Original Article
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Tibial Axis-to-Talus Distance: A Clinically Reliable Measurement for Sagittal Translation of the Talus in Total Ankle Arthroplasty

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Background: Sagittal talar translation is an important factor influencing the sagittal alignment of total ankle arthroplasty (TAA). Thus, accurate measurement of sagittal talar translation is crucial. This study proposes a simple method (tibiotalar distance [TTD]) that can quantify talar translation without being affected by the ankle and subtalar joint condition or the talar component position in patients with TAA.

Methods: We enrolled 280 eligible patients (296 ankles) who underwent primary TAA between 2005 and 2019 and retrospectively reviewed them for sagittal talar translation. The TTD was measured for each patient on weight-bearing lateral ankle radiographs by 3 raters. In addition, we analyzed interrater and intrarater reliability for the TTD method.

Results: We found that the TTD method could quantify the talar translation and was not affected by the preoperative condition of the ankle joint surface, subtalar joint pathologies, or the postoperative talar component position. The TTD method showed an excellent intraclass correlation coefficient (> 0.9) in all interrater and intrarater reliability analyses. In the analysis of 157 healthy, unoperated contralateral ankles, we identified that TTD showed a Gaussian distribution ($p = 0.284$) and a mean of 38.91 mm (normal range, 29.63–48.20 mm).

Conclusions: The TTD method is a simple and reliable method that could be applied to patients with TAA to assess the sagittal talar translation regardless of the pre-and postoperative joint condition and implantation status.

Keywords: *Total ankle arthroplasty, Sagittal alignment, Talar translation*

Total ankle arthroplasty (TAA) is becoming more common as a first-line treatment for end-stage ankle arthritis.[1-3] Realigning the deformity is crucial for the longevity of TAA as postoperative malalignment can negatively affect the clinical outcomes of TAA.[4,5] Previous studies have mainly focused on coronal plane alignment, although sagittal alignment has also been emphasized recently.[6-10]

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Sagittal talar translation should be addressed to restore sagittal alignment. Previous studies have demonstrated that sagittal talar translation was restored to an anatomic position within the first 6 months postoperatively.[11,12] Two techniques are commonly used to measure sagittal talar translation in TAA (Fig. 1)[13,14]: the tibial axis-to-talus (T-T) ratio measurement and the lateral talar station (LTS) method. The T-T ratio measurement involves the calculation of the ratio in which the mid-longitudinal axis of the tibial shaft divides the longitudinal talar length.[13] The LTS method measures the distance between the mid-longitudinal axis of the tibial shaft and the center of the circle fitting the talar dome.[14] The T-T ratio measurement is a validated and reproducible method and is least affected by the ankle position and implantation status.[13-15] However,

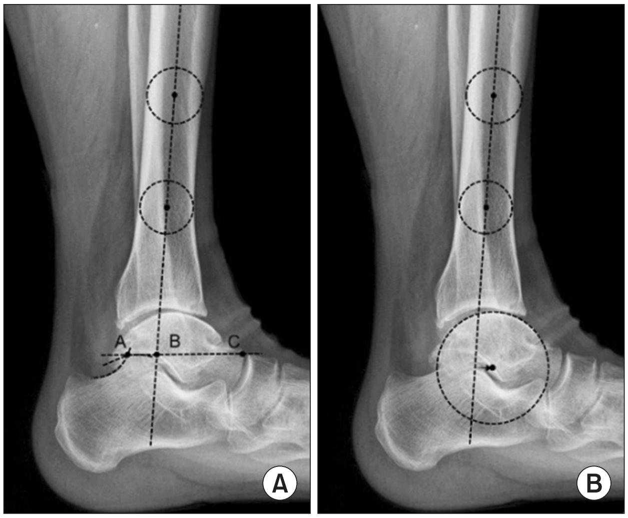

Fig. 1. (A) Radiographic measurement of tibial axis-to-talus ratio (AB / AC × 100). Posterior talar point (point A) is identified as the intersection between the contours of the posterior subtalar articular surface and the posterosuperior calcaneal cortex. Talar reference line is a line drawn through point A, parallel to the floor. Anterior talar point (point C) is the most anterior aspect of the talus. The tibia mid-diaphyseal axis is a longitudinal mid-bisecting line of the distal tibial shaft determined at 5 and 10 cm above the ankle. The intersection of the tibia mid-diaphyseal axis with the talar reference line is point B. (B) Radiographic measurement of lateral talar station (LTS). A circle was made fitting the talar dome, and the center of its rotation was measured perpendicular to the tibia mid-diaphyseal axis. This distance was defined as the LTS.

Table 1. Patient Demographics

Variable	Value
No. of patients	280
No. of ankles	296
Age (yr)	63.6 ± 9.9 (24–83)
Sex*	
Male	147 (49.7)
Female	149 (50.3)
BMI (kg/m^2)	25.9 ± 3.3 (18.1–39.5)
Diagnosis*	
Primary osteoarthritis	125 (42.2)
Posttraumatic osteoarthritis	
Post-fracture	61 (20.6)
Recurrent ankle sprain	95 (32.1)
Rheumatoid arthritis	11 (3.7)
Others†	4 (1.4)
Follow-up (mo)	77.7 ± 42.0 (24–207)

Values are presented as mean ± standard deviation with minimum and maximum range or number (%).
BMI: body mass index.
*The values are the number of ankles. †Others included 2 cases of osteonecrosis of the talus, 1 gouty arthritis, and 1 hemophilic arthropathy.

the distance of translation cannot be quantified because it is expressed as a percentage, its usage is relatively complicated in clinical settings, and it is difficult to determine in the presence of subtalar joint pathologies. In contrast, the LTS method has the advantage of being able to accurately quantify translation and is relatively easy to use. However, this method has a limitation in that it is affected by the postoperative talar component position and cannot be used in the case of preoperative talar dome erosion.

Considering these limitations, this study proposes a simple method that can quantify talar translation without being affected by the ankle and subtalar joint condition or the talar component position in patients with TAA. We hypothesized that the proposed method is an accurate and reliable method for the evaluation of sagittal talar translation in patients with TAA.

METHODS

Patients

This is a retrospective study using prospectively collected radiographic data from a single center. This study was approved by the Institutional Review Board of Chonnam National University Hospital (IRB No. CNUH-2022-315), and patient consent was waived due to the retrospective nature of this study. A total of 366 consecutive primary TAAs were performed in patients with end-stage ankle arthritis between January 2005 and December 2019, and the registry was reviewed to evaluate sagittal talar translation. All operations were performed by 2 surgeons (KBL and GWL) using mobile-bearing HINTEGRA prostheses (Newdeal, Integra Lifesciences).

This study included patients with a minimum follow-up period of 24 months after TAA. The exclusion criteria were sagittal deformity or malunion of tibia, talonavicular arthrosis or arthrodesis, loosening or subsidence of prosthesis, and the absence of weight-bearing radiographs. In addition, we excluded patients having lateral ankle radiographs showing < 10 cm of the distal tibial shaft, which would limit the delineation of a mid-diaphyseal line of the tibia. Finally, a total of 280 eligible patients (296 ankles) were enrolled as the study group and evaluated (Table 1). Among the 280 patients, 157 patients (157 ankles) having healthy contralateral ankles without sagittal malalignment were enrolled as the control group for the evaluation of the reference value of the TTD.

Radiographic Analyses

All radiographic values were analyzed using a standard tool in the Picture Archiving and Communication System (PACS; version 5.4; INFINITT Healthcare). Weight-bearing lateral ankle radiographs had been obtained preoperatively, at 1, 3, 6, and 12 months postoperatively, and then annually thereafter. Typically, the distal part of the tibia of > 10 cm in length was included in the field of view.

The tibiotalar distance (TTD) was defined as the distance between lines A and B (Fig. 2). A mid-diaphyseal axis (line A) was made by connecting the centers of the proximal and distal circles, which were 10 and 5 cm above the tibial plafond, respectively, and extended distally. Then, line B was drawn by parallel extension of line A to the anteriormost end of the talar head.

Three independent raters (a professor [GWL], a fellow [WKK], and a resident [WCJ] in the department of orthopedic surgery) performed the radiographic assessments. The raters measured the TTD on each of the preoperative and final radiographs of the study group. The same images of the entire study group were remeasured by the 3 raters with > 1-month intervals to assess for interrater and intrarater reliability. In addition, the 3 raters measured the TTD once for the healthy, unoperated contralateral ankle of the 157 patients in the study group to establish the normal range of TTD in the absence of any pathologic conditions (e.g., arthritis, fracture). The amount of exact talar translation was calculated as the difference between the TTD values of the unoperated ankle and the operated ankle before and after TAA in 157 patients with healthy contralateral ankles. When calculating the mean of the amount of translation, absolute values were used to reduce errors due to positive (anterior translation) and negative (posterior translation) values. The average of the 3 raters' values for each item was calculated for the TTD measurement in Table 2. For the analysis of interrater reliability, the average values of all 3 raters' values were compared (Table 3).

Statistical Analyses

Descriptive statistics were reported as means and standard deviations for continuous variables. All radiographic data were checked for normality using the Shapiro-Wilk test. Reliability was assessed using an intraclass correlation coefficient (ICC) with a 95% confidence interval (CI). Intraclass correlation using 2-way random effects models was determined to analyze interrater and intrarater reliability. The ICC was categorized as poor (0.00–0.20), fair (0.21–0.40), moderate (0.41–0.60), good (0.61–0.80), and excellent (0.81–1.00).[16] Data were analyzed using IBM

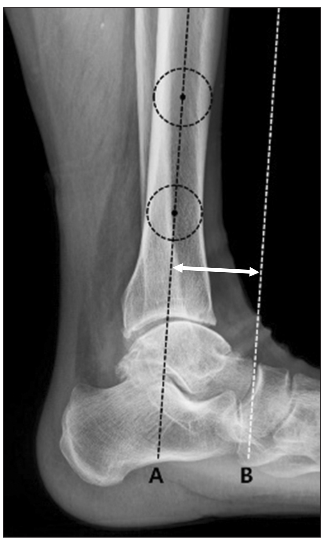

Fig. 2. Radiographic measurement of tibiotalar distance (TTD). The tibia mid-diaphyseal axis (line A, black dashed line) is a longitudinal mid-bisecting line of the distal tibial shaft determined at 5 and 10 cm above the ankle. The second line (line B, white dashed line), which is parallel to the mid-diaphyseal axis, is drawn to the most anterior aspect of the talus. The distance between 2 lines was defined as the TTD.

Table 2. Radiographic Outcomes of TTD Method

Variable	TTD (mm)
Study group (n = 296 ankles)*	
Preoperative	41.30 ± 7.11 (21.15 to 59.57)
Final	37.59 ± 5.35 (21.87 to 53.86)
Control group (n = 157 ankles)†	38.91 ± 4.64 (29.63 to 48.20)
Male (n = 75 ankles)	41.73 ± 3.74 (34.26 to 49.20)
Female (n = 82 ankles)	36.00 ± 3.57 (28.87 to 43.13)
Amount of translation (n = 157 ankles)‡	
Preoperative	4.89 ± 3.10 (–12.95 to 14.87)
Final	3.72 ± 2.42 (–9.09 to 15.35)

TTD: tibiotalar distance.
*Mean ± standard deviation (minimum and maximum range). †Mean ± standard deviation (normal range [mean ± 2 standard deviation]). ‡Mean ± standard deviation (minimum and maximum range). The amount of translation was calculated as the difference between the TTD values of the unoperated ankle and the operated ankle in 157 people with healthy contralateral ankles. When calculating the mean, absolute values were used to reduce errors due to positive (anterior translation) and negative (posterior translation) values.

Table 3. Interrater and Intrarater Reliability Analyses of the TTD Method

Variable	ICC agreement (95% CI)	Category	*p*-value
Preoperative radiographs (n = 296 ankles)			
Interrater reliability			
Professor vs. fellow	0.989 (0.978–0.994)	Excellent	< 0.001
Professor vs. resident	0.968 (0.926–0.982)	Excellent	< 0.001
Fellow vs. resident	0.991 (0.982–0.995)	Excellent	< 0.001
Intrarater reliability			
Professor	0.984 (0.974–0.989)	Excellent	< 0.001
Fellow	0.984 (0.980–0.988)	Excellent	< 0.001
Resident	0.987 (0.983–0.989)	Excellent	< 0.001
Final radiographs (n = 296 ankles)			
Interrater reliability			
Professor vs. fellow	0.985 (0.972–0.990)	Excellent	< 0.001
Professor vs. resident	0.947 (0.895–0.969)	Excellent	< 0.001
Fellow vs. resident	0.986 (0.972–0.992)	Excellent	< 0.001
Intrarater reliability			
Professor	0.977 (0.966–0.984)	Excellent	< 0.001
Fellow	0.978 (0.971–0.983)	Excellent	< 0.001
Resident	0.980 (0.973–0.984)	Excellent	< 0.001
Amount of translation (n = 157 ankles)			
Interrater reliability			
Preoperative			
Professor vs. fellow	0.961 (0.946–0.971)	Excellent	< 0.001
Professor vs. resident	0.901 (0.862–0.928)	Excellent	< 0.001
Fellow vs. resident	0.958 (0.940–0.970)	Excellent	< 0.001
Final			
Professor vs. fellow	0.934 (0.909–0.952)	Excellent	< 0.001
Professor vs. resident	0.908 (0.866–0.935)	Excellent	< 0.001
Fellow vs. resident	0.954 (0.908–0.973)	Excellent	< 0.001
Intrarater reliability			
Preoperative			
Professor	0.947 (0.911–0.967)	Excellent	< 0.001
Fellow	0.959 (0.943–0.971)	Excellent	< 0.001
Resident	0.965 (0.951–0.975)	Excellent	< 0.001

Table 3. Continued

Variable	ICC agreement (95% CI)	Category	*p*-value
Final			
Professor	0.959 (0.941–0.970)	Excellent	< 0.001
Fellow	0.966 (0.954–0.976)	Excellent	< 0.001
Resident	0.876 (0.812–0.915)	Excellent	< 0.001

TTD: tibiotalar distance, ICC: intraclass correlation coefficient, CI: confidence interval.

SPSS version 23.0 (IBM Corp.). All statistical analyses were reviewed by a statistician, and a $p < 0.05$ was considered significant.

RESULTS

Radiographic Analyses

A total of 296 ankles (280 patients) were included and analyzed for the TTD (Table 2). The mean preoperative TTD for the study group was 41.30 mm (range, 21.15–59.57 mm). The mean final TTD for the study group was 37.59 mm (range, 21.87–53.86 mm). In the same 280 patients, 157 patients with healthy, unoperated contralateral ankles (control group) were enrolled for the evaluation of the normal range of the TTD. The mean TTD for the control group was 38.91 mm (normal range, 29.63–48.20 mm); these TTD values showed a Gaussian distribution. The Shapiro-Wilk test was used to assess data normality (alpha = 0.05, $p = 0.284$). Regarding the amount of TTD, the mean value was 4.89 mm and 3.72 mm preoperatively and at the final follow-up, respectively.

Interrater and Intrarater Reliability

All TTD values of the study group measured twice by the 3 independent observers showed excellent agreement in interrater and intrarater reliability (Table 3). Regarding interrater reliability, the TTD showed the highest ICC between the fellow and the resident in preoperative radiographs (0.991, $p = 0.001$) and the lowest ICC between the professor and the resident in the final radiographs (0.947, $p = 0.001$). The highest intrarater ICC was observed for the resident in preoperative radiographs (0.987, $p = 0.001$). Regarding the amount of TTD, all of the inter- and intrarater reliability showed ICC above 0.9, except intrarater reliability by an orthopedic resident for the amount of TTD at the final follow-up.

DISCUSSION

Modern TAAs have expanded indications and are widely used.[1-3] The restoration of alignment is important to achieve excellent clinical outcomes and long-term survivorship in TAA.[4,5,8,17] Malalignment of TAA may result in early implant loosening due to uneven stress distribution. While past studies focused on the coronal plane alignment, sagittal alignment is now recognized as another important factor.[6-10] For sagittal alignment, sagittal talar translation is the most important factor that can affect kinematics, range of motion, soft-tissue tension, and even clinical outcomes.[5,8,9,18,19] Thus, the accurate measurement of sagittal talar translation is the first step for the evaluation of sagittal alignment.

In this study, we presented a reliable method for measuring sagittal talar translation by analyzing 296 TAAs. We introduced the TTD method in which the change in talar translation can be easily measured and compared before and after TAA. The TTD method was not affected by the preoperative condition of the ankle joint surface, subtalar joint pathologies, or the postoperative talar component position. In addition, it demonstrated excellent inter- and intrarater reliability, indicating that the measurement could be performed reliably by different readers with varying clinical experience.

Two widely used methods, T-T ratio measurement and the LTS method, are known to yield validated measurements.[13,14] The T-T ratio has been reported to be highly reproducible with the coefficients of determination for interobserver and intraobserver reliability being 0.98 and 0.96, respectively.[13] Braito et al.[4] also analyzed the measurement of radiographic coronal and sagittal alignment for TAA and reported that the highest inter- and intraobserver reliability was found for the T-T ratio. Furthermore, The T-T ratio is known to be least affected by the sagittal positional variation of the foot and ankle and is not affected by the preoperative condition of the ankle joint surface or the postoperative talar component position.[13] However, this method may be cumbersome in clinical settings as it involves drawing of the contours of the posterior subtalar articular surface and the postero-superior calcaneal cortex for calculating the ratio. Thus, subtalar joint pathologies, including arthritis and arthrodesis, can hinder accurate measurement. In the case of a severe flatfoot deformity, an additional vertical line should be drawn to set the anterior talar point. Of note, the T-T ratio provides the magnitude of talar translation but does not allow its quantification of distance.

In contrast, the LTS method is relatively simple to apply in clinical settings and provides the accurate distance of talar translation. In a previous study, the interobserver and intraobserver reliability of this method was found to be good to excellent (mean kappa values: 0.70 for interobserver and 0.83 for intraobserver reliability).[20] Another study also reported that the LTS method had a Gaussian distribution with a mean of 1.17 mm and showed an ICC over 0.9 in interobserver and intraobserver reliability.[14] However, to draw an accurate circle, the ankle position should be perfectly controlled to make a single talar dome line. If there is rotation or tilting of the talus, it is necessary to calculate the average value by drawing another circle that fits each of the medial and lateral talar domes. Veljkovic et al.[14] also reported this drawback, to overcome which they used image measurement software to obtain the average radius of the circle. However, it is difficult to measure LTS when there is erosion of the talar dome, which is commonly observed in arthritic ankles (Fig. 3). Moreover, the LTS method cannot have the same reference after TAA as before TAA, because the position and size of the circle are determined according to the talar component implantation. Further, it is difficult to apply the LTS method to patients with TAA because different implants have different radii of curvature (ROCs) of the talar component, and some implants even have asymmetric ROCs on the medial and lateral sides of the talar component. To overcome these limitations, Paley et al.[21] introduced another method (the T-L distance), which measures talar translation with the lateral process of the talus as a reference point. However, this method was identified to be sensitive to ankle malposition and was not reproducible.[15] These limitations can be minimized if the TTD method is applied in TAA. The characteristics of the 3 measurement methods are summarized in Table 4.

However, the TTD method also has some limitations. There are no issues when comparing the talar translation in the same ankle before and after surgery. However, there are certain restrictions when calculating the exact amount of talar translation in the operated ankle compared to the normal side. This is because the exact amount of talar translation can be assessed after measuring the TTD of the healthy contralateral ankle as a reference value. In this study, we analyzed the exact amount of TTD before and after TAA and it was confined to 157 patients with healthy, unoperated contralateral ankles. Furthermore, the mean value of the amount of TTD was relatively small at 4.89 mm preoperatively, which is presumed to be due to the exclusion of patients with moderate to severe talar translation from the control group. This is because most of these patients had bilateral ankle arthritis. Therefore, when there is a talar translation in the contralateral ankle, it could be limited in evaluating the exact amount of TTD value. In addition, while the reliability of the TTD method

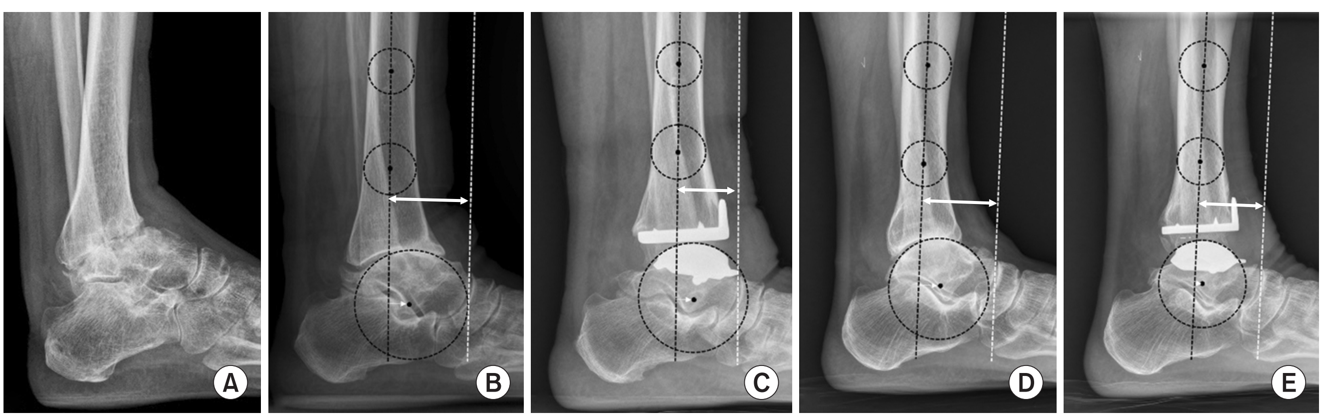

Fig. 3. (A) Quantification of anterior talar translation could not be determined as the lateral talar station (LTS) method could not be applied due to the talar dome erosion. (B, C) The anterior talar translation was restored by 9.42 mm posteriorly after total ankle arthroplasty (TAA) according to the tibiotalar distance (TTD) method. However, the difference was only 4.08 mm when it was assessed by the LTS method due to the talar component anterior implantation. (D, E) The anterior talar translation was restored by 6.92 mm posteriorly after TAA according to the TTD method. However, the difference was 10.93 mm when it was assessed by the LTS method due to the talar component posterior implantation.

Table 4. Comparison of Characteristics of 3 Methods for Measuring Sagittal Talar Translation

Method	T-T ratio (%)	LTS (mm)	TTD (mm)
Quantification of translation distance	-	Possible	Possible
Preoperative condition of the ankle joint surface	na	Affected	na
Subtalar joint pathology	Affected	na	na
Talonavicular joint pathology	Affected	na	Affected
Position of talar component implantation	na	Affected	na
Influence of sphericity of talar component	na	Affected	na

T-T ratio: tibia axis to talus ratio, LTS: lateral talar station, TTD: tibiotalar distance, na: not affected.

is high, it has a relatively wide normal range. This can also be a disadvantage compared to methods such as the LTS method, which has a smaller normal range.

This study has several limitations. First, this study retrospectively analyzed the prospectively collected radiographic data over a period of more than 10 years. These radiographs may not have been taken using the same protocol, including distance. Second, while the reliability of the TTD method was proven, the validity of this method remains to be established. Thus, further studies measuring TTD values in young patients with bilaterally healthy ankles are needed. This allows us to establish a more accurate normal reference value for the TTD and quantify talar translation using the TTD method in patients with bilateral ankle arthritis. Finally, we did not perform further analysis on how the rotation and weight-bearing ankle position (dorsiflexed or plantar flexed) affect the value of TTD in the same subject.

In conclusion, the TTD method is recognized as a reliable and feasible radiographic measurement for identifying sagittal talar translation in patients with TAA regardless of the joint condition and the implantation status.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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