The Journal of Foot & Ankle Surgery 56 (2017) 1036–1040

Contents lists available at ScienceDirect

The Journal of Foot & Ankle Surgery

journal homepage: www.jfas.org

Experimental Comparison of the Clinical Measurement of Ankle Joint Dorsiflexion and Radiographic Tibiotalar Position

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A R T I C L E I N F O

Level of Clinical Evidence: 3

Keywords:
ankle range of motion
equinus
goniometer
tibiotalar joint

A B S T R A C T

Clinical measurement of ankle dorsiflexion is typically used to diagnose limited ankle range of motion. Controversy and a lack of clarity continue regarding the most accurate clinical method of measuring ankle joint dorsiflexion and the effect that the foot position (supinated, neutral, pronated) has on the true tibiotalar position. We investigated the effects of supinated, neutral and pronated foot positions on the clinical dorsiflexion measurements in 50 healthy subjects and compared these results to the radiographic measurement of tibiotalar joint position with the ankle maximally dorsiflexed in each of the 3 foot positions. Interrater reliability was confirmed to be adequate among the 3 clinicians of varied skill levels. Radiographic measurements of the tibiotalar position showed very little change in each of the 3 foot positions, with a total difference of 0.35° between supination and pronation. However, we found a mean difference of 14° of dorsiflexion in the clinical measurements between the pronated and supinated foot position, with a 9.08° difference between the neutral and supinated positions. Motion of the foot between the neutral and supinated positions introduced an additional source of potential error from the measurement technique when using the neutral position as the standard, which has been recommended in the past. We recommend a supinated foot position as a more reliable foot position for measuring the clinical ankle joint range of motion and propose it as a potential standard.

Lack of ankle joint dorsiflexion (i.e., equinus) is a common anatomic state that can lead to pathologic compensation in the foot and is a contributor of a variety of foot and ankle disorders (1). Controversy exists regarding the optimal method to accurately measure ankle joint dorsiflexion in the clinical setting. Many clinicians have recommended measurement of ankle range of motion (ROM) with the subtalar joint in the neutral position as an arbitrary standard. The subtalar joint neutral position is difficult to accurately reproduce, and the wide variability in the application of this technique has introduced error into the measurement (2). Chen et al (2) investigated the subtalar joint neutral position in normal cadaveric feet by inserting pressure sensitive films into the anterior and posterior articulation of the subtalar joint. The subtalar joint neutral position was determined present when maximum contact area was achieved within the articulation. The results demonstrated that the most approximate subtalar joint neutral position was in the foot position of 10° of abduction, 20° of dorsiflexion, and 10° of eversion. They concluded that the subtalar joint is not necessarily in a neutral position when the rearfoot is placed in the commonly recommended "neutral position" (2). Elveru et al (3) examined the reliability of measurements of the subtalar joint neutral position and passive ankle ROM. They concluded that the clinical usefulness of measuring the position of the subtalar joint in the neutral position is limited owing to the poor interrater reliability.

Pronation of the foot during testing of ankle joint ROM produces erroneous measurement values owing to the flexibility of the midtarsal joint when the subtalar joint is in a pronated position.

Financial Disclosure: A grant from the American College of Foot and Ankle Surgeons.

Conflict of Interest: Dr. Dayton discloses a consultant/advisory role with Treace Medical Concepts; and he has received research funding from the ACFAS and IOER; and he has received honoraria in relation to multiple continuing medical education seminars; and he serves on committees for the ACFAS and is a Section Editor for the journal.

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http://dx.doi.org/10.1053/j.jfas.2017.05.008

This flexibility allows the midtarsal joint to dorsiflex, with the subsequent clinical measurement of ankle dorsiflexion a combination of foot motion and ankle motion. Because the spectrum of foot flexibility is wide, this foot motion adds error to the clinical assessment of ankle dorsiflexion. Bohannon et al (4) studied the surface landmarks to document and compare the magnitude of forefoot and hindfoot motion accompanying passive ankle dorsiflexion ROM. On average, the forefoot moved 2.7° more than did the hindfoot in passive ankle dorsiflexion range of motion (ADROM). They also reported that forefoot motion is minimized but not totally eliminated with the subtalar joint in the neutral position (4). Coetzee and Castro (5) studied the true ROM of the tibiotalar joint after total ankle arthroplasty and attempted to determine the contribution of foot motion to the clinical measurement of ankle ROM. Their aim was to present a reproducible method to accurately measure ankle ROM and negate the contribution of midfoot motion in the clinical assessment (5). They concluded that midfoot motion contributed to errors in the assessment of true ankle joint ROM (5). Lateral radiographs were taken with the patient weightbearing and in maximum dorsiflexion and plantarflexion. They found that it was possible to measure the individual components of ankle and midfoot motion and that radiographic measurements should be used when reporting the results of ankle replacement (5).

Accurate and reproducible clinical methods for assessing ankle dorsiflexion are vital for diagnosis, formulating treatment decisions, and monitoring the progress of the patient during the treatment of equinus. Clarity in this area must be obtained to confidently recommend and teach the most accurate and reproducible method of measurement. We hypothesized that a significant difference would be present in the clinical amount of ankle dorsiflexion measured when the foot is in a supinated, neutral, and pronated position. We investigated the relationship of the clinical ankle dorsiflexion measurement to the radiographic ankle position using the following research questions:

1. Does a clinically significant difference exist in the measured amount of dorsiflexion when the foot is positioned in a supinated, neutral, or pronated position?
2. What effect does supination and pronation of the foot have on actual tibiotalar movement in the sagittal plane as assessed on radiographs?

Patients and Methods

To answer the clinical questions, a level III diagnostic prospective comparative observation was performed. The Des Moines University institutional review board approved the human subjects study. An a priori power analysis was performed to determine the adequate number of subjects. Based on the observed effect size of Allington et al (6) and using an 80% power and α set at 0.5, a liberal estimate was determined to be 9 subjects per comparison and a conservative estimate of 26 subjects per comparison. Based on our previous experience, we selected a total of 50 subjects. Because of the self-selection process, we estimated that no >10%, or 5 additional individuals, would participate in the screening process and ultimately be excluded. The exclusion criteria included pregnancy; previous foot or ankle surgery; gross deformity in the foot, ankle, or tibia; physical limitations preventing examination and radiography; foot, ankle, or leg pain; and/or a neurologic or muscular disorder. The mean subject age was 24.8 (range 22 to 31) years. Of the 50 subjects, 15 were males and 35 were females.

All subjects had undergone cross-table lateral radiographs by a single experienced clinician (P.D.). Radiographs were taken while the clinician passively dorsiflexed the ankle to resistance, with the foot in a supinated, neutral, and pronated position, with the subject's knee in full extension, the patient relaxed (no active muscle function), and the foot parallel to the x-ray plate. Three radiographs were taken, one in each of the positions, per side, for a total of six radiographs per subject. The images were saved as Digital Imaging and Communications in Medicine file images in PACS software, and measurements were taken from these images. The appropriate Des Moines University radiation safety protocols and institutional review board-approved processes were used to protect both the subjects and the investigators and to minimize the level of exposure.

After obtaining the radiographs, the clinical measurements of ankle dorsiflexion ROM was performed for each subject. The clinical measurements were performed by an experienced clinician (M.F.), a third-year podiatric surgery resident (M.K.), and a second-year podiatric medical student (J.W.) who had been trained in the positioning and measurement technique. We used the plantar foot surface and the longitudinal line of the supporting surface as our index points owing to the ease of measurement and for reproducibility. This was a variation on the measurement described by McGlamry (7), in which the bisection of the lateral leg and the lateral foot in the sagittal plane was used. Using a flat solid surface, each examiner maneuvered the foot into the maximum passive pronation, neutral position, and moderate supination, just past the traditional neutral position. The lateral foot position, as represented by the flat surface placed against the bottom of the foot relative to the longitudinal line of the supporting surface, was recorded for each position. The knee of each subject was held stable in the frontal plane by an assistant during the positioning and while the measurements were taken. Once the subject was in the correct position, the clinician positioning the patient communicated this to the clinician manipulating the digital goniometer, and the measurement was taken and recorded on the patient's data collection sheet. The Tracker Freedom digital goniometer (JTECH Medical, Midvale, UT) was used for all clinical measurements (Fig. 1).

The amount of sagittal plane movement of the tibiotalar joint was measured on the radiographs using the method described by Coetzee and Castro (5). Two lines were drawn on each lateral radiograph (Fig. 2). The first line was the stable line, which was drawn from the posterior to the anterior lip of the distal tibial plafond. The second line was drawn along the inferior aspect of the talus at the surface of the posterior subtalar joint facet. One observer (M.K.) measured all the radiographs.

All data were analyzed by a trained statistician (R.R.). SPSS statistical software (IBM Analytics, IBM Corp., Armonk, NY) was used to perform repeated measures analysis of variance and a post hoc paired t test. A 2-tailed p-value was obtained, with $p < .05$ set as significant.

Results

Fifty subjects were enrolled in the study with measurements collected from 100 feet and ankles. After radiography, the inclusion criteria led to elimination of 1 foot, for inclusion of 99 feet. Interrater reliability among the 3 clinician measurements all demonstrated internal consistency, with pronation = 0.78, supination = 0.74, and neutral = 0.70, with an acceptable Cronbach's α coefficient of $\geq$0.70. The clinical measures used in the analyses were an average of all 3 clinicians' measurements. For all positions, elimination of any of the clinician measurements did not improve the Cronbach α score (8).

The mean radiographic measurements for all positions was 45.89° to 46.24°, for a total difference of 0.35°, well within the margin of error. This measurement, as described in the Patients and Methods section reported the movement of the talus relative to the tibia and reported only a relative position change, not an absolute degree of

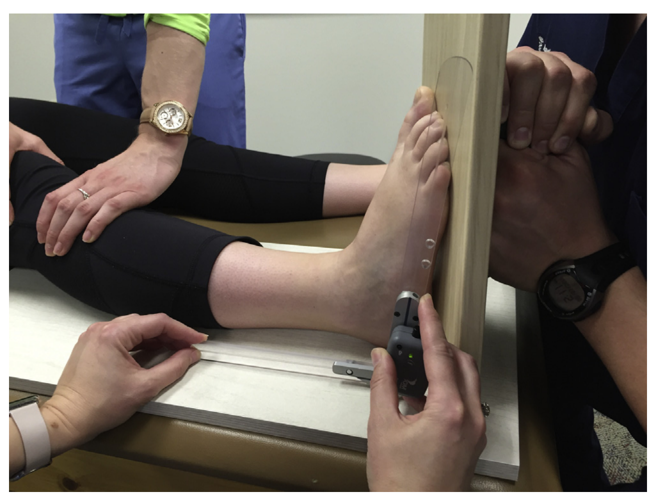

Fig. 1. Clinical measurement of ankle range of motion in pronated position using Tracker Freedom digital goniometer (JTECH Medical). As noted in the Patients and Methods section, the landmarks of measurement were the flat surface of the tibia and the lateral margin of the foot. Shown with permission of JTECH Medical.

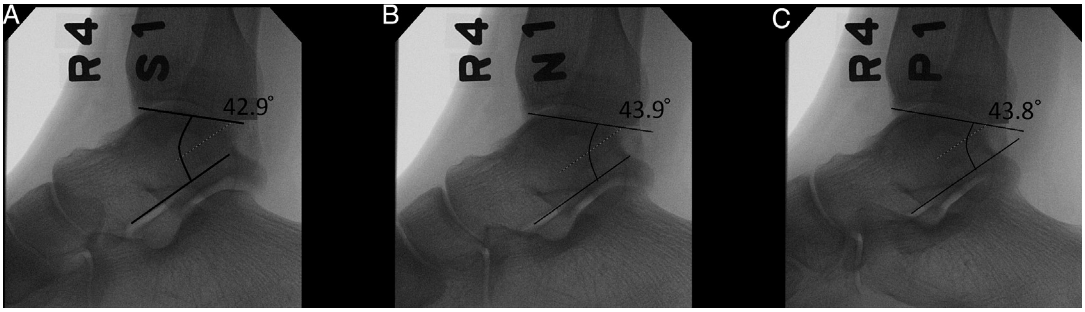

Fig. 2. Radiographs from 1 subject with the foot in (*A*) supination, (*B*) neutral, and (*C*) pronation showing very little actual change in the radiographic tibiotalar position. One line was drawn posterior to the anterior lip of the distal tibial plafond. The second line was drawn along the inferior aspect of the talus at the parallel to the surface of the posterior subtalar joint facet.

movement. It should be noted that a smaller value for the radiographic measurement indicates a more dorsiflexed position of the talus relative to the tibia (Table 1).

Clinically, the mean measurement of ankle dorsiflexion with the subtalar joint in a supinated position was −5.18°, in a neutral position was 4.04°, and in a pronated position was 8.84°. All these angles were in reference to the foot at 90°, with a negative number representing plantarflexion relative to neutral and a positive number, dorsiflexion relative to neutral. The difference between the mean supinated and mean pronated positions resulted in a shift of approximately 14°. The greatest degree of dorsiflexion was observed when the foot was in a pronated position and the least when it was supinated. The difference between all positions was statistically significant ($p < .05$; Tables 2–4).

Discussion

Our results showed statistically and clinically significant differences in the clinical measurement of ankle dorsiflexion with the foot in various positions, with supination resulting in less dorsiflexion measured and neutral and pronation resulting in greater dorsiflexion measured. Despite these differences in the clinical measurements, the ankle joint actually did not exhibit a corresponding change in dorsiflexion on the radiographs. The radiographic measurements were almost identical (mean values for dorsiflexion with supination of 45.89° versus with pronation of 46.24°), with a mean difference of 0.35°. The variability in the clinical measurements and consistency of the radiographic measurements confirmed our hypothesis that a component of the clinical measurement of ankle dorsiflexion when the foot is in a neutral or pronated position results from motion occurring more distally. The data suggest that a component of foot movement remains in the goniometric measurement of ankle dorsiflexion with the foot held in a neutral subtalar joint position that is similar to the error previously identified between the neutral and pronated foot positions.

The variation of measured ROM in the different positions occurred despite the consistency of the measurements among the raters for each foot position. Our results showed the clinical measurements to be reliable among the raters despite the differing levels of experience

Table 1
Descriptive statistics (N = 99 ankles in 50 patients)

Measure	Mean ± Standard Deviation
Radiographic	
Supination	46.24 ± 8.62
Neutral	45.59 ± 8.45
Pronation	45.89 ± 8.33
Clinical	
Supination	−5.18 ± 4.38
Neutral	4.04 ± 4.14
Pronation	8.83 ± 4.26

(e.g., student, resident, experienced clinician), with the neutral position the least reliable of the 3 positions. This is in contrast to the work of Kim et al (9), who found moderate interrater reliability and poor interrater reliability. They performed test-retesting on separate days, which might have led to the decreased results of reliability. In their work, they also assessed whether reliability is related to the measuring technique or level of examiner experience. It was concluded that neither a standardized technique nor the years of experience affected the reliability results they found (9). Other researchers have found results more similar to ours, with good interrater reliability (6,10).

Although all positions of clinical measurement had acceptable reliability, the clinical measurement might be an inaccurate measurement of true ankle position depending on the foot position according to our radiographic evaluation, which demonstrated minimal changes in the tibiotalar position. Allington et al (6) found similar results in assessing the intra- and interobserver reliability and reproducibility of goniometry and a visual estimation of ankle joint ROM measurements in children with spastic cerebral palsy. The global mean measurement error for intra- and interobserver was 5° and 3° for goniometry versus visual estimation, respectively. Statistical analysis showed high reliability for the intra- and interobserver measurements between visual estimation and goniometry. They concluded that both visual and goniometry ankle ROM measurements are reliable and reproducible in spastic cerebral palsy children if a strict protocol is applied, although an error range of 0° to 10° needs to be considered (6). Backer and Kofoed (11) compared the goniometric assessment of passive ankle movement with radiographic measurements in 100 normal ankles. They determined that no linear correlation exists between the clinical and radiographic measurements in dorsiflexion. The clinical measurements tended to overestimate small radiographic ranges of motion and to underestimate large radiographic ranges (11).

Our results are consistent with these published findings and strengthen the notion that the foot position must be controlled and standardized during clinical measurements of ankle dorsiflexion to prevent error. The mean measurement of ankle dorsiflexion in a subtalar joint supinated position was −5.18°, in a neutral subtalar joint position was 4.04°, and in a subtalar joint pronated position was 8.84°, for a total range of 14.01°. The greatest degree of dorsiflexion was observed with the foot in a pronated position and the least in a supinated position. As noted, even neutral and supinated positions exhibited a large clinical variation of 9.18°. The large amount of measurement variability crosses the typical range of normal and abnormal for ankle dorsiflexion and therefore could shift the clinical diagnosis of equinus from positive to negative in the same patient depending solely on the measurement technique used. Even with the large range of clinical measurement that would change the diagnosis of equinus, a minimal difference was found in ankle joint motion with radiographic measurements for supination (45.89°) versus pronation (46.24°), with a total difference of 0.35° of actual ankle joint motion

Table 2
Results of paired *t* tests of radiographic measurements (N = 99 ankles in 50 patients)

Foot Position	Mean	n	SD	SEM	*p* Value
Neutral	45.59	99	8.46	0.85	.04
Supination	46.24	99	8.62	0.87	
Neutral	45.59	99	8.46	0.85	.08
Pronation	45.89	99	8.33	0.84	
Supination	46.24	99	8.62	0.87	.31
Pronation	45.89	99	8.33	0.84	

Abbreviations: SD, standard deviation; SEM, standard error of the mean.

between the different positions. If the goal of goniometric measurement is to assess tibiotalar motion and diagnose equinus, foot motion must be controlled for accurate measurements. Additionally, for meaningful discussion of the clinical findings and research results, we must have a consistent basis for measurement and reporting. Considering the difficulty and inconsistency of clinically finding and maintaining the subtalar joint neutral position during examination and the large variation in clinical measurements between the positions, we conclude that using a supinated foot position is desirable. Positioning the foot on the supination side of the clinical neutral position is quite easy and also quite easy to maintain during measurement. This and the large component of foot motion present between the neutral and supinated positions have led us to recommend supination as the ideal position. Thus, a small error in determining or maintaining the neutral subtalar joint position can lead to a large error in the ankle dorsiflexion value measured clinically. Positioning the foot in slight supination locks the midtarsal joint and prevents the midtarsal joint from dorsiflexing during the assessment of ankle ROM, thus eliminating this source of error.

Measurement landmarks are also an important consideration when comparing clinical ankle ROM measurements. We chose to use the plantar foot surface and the longitudinal line of the supporting surface of the leg as our index points owing to the ease of performance and reproducibility of the measurement. This could have introduced some variation in our values compared with those from other researchers based on calf muscle size and overall foot structure. Despite the arbitrary assignments of these landmarks, the consistency of our results was adequate. Also, we did not set out to calculate normal or pathologic ranges for ankle dorsiflexion; thus, our values would not be comparable to normal ranges calculated previously.

The absolute values between research studies can only be compared if the measurement techniques and protocols were identical. We undertook the present study to help better understand the contribution of foot motion to the clinical measurement of ankle dorsiflexion relative to the radiographic movement identified. Our goal was to advance the discussion in determining the standard foot position to be used for future research. Having an easily obtainable and reproducible method would make communication and comparisons possible between clinicians and researchers. In reality, using the fibular shaft as the longitudinal axis landmark is quite subjective and based on operator perspective. Bohannon et al (4) described and compared ADROM measurements obtained using 3 distal landmarks, the heel, fifth metatarsal, and plantar surface of the foot. The ankle was then dorsiflexed under 3 conditions: passive ankle dorsiflexion with a submaximal force adequate to achieve notable tension; passive dorsiflexion with maximal force; and maximal force actively assisted by the patient. The subtalar joint was maintained in “neutral throughout motion.” Photographs from a camera were used to analyze the ADROM. Analysis of variance demonstrated that ADROM measurements were significantly different ($p < .0001$) under the 3 conditions when the different landmarks were used. Measurements of ADROM will differ depending on the conditions of measurement and landmarks used (11).

Table 3
Paired samples *t* tests comparing clinician measurement of foot positions (N = 99 ankles in 50 patients)

Foot Position	Mean	n	SD	SEM	*p* Value
Neutral	4.04	99	4.14	.42	.00
Supination	−5.18	99	4.38	.44	
Neutral	4.04	99	4.14	.42	.00
Pronation	8.84	99	4.26	.43	
Supination	−5.18	99	4.38	.44	.00
Pronation	8.84	99	4.26	.43	

Abbreviations: SD, standard deviation; SEM, standard error of the mean.

Table 4
Paired *t* test with paired differences of clinical measurements (N = 99 ankles in 50 patients)

Foot Position	Paired Differences			*t*	df	*p* Value
	Mean ± SD	SEM	95% CI of Difference			
Neutral versus supination	9.22 ± 2.62	0.26	8.70 to 9.74	35.00	98	.000
Neutral versus pronation	−4.80 ± 1.81	0.18	−5.16 to −4.44	−26.38	98	.000
Supination versus pronation	−14.02 ± 3.07	0.31	−14.63 to −13.41	−45.33	98	.000

Abbreviations: CI, confidence interval; df, degrees of freedom; SD, standard deviation; SEM, standard error of the mean.

Some limitations of the present study were that only 1 clinician positioned the foot for the radiographs and 1 person measured the tibiotalar joint angle. It would have been ideal to have 3 clinicians position the foot and 3 clinicians measure the tibiotalar joint angle on each radiograph to test for interrater reliability, such as was performed with the clinical measurements. Although 3 separate people positioned the foot for the goniometer measurements, 2 people alternated in positioning the goniometer. It might have been beneficial to have the same person position the foot and hold the goniometer, because this would have translated well to the true clinical application. Moreover, we analyzed 99 feet in 50 patients, so true data independence was not upheld.

Because we did not set out to determine a normal or average clinical dorsiflexion ROM, we could not comment on what our clinical measurements mean with respect to the normal and pathologic ankle joint ROM or other reported values. Once the method for clinical measurement of ankle dorsiflexion has been standardized, we will be able to further study and agree on the “normal” ROM and the true definition of pathologic equinus. Currently, disagreement exists regarding the value of dorsiflexion that defines equinus. In large part, this is because, currently, no clarity or consensus has been reached regarding how this measurement should be made clinically and, therefore, research data cannot be compared.

We found a statistically significant difference in the values when clinically measuring ankle dorsiflexion in the supinated, neutral, and pronated positions. The least reliable method determined by the lowest interrater reliability value was the traditional neutral position. Although the neutral and pronated positions had a larger degree of clinically measured dorsiflexion compared with the supinated position, our radiographic measurement proved the true movement of the tibiotalar joint was not meaningfully different in any of the positions. The interesting finding is that foot motion remained, allowing for additional dorsiflexion to be measured between the neutral and supinated foot positions. The discrepancy between the clinical and radiographic measurements suggests the traditional clinical method of ankle dorsiflexion measurement in a neutral position does not solely measure ankle ROM but also measures midtarsal joint motion. This is similar to what is known about the motion of the midfoot with the foot in a pronated position. In contrast to previous reports, our results showed the clinical measurements were reliable among raters. Despite the differing levels of experience (e.g., student, resident, experienced clinician), the foot positioning technique we used was intuitive and reproducible. Based on our findings, and the ease of performance compared with using the neutral position, we recommend that a moderately supinated position of the foot be used for clinical measurement of ankle joint dorsiflexion.

Acknowledgments

We thank Jordan Gardner, DPM, Kristin Kindred, DPM, Molly Lyon, DMU Research Office, Taylor Heck, Evan Smith, Zach Croy, Matt Sieloff, Rachel Egdorf, Lindsey Hjelm, and Lizzy Burns for their assistance with data collection for this study.

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