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Original Article

Proposals for talonavicular joint assessment using ultrasound imaging and its reliability and validity

Keisuke Hirakawa, RPT, MSc[1)], Masahiro Tsutsumi, RPT, PhD[2)], Isao Yamaguchi, RT, PhD[1, 3)], Shintarou Kudo, RPT, PhD[1, 2, 4)*]

[1)] *Graduate School of Health Sciences, Morinomiya University of Medical Sciences: 1-26-16 Nanko-kita, Suminoe-ku, Osaka-shi, Osaka 559-0034, Japan*
[2)] *Inclusive Medical Sciences Research Institute, Morinomiya University of Medical Sciences, Japan*
[3)] *Department of Radiological Science, Faculty of Health Science, Morinomiya University of Medical Sciences, Japan*
[4)] *AR-Ex Medical Research Center, Japan*

Abstract. [Purpose] We aimed to develop a noninvasive specific ultrasonographic assessment of the talonavicular joint during loading to facilitate the analysis of treatment of flatfoot. [Participants and Methods] Sixty healthy participants underwent ultrasound imaging of the talonavicular joint while sitting and standing. The talonavicular angle was defined as the intersection of the line connecting the navicular and talar heads and the line connecting the talar head and sustentaculum tali. Talonavicular coverage was assessed using X-ray images of 15 participants. [Results] Ultrasonographic assessment of the talonavicular joint showed a lateral shift of the navicular relative to the head of the talus from sitting to standing. The talonavicular angle was significantly larger when standing than in the sitting position. The difference in talonavicular angle values between sitting and standing significantly correlated with the differences in the talonavicular coverage values. [Conclusion] We showed that ultrasonographic talonavicular angle assessment has good reliability and moderate validity for detecting significant alignment changes in the talonavicular joints due to loading. In the future, this evaluation method should be performed before and after exercise therapy to assess and develop appropriate exercise therapy for flatfoot.
Key words: Flatfoot, Talonavicular joint-specific assessment, Ultrasound imaging

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INTRODUCTION

Adult acquired flatfoot deformity, also known as progressive collapsing foot deformity, is a three-dimensional foot deformity that includes medial longitudinal arch collapse, hindfoot valgus, and forefoot abduction[1–5)]. To accurately diagnose and treat flatfoot deformities, it is essential to evaluate their mobility and changes of the foot under loading conditions[5, 6)]. Recent biomechanical and weight-bearing computed tomography (CT) studies have suggested that the evaluation of peritalar subluxation at the transverse tarsal joints, especially abduction of the talonavicular joints, is important for flatfoot deformity evaluation[5, 7–10)]. Therefore, there is a high demand for a clinically accessible method to evaluate talonavicular joint mobility and changes during loading.

Talonavicular coverage angle evaluation using radiography is a gold standard for clinically assessing the talonavicular joint[11, 12)]. However, this method involves radiation exposure and cannot be used frequently to examine the effects of conservative therapy, such as before and after exercise therapy. In addition, other common assessments of foot alignment, such

*Correspondence author. Shintarou Kudo (E-mail: kudo@morinomiya-u.ac.jp)

as the arch height index[13], arch height flexibility[14], and 6-item foot posture index[15, 16], are convenient, but do not independently assess the talonavicular joint. Pasapula et al.[17] recently developed the "neutral heel lateral push test", but this method cannot evaluate the talonavicular joint under loading conditions. In recent years, ultrasound imaging has been employed as a simple and non-invasive method for assessing joint morphology and mobility under loading conditions[18, 19]. Therefore, we hypothesized that ultrasound imaging could also be used to assess talonavicular joint mobility and changes during loading.

We aimed to develop an assessment of talonavicular joint mobility using ultrasound imaging and to examine the validity and reliability of the method.

PARTICIPANTS AND METHODS

Sixty healthy volunteers (42 males and 18 females; mean age [mean ± standard deviation], 26.4 ± 11.0 years; height, 170 ± 10 cm; weight, 62.1 ± 11.6 kg) at our university were investigated. We recruited individuals with no history of foot or ankle surgery, or foot pain and without neurological or muscular abnormalities. The study design was approved by the ethics committee of our university (approval no.: 2021-081). All procedures were performed in accordance with the Declaration of Helsinki (last modified in 2013) and the Japanese guidelines entitled, "Ethical Guidelines for Medical and Health Research Involving Human Subjects". All potential participants were informed about the study requirements, benefits, and risks, and those desiring to participate provided written informed consent.

Ultrasound assessment was performed on one foot (pivot foot) of all participants, in addition to the following conventional foot alignment assessments: arch height index (in sitting and standing positions), arch height flexibility, and 6-item foot posture index[13–16]. Moreover, in 15 of the 60 feet, bony alignment was also assessed by plain X-ray examination.

Ultrasound assessment was performed using an ultrasound scanner (SNiBLE; Konica Minolta, Tokyo, Japan) with a 4–18 MHz linear transducer. To acquire a B-mode image of the talonavicular joint, we simultaneously visualized the following bony structures at dorsiflexion of 0° in the sitting and standing positions: the dorsal edge of the navicular, the head of the talus, and the sustentaculum tali (Fig. 1). The detailed visualization methods are described below. First, the sustentaculum tali and navicular tuberosity were evaluated via palpation. Second, the sustentaculum tali was detected by the transducer parallel to the plantar surface and adjacent inferior to the medial malleolus. Third, by obtaining medial aspect images of the head of the talus, the long-axis images of the spring ligament were identified. Finally, we simultaneously visualized the dorsal edge of the navicular, the head of the talus, and the sustentaculum tali by rotating the navicular side of the transducer slightly in the dorsal direction until the dorsal edge of the navicular was depicted. Based on the ultrasound images, the talonavicular angle (TNA) and its excursion (TNA-E) were obtained and analyzed using ImageJ software version 1.52 (National Institutes of Health, Bethesda, MD, USA). The TNA was defined as the angle between the line connecting the navicular and head of the talus and that connecting the head of the talus and sustentaculum tali. The TNA-E was defined as the difference in

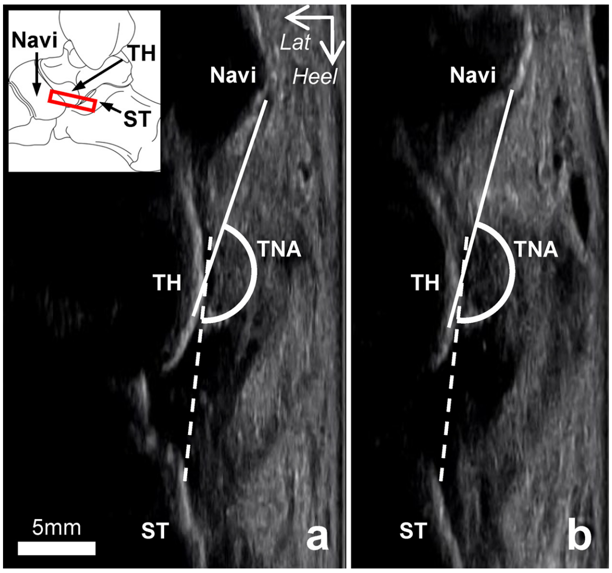

Fig. 1. Ultrasound assessment of the talonavicular angle.
The talonavicular angle (TNA) was assessed using ultrasound imaging in sitting (a) and standing positions (b). The upper-left image in (a) shows a schematic illustration of the medial aspect of the right ankle, and the red box indicates the location of the ultrasound transducer. The TNA was defined as the angle formed by the solid line connecting the navicular (Navi) and the head of the talus (TH), with the dotted line connecting the TH and sustentaculum tali (ST). *Lat*: lateral.

TNA values in the sitting and standing positions. One measurement each of the TNA and TNA-E was recorded by a single examiner (K.H. is a licensed physical therapist with 5 years of clinical experience and an additional 5 years of experience with ultrasonography) for statistical analysis.

To assess intra-rater reliability, a single examiner (K.H.) repeated the measurement twice on both feet of the randomly selected seven participants on different days. Moreover, to assess inter-rater reliability, the measurement was performed by two examiners (K.H. and Y.F. [Y.F. is a licensed physical therapist with 6 and 2 years of clinical experience and experience with ultrasonography, respectively]) on both feet of seven participants on the same day. Intra-class correlation coefficients (ICCs) were calculated to determine the intra- and inter-rater reliabilities of each measured value.

Plain X-ray examination of the talonavicular joint was performed using X-ray equipment (MRAD-A325; Canon Medical Systems, Otawara, Japan). To assess the talonavicular coverage angle (TNCA)[11, 12], anteroposterior radiographs of the feet were obtained in a standardized manner at dorsiflexion 0° in sitting and standing. The X-ray parameters were as follows: tube voltage, 50 kV; tube current, 100mA; tube current-exposure time product, 0.025 mAs; source-to-detector distance, 150 cm; incident angle, 20°, angled posteriorly toward the heels. Based on the recorded X-ray images, the TNCA, namely the angle between the line connecting the edges of the articular surface of the talus and those connecting the edges of the articular surface of the navicular, was analyzed using ImageJ. In addition, the excursion of the TNCA (TNCA-E) was defined as the difference in TNA measurement values in the sitting and standing positions and was measured using ImageJ.

Statistical tests were performed using SPSS (version 27.0; IBM Corp., Armonk, NY, USA). Distributions of all measurements, including TNA, did not pass the Shapiro–Wilk test for normal distribution, and so the data were expressed as medians and interquartile ranges (IQRs).

Statistical comparisons of the TNA values in the sitting and standing positions was performed using the Wilcoxon signed-rank sum test, and the significance level was set at $p<0.05$. To examine the reproducibility of the TNA measurements, the ICCs, standard error of the mean (SEM), and minimal detectable change with a confidence level of 95% (MDC95) (Eq. 1) were calculated.

$$MDC95 = SEM \times 1.96 \times \sqrt{2} \quad \text{(Eq. 1)}$$

The qualitative cut-offs for ICCs were in accordance with previous studies: poor, <0.40; fair, 0.40–0.59; good, 0.60–0.74; and excellent, 0.75–1.0[20]. To examine the validity of TNA-E, its statistical correlation with the TNCA-E was examined using Spearman's rank correlation coefficient, with a significance level of $p<0.05$. In addition, the statistical correlation between the TNCA-E and conventional foot alignment assessment (arch height index in sitting and standing positions, arch height flexibility, and 6-item foot posture index) was examined, and the significance level was set at $p<0.05$. A post-hoc power analysis was performed to investigate the statistical correlation between TNA-E and TNCA-E using G*Power software (Heinrich Heine University, Düsseldorf, Germany). The power was 0.89, confirming that the analysis was performed with a sufficiently large sample size.

RESULTS

The participant characteristics based on conventional foot alignment assessment are shown in Table 1. Ultrasonographic assessment of the talonavicular joint showed that the navicular shifted laterally relative to the head of the talus from sitting to standing (Fig. 1). The TNA was significantly larger in the standing (median [IQR]:166° [159°–173°]) than in the sitting position (156° [145°–166°]) ($p<0.001$, Table 2). All ICCs of the TNA measurement were ≥0.69 (range, 0.69–0.99) (Table 2). The conventional foot alignment assessments showed no significant correlation with TNCA-E (Fig. 2a–2d), while the TNA-E (7.5° [4.0°–13.1°]) showed a moderately significant correlation with TNCA-E (rho=0.67, $p=0.02$, Fig. 2e).

DISCUSSION

This study revealed that TNA measured using ultrasonography can detect significant alignment changes in the talonavicular joints under loading conditions. The assessment developed herein showed good reliability, and its excursion value (TNA-E) was significantly correlated with the TNCA-E measured using X-ray.

Table 1. Conventional assessment of foot alignment

Foot alignment assessment	(n=60)
Arch height index (sitting)	0.36 [0.35–0.38]
Arch height index (standing)	0.33 [0.32–0.36]
Arch height flexibility	9.62 [7.31–13.61]
6-item foot posture index	3 [1–4]

Data are presented as median and interquartile range.

Table 2. Talonavicular angle and its reproducibility in sitting and standing positions

	Median [IQR], n=60	ICC (95% CI), n=14		SEM, n=14	MDC95, n=14
		Intra-rater reliability	Inter-rater reliability		
TNA in sitting	155.8° [145.1°–166.4°]	0.96 (0.89–0.98)	0.89 (0.69–0.96)	3.2°	9.1°
TNA in standing	165.8° [159.0°–172.8°]	0.97 (0.91–0.99)	0.89 (0.70–0.96)	2°	5.8°
TNA-E	7.5° [4.0°–13.1°]				

CI: confidence interval; ICC: intraclass correlation coefficient; IQR: interquartile range; MDC95: Minimal Detectable Change 95; SEM: standard error of the mean; TNA: talonavicular angle; TNA-E: excursion of the TNA.

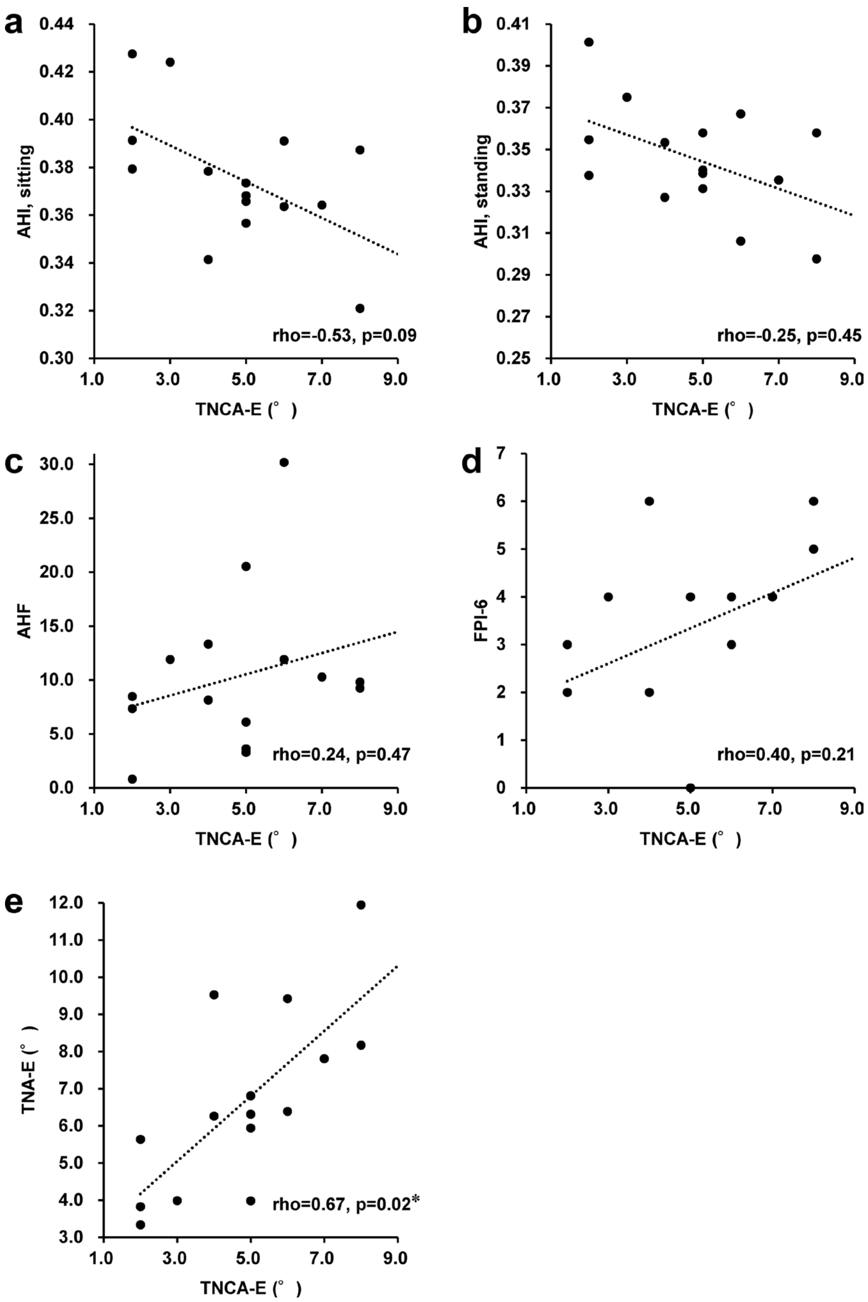

Fig. 2. Relationships between the foot alignment assessments and talonavicular coverage angle excursion between the measurement values in sitting and standing positions.

Scatter plots demonstrating the relationship between talonavicular coverage angle excursion (TNCA-E) and the following foot alignment assessments: arch height index (AHI, a, sitting and b, standing), arch height flexibility (AHF, c), 6-item foot posture index (FPI-6, d), and talonavicular angle excursion (TNA-E, e). Only TNA-E significantly correlated with TNCA-E (Spearman's rank correlation coefficient; rho=0.67, p=0.02).

TNCA assessed using radiography is the gold standard method for evaluating the talonavicular joint under loading conditions; it may be associated with 3D coverage of the talonavicular joint and evaluation using weightbearing CT[10, 21]. In addition, talonavicular joint assessment methods, other than CT-based approaches, that significantly correlate with TNCA, have rarely been reported. Therefore, a strength of our ultrasound-based assessment method is that the findings have good correlation with TNCA. Kido et al.[22] reported 3.1 ± 2.8° and 4.3 ± 2.3° abduction of the talonavicular joint during loading in healthy feet and flatfoot cases, respectively, while Kitaoka et al.[23] reported a value of 13.6 ± 5.0° in a cadaveric study. In our study, talonavicular joint abduction during loading was 7.5°; the difference in values from the previous studies may be due to differences in standing conditions, or whether the participant was alive or a cadaver. However, the difference in values was slight, and the abduction angles in this study were as valid as those in previous studies.

In general, the effect of exercise therapy has been evaluated using conventional foot alignment assessments, such as the 6-item foot posture index[24, 25]. However, the 6-item foot posture index did not significantly correlate with TNCA in the present study despite evaluating talonavicular joint abduction by visual inspection and palpation[15, 16]. Therefore, conventional foot alignment assessments may not have appropriately evaluated the efficacy of exercise therapy with respect to talonavicular joint mobility. In the future, the new evaluation method proposed here should be performed before and after exercise therapy to assess and develop appropriate exercise therapies for flatfoot cases.

Our study has certain limitations. First, the study was limited to healthy individuals. Because we did not compare pathological groups, we failed to address whether the evaluation method in the present study was capable of detecting differences between pathological and normal conditions. However, only asymptomatic patients were considered sufficient in number to confirm the validity and reliability of this measurement method. Second, three-dimensional motion of the talonavicular joint could not be evaluated. In particular, we cannot exclude the possibility that foot eversion movements during loading may have affected our results. However, we believe that the abduction motion of the talonavicular joint in the horizontal plane can be evaluated effectively.

In conclusion, TNA measured using the ultrasonographic technique in this study was able to detect significant alignment changes in the talonavicular joints under loading conditions with good reliability and moderate validity.

Funding and Conflict of interest

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