The Journal of Foot & Ankle Surgery 58 (2019) 893–897

Contents lists available at ScienceDirect

The Journal of Foot & Ankle Surgery

journal homepage: www.jfas.org

Foot and Ankle Radiographic Parameters in Korean Adults Vary by Sex and Age

Dong-Oh Lee, MD[1], Kee Jeong Bae, MD[2], Eo Jin Kim, MD[3], Kang Baek Kim, MD[4], Doo Jae Lee, MD[5], Kyoung Min Lee, MD[6], Dong Yeon Lee, MD[7]

[1] *Professor, Department of Orthopedic Surgery, Myongji Hospital, Hanyang University College of Medicine, Seoul, Korea*
[2] *Professor, Department of Orthopedic Surgery, Seoul National University Boramae Hospital, Seoul, Korea*
[3] *Surgeon, Department of Orthopedic Surgery, Hanil General Hospital, Seoul, Korea*
[4] *Surgeon, Department of Orthopedic Surgery, Seoul National University Hospital, Seoul, Korea*
[5] *Professor, Department of Orthopedic Surgery, Kangwon National University Hospital, Gangwon, Korea*
[6] *Professor, Department of Orthopedic Surgery, Seoul National University Bundang Hospital, Seoul, Korea*
[7] *Professor, Department of Orthopedic Surgery, Seoul National University Hospital, Seoul, Korea*

ARTICLE INFO

Level of Clinical Evidence: 3

Keywords:
age
ankle
deformity
foot
normal radiographic angle
sex

ABSTRACT

Although many radiographic measurements of the foot and ankle have been used, reference values for normal functional groups are rarely reported. These can change according to sex and age; therefore, this study aimed to: (1) determine reference values for radiographic foot and ankle angles in an asymptomatic healthy Korean population, and (2) compare differences in the measurements according to sex and age. A total of 200 healthy volunteers were recruited, including 100 young adults (50 males, 50 females) aged 20 to 35 years, and 100 older adults (50 males, 50 females) aged 60 to 69 years. Weightbearing ankle anteroposterior views, talar tilt, and tibiotalar angles were measured. On the weightbearing foot anteroposterior views, the hallux valgus, hallux interphalangeal, and talo-first metatarsal angles were measured. On the weightbearing lateral foot views, the calcaneal pitch, lateral talo-calcaneal, lateral talo-first metatarsal, and lateral calcaneo-first metatarsal angles were measured. Values were stratified by sex and age, and statistically compared. The hallux valgus, calcaneal pitch, and lateral calcaneo-first metatarsal angles were affected by both sex and age; the hallux interphalangeal angle was affected by age and the lateral talo-first metatarsal angle by sex. We presented reference values for foot and ankle radiographic measurements in a healthy Korean population; several radiographic indices varied significantly by sex or age, which were grossly similar to previous studies based on white race. The study data can serve as a basis for evaluation of foot and ankle disorders.

Deformities of the foot and ankle can lead to pain, keratosis, joint stiffness, and other symptoms; therefore, patients may need conservative treatment or even surgical procedures to remedy those conditions. Orthopedic interventions are commonly based on physical examination and simple radiographs for bony alignment (1,2). Because radiographic angles of pedal structures have important roles in surgical planning and diagnosis, normal reference values for these relationships can be useful. Unfortunately, however, most available radiographic angles used as surgical references lack comprehensive scientific evidence for their validity (1,3). Several previous studies reported radiographic angles in normal feet, but had various limitations such as small study populations and limited age ranges (1,3–8). Moreover, there are few studies on Asian populations, despite possible ethnical differences (9); thus, accurate data are needed to provide clinicians with standard values for foot and ankle measurements.

Another concern in determining reference angles in weightbearing radiographs is whether there is a relationship between sex or age, and the foot and ankle radiographic indices of interest. Advancing age could be related to progressive foot deformities, reduced range of motion, and strength (10–13). Sex differences also affect foot and ankle structure and function, as well as surgical decisions and outcomes (14). For these reasons, we aimed to: (1) determine reference values for commonly used weightbearing radiographic indices of foot and ankle bony structures in a healthy Korean population; (2) analyze the influence that sex and age had on the radiographic measurements; and (3) compare the observed measurements to those already described in the published literature available for other races. Our hypothesis was that measured radiographic findings

Financial Disclosure: This research was supported by the Bio & Medical Technology Development Program of the National Research Foundation (NRF) funded by the Ministry of Science & ICT (NRF-2017M3A9E2063104).

Conflict of Interest: None reported.

Address correspondence to: Dong Yeon Lee, MD, Department of Orthopedic Surgery, Seoul National University Hospital, Yeongeon-dong, Jongno-gu, Seoul, Korea, 110-744.

E-mail address: leedy@snu.ac.kr (D.Y. Lee).

1067-2516/$ - see front matter © 2019 by the American College of Foot and Ankle Surgeons. All rights reserved.
https://doi.org/10.1053/j.jfas.2019.01.003

would be similar to those already published in the foot and ankle surgical literature, and that sex and age would influence the measurements.

Patients and Methods

The study design was approved by the institutional review board of our hospital, and we received informed consent from all of the subjects, which was a requirement of our institutional review board. Healthy volunteers were recruited from our health care center, which participated in response to an advertisement for the study. Potentially eligible participants completed a medical history survey and underwent an initial evaluation by 2 of our coauthors (D.J.L., K.B.K.). The following inclusion criteria were used: (1) no history of lower extremity fracture or surgery; (2) no subjective symptoms during gait; (3) no abnormal findings on standard foot radiographs (such as congenital deformity or osteoarthritis); (4) no known systemic disease (such as rheumatoid arthritis); (5) normal function of the foot and ankle (based on the American Orthopaedic Foot and Ankle Society ankle-hindfoot questionnaire) (3,15,16); and (6) a measured body mass index <30 kg/m^2 (1). Based on these criteria, a total of 200 volunteers without known disease affecting their foot structure were recruited, and we focused on 1 foot per participant only. To ensure statistical independence, radiographic angles of only the right foot of each participant was measured and analyzed (17). Included in the analyses were 100 feet of 100 healthy adults (50 males and 50 females) aged 20 to 35 years, and 100 feet of 100 healthy adults (50 males and 50 females) aged 60 to 69 years. We chose to analyze 200 feet in 200 patients based on prospective sample size analysis, which is described in the statistical analyses section.

Radiographic Measurements

Radiologic measurements of interest were selected by consensus of 4 orthopedic surgeons with reference to methods based on previous literature (18), with the aim of selecting variables that were prevalent indices of foot structure described in the existing literature. Weightbearing ankle anteroposterior (AP), foot AP, and lateral radiographs were obtained. The talar tilt angle and tibiotalar angle were measured on weightbearing ankle AP views (Fig. 1). The hallux valgus angle, hallux interphalangeal angle, and AP talo-first metatarsal angle were measured on weightbearing foot AP views (Fig. 2). The calcaneal pitch, lateral talo-calcaneal angle, lateral talo-first metatarsal angle (Meary's angle), and lateral calcaneo-first metatarsal angle (Hibbs angle) were measured on weightbearing foot lateral views (Fig. 3).

Intra- and Interobserver Reliability

To evaluate intra- and interobserver reliability, 2 orthopedic surgeons and 1 orthopedic trainee assessed radiographic measurements in 2 sessions with a minimum 2-week interval between sessions (17,19). Intraclass correlation coefficients (ICCs) were used for reliability testing. An ICC value of 1 indicated perfect reliability; ICC >0.8 indicated excellent reliability (18,20).

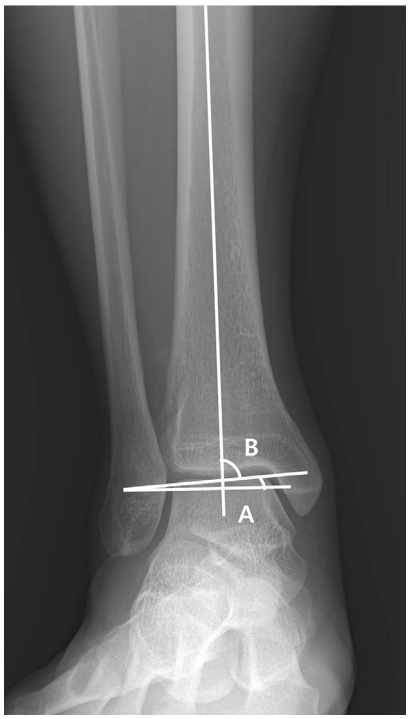

Fig. 1. Weightbearing ankle anteroposterior view of the (*A*) tibiotalar tilt angle and (*B*) tibiotalar angle.

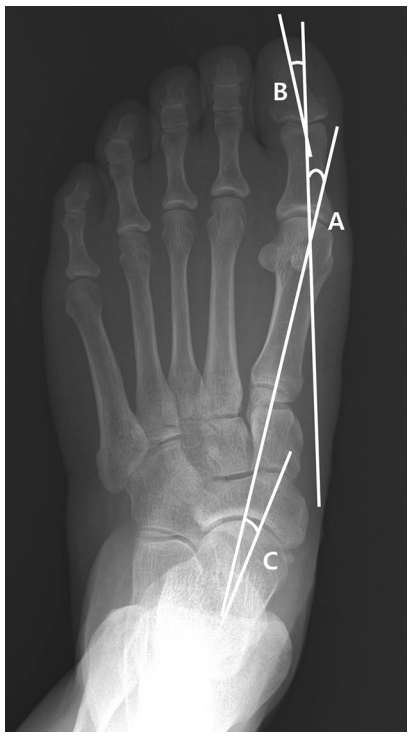

Fig. 2. Weightbearing foot anteroposterior view of the (*A*) hallux valgus angle, (*B*) hallux interphalangeal angle, and (*C*) anteroposterior talo-first metatarsal angle.

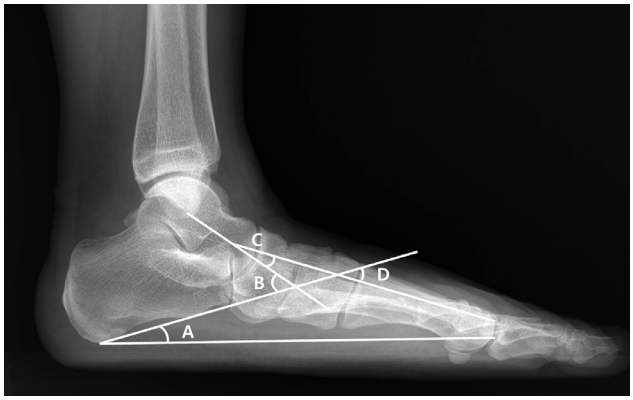

Fig. 3. Weightbearing lateral view of the (*A*) calcaneal pitch, (*B*) lateral talo-calcaneal angle, (*C*) lateral talo-first metatarsal angle (Meary's angle), and (*D*) lateral calcaneo-first metatarsal angle (Hibbs angle).

Statistical Analyses

We used hallux valgus angle as the primary outcome and set a difference of 2.9° with a standard deviation of 7.1° in the overall populations, for an effect size of 0.4° according to the outcome of previous study (3). The power analysis therefore indicated that a sample size of 100 in each group would provide 80% statistical power to detect an effect of this size between the 2 groups ($\alpha = 0.05$, $\beta = 0.2$) with use of the *t* test. All measurements were recorded and considered in terms of type and distribution and described as means and standard deviations. To determine the relationship between sex and age and radiographic indices, we used generalized mixed model analyses while considering sex or age as the random factor. When statistical analysis was performed, younger subjects were coded as 0 and older subjects as 1 in our regression models. All results with $p \leq .05$ were considered statistically significant. All statistical

Table 1
Demographics (N = 200 feet in 200 participants)

Sex	Male (n = 100)			Female (n = 100)		
Age Group	Young (20 to 35 y) (n = 50)	Older (60 to 69 y) (n = 50)	*p* Value*	Young (20 to 35 y) (n = 50)	Older (60 to 69 y) (n = 50)	*p* Value*
Age, y	29.1 ± 3.2	64.6 ± 2.9	<.001†	27.3 ± 4.0	64.6 ± 2.9	<.001†
Height, cm	174.4 ± 6.2	167.8 ± 6.0	<.001†	160.8 ± 5.0	154.0 ± 5.1	<.001†
Weight, kg	71.6 ± 10.3	68.8 ± 8.2	.151	54.8 ± 7.1	57.9 ± 7.4	.033
Body mass index	23.5 ± 2.8	24.5 ± 2.6	.068	21.2 ± 2.6	24.4 ± 3.0	<.001†
Foot length, cm	25.5 ± 1.3	24.7 ± 1.1	.062	23.0 ± 1.0	22.7 ± 2.1	.358
Foot width, cm	10.1 ± 0.5	10.3 ± 0.4	.109	9.2 ± 0.5	9.8 ± 2.0	.056
Age Group	Young (20 to 35 y) (n = 100)			Older (60 to 69 y) (n = 100)		
Sex	Male (n = 50)	Female (n = 50)	*p* Value*	Male (n = 50)	Female (n = 50)	*p* Value*
Age, y	29.1 ± 3.2	27.3 ± 4.0	.015	64.6 ± 2.9	64.6 ± 2.9	.956
Height, cm	174.4 ± 6.2	160.8 ± 5.0	<.001	167.8 ± 6.0	154.0 ± 5.1	<.001
Weight, kg	71.6 ± 10.3	54.8 ± 7.1	<.001	68.8 ± 8.2	57.9 ± 7.4	<.001
Body mass index	23.5 ± 2.8	21.2 ± 2.6	<.001	24.5 ± 2.6	24.4 ± 3.0	.948
Foot length, cm	10.1 ± 0.5	23.0 ± 1.0	<.001	24.7 ± 1.1	22.7 ± 2.1	<.001
Foot width, cm	10.1 ± 0.5	9.2 ± 0.5	<.001	10.3 ± 0.4	9.8 ± 2.0	.108

Data presented as mean ± standard deviation.
* Student's *t* test.
† Statistical significance.

Table 2
Radiographic Angular Measurements According to Sex and Age

Angle, °	Sex (n = 200)			Age (n = 200)		
Age Group	Male (n = 100)	Female (n = 100)	*p* Value*	Young (20 to 35 y) (n = 100)	Older (60 to 69 y) (n = 100)	*p* Value*
Talar tilt	1.87 ± 0.70	1.99 ± 0.77	.143	1.24 ± 0.74	1.79 ± 0.75	.313
Tibiotalar	89.09 ± 0.67	90.09 ± 0.58	.273	89.2 ± 0.63	89.90 ± 0.63	.088
Hallux valgus	13.17 ± 1.19	15.31 ± 1.42	.027†	12.73 ± 1.04	15.75 ± 1.50	.002†
Hallux interphalangeal	14.47 ± 0.83	13.90 ± 0.99	.399	14.93 ± 0.89	13.45 ± 0.93	.027†
AP talo-first metatarsal	11.04 ± 1.01	11.80 ± 1.11	.327	11.63 ± 1.03	11.23 ± 1.10	.608
Calcaneal pitch	21.15 ± 1.03	19.76 ± 0.90	.050†	19.48 ± 0.88	21.39 ± 1.02	.007†
Talo-calcaneal	46.11 ± 1.30	45.77 ± 1.14	.697	45.72 ± 1.06	46.15 ± 1.36	.632
Meary's	1.91 ± 1.44	−1.90 ± 1.47	<.001†	−0.97 ± 1.22	0.88 ± 1.76	.089
Hibbs	48.03 ± 1.52	43.75 ± 1.21	<.001†	44.78 ± 1.18	46.88 ± 1.61	.044†

Abbreviations: AP, anteroposterior.
Data presented as mean ± standard deviation unless otherwise noted.
* Student's *t* test.
† Statistical significance.

analyses were performed using SPSS, version 21, for Windows (SPSS Inc., Chicago, IL), and conducted by 1 of the authors (D.O.L.).

Results

Demographic data for the participants are shown in Table 1. This table shows the difference of body size or weight according to sex and age in the study population. Body mass index and foot width reflecting volume of body significantly increased in the older female group compared with the younger female group (Table 1). The radiographic measurements, stratified by age and sex, are presented in Table 2. This table shows detailed measures according to both sex and age in all radiographic remarks, some of which showed significant difference by sex and or age. Table 3 shows the probabilities of the null hypothesis for angular measurements by sex and age. The hallux valgus angle, hallux interphalangeal angle, calcaneal pitch, and Meary's and Hibbs angles showed significant differences according to sex and or age, whereas others did not. Table 4 reveals comparisons between previously reported radiographic angular measurements and those observed in this investigation. These comparisons show a difference of 10° (45%) in the AP talo-first metatarsal angle, whereas there was no substantial difference (<10%) in other angles.

Discussion

Most radiographic angles measured in this study showed relatively small differences (<5°, 10%) in comparison to previously reported measurements, other than for the AP talo-first metatarsal angle. When stratified by sex and age, some radiographic angles showed significant differences. The hallux valgus angle increased in the female group and

Table 3
Probabilities of the Null Hypothesis for Determining the Statistical Significance of the Association of Sex and Age on Radiographic Measurements (N = 200 feet in 200 patients)

Angle	Sex Association, *p* Value	Age Association, *p* Value*
Talar tilt	.141	.308
Tibiotalar	.276	.093
Hallux valgus	.022†	.001†
Hallux interphalangeal	.374	.025†
AP talo-first metatarsal	.333	.614
Calcaneal pitch	.050†	.007†
Talo-calcaneal	.685	.663
Meary's	<.001†	.073
Hibbs	<.001†	.037†

* Aged 20 to 35 years or 60 to 69 years.
† Statistically significant at the 5% level.

Table 4
Comparison with Published Normal Foot and Ankle Angles

Radiographic Angle, °	Steel et al (5), 1980 (N = 41)	Bryant et al (6), 2000 (N = 30)	Davids et al (22), 2005 (N = 60)	Knupp et al (21), 2005 (N = 168)	Thomas et al (3), 2006 (N = 100)	Lamm et al (1), 2016 (n = 24)	Present Study (N = 200)
Talar tilt	NR	NR	NR	NR	NR	NR	1.8 ± 0.8
Tibiotalar	NR	NR	91.1 ± 3.8	92.4 ± 3.1	NR	NR	89.6 ± 0.6
Hallux valgus	12 ± 2.4	10.3 ± 4.0	NR	NR	10.4 ± 7.1	7.7 ± 3.8	14.3 ± 6.8
Hallux interphalangeal	14.5 ± 2.8	9.0 ± 3.3	NR	NR	NR	10.9 ± 3.5	14.2 ± 4.7
AP* talo-first metatarsal	NR	NR	10 ± 7.0	NR	21.1 ± 6.0	21.1 ± 5.5	11.4 ± 5.4
Calcaneal pitch	22 ± 2.5	24.2 ± 5.8	17 ± 6.0	NR	19.6 ± 6.2	17.9 ± 5.3	20.4 ± 5.0
Talo-calcaneal	NR	NR	49 ± 6.9	NR	NR	39.9	45.9 ± 6.3
Meary's	NR	NR	13 ± 7.5	NR	4.0 ± 5.5	5.5 ± 3.9	0 ± 7.7
Hibbs	NR	NR	NR	NR	42.2	40.6	45.8 ± 7.3

Abbreviations: AP, anteroposterior; NR, not reported.
Data presented as mean ± standard deviation unless otherwise noted.

the older group. The calcaneal pitch angle decreased in the female group but increased in the older group. Similarly, Hibbs angle decreased in the female group but increased in the older group. All of these were affected by both sex and age. The hallux interphalangeal angle decreased in the older group only, whereas Meary's angle decreased in the female group only. Other parameters showed no significant differences according to sex or age.

Radiographic measurements in weightbearing AP ankles are commonly used to diagnose and treat diseases or deformities. Reference values can be used for surgical planning of a supramalleolar osteotomy, total ankle arthroplasty, and other procedures. Nevertheless, few studies have reported reference angles for weightbearing AP ankle views compared with those for weightbearing AP and lateral foot views; moreover, no comprehensive report included combined ankle and foot values, as shown in Table 3 (21,22). There was no gross difference <5° in the tibiotalar angle between the present and previous studies.

In comparing our results with those of previous studies, there was a prominent difference of 10° in the AP talo-first metatarsal angle, whereas there was no significant difference in other angles; however, only the mean AP talo-first metatarsal angle, as reported in children by Davids et al (22), was generally similar to that in our study. Accordingly, the AP talo-first metatarsal angle, which is related to forefoot-valgus position, might increase with age or weight. More study may be required to determine whether this difference is caused by substantial ethnic differences or measurement errors.

The hallux valgus angle was significantly greater in females and older groups than in others, similar to previous reports (Tables 3 and 4) (23). Interestingly, the hallux interphalangeal angle was affected by age only, which implies that this angle may be increased by daily activity, because people wear shoes narrowing distal phalanges regardless of sex. Bryant et al (6) also reported a greater hallux interphalangeal angle in a hallux arthritis group than in a hallux valgus group. Because females may be more likely to wear shoes with a narrow toe box, this might contribute to the observation of the effect that sex had on the hallux valgus angle.

Regarding the weightbearing lateral foot radiographic angles, the calcaneal pitch angle and Hibbs angle showed significant differences according to both sex and age (Table 3). Before this study, we had hypothesized that the foot became more flatfooted when individuals get older. Although our study was not a longitudinal follow-up study of the same individuals, healthy older adults did not have lower arches than younger adults. Accordingly, we speculated that progression of flatfoot or cavus foot with age might be more affected by nonphysiologic degeneration or disease progression rather than by natural aging process.

There are some limitations to our study. First, although we recruited a greater number compared with previous studies, our subjects still would be insufficient to represent the normal Korean population. Nevertheless, the strength of this study is all subjects were volunteers without any medical problems, compared with most previous studies based on review of patient medical records. Moreover, this study was based on a large, healthy population, in comparison to prior publications; and, to the best of our knowledge, this is the first report based on an Asian population, so it could be helpful to investigators focusing on such a population. Second, we included only some radiographic indices compared with previous studies. The indices we selected were believed to be relatively common markers that could provide clinicians with valuable information. Third, the effect of sex or advancing age on radiographic angles shown in this study does not guarantee the same results in other studies, because differences, if any, were <5°, which is within measurement error despite reliability testing. Regarding the effect of age, a study design with longitudinal follow-up visits may be more appropriate. Finally, some surgeons may believe that other radiographic measurements should be included to provide useful information for foot alignment.

In conclusion, we presented reference values for foot and ankle radiographic measurements in a large, healthy Korean population. Several radiographic indices showed differences in values in association with sex and age. The findings in this study can be used to evaluate foot and ankle disease by providing basic data.

References

1. Lamm BM, Stasko PA, Gesheff MG, Bhave A. Normal foot and ankle radiographic angles, measurements, and reference points. J Foot Ankle Surg 2016;55:991–998.
2. Lamm BM, Paley D. Deformity correction planning for hindfoot, ankle, and lower limb. Clin Podiatr Med Surg 2004;21:305–326.
3. Thomas JL, Kunkel MW, Lopez R, Sparks D. Radiographic values of the adult foot in a standardized population. J Foot Ankle Surg 2006;45:3–12.
4. Fuson SM, Smith SD. Angular relationships of the metatarsal, talus and calcaneus: a radiographic analysis. J Am Podiatry Assoc 1978;68:463–466.
5. Steel MW 3rd, Johnson KA, DeWitz MA, Ilstrup DM. Radiographic measurements of the normal adult foot. Foot Ankle 1980;1:151–158.
6. Bryant A, Tinley P, Singer K. A comparison of radiographic measurements in normal, hallux valgus, and hallux limitus feet. J Foot Ankle Surg 2000;39:39–43.
7. Saltzman CL, Brandser EA, Berbaum KS, DeGnore L, Holmes JR, Katcherian DA, Teasdall RD, Alexander IJ. Reliability of standard foot radiographic measurements. Foot Ankle Int 1994;15:661–665.
8. Dominguez-Maldonado G, Munuera-Martinez PV, Castillo-Lopez JM, Ramos-Ortega J, Albornoz-Cabello M. Normal values of metatarsal parabola arch in male and female feet. Sci World J 2014;2014:505736.
9. Golightly YM, Hannan MT, Dufour AB, Jordan JM. Racial differences in foot disorders and foot type. Arthritis Care Res (Hoboken) 2012;64:1756–1759.
10. Scott G, Menz HB, Newcombe L. Age-related differences in foot structure and function. Gait Posture 2007;26:68–75.
11. Kernozek TW, Elfessi A, Sterriker S. Clinical and biomechanical risk factors of patients diagnosed with hallux valgus. J Am Podiatr Med Assoc 2003;93:97–103.
12. James B, Parker AW. Active and passive mobility of lower limb joints in elderly men and women. Am J Phys Med Rehabil 1989;68:162–167.
13. Endo M, Ashton-Miller JA, Alexander NB. Effects of age and gender on toe flexor muscle strength. J Gerontol A Biol Sci Med Sci 2002;57:M392–M397.
14. Xu HX, Choi MS, Kim MS, Park KS, Lee KB. Gender differences in outcome after modified Brostrom procedure for chronic lateral ankle instability. Foot Ankle Int 2016;37:64–69.

15. Ibrahim T, Beiri A, Azzabi M, Best AJ, Taylor GJ, Menon DK. Reliability and validity of the subjective component of the American Orthopaedic Foot and Ankle Society clinical rating scales. J Foot Ankle Surg 2007;46:65–74.
16. Kitaoka HB, Alexander IJ, Adelaar RS, Nunley JA, Myerson MS, Sanders M. Clinical rating systems for the ankle-hindfoot, midfoot, hallux, and lesser toes. Foot Ankle Int 1994;15:349–353.
17. Lee KM, Chung CY, Park MS, Lee SH, Cho JH, Choi IH. Reliability and validity of radiographic measurements in hindfoot varus and valgus. J Bone Joint Surg Am 2010;92:2319–2327.
18. Lee DY, Seo SG, Kim EJ, Kim SJ, Lee KM, Farber DC, Chung CY, Choi IH. Correlation between static radiographic measurements and intersegmental angular measurements during gait using a multisegment foot model. Foot Ankle Int 2015;36:1–10.
19. McKelvie SJ. Does memory contaminate test-retest reliability? J Gen Psychol 1992;119:59–72.
20. Lee KM, Lee J, Chung CY, Ahn S, Sung KH, Kim TW, Lee HJ, Park MS. Pitfalls and important issues in testing reliability using intraclass correlation coefficients in orthopaedic research. Clin Orthop Surg 2012;4:149–155.
21. Knupp M, Ledermann H, Magerkurth O, Hinterman B. The surgical tibiotalar angle: a radiologic study. Foot Ankle Int 2005;26:713–716.
22. Davids JR, Gibson TW, Pugh LI. Quantitative segmental analysis of weight-bearing radiographs of the foot and ankle for children: normal alignment. J Pediatr Orthop 2005;25:769–776.
23. Dufour AB, Casey VA, Golightly YM, Hannan MT. Characteristics associated with hallux valgus in a population-based foot study of older adults. Arthritis Care Res (Hoboken) 2014;66:1880–1886.