An Imaged-Based Three-Dimensional Study of First Metatarsal Protrusion Distance in Women with and Without Hallux Valgus

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Background: First metatarsal protrusion distance (MPD) has been commonly studied as a characteristic of hallux valgus deformity. To date, the majority of investigations have used radiographic methods, with most reporting first metatarsal (ray) protrusion to be associated with deformity. As an alternative, this study used a three-dimensional (3-D) image acquisition and data analysis method to quantify MPD.

Methods: Magnetic resonance images were acquired in weightbearing on 29 women (19 with hallux valgus; 10 controls). After the 3-D images were reconstructed into virtual bone models, two examiners measured MPD in relation to the navicular. In addition to a reliability analysis, a *t* test assessed for group differences in demographics, foot posture (hallux valgus, intermetatarsal angles), and MPD.

Results: Group demographics were not different, while measures of hallux valgus and intermetatarsal angles were different ($P < 0.01$) between groups. The measurement of MPD was highly reliable (ICC $\geq$ 0.99; SEM $\leq$ 0.78 mm). Metatarsal protrusion averaged approximately –2.0 mm in both groups. There was no statistical group difference ($P = 0.89$) in MPD.

Conclusions: The reconstructed image datasets captured the 3-D spatial relationship of the anatomy. Measurements of MPD were reliable. The first ray measured 2 mm shorter than the second ray in both the hallux valgus and control groups. Though unexpected, this result may prompt future study of the pathokinematics associated with hallux valgus that include the quantification of metatarsal protrusion with 3-D methods, instead of relying solely on single-plane radiograph reports. (J Am Podiatr Med Assoc 107(6): 531-537, 2017)

Clinical studies[1-6] have often used radiographic methods to measure relative first metatarsal protrusion distance (MPD) in people with hallux valgus deformity. Though the etiology of hallux valgus is poorly understood, deformity is most prevalent in aging women.[7] The principle underlying this area of research is that when the first metatarsal protrudes distal to the second metatarsal, the load carried by the hallux is increased.[8] This increase in load, the trajectory of the center of pressure,[9] and the compression of shoewear during gait propulsion[5,10] culminates to push the hallux laterally into valgus deformity. A meta-analysis by Nix et al[11] evaluated the literature reporting first metatarsal protrusion in patients with hallux valgus. Citing only primary-source radiograph reports,[1-6] the review concluded that protrusion of the first metatarsal is strongly associated with hallux valgus.[11]

The studies[1-6] identified in the Nix meta-analysis[11] used two different techniques[12,13] to measure MPD on radiographs. One study[5] also used a less conventional technique to measure the relative difference in the actual length of the first and second metatarsals. Four of the studies[2-4,6] used a method that generates a proximal point of reference at the intersection of the bisections of the first and second metatarsals.[13] This proximal point of intersection can be located on the talus, calcaneus, or outside the foot depending on the size of the first intermetatarsal angle. The other study[5] followed the Hardy and Clapham[12] method, which produced a

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proximal point of reference on the talus. All techniques[1-6] mark the tip of the first and second metatarsal heads for the distal point of measurement. Though the selection of the proximal point of reference is dependent on method,[14] MPD averages between plus or minus 2 millimeters (mm) in adults.[1-6,15-18] A positive value indicates protrusion of the first metatarsal.[15,19]

Metatarsal protrusion distance was measured in this study using a technique called for by LaPorta et al,[16] but with modification to record the relative difference in the actual length of the first and second rays. The first ray (metatarsal and cuneiform) was measured relative to the navicular.[20,21] Likewise, the second ray (metatarsal and cuneiform) was measured from a point on the navicular joint surface (Fig. 1). Measuring the length of the first and second rays in relation to the navicular makes anatomical sense, because the first and second cuneiforms rest in direct contact with each other, and their proximal joint surfaces articulate on neighboring facets of the navicular. Based on a kinematic and kinetic perspective, the metatarsocuneiform joints and surrounding ligaments[22] allow limited motion ($< 4°$ in the sagittal plane),[23,24] and instead, the joints function to stabilize the midfoot and to distribute load across the medial longitudinal arch.[22-26]

As an alternative to measuring MPD on radiographs, this research employed a 3-D image acquisition and data analysis method for the purpose of studying the relative measurement of MPD in women with and without hallux valgus, and tested the null hypothesis of no group difference.

Methods

Participants

This study conducted a retrospective review of magnetic resonance (MR) images acquired on 29 women enrolled in a comprehensive study of hallux valgus.[27-32] The weightbearing images were acquired from 2008 to 2010. Nineteen of the women had hallux valgus,[29,31,32] as defined by an enlarged hallux angle. A screening measurement of a hallux angle larger than 15 degrees served as the threshold for indicating deformity.[19] In cases where both feet were affected, the foot having the largest hallux angle was studied. Nine women with hallux valgus also had rheumatoid arthritis.[29] Control participants ($n = 10$) were group-matched by age. A more thorough description of the inclusion criteria and demographics of the participants have been reported.[29,31,32] Consent was obtained at time of enrollment, and this review of the images was performed in accordance with University of Minnesota Institutional Review Board (#1404E49482) guidelines.

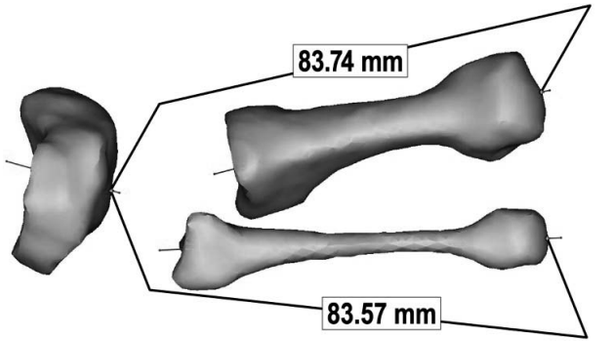

Figure 1. The navicular, first, and second metatarsals displayed as 3-D virtual bone models. Though the first and second cuneiforms are not displayed, they occupy the space between the respective metatarsals and navicular. Metatarsal protrusion was measured in reference to the navicular using a computer tool, as indicated by the superimposed lines and measurement data (mm). The distal end of the bones was defined by location of the longitudinal axis of a coordinate system embedded in the respective models. The relative difference in measurements (recorded as MPD) for this participant (ID #10 control) was 0.17 mm.

Procedures

The women were imaged in an open-upright 0.6-Tesla Fonar Upright MRI (Fonar Ink, Melville, New York). Participants were positioned with weight distributed on both feet,[29,31] and with their ankle joints dorsiflexed 5 degrees to simulate standing.[33] The scan field, composed of 128 slices, was centered to capture the entire foot and ankle. The image was acquired in the sagittal plane at a slice thickness of 1.0 mm, and the scan took 6 minutes to complete. The resolution of the image was 1.0×1.0 mm. Further details of the scanning protocol have been reported elsewhere.[9,29,31]

Images were imported into Mimics 17.01 (Materialise, Leuven, Belgium) software for reconstruction. The virtual bone models displayed for analysis in this study were the first metatarsal, second metatarsal, and navicular. Additional bones were reconstructed for analysis in previous work,[9,29,31] and the hallux angle and intermetatarsal angles were quantified (Table 1). The size of these two

Table 1. Group Demographics and Foot Posture Measurements[a]

	Hallux Valgus (n = 19)	Control (n = 10)	*P* Value
Demographics			
Age (y)	50 ± 17 (22–73)	45 ± 18 (23–71)	.46
Body mass index (kg/m^2)	26 ± 5.8 (20–39)	26 ± 4.3 (19–32)	.98
Foot Posture, degrees			
Hallux angle	33 ± 12.4 (19–48)	8 ± 5.4 (–3–15)	< .01
Intermetatarsal angle	15 ± 3.2 (11–20)	11 ± 1.4 (9–13)	< .01

Note: Values are mean ± SD (range).
[a]The data in Table 1 have been reported previously.[35]

angles, in particular, were used to gauge the presence and severity of hallux valgus deformity.[19]

Critical to the measurement of MPD, the first metatarsal, second metatarsal, and navicular were each embedded with a principal axis coordinate system.[34] The orthogonal coordinate systems defined the spatial orientation of the bone models,[9,29,31] such that the longitudinal axis (Fig. 1) of the coordinate system located the distal most point of each bone. Two physical therapy students (M.W.R. and K.E.P.), blinded from each other's results, used a computer tool to measure the distance between the most distal points of first and second metatarsals, and the navicular (Fig. 1).[35] The distance essentially captured the respective lengths of the first and second rays.[21] The relative difference in measurements was calculated as MPD, with the average of the two examiner measurements recorded for analysis.

Group differences in the demographics and foot posture measurements (Table 1) were assessed with a two-tailed independent t test. The strength-of-agreement (reliability) for the examiner measurements of MPD was evaluated for each group independently with Intraclass Correlation Coefficient [ICC (2,1)] and a standard error of measurement (SEM).[36] Group difference in MPD was also evaluated with a two-tailed independent t test. Significance was set at $P < 0.05$.

Results

The group comparisons of demographics and foot posture measurements are shown in Table 1. There was no group difference in age or BMI ($P < 0.46$). Both the hallux angle and intermetatarsal angle were larger ($P < 0.01$) in the group with hallux valgus, indicating deformity.

The measurement of MPD was highly reliable (ICC $\geq$ 0.99; SEM $\leq$ 0.78 mm) in all cases. The MPD ranged from –7.1 to 4.0 mm in the women sampled (Fig. 2). The mean values of MPD were –2.1 mm for the group with hallux valgus compared to –2.0 mm in the control group. There was no group difference ($P = 0.89$) in MPD.

Discussion

The presence of hallux valgus is defined by the offset in alignment of the first metatarsophalangeal joint as measured on weightbearing images from a anteroposterior view.[19] In this present study, the hallux angle measured 25° larger, and the first and second intermetatarsal angle measured 4° larger in the group with deformity as compared to controls (Table 1). First metatarsal protrusion can also be

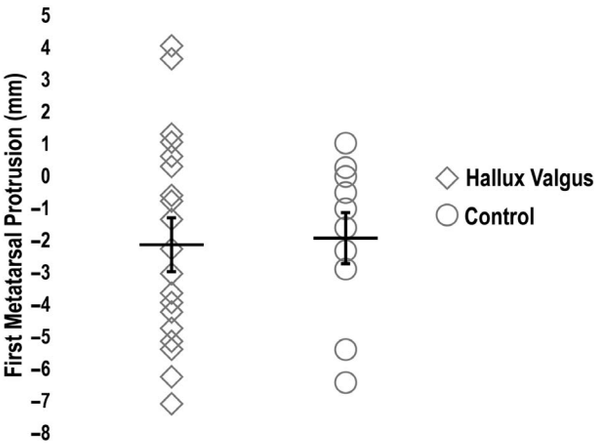

Figure 2. Group comparison of MPD data collected on 29 women (19 with hallux valgus, 10 controls). The relative difference is displayed around a 0 mm baseline. A positive value indicates a long first ray, whereas a negative value indicates short first ray in comparison to the second. Six of the 19 (31%) women with hallux valgus had a long first metatarsal, as did two of 10 (20%) in the control group. The group means are represented by a horizontal line with attached error bars (standard errors of the mean). There was no statistical difference ($P = 0.89$) between groups.

quantified on the same image, thus MPD is often reported in clinical studies of hallux valgus deformity.[1-6]

Although angle and distance measurements are easily recorded on conventional radiographs, the measures display only a two-dimensional (2-D) spatial analysis of the anatomy. To overcome this limitation, this study recorded MPD from MR images reconstructed into 3-D virtual bone models.[34] The method is commonly used in motion analysis laboratories,[37,38] and its growing use in clinic-based studies can be traced to advancements in computer technology and commercially available software. The chief drawback remains the cost of 3-D imaging, but perhaps as more sophisticated data reduction methods are demonstrated reliable, such as generating 3-D finite element bone models from 2-D radiographs,[39] clinicians will be able to accurately quantify the morphological traits (size and shape) of the foot bones with radiographic evaluations. Until then, 3-D image acquisition and data analysis offer a feasible, albeit a more expensive, alternative to radiographs.

In addition to using a 3-D methodology, this study quantified MPD using a mechanical axis approach advanced by LaPorta et al.[16] In introducing a paradigm to better measure the intermetatarsal angle, they described how the anatomic axis of a long bone differs from its mechanical axis. The anatomic axis is simply defined by the mid-diaphysis shaft of a bone, whereas the mechanical axis is represented on an image with a line drawn by an examiner that connects the distal and proximal ends of any combination of bones that function as a single segment in supporting weight.[16] After making this distinction, LaPorta and coworkers[16] represented the mechanical axis of the first and second rays with lines drawn on a radiograph. The lines bisected the heads of the first and second metatarsals distally, and converged on the talus proximally. The investigation then compared the intermetatarsal angles in patients with hallux valgus to a control group. The study, however, did not report MPD in the populations sampled.[16]

To apply this mechanical axis reasoning to the measurement of MPD, an examiner must first decide on what constitutes a single-functioning segment. Though the second ray has been less studied, the first ray behaves as a single segment because the metatarsocuneiform joint surfaces interlock,[26] while allowing the first ray to move independent of the second when the foot carries weight.[24,27,29,31] Since both rays articulate on the navicular, their lengths were recorded in this study from the distal tip of each metatarsal to a common point located on the navicular (Fig. 1). Future work could compare MPD data collected by measuring the relative difference in the length of the first and second rays to the variety of techniques described in clinical studies that measured MPD on radiographs in the study of hallux valgus.[1-6]

The measurement of MPD averaged approximately –2.0 mm regardless of group assignment (Fig. 2). Accordingly, there was no group difference ($P = 0.89$). The negative value indicates that the first ray was short compared to the second. These results stand apart from the existing literature,[11] as studies recording MPD on radiographs have, on a consistent basis, reported a positive (long) first metatarsal result in people with hallux valgus.[1-6] The findings reported by D'Arcangelo et al[3] were particularly interesting. In addition to identifying metatarsal protrusion, their work demonstrated that measures of MPD made on radiographs are predictive for grading the stages of hallux valgus severity on the Manchester scale of visual observations.[3,40] The Manchester scale[40] requires an examiner to grade deformity as none, mild, moderate, and severe from a photograph of the foot. D'Arcangelo[3] found a linear relationship, in which MPD averaged 0.3 mm in the group without deformity, 1.1 mm with mild deformity, 2.1 mm with moderate deformity, and 4.2 mm with severe deformity. In this current investigation, women with hallux valgus were grouped by the measurement of hallux angle. Upon finding no group difference ($P = 0.89$) in MPD, but still wanting to explore the hallux valgus group ($N = 19$) for any evidence of association between MPD and the hallux angle of deformity, a subsequent Pearson's correlation coefficient analysis was run to assess the strength of relationship between variables. This *post hoc* analysis revealed no linear relationship ($r = –0.004$). Thus we speculate that judgements made in classifying the deformity with the Manchester scale do not correspond with the size of the hallux angle as it displays on reconstructed MR image datasets. Further research is warranted.

The validity of analyzing MPD with standard radiographic methods has been questioned.[5,41] For this purpose, Grady et al[41] investigated the effect of radiographic distortion on the measurement of first metatarsal length, and found relative length differed by an average of 3.8 mm when the measurement was acquired on an anteroposterior view compared to a lateral view radiograph. Height of the medial

longitudinal arch may account for this difference. On the basis of variability in foot structure, the first ray may appear *short* relative to the second ray on the anterioposterior view concurrent to plantar flexion of the first ray as presents in the high arch (cavus) foot. Conversely, the first ray may appear *long* concurrent to dorsiflexion of the first ray as presents in the low arch (planus) foot. Grady[41] concludes the report by cautioning surgeons not to make metatarsal shortening or lengthening decisions based solely on anteroposterior radiograph measures. This advice is also germane for research planning to quantify MPD in patient populations. Additionally, since collapse of the arch is a common predisposition of hallux valgus,[27,30,42] radiographic distortion attributed to arch height may, in part, explain why first metatarsal protrusion has been so consistently recorded on radiographs in the study of hallux valgus.

Because this study measured MPD with 3-D methods instead of single-plane radiographs, and recorded the measure in relation to the navicular, which is novel, we cannot know whether these findings are indicative of the cohorts sampled, or a manifestation of the methods. Therefore, inferences drawn from this research should be made with prudent judgement until these results can be replicated. In support of these methods and results, the measure of MPD was demonstrated reliable (ICC $\geq$ 0.99; SEM $\leq$ 0.78 mm), and the data reported (Fig. 2) falls within a normal range for adults.[15-18] Despite the experimental nature of this study, one immediate application taken from this research is that future study of MPD and hallux valgus should employ methods that capture the 3-D spatial relationship of the anatomy of the foot.

A weakness of this retrospective study design was that radiographs were not obtained in the original inestigation.[27-32] Therefore, measurements of MPD cannot be compared to data acquired by conventional radiographic methods. This limitation is notable, because despite the advancements in 3-D image-based technology,[35,37,38] radiographic evaluations remain the standard in clinical practice. Future work could compare 2D and 3D measurements of first metatarsal protrusion, quantify the error associated with measuring MPD on images, and assess the degree to which error affects decision making when length of the metatarsals is changed with osteotomy procedures[43] or joint replacement surgery.[44]

This research had further limitations. The group size was kept small[9,29,31] due to the high cost of MR imaging. This limited the generalizability of the results, and reduced the power of statistical tests to detect group differences. Though underpowered, the group difference in MPD (Fig. 2) was only 0.1 mm, a clinically meaningless amount. Another limitation was that nine women with hallux valgus also had rheumatoid arthritis,[29] so erosion of the metatarsal head may have impacted the measurement of MPD in the experimental group.

Conclusions

In summary, this retrospective cohort study performed a 3-D comparison of MPD in women with and without hallux valgus. The measurement was highly reliable. The first ray averaged 2 mm shorter than the second ray in both groups, and there was no group difference. These experimental results generally do not support the existing literature, though all previous investigations to report MPD in patients with hallux valgus collected data on single plane radiographs.[1-6] Study is now needed to compare 2-D and 3-D measurements of MPD, as research continues to investigate metatarsal protrusion as a characteristic of hallux valgus, and to help guide the selection of corrective surgical procedures in the treatment of foot deformity.

Financial Disclosure: This study was funded by the Arthritis Foundation North Central Chapter, St. Paul, Minnesota.
Conflict of Interest: None reported.

References

1. Bryant A, Tinley P, Singer K: A comparison of radiographic measurements in normal, hallux valgus, and hallux limitus feet. J Foot Ankle Surg **39:** 39, 2000.
2. Bryant A, Tinley P, Singer K: Radiographic measurements and plantar pressure distribution in normal, hallux valgus and hallux limitus feet. The Foot **10:** 18, 2000.
3. D'Arcangelo PR, Landorf KB, Munteanu SE, et al: Radiographic correlates of hallux valgus severity in older people. J Foot Ankle Res **3:** 20, 2010.
4. McCluney JG, Tinley P: Radiographic measurements of patients with juvenile hallux valgus compared with age-matched controls: a cohort investigation. J Foot Ankle Surg **45:** 161, 2006.
5. Munuera PV, Polo J, Rebollo J: Length of the first metatarsal and hallux in hallux valgus in the initial stage. Int Orthop **32:** 489, 2008.
6. Taranto J, Taranto MJ, Bryant AR, et al: Analysis of

dynamic angle of gait and radiographic features in subjects with hallux abducto valgus and hallux limitus. JAPMA **97:** 175, 2007.
7. Nix S, Smith M, Vicenzino B: Prevalence of hallux valgus in the general population: a systematic review and meta-analysis. J Foot Ankle Res **3:** 21, 2010.
8. Morag E, Cavanagh PR: Structural and functional predictors of regional peak pressures under the foot during walking. J Biomech **32:** 359, 1999.
9. Glasoe WM, Pena FA, Phadke V: Cardan angle rotation sequence effects on first-metatarsophalangeal joint kinematics: implications for measuring hallux valgus deformity. J Foot Ankle Res **7:** 29, 2014.
10. Menz HB, Roddy E, Marshall M, et al: Epidemiology of shoe wearing patterns over time in older women: associations with foot pain and hallux valgus. J Gerontol A Biol Sci Med Sci **71:** 1682, 2016.
11. Nix SE, Vicenzino BT, Collins NJ, et al: Characteristics of foot structure and footwear associated with hallux valgus: a systematic review. Osteoarthritis Cartilage **20:** 1059, 2012.
12. Hardy R, Clapham J: Observations on hallux valgus: based on a controlled series. J Bone Joint Surg **33-B:** 376, 1951.
13. Mancuso J, Abramow S, Landsman M, et al: The zero-plus first metatarsal and its relationship to bunion deformity. J Foot Ankle Surg **42:** 319, 2003.
14. Chauhan D, Bhutta MA, Barrie JL: Does it matter how we measure metatarsal length? Foot Ankle Surg **17:** 124, 2011.
15. Dominguez G, Munuera PV, Lafuente G: Relative metatarsal protrusion in the adult: a preliminary study. JAPMA **96:** 238, 2006.
16. LaPorta GA, Nasser EM, Mulhern JL, et al: The mechanical axis of the first ray: a radiographic assessment in hallux abducto valgus evaluation. J Foot Ankle Surg **55:** 28, 2016.
17. Smith R, Reynolds J, Stewart M: Hallux valgus assessment: report of research committee of American Foot and Ankle Society. Foot Ankle **5:** 92, 1984.
18. Steel MW, 3rd, Johnson KA, DeWitz MA, et al: Radiographic measurements of the normal adult foot. Foot Ankle **1:** 151, 1980.
19. Coughlin MJ, Jones CP: Hallux valgus: demographics, etiology, and radiographic assessment. Foot Ankle Int **28:** 759, 2007.
20. Glasoe WM, Yack HJ, Saltzman CL: Anatomy and biomechanics of the first ray. Phys Ther **79:** 854, 1999.
21. Hicks JH: The mechanics of the foot. I. The joints. J Anat **87:** 345, 1953.
22. Kitsukawa K, Hirano T, Niki H, et al: MR imaging evaluation of the Lisfranc ligament in cadaveric feet and patients with acute to chronic Lisfranc injury. Foot Ankle Int **36:** 1483, 2015.
23. Romash M, Fugate D, Yanklowit B: Passive motion of the first metatarsal cuneiform joint: preoperative assessment. Foot Ankle **10:** 293, 1990.
24. Wolf P, Stacoff A, Liu A, et al: Functional units of the human foot. Gait Posture **28:** 434, 2008.
25. Glasoe WM, Yack HJ, Saltzman CL: Measuring first ray mobility with a new device. Arch Phys Med Rehabil **80:** 122, 1999.
26. Wanivenhaus A, Pretterklieber M: First tarsometatarsal joint: anatomical biomechanical study. Foot Ankle Int **9:** 153, 1989.
27. Glasoe W, Pena F, Phadke V, et al: Arch height and first metatarsal joint axis orientation as related variables in foot structure and function. Foot Ankle Int **29:** 647, 2008.
28. Glasoe WM: Treatment of progressive first metatarsophalangeal hallux valgus deformity: a biomechanically based muscle-strengthening approach. J Orthop Sports Phys Ther **46:** 596, 2016.
29. Glasoe WM, Jensen DD, Kampa BB, et al: First ray kinematics in women with rheumatoid arthritis and bunion deformity: a gait simulation imaging study. Arthritis Care Res **66:** 837, 2014.
30. Glasoe WM, Nuckley DJ, Ludewig PM: Hallux valgus and the first metatarsal arch segment: a theoretical biomechanical perspective. Phys Ther **90:** 110, 2010.
31. Glasoe WM, Phadke V, Pena FA, et al: An image-based gait simulation study of tarsal kinematics in women with hallux valgus. Phys Ther **93:** 1551, 2013.
32. Glasoe WM, Wolff K, Wicks A, et al: Prediction of the first ray axis from clinical measurements: implications for the treatment of bunion. Clin Res Foot Ankle **2:** 1, 2014.
33. Rattanaprasert U, Smith R, Sullivan M, et al: Three-dimensional kinematics of the forefoot, rearfoot, and leg without function of tibialis posterior in comparison with normals during stance phase of walking. Clin Biomech **14:** 14, 1999.
34. Hirsch B, Udupa J, Samarasekera S: New method of studying joint kinematics from three-dimensional reconstructions of MRI data. JAPMA **86:** 4, 1996.
35. Swanson JE, Stoltman MG, Oyen CR, et al: Comparison of 2D-3D measurements of hallux and first ray sagittal motion in patients with and without hallux valgus. Foot Ankle Int **37:** 227, 2016.
36. Fleiss JL: *The Design and Analysis of Clinical Experiments*, John Wiley and Sons, New York, 1986.
37. Gutekunst DJ, Liu L, Ju T, et al: Reliability of clinically relevant 3D foot bone angles from quantitative computed tomography. J Foot Ankle Res **6:** 38, 2013.
38. Telfer S, Kindig M, Sangeorzan B, et al: Metatarsal shape and foot type: a geometric morphometric analysis. J Biomech Eng **139:** 031008, 2017.
39. Thevenot J, Koivumaki J, Kuhn V, et al: A novel methodology for generating 3D finite element models of the hip from 2D radiographs. J Biomech **47:** 438, 2014.
40. Garrow AP, Papageorgiou A, Silman AJ, et al: The grading of hallux valgus. The Manchester Scale. JAPMA **91:** 74, 2001.
41. Grady J, Trotter K, Ruff J, et al: Radiographic

investigation of the absolute and relative first metatarsal lengths in the asymptomatic foot. JAPMA **105:** 478, 2015.
42. Steinberg N, Finestone A, Noff M, et al: Relationship between lower extremity alignment and hallux valgus in women. Foot Ankle Int **34:** 824, 2013.
43. Maestro M, Besse JL, Ragusa M, et al: Forefoot morphotype study and planning method for forefoot osteotomy. Foot Ankle Clin **8:** 695, 2003.
44. Akkurt M, Sesen H, Ozdemir M, et al: Reduced postoperative functional length ratio influences patient satisfaction in first metatarsophalangeal joint replacement. J Foot Ankle Surg **55:** 743, 2016.