51	7.52	7.83	7.14	8.64	7.14	6.83	6.64	7.50
20	23.48	24.74	24.04	24.06	23.60	23.88	22.41	22.28	21.51	22.09	13.15	12.78	12.29	12.18	9.70	9.81	7.13	5.94	24.40	24.84	8.26	7.96	8.95	8.52	6.55	8.94	6.23	6.23
21	30.54	30.84	26.70	26.60	25.41	25.50	23.35	23.98	23.02	21.80	13.27	14.60	11.11	12.87	9.89	10.62	7.26	5.29	25.28	27.59	8.72	8.93	7.07	8.37	7.53	8.37	4.82	6.53
22	29.59	30.08	30.34	29.44	27.38	27.32	25.64	25.86	23.08	22.27	12.84	11.51	11.88	7.07	9.03	5.56	5.01	4.08	24.28	23.54	5.78	6.04	6.31	5.05	5.92	3.80	4.59	5.00
23	30.98	31.85	29.73	29.33	27.86	27.18	26.32	24.83	23.75	22.24	14.29	15.02	13.73	13.64	8.30	9.63	7.63	6.15	25.57	25.17	9.96	11.62	8.78	10.6	8.03	8.76	8.78	9.53
24	33.92	34.24	29.84	30.05	27.57	28.67	25.27	26.03	25.07	24.45	10.80	11.86	8.69	10.86	7.07	8.17	5.79	3.55	19.57	19.07	5.74	4.03	6.11	4.12	5.81	4.01	5.14	5.92
25	25.85	27.07	24.20	23.33	21.61	22.34	21.66	21.18	20.78	20.37	7.85	6.89	5.60	5.72	5.33	4.31	4.71	4.50	22.88	21.69	8.09	6.75	7.46	6.59	5.14	4.00	5.39	4.49
26	26.15	26.35	26.26	24.57	24.63	22.27	21.72	20.71	18.32	18.27	10.12	10.52	7.78	5.61	4.34	5.14	4.49	4.38	21.03	20.61	5.56	6.32	5.35	6.57	5.61	5.79	4.10	4.52
27	22.77	20.60	20.40	20.25	18.92	18.37	17.31	17.02	16.22	15.78	8.80	6.48	6.48	6.15	4.73	5.05	4.56	4.37	17.22	17.55	6.79	5.12	6.44	4.45	5.17	3.54	3.06	2.93
28	27.51	27.53	25.22	24.27	23.35	23.64	22.72	22.36	20.01	20.45	11.66	9.31	8.69	8.32	5.58	8.35	5.30	7.53	17.43	17.34	6.14	6.09	5.17	5.08	5.00	5.06	4.18	4.32
29	32.45	32.35	29.11	28.68	25.49	26.96	24.41	25.15	22.33	23.90	12.01	12.24	12.01	12.19	10.30	11.79	6.89	7.35	21.01	20.78	6.01	5.97	4.79	4.43	4.03	3.98	3.95	3.82
30	26.00	25.17	23.75	23.02	22.28	22.23	21.22	20.38	19.80	19.54	9.10	10.90	9.08	7.03	6.94	6.10	6.10	5.71	21.87	21.18	10.97	10.58	9.70	9.31	8.61	8.27	7.11	7.21

MASTER CHART FOR PHALANGES-2

S.No	LENGTH OF PHALANX (mm)																											
	PROXIMAL										MIDDLE								DISTAL									
	1		2		3		4		5		2		3		4		5		1		2		3		4		5	
	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
31	26.62	22.72	24.90	23.79	23.66	22.59	21.97	20.92	18.85	19.11	9.07	10.93	7.99	10.15	7.90	7.79	5.60	5.88	18.33	19.26	5.68	7.25	4.37	6.72	4.01	5.62	3.00	4.28
32	28.90	28.97	26.30	25.33	24.03	24.27	22.25	21.94	20.17	20.48	9.45	9.85	6.30	6.62	5.73	5.92	5.74	5.34	23.41	24.00	7.94	7.60	7.58	7.40	5.41	6.41	5.28	4.49
33	21.70	14.48	21.98	21.13	19.78	20.69	19.04	17.96	17.59	16.74	8.72	9.10	5.76	5.02	5.68	5.03	4.10	3.77	19.34	20.08	6.01	6.46	4.31	4.84	4.02	4.53	3.57	4.17
34	29.86	29.89	27.81	27.81	23.69	25.30	22.73	23.51	21.08	21.61	11.76	11.86	11.10	11.00	7.03	7.11	4.21	4.58	23.62	24.19	9.18	9.91	9.01	9.71	8.61	8.71	7.47	7.63
35	24.39	23.82	22.50	22.64	21.92	20.64	20.13	19.08	17.83	17.81	8.73	8.63	7.24	8.91	5.16	5.19	5.19	5.18	17.62	17.30	4.95	5.20	3.85	4.81	3.89	4.25	3.55	3.65
36	27.91	28.1	27.73	27.89	26.22	25.95	24.92	25.21	22.85	22.86	13.32	13.52	13.32	13.31	12.15	11.48	5.47	5.95	24.76	25.70	8.03	8.71	8.33	7.63	7.33	7.01	6.48	4.77
37	25.58	27.5	27.44	27.29	24.44	26.38	21.44	23.88	18.94	21.10	11.16	13.03	10.87	12.61	7.71	10.78	5.36	5.56	22.93	22.91	7.68	8.87	7.23	7.82	6.13	6.62	3.87	4.08
38	26.78	27.32	25.88	25.29	24.02	24.57	22.16	22.44	19.97	20.79	7.98	8.60	6.64	6.84	5.90	5.15	4.72	4.79	23.73	23.33	5.62	5.81	5.13	5.03	4.37	4.73	4.10	4.49
39	28.24	26.39	26.81	24.89	26.13	24.38	24.58	23.06	22.04	21.43	6.46	6.29	5.88	6.04	5.04	5.40	5.18	4.95	24.94	23.17	8.12	8.85	7.27	7.93	6.59	5.71	6.16	4.71
40	26.01	26.58	25.01	24.7	23.60	22.43	21.35	20.11	19.47	18.95	11.21	10.35	7.09	6.92	6.21	5.81	6.21	5.39	20.51	20.49	6.48	7.30	6.98	6.74	6.01	5.72	5.31	4.66
41	28.24	27.63	26.75	26.18	24.23	24.37	22.77	22.29	20.77	19.20	12.32	13.05	12.04	12.63	6.51	6.81	5.15	5.40	24.34	24.13	3.73	5.58	4.77	6.20	5.36	5.24	3.92	3.71
42	24.44	24.70	23.66	24.32	22.05	22.2	20.33	19.83	18.55	18.69	9.92	8.63	5.60	6.54	4.65	6.58	4.19	6.23	21.14	21.60	8.41	4.68	7.92	4.28	4.97	4.06	4.53	3.40
43	25.75	26.83	24.38	23.96	22.52	22.42	21.00	20.80	19.24	19.16	12.49	12.01	9.57	10.40	7.71	7.56	5.19	5.15	20.07	19.51	7.11	6.63	6.52	6.75	6.07	5.26	5.85	4.41
44	23.68	23.51	21.99	21.3	20.77	19.68	19.93	19.58	19.23	18.98	9.39	7.57	6.11	5.88	5.37	5.13	5.36	4.80	20.7	21.13	7.18	8.00	6.24	6.85	5.53	6.05	4.95	5.11
45	24.75	25.85	25.27	25.38	24.21	23.87	22.26	21.41	19.86	21.22	12.17	11.03	10.33	9.88	5.35	5.44	4.18	5.28	22.42	22.06	4.92	4.77	3.92	4.15	3.57	3.88	3.87	3.80
46	27.51	26.71	25.11	25.9	23.78	24.48	22.39	23.32	22.03	22.50	7.38	7.65	6.01	5.63	5.01	4.70	4.73	4.70	22.05	22.07	7.68	8.48	7.66	10.03	8.17	10.16	6.30	7.54
47	26.52	26.59	24.84	25.02	22.58	22.65	20.23	20.58	20.13	21.59	10.83	9.77	9.78	8.72	6.72	6.99	6.17	5.71	20.27	20.76	6.50	6.79	4.90	6.42	4.22	5.65	4.00	5.53
48	30.9	30.48	27.55	27.77	24.34	25.27	23.2	23.86	21.23	20.16	5.47	6.07	5.86	5.18	4.20	4.12	4.67	4.09	22.37	23.35	6.01	5.22	5.07	4.53	4.31	3.61	3.90	3.22
49	24.69	25.39	22.14	22.82	20.88	20.95	19.26	19.24	19.14	18.86	5.95	6.94	5.36	5.43	3.75	4.85	3.61	4.01	18.57	18.64	5.52	6.43	4.17	5.08	3.59	3.79	3.27	2.98
50	26.69	27.17	24.84	25.41	24.13	23.68	21.46	22.41	18.39	18.63	9.90	9.57	6.22	6.47	4.90	4.92	4.90	4.75	19.90	20.53	5.11	6.45	4.84	5.26	3.86	4.00	3.29	3.27
51	31.81	31.85	29.34	29.29	26.83	26.91	25.21	24.64	23.73	23.78	13.42	12.13	12.05	10.73	10.64	10.1	7.71	5.94	25.08	25.41	7.99	6.26	7.49	6.21	5.82	5.74	5.71	5.65
52	28.01	26.39	26.46	25.85	25.05	24.81	23.45	23.01	21.83	20.86	10.25	10.57	10.25	10.34	8.29	7.61	6.93	6.58	20.90	19.04	5.21	5.45	6.61	4.75	5.09	4.31	4.01	3.86
53	25.88	27.24	21.67	24.24	21.44	22.73	20.35	21.33	17.02	19.07	5.80	6.33	4.77	5.83	4.23	5.24	4.10	5.01	19.66	20.79	7.90	6.38	7.23	6.56	5.02	5.35	4.83	5.30
54	25.47	24.84	24.3	23.31	23	22.99	21.65	21.53	20.16	20.66	5.53	5.27	5.01	4.65	4.48	4.20	4.44	3.94	20.74	20.62	7.11	6.96	6.03	6.22	4.97	5.29	4.31	4.63
55	26.88	28.12	25.49	24.19	22.97	22.11	21.07	17.94	18.76	17.81	10.36	11.55	5.79	6.95	5.15	5.87	4.30	5.85	20.53	18.15	4.74	6.35	3.99	6.14	3.68	5.58	2.65	4.70
56	24.15	25.14	23.27	23.68	22.07	21.94	19.81	20.03	18.88	19.76	10.44	9.82	9.07	7.37	4.88	4.67	4.27	4.23	21.71	21.66	7.96	5.32	6.79	4.50	4.87	4.01	4.81	2.69
57	26.55	26.22	24.70	23.82	22.41	21.99	21.63	20.68	20.01	20.56	6.87	7.01	5.40	6.21	4.21	3.93	4.33	3.93	20.61	21.26	7.56	6.95	6.06	7.48	5.03	5.37	2.97	3.55
58	27.87	27.54	25.66	26.64	21.99	23.21	20.87	21.05	19.33	20.23	11.37	10.79	11.35	11.84	5.45	6.71	4.48	5.49	19.43	21.35	4.95	4.88	6.48	4.85	5.44	4.65	4.32	4.34
59	24.75	25.85	25.27	25.38	24.21	23.87	22.26	21.41	19.86	21.22	12.17	11.03	10.33	9.88	5.35	5.44	4.18	5.28	22.42	22.06	4.92	4.77	3.92	4.15	3.57	3.88	3.87	3.80
60	26.52	26.59	24.84	25.02	22.58	22.65	20.23	20.58	20.13	21.59	10.83	9.77	9.78	8.72	6.72	6.99	6.17	5.71	20.27	20.76	6.50	6.79	4.90	6.42	4.22	5.65	4.00	5.53

PROFORMA

1. Name: _____ .

2. Date of birth: _____ Age :_____ Years

3. Sex : _____ .

4. Department: _____ .

5. Contact telephone number: _____ .

6. Native of _____(Place), _____(State).

7. Any history of

a) Birth defects :_____
b) Major injury to the feet :_____
c) Surgeries on feet :_____
d) Congenital deformities of feet :_____

8. Height : _____cm.

9. Weight : _____ kg.

10. Length of foot:

a) Right_____ cm, b) Left _____ cm.

11. Width of foot (widest diameter) _____ .

12. S. No of radiograph _____ dated _____ .

13. Lengths of Metatarsals on radiographs. (in millimeters)

	MT1	MT2	MT3	MT4	MT5
Right					
Left					

14. Lengths of Phalanges on radiographs. (in millimeters)

	PP 1	PP 2	PP 3	PP 4	PP 5	MP 2	MP 3	MP 4	MP 5	DP 1	DP 2	DP 3	DP 4	DP 5
Right														
Left														

RESEARCH PARTICIPATION INFORMATION AND CONSENT FORM

Mr./ Ms./ Dr. _____

You are hereby invited to participate in the research study '**RADIOLOGICAL AND MORPHOMETRIC STUDY OF HUMAN METATARSALS AND PHALANGES'.**

You are eligible to participate in this study since you are from _____ State, India. This study is about the measurement of lengths and widths of metatarsals and phalanges (small bones of the foot), on radiographs. The results of the study may help in planning of surgeries for lengthening / shortening or reconstructive surgeries of the foot.

Your participation in this study is entirely voluntary and you may withdraw from the study at any time. You will have to undergo exposure to X- ray radiation to your feet. The side effects of such an exposure are minimal and comparable to that of a routine X-ray. Exposure of pelvis and abdomen will be minimized by use of a lead apron.

You will be informed of new literature regarding the subject of research.

All information collected about you will be kept confidential to the extent permitted by law and may be used in the studies in future. You will have no rights over the X-ray film (s) of your feet.

No cost will be incurred by you for the study. There is no commitment for compensation for the participant.

PRINCIPAL INVESTIGATOR:

Name & Designation -
Address -
Telephone No. -

GUIDE

Name & Designation -
Address -
Telephone No. -

CHAIRMAN

Ethical Clearance Committee
Name & Designation -
Address –
Telephone No. -

Signature or Left Thumb Print of participant or legally authorized representative:

_____ Participant's name _____ Signature/ Thumb print

_____ Experimenter's name _____ Signature

_____ Witness name _____ Signature/ Thumb print

_____ Date

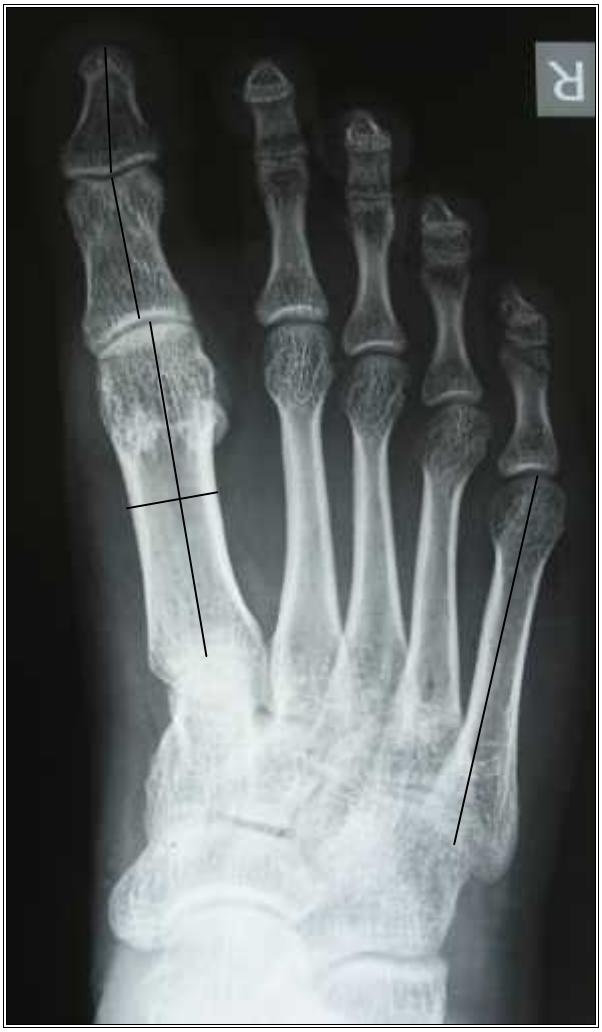


Figure No. 7 – An AP radiograph of the foot showing the position of points of reference for taking measurements of the lengths and widths of metatarsals and lengths of phalanges.

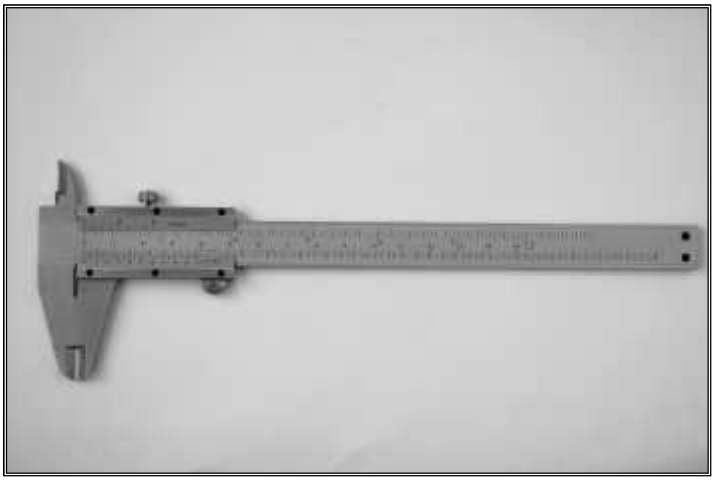


Figure No. 8 – Vernier calipers