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Nonradiographic Measurement of Hallux Valgus Angle Using Self-photography

Hallux valgus is one of the most common foot deformities, with a prevalence of 23% in adults under the age of 65 years and 36% in elderly people aged 65 years and older.[16] The deformity tends to progress slowly over time, with an increasing incidence with age.[11] Screening for hallux valgus and detecting deformity at an early stage could help prevent or minimize its progression. For example, modifying footwear habits in mid life may reduce the risk of hallux valgus in later life.[7,13] Additionally, rehabilitation, such as abductor hallucis muscle exercise, is more effective in patients with mild deformity than in patients with moderate or severe deformity.[20] Monitoring the progression of deformity is also of clinical significance, because there is a progressive reduction in quality of life with increasing severity of hallux valgus deformity.[14] The evaluation of the progression may help determine the need for and timing of surgical intervention.

Hallux valgus is generally defined as a hallux valgus angle of 20° or more.[6] The reference standard of hallux valgus angle measurement is to use weight-bearing radiographs of the feet.[22] However, the availability and use of radiographs are constrained due to cost and radiation exposure, particularly for a screening tool and for large-scale epidemiologic research that includes asymptomatic participants.[15] Furthermore, the location of image acquisition is limited to medical facilities where radiography is available. Thus, more accessible and less invasive assessments have been reported as alternatives to this means of measurement. For example, categorical grading scales by which hallux valgus deformity is visually classified into 4 or 5 grades have been used in cohort studies.[12,18] The reliability of the visual grading was higher when an experienced rheumatologist assessed participants' feet than when the participants assessed their own feet.[18]

Digital photography has been used increasingly to measure musculoskeletal deformities, including those of the spine,[5] knee,[19] and foot.[15,17,25] Nix et al[15] reported a quantitative measurement of hallux valgus angle using digital photographs, and showed that the measurement was reliable compared to radiographic measurement. However, in that study, the photographs were taken by an experienced rater, under strict parameters, so that the position and the angle of the camera corresponded exactly to those used in radiography.

BACKGROUND: Radiographs of the feet are the reference standard for measuring the hallux valgus angle. However, the availability and use of radiographs are constrained due to cost and radiation exposure. Less invasive, nonradiographic assessments have been proposed, although measurement using self-photography has not been reported.

OBJECTIVES: To determine (1) reliability of photographic hallux valgus angle (pHVA) measurement using the same photographs of the feet, (2) reliability of repeated self-photography trials, and (3) measurement error when the radiographic hallux valgus angle (rHVA) is estimated using the pHVA.

METHODS: In this reliability study, participants took photographs of their own feet using a digital camera. The intrarater and interrater reliability of pHVA measurements were then assessed using the intraclass correlation coefficient (ICC) and 95% minimum detectable change (MDC). The participants took photographs twice, and the reliability of repeated self-photography trials was examined. Participants also received radiographs of their feet, from which the rHVA was measured. The measurement error was assessed using the mean difference and 95% limits of agreement.

RESULTS: The intrarater and interrater ICC of pHVA measurement was 0.99, with MDCs less than 2°. The ICC of pHVA measurement for repeated self-photography was 0.96, and the MDC was 6.9°. The pHVA was systematically lower than the rHVA, by 5.3°.

CONCLUSION: Measurement of the pHVA using self-photography was reproducible, although pHVA measurement underestimated the rHVA. The pHVA can be a useful nonradiographic method to quantify hallux valgus deformity. *J Orthop Sports Phys Ther 2019;49(2):80-86. Epub 12 Sep 2018. doi:10.2519/jospt.2019.8280*

KEY WORDS: *clinical measurement, digital camera, foot, hallux valgus, radiology, self-photography*

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Self-photography has the potential to expand the accessibility of digital photography assessments.[4] However, there are potential sources of error that are specific to hallux valgus angle measurement using self-photography that have not been determined, including the variability of the angular measurement and of photographs taken on separate occasions by the same individual. Hence, the purpose of this study was to determine (1) the intrarater and interrater reliability of hallux valgus angle measurement using the same photographs of the feet, (2) the reliability of hallux valgus angle measurement using the photographs taken in repeated self-photography trials, and (3) the measurement error when radiographic measurement was estimated using photographic measurement. In this study, the participants were people with and without foot disease, and the raters were a certified orthopaedic surgeon and a resident physician.

METHODS

Participants

This study was approved by the Institutional Review Board of the Graduate School of Medicine, Chiba University, and was reported according to the Guidelines for Reporting Reliability and Agreement Studies.[9] All participants provided written informed consent. Participants consisted of 3 groups: asymptomatic (n = 50), symptomatic 1 (n = 127), and symptomatic 2 (n = 50) (**FIGURE 1**). The measurement data from the asymptomatic and symptomatic 2 groups were used for the assessment of intrarater and interrater measurement repeatability and the repeatability of the self-photography trials. The data from participants in the symptomatic 1 group were used to quantify the difference between the radiographic and photographic measurements and to clarify the influencing factors.

Participants in the asymptomatic group were recruited from the employees of Chiba University Hospital from February 2016 to June 2016. These participants volunteered through the hospital's outpatient clinic. Exclusion criteria included (1) younger than 20 years of age, (2) history of surgery to or a current medical condition of the foot and ankle (eg, inflammatory arthritis), (3) inability to stand in a plantigrade position, and (4) inability to perform self-photography. In order to include a wide range of ages, 5 women and 5 men from each age decade between 20 and 60 years of age were recruited. The participants in the asymptomatic group performed self-photography of their feet on 2 occasions during an interval of 1 month.

For the symptomatic 1 group, patients who attended the foot and ankle clinic of Chiba University Hospital from February 2016 to June 2016 and underwent a weight-bearing dorsoplantar radiograph of the foot were recruited. Patients with acute inflammatory diseases, such as cellulitis and gout, and with histories of foot and ankle surgery, fracture, or dislocation within the prior year were excluded.[15] Patients with a bunion were not excluded. The participants of the symptomatic 1 group performed self-photography and underwent radiography at the time of their clinic visits.

The symptomatic 2 group comprised a subset of the participants in the symptomatic 1 group who visited the clinic a second time during the recruitment period. The participants of the symptomatic 2 group performed self-photography again at the time of their second visit.

Self-photography of the Feet

An instruction sheet (**APPENDIX**, available at www.jospt.org) was given to each subject to standardize the position of the foot in the photographs. Participants took photographs of their own feet using a digital camera or a smartphone and according to the instruction sheet. The type of camera (or smartphone) was not specified. A digital camera (IXY 150; Canon Inc, Tokyo, Japan) was provided to participants who did not have a camera or smartphone. The participants received no additional instruction or support from the research staff.

Photographic Hallux Valgus Angle

Each photograph was anonymized, saved in a JPEG format, and loaded into open-source image-analysis software (Karasunpo; Katayama Hirofumi MZ, Japan). The photographic hallux valgus angle (pHVA) was defined as the angle between 2 lines digitally drawn on the medial side of the hallux and the medial side of the foot (**FIGURE 2A**).[8,10] The distal line passed along the medial sides of the first interphalangeal joint and first metatarsal head. The proximal line passed along the

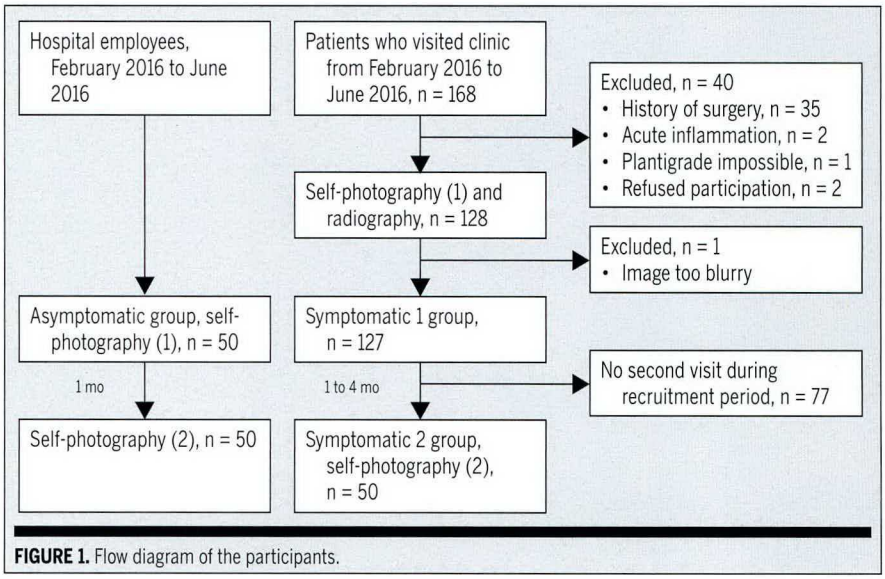

FIGURE 1. Flow diagram of the participants.

medial sides of the first metatarsal head and navicular tuberosity. The measurements were obtained with an increment of 0.1° and rounded to the nearest whole number for analysis.

Photographs were independently evaluated by 2 raters who were blinded to participant background and any previous measurement values. A certified orthopaedic surgeon (rater 1) measured the pHVA from the photographs of the asymptomatic group, and those of the symptomatic 2 group taken at the first visit, twice in an interval of 1 month.[12] A 1-month interval was considered long enough for the examiner to be unable to recall the first measurement.[12] In addition, an orthopaedic senior resident (rater 2) measured the pHVA of the same participants using the photographs obtained at the first visit.

Radiographic Hallux Valgus Angle

Participants stood in a relaxed position with the feet parallel and foot-width apart. The X-ray beam was inclined 15° from vertical at a distance of 100 cm, directed parallel to the long axis of the foot, and centered on the second tarsometatarsal joint.[24] When radiographs of both feet were taken, images of right and left feet were captured separately. The radiographic hallux valgus angle (rHVA) was defined as the angle formed by the intersection of a line drawn through the longitudinal axis of the first metatarsal with that drawn through the longitudinal axis of the first proximal phalanx (**FIGURE 2B**).[2] The longitudinal axis of each bone was defined by the centers of the proximal and distal metaphyseal/diaphyseal regions. The measurements were obtained with an increment of 0.1° using the angular measurement function of the picture archiving and communication system and rounded to the nearest whole number for analysis.

All images were anonymized prior to measurement and independently evaluated by 2 raters. Both raters were blinded to participant backgrounds and any previous measurement values. The intraclass correlation coefficient (ICC) model 2,1 values for the intrarater and interrater reliability of the rHVA measurement were both 0.99. The minimum detectable change at the 95% confidence level (MDC_{95}) values were 2.9° and 2.5°, respectively.

Statistical Analysis

Although the photographs captured both feet, 1 foot was selected from each participant and used for analysis. For the asymptomatic group, the foot with the more severe deformity was selected. For the symptomatic groups, the side that underwent radiography was used. If radiographs were obtained from both feet, then the foot with the more severe deformity was selected. Descriptive statistics, including means and standard deviations, were used to report participant characteristics and measurement values.

For the evaluation of the intrarater and interrater reliability of the pHVA measurements, the photographs of the asymptomatic group and those of the symptomatic 2 group taken at the first visit were used. Intrarater reliability of the pHVA measurement was assessed using ICC model 2,1 with a 95% confidence interval (CI), standard error of measurement (SEM), and the MDC_{95}.[3,21] The MDC_{95} was calculated as $1.96 \times \sqrt{2} \times SEM$. The overall values of both the asymptomatic and symptomatic 2 groups, as well as the values for each group, were calculated. The first measurements made by rater 1 and the measurements made by rater 2 were used to assess interrater reliability. The ICC (model 2,1) with 95% CI, SEM, and MDC_{95} were calculated.

To assess the reliability of pHVA measurement using the photographs obtained

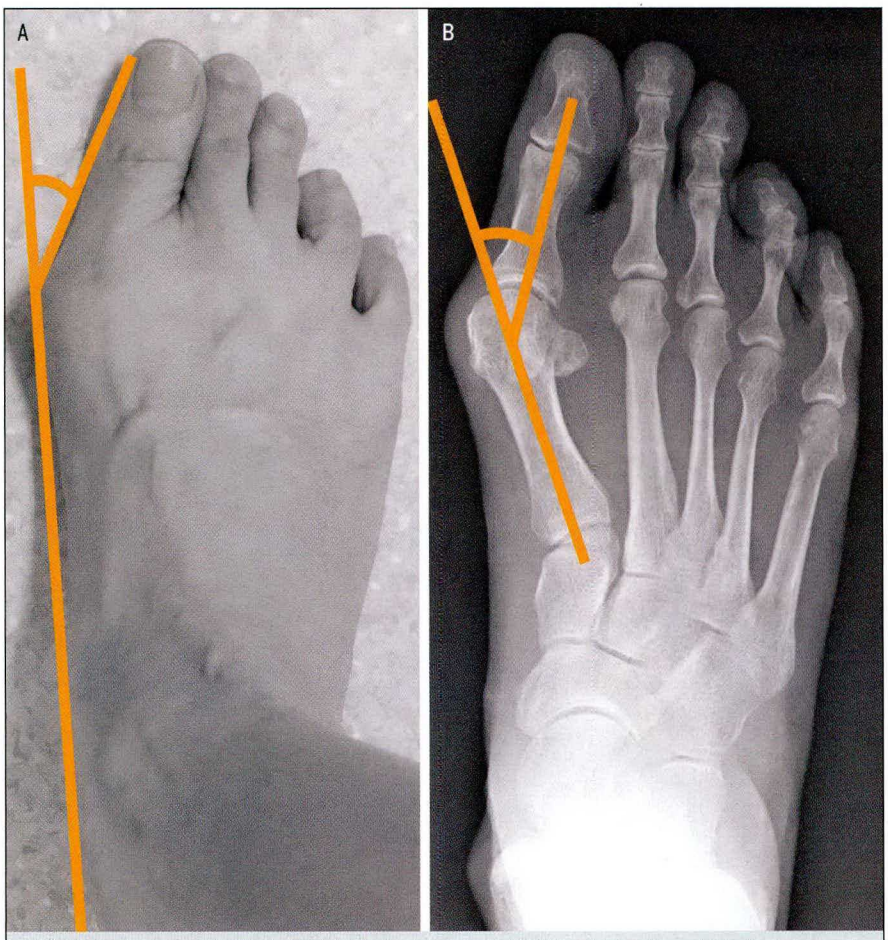

FIGURE 2. Measurements of (A) photographic hallux valgus angle (28.5°) and (B) radiographic hallux valgus angle (30.5°).

from repeated self-photography trials, the pHVA as measured by rater 1 was used from the first and second photographs of the asymptomatic and symptomatic 2 groups. The reliability was evaluated using ICC model 1,1 with 95% CI, SEM, and MDC_{95}.

The measurement error of the pHVA, with the rHVA as the reference standard, was assessed using the data from the symptomatic 1 group, measured by rater 1. The measurement error was assessed by the mean difference, with a 95% CI and 95% limits of agreement.[1] Simple linear regression was performed, with rHVA as the objective variable and pHVA as the explanatory variable. Statistical analyses were performed using JMP Version 11.2.1 (SAS Institute Inc, Cary, NC). Statistical significance was set at $P<.05$.

RESULTS

The characteristics of the participants included in each group are shown in **TABLE 1**.

Intrarater and Interrater Reliability of the pHVA Measurement

The ICC value for the intrarater and interrater reliability of the pHVA measurement was 0.99 in both the asymptomatic and symptomatic 2 groups (**TABLE 2**). The MDC_{95} values ranged from 1.5° to 1.8°.

Reliability of Repeated Self-photography

The ICC values for the reliability of pHVA measurement for repeated self-photography were above 0.80 in both the asymptomatic and symptomatic 2 groups (**TABLE 3**). The MDC_{95} values were 6.4° and 7.4° for the asymptomatic and symptomatic 2 groups, respectively. The mean ± SD differences between repeated self-photography trials were −0.6° ± 4.0° in participants with an interval between trials of 1 month (n = 38) and 0.7° ± 2.7° in those with intervals of 2 to 4 months (n = 12). There was no significant difference between the 2 participant groups (P = .24, t test), indicating that the time interval did not have an impact on reliability.

Comparison of pHVA and rHVA

The pHVA had a systematic error, in which the pHVA values were lower than the rHVA values, with a mean difference of −5.3° (95% CI: −4.3°, −6.2°) (**FIGURE 3**). The 95% limits of agreement were 5.3° and −15.9°. Simple linear regression showed that the rHVA was predicted by the following equation: rHVA = 5.6 + 0.98 × pHVA (R^2 = 0.891, $P<.001$).

TABLE 1 Participant Characteristics

	Asymptomatic	Symptomatic 1*	Symptomatic 2†
Participants, n	50	127	50
Laterality, n			
Right	21	71	22
Left	29	56	28
Age, y‡	44 ± 14	61 ± 13	62 ± 14
Sex, n			
Female	25	96	33
Male	25	31	17
Height, m‡	1.63 ± 0.06	1.58 ± 0.09	1.60 ± 0.09
Body mass, kg	61 ± 13	61 ± 14	62 ± 13
Body mass index, kg/m²	23 ± 6	24 ± 4	24 ± 4

**The most frequent clinical diagnosis was hallux valgus (n = 52), followed by osteoarthritis of the foot and ankle (n = 23), adult flatfoot (n = 11), rheumatoid arthritis (n = 10), trauma (n = 9), foot and ankle deformity (n = 6), tendinopathy (n = 6), and other (n = 10).*
†The most frequent clinical diagnosis was hallux valgus (n = 24), followed by osteoarthritis of the foot and ankle (n = 6), adult flatfoot (n = 6), tendinopathy (n = 6), other (n = 3), rheumatoid arthritis (n = 3), trauma (n = 1), and foot and ankle deformity (n = 1).
‡Values are mean ± SD.

TABLE 2 Intrarater and Interrater Reliability of Photographic Hallux Valgus Angle Measurement

	Overall (n = 100)	Asymptomatic (n = 50)	Symptomatic 2 (n = 50)
pHVA*			
Rater 1			
Measurement 1	16.9 ± 12.4	10.2 ± 5.3	23.7 ± 13.7
Measurement 2	16.9 ± 12.5	10.1 ± 5.4	23.7 ± 13.8
Rater 2	16.8 ± 12.5	9.9 ± 5.4	23.7 ± 13.9
Intrarater reliability			
$ICC_{2,1}$†	0.998 (0.996, 0.998)	0.989 (0.980, 0.994)	0.998 (0.996, 0.999)
SEM	0.6	0.6	0.6
MDC_{95}	1.7	1.6	1.8
Interrater reliability			
$ICC_{2,1}$†	0.998 (0.997, 0.998)	0.989 (0.979, 0.994)	0.998 (0.996, 0.999)
SEM	0.6	0.6	0.7
MDC_{95}	1.7	1.5	1.8

Abbreviations: ICC, intraclass correlation coefficient; MDC_{95}, minimum detectable change at the 95% confidence level; pHVA, photographic hallux valgus angle; SEM, standard error of measurement.
**Values are mean ± SD.*
†Units are degrees except for the ICC values. Values in parentheses are 95% confidence interval.

DISCUSSION

The authors assessed the reliability of pHVA measurement, as well as the reliability of the self-photography technique. The intrarater and interrater reliability of pHVA measurement was relatively high, with ICCs greater than 0.98 and MDC_{95} values less than 2°. The reliability of pHVA measurement for repeated self-photography was lower than the intrarater and interrater reliability, and the MDC_{95} value was 7°. Moreover, the measured pHVA was lower than the rHVA, with a systematic error of 5°. The pHVA measurement using self-photography is a simple nonradiographic technique to estimate the rHVA and may be used for the screening and monitoring of hallux valgus deformity.

The high intrarater and interrater reliability of the pHVA measurement was likely, because the 2 reference lines for the measurement, the tangential lines of the medial sides of the hallux and the foot, were easy to define. Similar to the current study, Nix et al[15] measured the hallux valgus angle using digital photographs of the foot, but with different reference lines. The rater visually imagined the shapes of the first proximal phalanx and first metatarsal on a photograph of the foot, and drew the 2 bisection lines of the imagined bones to replicate the rHVA measurement. This method requires a superior grasp of the surface anatomy of the foot and experience in its measurement.[15] In the Nix et al[15] study, the intrarater and interrater 90% MDC values were 4.1° and 4.7°, respectively. The rHVA measurement method in the present study showed better measurement reliability.

The MDC_{95} for the reliability of pHVA measurement using repeated self-photography trials, which represents the smallest change in the pHVA that likely reflects true changes rather than measurement error alone,[23] was 6.9°. In other words, if the pHVA of a participant increases by more than 6.9° in longitudinal observations, then the deformity is expected to have changed beyond error. The severity of hallux valgus deformity is generally graded in 10° to 15° increments,[6,18] although the minimal clinically important change in hallux valgus angle has not been determined to date. Therefore, the self-photography technique could detect large hallux valgus angle changes between grades; however, detecting small changes within a grade may be difficult.

In this study, the participants took the photographs by themselves, rendering the photographic conditions potentially variable between participants and photographs. For example, the distance between the foot and camera and the angle of the camera were clearly altered depending on the height of each participant. Moreover, the posture of the participants while taking the photographs may have been inconsistent between the photographs of the same subject. The reliability of digital photography was previously reported to be excellent for the measurement of foot arch[17] and scoliosis.[5] In these studies,[5,17] photographs were taken by raters in laboratory settings where the photographic conditions, such as the positioning of the participants and camera, were strictly controlled to minimize potential sources of error. Although the self-photography technique might have sacrificed precise reliability, the self-photography of the feet appeared, overall, to have sufficient reliability to detect changes in hallux valgus deformity across clinical grades.

The pHVA values were lower by 5.3° than the rHVA values. The difference appears to be due to the anatomical varus position of the first metatarsal relative to the tangential line of the medial side of the foot, which usually connects the medial sides of the first metatarsal head and the navicular tuberosity.[8] Klein et al[8] measured a "simulated" nonradiographic hallux valgus angle using a soft tissue shadow on the foot radiograph instead of a photograph, as used in the current study. The measured hallux valgus angle

TABLE 3 Reliability of Photographic Hallux Valgus Angle Measurement for Repeated Self-photography*

	Overall (n = 100)	Asymptomatic (n = 50)	Symptomatic 2 (n = 50)
pHVA			
Photography 1	16.9 ± 12.4	10.2 ± 5.3	23.7 ± 13.7
Photography 2	16.7 ± 13.0	9.4 ± 5.3	24.0 ± 14.3
Reliability			
$ICC_{1,1}$†	0.96 (0.94, 0.97)	0.81 (0.69, 0.89)	0.96 (0.94, 0.98)
SEM	2.5	2.3	2.7
MDC_{95}	6.9	6.4	7.4

Abbreviations: ICC, intraclass correlation coefficient; MDC_{95}, minimum detectable change at the 95% confidence level; pHVA, photographic hallux valgus angle; SEM, standard error of measurement.
**Values are mean ± SD unless otherwise indicated. Units are degrees except for the ICC values.*
†*Values in parentheses are 95% confidence interval.*

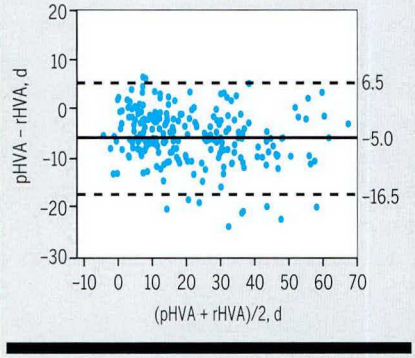

FIGURE 3. Bland-Altman plot of the difference between pHVA and rHVA. The solid line indicates the mean difference, and the dotted lines indicate the 95% limits of agreement. Abbreviations: pHVA, photographic hallux valgus angle; rHVA, radiographic hallux valgus angle.

was 4.8° lower than the rHVA, which is comparable to the results of this study. In clinical practice, the pHVA can be adjusted by adding 5.3° to estimate the rHVA. However, the 95% limits of agreement were 5.3° and −15.9°. Thus, the authors caution that the measurement error of the pHVA was more than 10° in about 5% of participants.

There are several limitations to this study. First, the measurement error of the pHVA was assessed using the data from the participants with foot and ankle disease; thus, results may not be extrapolated to those without foot and ankle disease. However, the symptomatic 1 group consisted of patients with and without hallux valgus, and thus included a wide range of hallux valgus angles. Second, the authors did not assess the quality of photographs, such as blurriness and distortion, or the positioning of the participants and cameras. The inconsistency in these factors may have negatively affected the reliability of the pHVA measurement and the reliability of repeated self-photography.[25] Although further research is necessary to clarify the factors that affect measurement reliability, the results of the current study represent the level of measurement reliability in a clinical setting, including all sources of variability. Third, 2 orthopaedic surgeons measured the pHVA in this study. The measurement reliability may have been lower using nonmedical raters, although the reference lines to measure the pHVA are fairly easy to draw, and no anatomical knowledge is necessary. Fourth, the researchers did not assess the presence of bunions, which frequently accompany hallux valgus deformity. Large bunions might have influenced the measurement difference between the pHVA and rHVA, and further research is necessary to clarify this issue. Finally, the self-photography was performed in a medical facility setting. The authors tried to minimize external support while participants took photographs. However, further research is necessary to confirm whether self-photography can be reproduced outside of a medical facility.

CONCLUSION

In conclusion, while the intrarater and interrater reliability of pHVA measurement was sufficiently high, the reliability of pHVA measurement for repeated self-photography trials was lower. Furthermore, the pHVA measurement systematically underestimated the hallux valgus angle by 5° as compared with the rHVA measurement, with higher errors occurring in some patients. Within these limitations, the pHVA might be used as a nonradiographic method to assess hallux valgus deformity, and may be relevant for use in a screening and cohort study of hallux valgus. ◉

KEY POINTS

FINDINGS: Measurement of the photographic hallux valgus angle (pHVA) using self-photography was reliable and is a predictor of radiographic hallux valgus angle.

IMPLICATIONS: The pHVA may be a useful nonradiographic method to assess hallux valgus deformity and thus may be relevant for use in a screening and cohort study of hallux valgus.

CAUTION: The pHVA systematically underestimated the radiographic hallux valgus angle by 5°. The minimum detectable change at the 95% confidence level for repeated self-photography trials was 7°.

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