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Original Article

Anatomy Section

Radiological Biometric Study of Metatarsals and Phalanges

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ABSTRACT

Introduction: Several diseases affect the forefoot bones. Relative dimensions of the forefoot bones are important considerations for preoperative and postoperative assessment of surgeries. The choice of a particular surgery over another can also be made if the surgeon knows the length to which a bone needs to be lengthened or shortened in comparison to other bones of the forefoot.

Aim: To measure the dimensions of the metatarsals and phalanges on standardized radiographs and to determine possible correlations amongst them.

Materials and Methods: A cross-sectional prospective study was conducted on 60 volunteer participants of either sex. The dimensions of metatarsals and phalanges were measured on standardized radiographs of both feet in 60 healthy adults. The mean, range and standard deviation were calculated. Correlation analysis was done to assess the association between the variables.

Results: The first metatarsal was the shortest (56.42±4.41 mm in males and 50.09±3.06 mm in females) and widest of all metatarsals (13.7±1.00 mm in males and 11.7±0.91 mm in females). The first proximal phalanx was the longest (28.0±2.40 mm in males and 25.8±2.21 mm in females) and the fifth distal phalanx (5.2±1.33 mm in males and 4.4±1.03 mm in females) was the shortest of all phalanges. A strong correlation ($p<0.001$) exists amongst the lengths of metatarsals, proximal phalanges and middle phalanges, within their own groups.

Conclusion: Correlation of the lengths and widths of the forefoot bones amongst themselves and between types can be calculated mathematically utilising standardized radiographs. This helps in assessment of forefoot disorders, choose an appropriate surgical technique and postoperative evaluation.

Keywords: Correlation, Metatarsalgia, Osteotomy, Podiatry, Reconstruction, Standardized radiograph

INTRODUCTION

The distribution of forces and weight in the foot, either when a person is standing erect at one place or when walking, running and jumping, keeps shifting continuously, especially in the forefoot. All the metatarsal heads bear weight. The first metatarsal bears double the weight of each of the remaining four. The weight is distributed in the ratio of 2:1:1:1:1 [1]. Even a minor variation in this ratio may have a bearing on the health of the individual and the quality of life. Structural variations of the foot, may be encountered as isolated defects as in Congenital Talipes Equinovarus (CTEV) or as part of a complex syndrome. Industrial and motor vehicle accidents affecting the foot may lead to alterations of lower extremity kinematics and may predispose the individual to characteristic musculoskeletal injuries [2,3]. 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. Restoring the lengths and widths of the metatarsals and phalanges to their correct measurements is crucial in achieving an optimal surgical outcome. Podiatric surgeons need to plan preoperatively the exact lengths to which a metatarsal is to be either lengthened or shortened [4].

Disorders of the forefoot bones may exist as part of familial or congenital syndromes [5]. Industrial injuries to the metatarsals are very common to the first and second metatarsals. Hallux valgus is one of the major disorders affecting the great toe, the exact incidence of which is difficult to estimate [6] and itself may tend to cause other forefoot abnormalities like corns, calluses, arthritis and metatarsalgia [7,8]. Various authors have described procedures on metatarsals for lengthening and shortening in an attempt to restore their correct functional lengths [9].

The objective of the present study was to measure the lengths and widths of metatarsals and lengths of phalanges of the feet, on standardized radiographs and to determine the possible correlation between the forefoot bones amongst themselves.

MATERIALS AND METHODS

Sixty healthy individuals (33 males and 27 females) above the age of 21 years (to allow for completion of ossification), were selected randomly for the study by adopting convenience sampling. The study was conducted between December 2008 and October 2009, after obtaining Institutional Ethical Committee approval and consent from the participants. They were healthy adults of the teaching institute in which the study was conducted. Subjects with history of major and/or long term injuries to the feet, past surgeries on the feet or those with long standing pain in the feet were excluded from the study.

Standardized Antero-Posterior (AP) radiographs of both feet of the individuals were taken. AP radiographs of both feet were taken one at a time. Subject was seated, foot was placed flat on the cassette and X-ray beam was centred on the base of third metatarsal which was identified by palpation. Source- Image receiver distance was fixed at 100 cm. 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. The radiographs were screened for readability.

Measurement technique- 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 as described. 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. Measurements for lengths of phalanges were taken from the middle of the articular surfaces both proximally and distally. Measurements for widths of all the bones were taken at mid-shaft level [Table/Fig-1].

[Table/Fig-1]: An Antero-Posterior 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.

STATISTICAL ANALYSIS

The mean, range and Standard Deviations (SD) of different measurements were calculated. Correlation analysis was done to assess the association between different variables. The significance threshold was set at 0.05.

RESULTS

The mean age of males was 27.78 (21–36) years and that for females was 27.96 (21-37) years. Lengths of metatarsals and phalanges on standardized radiographs of both feet were measured and tabulated. The mean, SD and range were calculated [Table/Fig-2,3]. Correlation of the lengths of the bones amongst their own group were calculated, i.e., metatarsals within themselves [Table/Fig-4], proximal phalanges within themselves [Table/Fig-5], middle phalanges within themselves [Table/Fig-6] and distal phalanges within themselves [Table/Fig-7]. There was strong correlation in these groups within themselves.

The second and the first metatarsals were the longest and shortest metatarsals, respectively. The mean lengths of these were; first metatarsal- 56.42±4.41 mm and 50.09±3.06 mm; second metatarsal - 67.61±3.49 mm and 62.46±3.45 mm, in males and females respectively.

The longest phalanx in both the sexes was the first proximal phalanx (28.0±2.40 mm in males and 25.8±2.21 mm in females). The fifth distal phalanx (5.2±1.33 mm in males and 4.4±1.03 mm in females) was the shortest.

Widths of all metatarsals were measured and tabulated. The mean and SD and range were calculated [Table/Fig-8]. The widest metatarsal in the present study was the first metatarsal (13.7±1.00 mm in males and 11.7±0.91 mm in females). The narrowest metatarsal was the third metatarsal (6.8±0.65 mm in males and 5.9±0.57 mm in females). The correlation of the widths of metatarsals amongst themselves was not significant in most [Table/Fig-9].

Metatarsal	Length (mm)		Range (in mm)			
	Male	Female	Male		Female	
	Mean ± SD	Mean ± SD	Maximum	Minimum	Maximum	Minimum
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

[Table/Fig-2]: Mean, Standard deviation and range of lengths of metatarsals.
MT1, MT2, MT3, MT4 and MT5 – First, Second, Third, Fourth and Fifth metatarsals respectively

Phalanx	Length (mm)		Range (in mm)			
	Male	Female	Male		Female	
	Mean ± SD	Mean ± SD	Maximum	Minimum	Maximum	Minimum
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

[Table/Fig-3]: Mean, Standard deviation and range of lengths of phalanges.
PP – Proximal phalanx, MP – Middle phalanx, DP – Distal phalanx, SD – Standard deviation

	Male				Female			
	MT2	MT3	MT4	MT5	MT2	MT3	MT4	MT5
MT1	0.631 (<0.001)	0.572 (<0.001)	0.600 (<0.001)	0.528 (<0.001)	0.739 (<0.001)	0.691 (<0.001)	0.665 (<0.001)	0.624 (<0.001)
MT2	-	0.850 (<0.001)	0.843 (<0.001)	0.742 (<0.001)	-	0.903 (<0.001)	0.877 (<0.001)	0.820 (<0.001)
MT3	-	-	0.856 (<0.001)	0.802 (<0.001)	-	-	0.872 (<0.001)	0.815 (<0.001)
MT4	-	-	-	0.834 (<0.001)	-	-	-	0.834 (<0.001)

[Table/Fig-4]: Correlation matrix for lengths of metatarsals amongst themselves.
MT1, MT2, MT3, MT4 and MT5 – First, Second, Third, Fourth and Fifth metatarsals respectively.
p Values are shown in parentheses

	Male				Female			
	PP2	PP3	PP4	PP5	PP2	PP3	PP4	PP5
PP1	0.851 (<0.001)	0.751 (<0.001)	0.776 (<0.001)	0.733 (<0.001)	0.772 (<0.001)	0.717 (<0.001)	0.678 (<0.001)	0.614 (<0.001)
PP2	-	0.916 (<0.001)	0.912 (<0.001)	0.801 (<0.001)	-	0.931 (<0.001)	0.798 (<0.001)	0.629 (<0.001)
PP3	-	-	0.934 (<0.001)	0.775 (<0.001)	-	-	0.918 (<0.001)	0.695 (<0.001)
PP4	-	-	-	0.821 (<0.001)	-	-	-	0.824 (<0.001)

[Table/Fig-5]: Correlation matrix for lengths of proximal phalanges amongst themselves.
PP1, PP2, PP3, PP4 and PP5 – First, Second, Third, Fourth and Fifth proximal phalanges respectively. p Values are shown in parentheses

	Male			Female		
	MP3	MP4	MP5	MP3	MP4	MP5
MP2	0.784 (<0.001)	0.635 (<0.001)	0.390 (<0.001)	0.819 (<0.001)	0.746 (<0.001)	0.571 (<0.001)
MP3	-	0.806 (<0.001)	0.563 (<0.001)	-	0.778 (<0.001)	0.519 (<0.001)
MP4	-	-	0.634 (<0.001)	-	-	0.774 (<0.001)

[Table/Fig-6]: Correlation matrix for lengths of middle phalanges amongst themselves.
M1, MP2, MP3, MP4 and MP5 – First, Second, Third, Fourth and Fifth middle phalanges respectively. p values are shown in parentheses

	Male				Female			
	DP2	DP3	DP4	DP5	DP2	DP3	DP4	DP5
DP1	0.480 (0.005)	0.471 (0.006)	0.433 (0.012)	0.282 (0.112)	0.465 (0.015)	0.592 (<0.001)	0.460 (0.016)	0.440 (0.022)
DP2	-	0.929 (<0.001)	0.871 (<0.001)	0.711 (<0.001)	-	0.864 (<0.001)	0.712 (<0.001)	0.737 (<0.001)
DP3	-	-	0.871 (<0.001)	0.679 (<0.001)	-	-	0.885 (<0.001)	0.826 (<0.001)
DP4	-	-	-	0.822 (<0.001)	-	-	-	0.853 (<0.001)

[Table/Fig-7]: Correlation matrix for lengths of distal phalanges amongst themselves.
DP1, DP2, DP3, DP4 and DP5 – First, Second, Third, Fourth and Fifth distal phalanges respectively. p Values are shown in parentheses

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

[Table/Fig-8]: Mean, Standard deviation and range of widths of metatarsals.
MT1, MT2, MT3, MT4 and MT5 – First, Second, Third, Fourth and Fifth metatarsals respectively

	Male				Female			
	MT2	MT3	MT4	MT5	MT2	MT3	MT4	MT5
MT1	0.062 (0.730)	0.445 (0.011)	0.468 (0.007)	0.041 (0.842)	0.070 (0.730)	0.053 (0.292)	0.310 (0.116)	0.187 (0.300)
MT2	-	0.486 (0.005)	0.313 (0.081)	0.348 (0.051)	-	0.688 (<0.001)	0.217 (0.277)	0.226 (0.256)
MT3	-	-	0.713 (<0.001)	0.230 (0.205)	-	-	0.525 (0.005)	0.267 (0.178)
MT4	-	-	-	0.522 (0.022)	-	-	-	0.504 (0.007)

[Table/Fig-9]: Correlation matrix for widths of metatarsals amongst themselves.
MT1, MT2, MT3, MT4 and MT5 – First, Second, Third, Fourth and Fifth metatarsals respectively. p-values are shown in parentheses

DISCUSSION

Measurements of the dimensions of the forefoot bones help in assessment of the severity of the disorder, planning of surgery, choosing one corrective procedure over another and also in postoperative assessments.

Measurement of Bones of the Forefoot

Morphometric studies of metatarsals and phalanges involve conducting measurements either directly on dry macerated bones or on radiographic films. Radiographic studies have been mainly on angle measurements for formulating theories of hallux valgus development, its preoperative assessment, the surgical techniques to be used for correction [9] and assessment of results of surgeries [10]. Researchers, in their review of the principles of osteotomies of the first metatarsal indicate the need for length measurements to choose the correct procedure [11]. Our study involves measurements of the dimensions of the bones of the foot on standardized radiographs in healthy adults.

Dogan A et al., found that the longest metatarsal was the fifth (72.10±5.55 mm in males and 68.56±3.19 mm in females) followed by second, third, fourth. In our study we found the second metatarsal to be the longest (67.61±3.49 mm in males and 62.46±3.45 mm in females) [5]. This difference is probably because we have not taken the styloid process of the fifth metatarsal into consideration. Dogan A et al., have not mentioned about the styloid process of the fifth metatarsal [5]. The shortest was the first metatarsal in the study by Dogan A et al., (8.89±0.79 mm in males and 7.83±0.72 mm in females) and this is in agreement with our findings [5]. In another study by Abdel Moneim WM et al., the lengths of the metatarsals (in centimeters) in males and females respectively was, first - 6.4±0.22 cm and 5.1±0.12 cm , second - 7.0±0.38 cm and 6.1±0.12 cm, third - 7.0±0.12 cm and 6.4±0.09 cm, fourth - 6.9±0.88 cm and 6.6±0.13 cm and fifth - 7.5±0.25 cm and 6.4±0.10 cm [12]. In this study, the points of reference for measurement of lengths of each metatarsal bone were the highest and the lowest points [12].

The widest metatarsal in studies by Dogan A et al., and Abdel Moneim WM et al., was the first metatarsal, which is the same as in our study [5,12]. The third was the narrowest metatarsal in the study by Dogan et al., (15.60±1.49 mm in males and 13.14±1.03 mm in females) and ours [5]. However, in the study by Abdel Moneim et al., the narrowest in males was the fifth metatarsal (0.89±0.1 cm) and that in females was the second metatarsal (0.57±0.08 cm) [5,12].

In our study, the longest of the phalanges, were first proximal phalanx and the shortest was the fifth distal phalanx. In the study by Dogan A et al., the longest and shortest phalanges were first proximal phalanx (31.81±2.76 mm in males and 28.29±2.56 mm in females) and fifth middle phalanx (7.78±1.46 mm in males and 6.59±0.90 mm in females) respectively [5].

Radiographic Analysis of the Feet

a. 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 adverse 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 abnormal length of a 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. Various methods of determining the metatarsal parabola have been described [13]. Bilateral radiographs are useful, in assessing patients with multiple short metatarsals in one of the feet. 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 [14].

b. AP, 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 important for formulating a preoperative plan and in placement of the external fixator and the osteotomy level [9]. Researchers have elucidated the need for preoperative assessment of the lengths of the metatarsals [14]. Preoperative 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. Preoperative AP radiographs of both feet have been used in assessing the immediate and long term outcome of surgeries for hallux valgus. 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 [15]. In the evaluation of surgical techniques for correction of hallux valgus, preoperative and postoperative radiographs have been used by some 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 second metatarsal hypertrophy [16]. Newer surgical techniques and concepts have been devised utilizing radiographic assessments of procedures. Baek GH and Chung MS who earlier had viewed favourably, lengthening of metatarsal by using iliac bone graft ; later along with Kim, utilizing preoperative radiographic measurements and planning could achieve the same surgical outcome by combined lengthening and shortening procedures without going in for bone graft harvest from a second site [17].

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 preoperative assessment of patients. Opposition to use radiographic measurements as the sole criterion for formulating treatment plans has been advanced by a few surgeons [18]. Some researchers prefer basing surgical corrections on intraoperative assessments rather than radiographic measurements. Even so, for assessing the outcomes of surgeries, they have relied on radiographic measurements in addition to clinical scoring systems [19]. The utility of using radiographic assessment of the feet in diagnosis and treatment of foot pathologies thus cannot be denied.

Significance of Measurements in the Context of Surgeries on the Forefoot

Metatarsals may need either lengthening or shortening for correction of disabilities. Osteotomies of the forefoot are some of the most common procedures performed by both orthopaedic surgeons and podiatrists. One of the three criteria to achieve an ideal osteotomy is to maintain adequate length [20]. Hallux valgus, metatarsalgia and dislocations of the lesser metatarsophalangeal joints are some of the indications for surgeries. In such cases, preoperative measurement of all metatarsals and correlation between metatarsal lengths can be utilized.

The primary aim of surgeries on the metatarsals for correction of brachymetatarsia, metatarsalgia etc., is to restore the lengths of metatarsals according to the formula 1=2>3>4>5 [21,22].

Preoperative assessment of lengths of metatarsals is important in estimation: (i) of length of osteotomy required for a normal metatarsal parabola; (ii) of amount of shortening required (old 6=new10); (iii) for proper alignment of the lengthened metatarsal [23,24]; and (iv) to decide upon a particular technique of correction to be utilized. In multiple metatarsal surgeries [25] a lengthening of not more than 50% of the original length led to completely satisfactory clinical follow up with no serious or severe complications [22]. To avoid potential complications such as metatarsophalangeal joint subluxation, cavus foot and hallux valgus, the postoperative first metatarsal length should not exceed 40%-50% of the original length [26].

Preoperative and postoperative measurements of dimensions of metatarsals have been used in assessing the outcome of shortening osteotomies for plantar callosities, for assessing effectiveness of osteotomies and for information of the patient regarding risk of postoperative metatarsalgia in case a short metatarsal is already existing [27,28].

CONCLUSION

It is possible to arrive at a fixed correlation amongst the measurements of the bones of the forefoot. In our view, measurements of the metatarsals and phalanges both preoperatively and postoperatively when carried out on standardized AP radiographs will be helpful in: (a) clinical assessment of the forefoot disorders; (b) choice of surgical procedure to be employed; and in (c) evaluating the outcome of such a surgical procedure. If the lengths and widths of a forefoot bone are known, then the dimensions of the others can be calculated by using the correlation.

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REFERENCES

[1] Viladot A. Metatarsalgia due to biomechanical alterations of the forefoot. Orthop Clin North Am. 1973;4:165-78.
[2] 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.
[3] Al Abdulwahab SS, Kachanathu SJ. The effect of various degrees of foot posture on standing balance in a healthy adult population. Somatosensory and Motor Research. 2015;32(3):172-76
[4] Lamm BM, Paley D, Herzenberg JE. Percutaneous distraction osteogenesis for treatment of brachymetatarsia. In Scuderi GR, Tria AJ, editors. Minimally Invasive Surgery in Orthopaedics. New York: Springer Science & Business Media; 2009, Pp. 435-442.
[5] Dogan A, Uslu M, Aydinlioglu A, Harman M, Akpinar F. Morphometric study of the human metatarsals and phalanges. Clin Anat. 2007;20:209-14.
[6] Nix S, Smith M, Vicenzino B. Prevalence of hallux valgus in the general population: a systematic review and meta-analysis. J Foot Ankle Res. 2010;3:21.
[7] Richardson DR. Arthritis of the foot. In: Canale ST, Beaty JH editors. Campbell's Operative Orthopaedics, 12th ed, Philadelphia: Elsevier Mosby; 2013. pp. 4027-56.
[8] Murphy GA. Lesser toe abnormalities. In: Canale ST, Beaty JH editors. Campbell's Operative Orthopaedics, 12th ed: Philadelphia: Elsevier Mosby; 2013. pp. 3979-4026.
[9] Lamm BM. Metatarsal Lengthening. In: Rozbruch SR, Ilizarov S, editors. Limb Lengthening and Reconstruction Surgery. New York: CRC Press; 2006,pp. 291-301.
[10] 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.
[11] Nyska M. Principles of first metatarsal osteotomies. Foot Ankle Clin. 2001;6(3):399-408.
[12] 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.
[13] Domínguez-Maldonado G, Munuera-Martinez PV, Castillo-López JM, Ramos-Ortega J, Albornoz-Cabello M. Normal values of metatarsal parabola arch in male and female feet. The Scientific World Journal. 2014;2014:505736.
[14] Catanzariti AR. Revisional hallux valgus surgery : Evaluation and principles of salvage. Podiatry Institute; 2013; [cited 13 Jan 2017]. Available from http://www.podiatryinstitute.com/pdfs/Update_2013/2013-07.pdf
[15] 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.
[16] Grebing BR, Coughlin MJ. Evaluation of Morton's theory of second metatarsal hypertrophy. J Bone Joint Surg Am. 2004;86:1375-86.
[17] Baek GH, Chung MS. The treatment of congenital brachymetatarsia by one-stage lengthening. J Bone Joint Surg Br. 1998;80(6):1040-44.
[18] Perry MD, Mont MA, Einhorn TA, Waller JD. The validity of measurements made on standard foot orthoroentgenograms. Foot Ankle. 1992;13(9):502-07.
[19] Kennedy JG, Deland JT. Resolution of metatarsalgia following oblique osteotomy. Clin Orthop Relat Res. 2006;453:309-13.
[20] John V, Panagiotis KK, Polizois V, Dimitrios ES, Spyridon PG. Preservation of the length of the first metatarsal after modified Mitchell's osteotomy for hallux valgus deformity. Overview, technique and preliminary results. Clin Res Foot Ankle. 2015;3:164.
[21] Desai A, Lidder S, Armitage AR, Rajaratnam SS, Skyrme AD. Brachymetatarsia of the fourth metatarsal, lengthening scarf osteotomy with bone graft. Orthop Rev (Pavia). 2013;5(3):e21.

[22] Magnan B, Bragantini A, Regis D, Bartolozzi P. Metatarsal lengthening by callotasis during the growth phase. J Bone Joint Surg Br. 1995;77-B:602-07.
[23] Scher DM, Blyakher A, Krantzow M. A modified surgical technique for lengthening of a metatarsal using an external fixator. HSS Journal. 2010;6(2):235-39.
[24] Maestro M, Besse JL, Ragusa M, Berthonnaud E. Forefoot morphotype study and planning method for forefoot osteotomy. Foot Ankle Clin. 2003;8(4):695-710.
[25] Weinstein RB, Taylor GC, Lotufo C. Multiple Metatarsal Lengthening. Podaitry Institute. 2013; [cited 13 Jan 2017]. Available from http://www.podiatryinstitute.com/pdfs/Update_2013/2013-13.pdf
[26] Oh CW, Satish BR, Lee ST, Song HR. Complications of distraction osteogenesis in short first metatarsals. J Pediatr Orthop. 2004;24(6):711-15.
[27] Schemitsch E, Horne G. Wilson's osteotomy for the treatment of hallux valgus. Clin Orthop. 1989;240:221-25.
[28] Lee JY, Lee YS, Song KC, Choi KY. Change in first metatarsal length after proximal and distal chevron osteotomies for hallux valgus deformity. J Foot Ankle Surg. 2015;54(4):525-30.

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