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How Much Does the Talocrural Joint Contribute to Ankle Dorsiflexion Range of Motion During the Weight-Bearing Lunge Test? A Cross-sectional Radiographic Validity Study

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BACKGROUND: Ankle dorsiflexion range of motion is commonly measured during the weight-bearing lunge test (WBLT) as the horizontal knee distance traveled or tibial inclination. These measures are assumed to represent talocrural dorsiflexion, yet have not been validated against radiographic images.

OBJECTIVES: To determine the (1) contribution of the talocrural joint to tibial inclination during the WBLT, (2) validity of inclinometer and photographic measures of tibial inclination compared to radiographic images, and (3) the association between tibial inclination and horizontal distance measures.

METHODS: Tibial inclination using an inclinometer, horizontal distance via a ruler, and radiographic and photographic images were recorded in 20 participants in standing and during the end-range WBLT. Two assessors used computer software to measure talar rotation and tibial inclination from digital radiographs and photographs. The limits of agreement between photographic and inclinometer measures compared to radiographic measures, as well as correlations between measures, were calculated.

RESULTS: In the end-range WBLT, 91.8% of motion occurred at the talocrural joint, with 8.2% occurring distally. There were very strong correlations (all, $r \geq 0.88$, $P < .001$) between end-range radiographic and photographic measures, radiographic and inclinometer measures, and radiographic, inclinometer, and photographic measures of tibial inclination and horizontal lunge distance. Calculation of the limits of agreement indicated unacceptable agreement between inclinometer and radiographic measures (–7.84°, 5.92°) and acceptable agreement between photographic and radiographic measures (–2.17°, 2.49°).

CONCLUSION: Tibial inclination during the WBLT primarily occurs at the talocrural joint. While inclinometer and photographic measures of tibial inclination can reliably be used clinically to measure dorsiflexion range of motion during the WBLT, inclinometer results differ slightly from those obtained via radiographs. *J Orthop Sports Phys Ther 2019;49(12):934-941. Epub 23 Jul 2019. doi:10.2519/jospt.2019.8697*

KEY WORDS: *ankle, dorsiflexion, measurement, range of motion*

Ankle dorsiflexion is important for functional activities such as walking, jumping, and squatting.[2] Limited ankle dorsiflexion range of motion (ROM) is associated with a number of lower-limb injuries, including plantar fasciitis, Achilles tendinopathy, patellar tendinopathy, ankle sprains, and anterior cruciate ligament injuries.[1,21,26,31,35,36] In light of the importance of dorsiflexion for function and the relationship between dorsiflexion ROM and injury, restoration of dorsiflexion ROM in individuals with a deficit is an important component of injury management.[11,12] To determine effectiveness of treatment, accurate measurement of dorsiflexion ROM is required.

Dorsiflexion ROM can be measured in non–weight-bearing and weight-bearing positions. Weight-bearing tests are generally preferred due to better reliability and representation of function.[8] A highly reliable and commonly used clinical measure of dorsiflexion ROM is the weight-bearing lunge test (WBLT).[2,30,33] This is performed by lunging the knee forward, in alignment with the long axis of the foot, while keeping the heel on the ground. Horizontal distance from the tip of the longest toe to the horizontal projection of the knee and the inclination of the tibia relative to the horizontal are measured.[2,6,9,30,32]

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The WBLT is thought to primarily assess talocrural joint movement.[2,17,22,27] However, it has been suggested that tarsal and subtalar joint movement (particularly pronation) may also contribute to tibial inclination during the WBLT.[4,16] The contribution of the talocrural joint, compared to more distal joints, to tibial inclination during the WBLT has not been determined. Clinically, the ability to specifically measure talocrural motion is important, as treatments are often targeted to this joint,[19] with the aim of improving movement at the talocrural joint and decreasing compensatory movement and accompanying stress on tissues elsewhere in the lower limb.[20] Standard radiographs (X-rays) are the gold standard for evaluating the ROM or position of a joint.[28] Clinical measures of tibial inclination, using inclinometers or photography, have not previously been validated against radiographic images.

The primary aim of this study was to determine the extent to which movement at the talocrural joint contributes to tibial inclination during the WBLT. Secondary aims were to determine the validity of inclinometer and photographic measures of tibial inclination compared to measures taken via radiographic images, and to determine the association between tibial inclination and horizontal distance measures. We hypothesized that (1) the majority of tibial inclination during the WBLT would occur at the talocrural joint, (2) photographic measures of tibial inclination would be valid measures of dorsiflexion ROM compared to radiographs, (3) inclinometer measures of tibial inclination would differ from radiographic measures due to the anterior curvature of the tibia not being representative of the bisection of the tibia, and (4) there would be a strong association between tibial inclination and horizontal distance measures.

METHODS

Participants

A convenience sample of 20 participants was recruited for this cross-sectional study. Recruitment was conducted via word of mouth and posters at a university campus between March and June 2017. To be eligible for inclusion, participants had to be between 18 and 45 years of age. Participants were excluded if they had a current lower-limb musculoskeletal or neurological condition, had previous lower-limb surgery, were unable to perform the test protocol, or were unable to be exposed to radiation due to pregnancy or a history of cancer. This study was approved by the Research Ethics Committee at The University of Queensland. All participants provided informed written consent, and the rights of the participants were protected.

The WBLT of Dorsiflexion ROM

The WBLT was performed as described previously.[25] A custom-made device consisting of a movable upright post attached to a stable base was used to measure dorsiflexion ROM (**FIGURE 1**).[5,25,29] A line along the wooden base and metal upright post provided a reference for participant foot and knee alignment. The participant stood on the base of the device in stride stance (right leg in front). The right foot of each participant was positioned so that the horizontal line on the base of the device was between the second and third toes and bisected the calcaneus. Participants were instructed to lunge their knee forward, keeping their heel in contact with the platform, their pelvis facing forward, and the center of their knee in the middle of the line on the vertical upright post of the device. Participants lunged forward to a point just before the heel lifted, as determined by palpation of the calcaneus by an investigator. The WBLT was performed as it is performed in the clinic, with the device against a wall. However, the movable upright post on the device eliminated the need for the distance between the longest toe and the wall to be adjusted to find the distance equating to maximal dorsiflexion ROM. Participants performed 3 practice trials before performing 1 trial for data collection. Good test-retest reliability of the WBLT was previously reported in a systematic review, with intraclass correlation coefficients ranging from 0.65 to 0.99.[30] Testing of the WBLT on 2 occasions 1 week apart in our laboratory indicated excellent intrarater reliability (intraclass correlation coefficient = 0.96).

Experimental Protocol

A marker was placed on the center of the right medial malleolus for alignment of the radiography tube and a number was written on the participant's leg for identification. Two ball bearings were taped to the participant's tibia so that distinct tibial landmarks could be identified on radiographs. The ball bearings were placed in the middle third of the leg (one ball bearing was placed one third down from the tibiofemoral joint line and the second ball bearing was placed one third up from the talocrural joint line) bisecting the medial tibial border, as determined by palpation. The testing device was placed on the table immediately in front of the

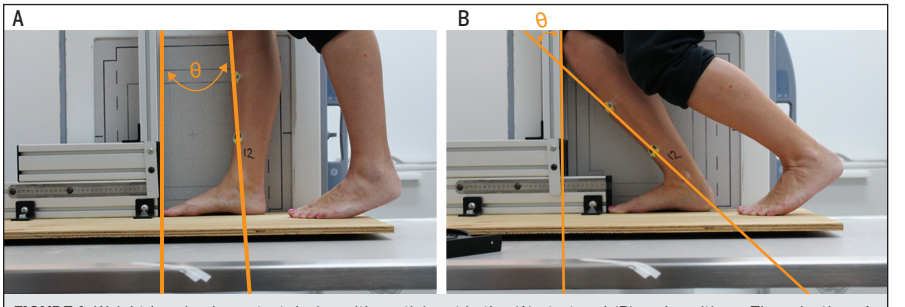


FIGURE 1. Weight-bearing lunge test device with participant in the (A) start and (B) end positions. The selection of ball bearings to form the line on the tibia and 2 points on the vertical upright post, to form the vertical reference line for measurement of the tibial inclination angle (θ) from the photographic images, is shown.

radiographic plate, and participants stood on the device as described above. A professional radiographer adjusted the radiographic plate so it was as close to the device as possible and the center of the radiograph tube was aligned with the marker on the medial malleolus.

A first radiograph was taken using a standard machine (DEFINIUM 6000; General Electric, Boston, MA) and a collimator (model AL01C; Siemens AG, Munich, Germany) with the participant standing upright on the device, prior to lunging the knee forward (baseline). The image was immediately checked to ensure that the base of the measurement device, the ball bearings on the tibia, and the entire foot were visible. In the same position, 3 photographs were taken with a digital single-lens reflex camera (Canon EOS 650D with 18-to-55-mm lens; Canon Inc, Tokyo, Japan). The camera, set at 35-mm zoom (to minimize barrel and pincushion distortion) and no flash, was aligned with the marker on the medial malleolus and placed in front of the X-ray tube, with the lens parallel to the ground.

Participants then performed a single trial of the WBLT. The same researcher (M.D.S.) provided instruction in the WBLT and assessments for all participants. At the maximal lunge position (determined as described above), participants were asked to maintain the position, while a linear measure of dorsiflexion ROM was read from a rigid ruler fixed to the device, tibial inclination was measured using an inclinometer (Australasian Medical and Therapeutic Instruments Pty Ltd, Brendale, Australia) positioned on the mid third of the anterior tibia, a second radiograph was taken, and the 3 photographic images were captured. The foot position was checked between measurements to confirm that the maximal lunge distance was maintained.

Data Analysis

Radiographic images were analyzed to obtain the sagittal plane talar rotation angle, tibial inclination angle, and calcaneal vertical displacement, while photographs were analyzed to obtain only the tibial inclination angle. Analysis of radiographic and photographic images was conducted using a custom telerehabilitation platform (NeoRehab Pty Ltd, Brisbane, Australia).

The tibial inclination angles for both radiographic and photographic images were measured by identifying the 2 ball bearings taped to the tibia relative to a vertical reference. A marker was placed in the center of each ball bearing to form

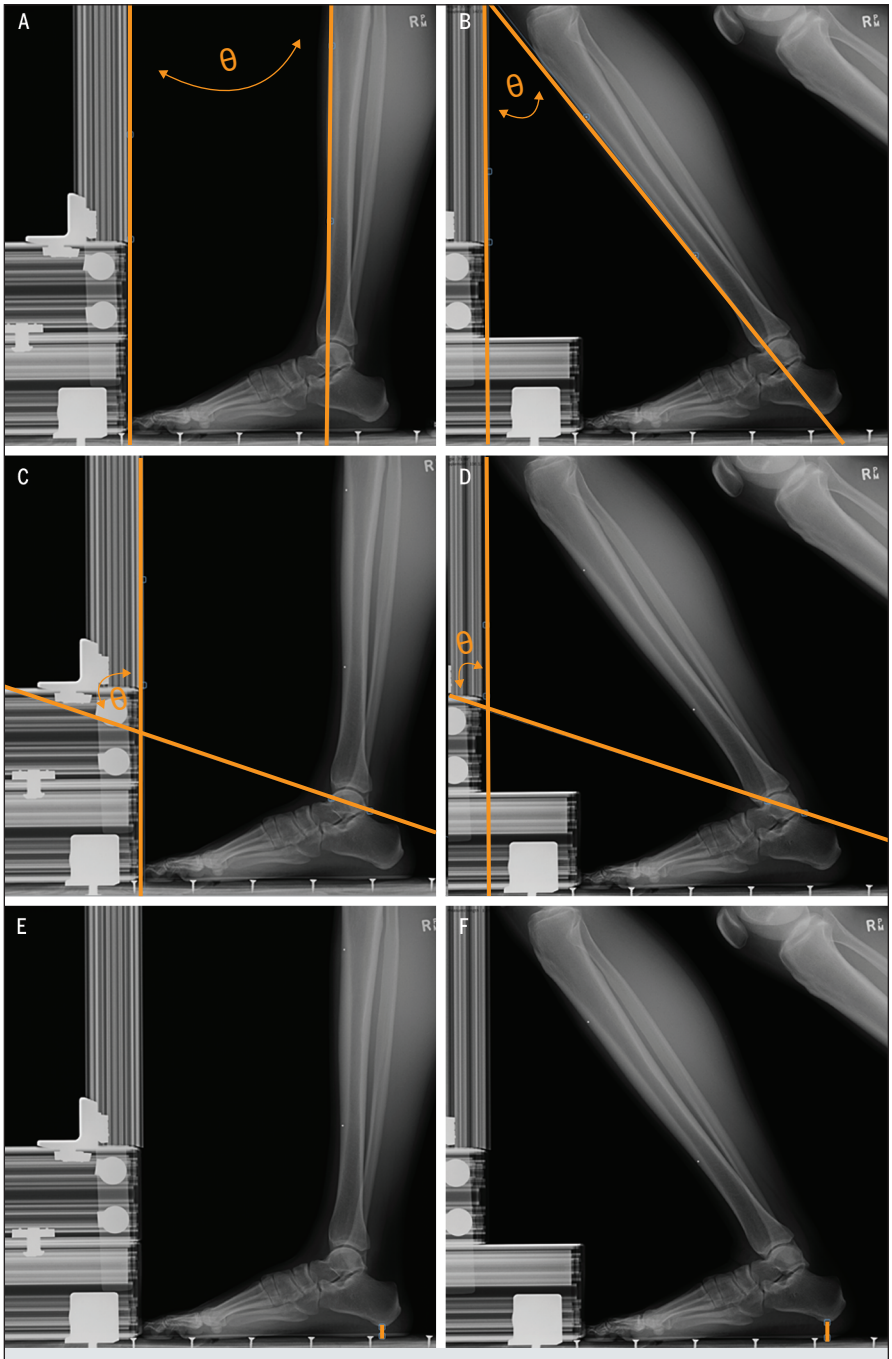


FIGURE 2. Analyses of radiographic images of (A) start and (B) end of tibial inclination, (C) start and (D) end of talar rotation, and (E) start and (F) end of calcaneal vertical displacement during the weight-bearing lunge test. The *θ* symbol indicates the angles measured for tibial inclination and talar rotation.

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the line of the tibia (**FIGURES 1** and **2**). The vertical reference line from which the tibial inclination angle was obtained was formed by 2 points selected on the metal vertical upright post on the measurement device. The tibial inclination angle relative to the vertical was calculated, with a positive angle defined as an angle less than 360° (counterclockwise). To calculate the amount of talar rotation between baseline and maximal lunge positions, a line was created between the inflection between the talar dome and neck of the talus and the most posterior aspect of the talus. The angle recorded was the superior angle between the talus and vertical (calculated as described above) (**FIGURE 2**). This method for selecting landmarks from radiographic[28,34] and photographic[28] images to measure joint position is similar to that used in previous research.

The measure of vertical displacement of the calcaneus was calibrated using an object of known length attached to the vertical piece of the testing device. This object was the same distance from the radiographic head as the midline of the calcaneus. A horizontal reference line was drawn along the most superior aspect of a line of screws in the base of the device. A second perpendicular line was drawn from the most inferior aspect of the calcaneus to the horizontal reference line. The length of the line (centimeters) measured the calcaneal vertical displacement (**FIGURE 2**).

Analyses of radiographic and photographic data were repeated on 2 occasions a week apart by the same examiner to calculate intrarater reliability. The examiner was blinded to the results from the first analysis. A second examiner, who was blinded to the first examiner's findings, analyzed data from 10 participants on 1 occasion for interrater reliability. The first measure from the first examiner was used to calculate interrater reliability. Both examiners performed 1 measure of tibial inclination, calcaneal displacement, and talar rotation in each position (start and end) and were blinded to previous analyses.

Mean change in measures (tibial inclination, calcaneal displacement, talar rotation) between the start and end of the WBLT was calculated by subtracting the start position from the end position. The percentage contribution of talar rotation to tibial inclination was determined by dividing the change in talar rotation by the change in tibial inclination and multiplying by 100.

Statistical Analysis

Intraclass correlation coefficients (model 2,1) and 95% confidence intervals (CIs) were calculated to assess intrarater and interrater reliability. Intraclass correlation coefficients were interpreted as excellent (0.9-1.0), good (0.75-0.9), moderate (0.5-0.75), or poor (0.0-0.5).[23] Standard error of the measurement (SEM) was also calculated as a measure of consistent reliability at a group level, using the formula SEM = SD/$\sqrt{n}$.[10] Smallest detectable change (SDC) at the 95% CI was calculated using the formula 1.96 × SEM × $\sqrt{2}$.[13]

Statistical analyses of data from radiographs and photographs were performed using the results from the first analysis by the primary examiner/rater (D.L.). Bland-Altman[3] plots were visually inspected to ensure that there was no systematic error in agreement between photographic and inclinometer measures compared to radiographic measures. The validity of photographic and inclinometer measurements compared to radiographic measurements was assessed by obtaining the 95% limits of agreement (LA) ($d \pm 1.96$ SD). This determines where 95% of the differences between the measures are expected to lie. An acceptable 95% LA range for measures was determined a priori as ±2.7°, which is the 95% CI for interrater reliability for tibial inclination at the maximal dorsiflexion ROM achieved during the WBLT, as measured using an inclinometer.[2] Using this LA margin, we were willing to accept a difference between radiographic and photographic or inclinometer measures that was no greater than the interreliability of the inclinometer itself.

The Pearson correlation coefficient (r) was used to assess the correlation between radiographic and photographic measures at end-range dorsiflexion ROM, radiographic and inclinometer measures at end-range dorsiflexion ROM, tibial inclination as measured on radiographs and via horizontal distance, and tibial inclination as measured by an inclinometer and by horizontal distance. The following guideline was used to interpret the strength of the associations: very strong, 0.8 to 1.0; moderately strong, 0.5 to 0.8; fair, 0.3 to 0.5; poor, 0.0 to 0.3.[7] All statistical analyses were conducted using Stata Version 14.0 (StataCorp LLC,

TABLE 1 Dorsiflexion ROM at Maximal Lunge Position Using Different Measurement Methods*

	Value
Maximal dorsiflexion ROM in the WBLT	
Horizontal lunge distance from a ruler, cm	7.7 ± 2.4 (3.0-12.0)
Tibial inclination from radiographs, deg	36.9 ± 7.6 (16.4-50.3)
Tibial inclination from photographs, deg	38.5 ± 5.8 (29.2-50.2)
Tibial inclination from an inclinometer, deg	35.7 ± 6.4 (20.0-47.0)
Change in position from radiographic data†	
Change in tibial inclination, deg	36.0 ± 6.5 (22.4-46.4)
Change in talar rotation, deg	1.6 ± 2.9 (−6.0 to 5.9)
Change in calcaneal vertical displacement, cm	0.30 ± 0.18 (0.03-0.67)

Abbreviations: ROM, range of motion; WBLT, weight-bearing lunge test.
**Values are mean ± SD (range).*
†*Change was calculated as end position minus start position.*

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College Station, TX). The statistical significance was set at $P<.05$.

RESULTS

Twenty healthy adults (14 women, 6 men; mean ± SD age, 25.5 ± 7.1 years; body mass index, 23.9 ± 3.8 kg/m^2) participated in this study.

Contributions to Dorsiflexion ROM

The mean ± SD horizontal distance and tibial inclination (measured from radiographs, photographs, and an inclinometer) during the WBLT, and change in tibial inclination, talar rotation, and calcaneal vertical displacement as measured on radiographic images from the start to the end of the WBLT, are reported in **TABLE 1**. The average percentage contribution of talar movement (considered to represent movement at the subtalar joint and distally) to the change in tibial inclination was 8.2% (range, 1.2%-26.9%), with the remaining 91.8% (range, 73.1%-98.8%) of movement occurring at the talocrural joint.

Reliability of Measures

The intrarater reliability of measures taken by a single examiner on 2 separate occasions was 0.99 to 1.00 (95% CI: 0.99, 1.00) for both radiographic and photographic measures (**TABLE 2**). The SEM and SDC for radiographic and photographic measures indicated a high test-retest reliability for both measures (**TABLE 2**). The interrater reliability for measures taken by 2 different examiners was 0.99 to 1.00 (95% CI: 0.94, 1.00) for the tibial and calcaneal measures and 0.53 to 0.67 (95% CI: −0.10, 0.91) for the talar measures (**TABLE 2**).

Validity of Inclinometer and Photographic Measures Compared to Radiographic Measures

Calculation of the 95% LA for radiographic and inclinometer measures of tibial inclination at end-range dorsiflexion ROM taken by the first examiner on the first measurement occasion indicated an unacceptable agreement (−7.84°, 5.92°) with a bias (−0.96). The Pearson correlation coefficient between radiographic and inclinometer measures of tibial inclination at end-range dorsiflexion ROM indicated a very strong correlation between the measures (r = 0.94, $P<.001$) (**FIGURE 3**). Analysis of radiographic and photographic measures of tibial inclination at end-range dorsiflexion ROM indicated acceptable 95% LA (−2.17°, 2.49°) with a low bias (0.16). The Pearson correlation coefficient indicated a very strong correlation between radiographic and photographic measures at end-range dorsiflexion ROM (r = 0.88, $P<.001$) (**FIGURE 3**).

Correlation Between Tibial Inclination and Weight-Bearing Lunge Distance

There were very strong correlations between tibial inclination, measured on radiographs, photographs, and using an inclinometer, and horizontal lunge distance at end-range dorsiflexion ROM (all, r = 0.92, $P<.001$) (**FIGURE 4**). There was a poor correlation between tibial inclination angle and talar rotation (r = 0.15, P = .52) (**FIGURE 4**).

DISCUSSION

The primary aim of this study was to examine the contribution of the talocrural joint to tibial inclination during the WBLT. Consistent with our hypothesis, data indicated that the majority of movement during the WBLT occurred at the talocrural joint, with an average of 91.8% of tibial inclination attributed to talocrural joint movement and only approximately 8.2% of inclination due to movement in more distal joints (ie, the

TABLE 2 Intrarater and Interrater Reliability for Radiographic and Photographic Measures

	Mean Difference*		Intrarater†			Interrater†		
	Rater 1 (time 1 versus time 2)	Rater 1 Versus Rater 2	$ICC_{2,1}$	SEM	SDC_{95}	$ICC_{2,1}$	SEM	SDC_{95}
Radiographic measures								
Talus start	0.3 ± 0.4	5.3 ± 4.0	0.99 (0.99, 1.00)	0.09	0.25	0.53 (−0.10, 0.86)	0.91	2.51
Talus end	0.4 ± 0.4	5.3 ± 2.9	0.99 (0.99, 1.00)	0.08	0.23	0.67 (0.12, 0.91)	0.65	1.80
Tibia start	0.1 ± 0.1	0.03 ± 0.02	>0.99 (0.99, 1.00)	0.02	0.05	1.00 (1.00, 1.00)	<0.01	0.01
Tibia end	0.1 ± 0.1	0.06 ± 0.05	>0.99 (1.00, 1.00)	0.02	0.07	1.00 (1.00, 1.00)	0.01	0.03
Calcaneus start	0.01 ± 0.01	0.02 ± 0.02	>0.99 (1.00, 1.00)	<0.01	<0.01	0.99 (0.97, 1.00)	<0.01	0.01
Calcaneus end	0.01 ± 0.01	0.02 ± 0.02	>0.99 (1.00, 1.00)	<0.01	<0.01	0.99 (0.98, 1.00)	<0.01	0.01
Photographic measures								
Tibia start	0.1 ± 0.2	0.3 ± 0.5	>0.99 (1.00, 1.00)	0.04	0.10	0.99 (0.94, 1.00)	0.11	0.31
Tibia end	0.2 ± 0.2	0.4 ± 0.4	>0.99 (1.00, 1.00)	0.05	0.14	0.99 (0.97, 1.00)	0.10	0.27

Abbreviations: ICC, intraclass correlation coefficient; SDC, smallest detectable change; SEM, standard error of the measurement.
**Values are mean ± SD.*
†Values in parentheses are 95% confidence interval.

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subtalar and tarsal joints). The findings of our study support the use of the WBLT as a measure of talocrural dorsiflexion ROM. Thus, the WBLT is an appropriate test for clinical and research purposes to identify limitations in talocrural dorsiflexion ROM and to determine the effect of targeted treatments on such limitations. Both radiographic and photographic measures of tibial inclination on the WBLT were highly reliable, and the SDC data provide an indication of the difference between repeat measures needed to indicate a change in dorsiflexion ROM.

There was a poor relationship between maximal tibial inclination achieved during the WBLT and the rotation of the talus, which represents the contribution of movement at locations distal to the talocrural joint to dorsiflexion ROM. This suggests that movement distal to the talocrural joint does not consistently occur during the WBLT. It has been proposed that lack of talocrural dorsiflexion ROM may be compensated by increasing motion in other areas of the foot and ankle (such as the subtalar joint).[4,16] This requires testing in individuals with limited dorsiflexion ROM.

It must be noted that the WBLT is often performed differently in both research and clinical practice.[2,14] For example, Bennell et al[2] stabilized the heel during the movement and allowed the foot to move out of neutral alignment (ie, into supination or pronation), whereas Hall and Docherty[14] attempted to control subtalar movement. Research has not compared tibial inclination or horizontal distance measures using these different WBLT procedures, but reported maximal mean horizontal distance and tibial inclination (measured using an inclinometer) differ between procedures/studies (Hall and Docherty,[14] 10.3 ± 3.0 cm and 39.0° ± 4.6°; Bennell et al,[2] 13.8 ± 3.8 cm and 50.4° ± 8.1°; our data, 7.7 ± 2.4 cm and 35.7° ± 6.4°, respectively). While differences between studies may be due to differences in participant ability, it is possible that different procedures in conducting the WBLT contributed to the greater dorsiflexion ROM reported in other studies. We used a device that facilitated maintenance of the midpoint of the anterior knee, the midpoint of the posterior heel, and the web space of the second to third toes in one plane, which was perpendicular to the floor in the frontal plane. The end point of the test was just prior to heel lift, as determined by calcaneal palpation. Our data indicate that when using the procedure, the WBLT is a test of talocrural dorsiflexion.

Secondary aims of this study were to determine the validity of inclinometer and photographic measures of tibial inclination (validity compared to that of radiographic images), and to determine the association between tibial inclination and horizontal distance measures. Our data indicate excellent correlations between radiographic, photographic, and inclinometer measures of tibial inclination at end-range dorsiflexion ROM during the WBLT. Photographic measures were valid and had acceptable 95% LA compared to radiographic measures. The use of the same landmarks (2 ball bearing markers that bisected the long axis of the tibia on the middle third of the medial border) to measure tibial inclination would have contributed to the high agreement between these measures. Thus, while our data suggest that photographic measures of dorsiflexion ROM at the maximal lunge distance can be used clinically to reflect talocrural dorsiflexion ROM with high reliability and validity compared to

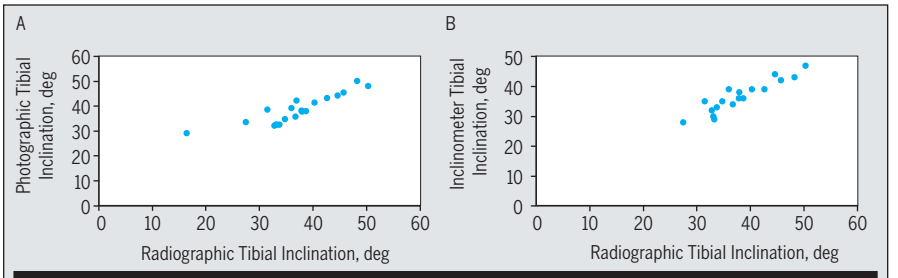


FIGURE 3. Correlation for the tibial inclination end position between (A) radiographic and photographic measures (r = 0.88, P<.001), and (B) radiographic and inclinometer measures (r = 0.94, P<.001).

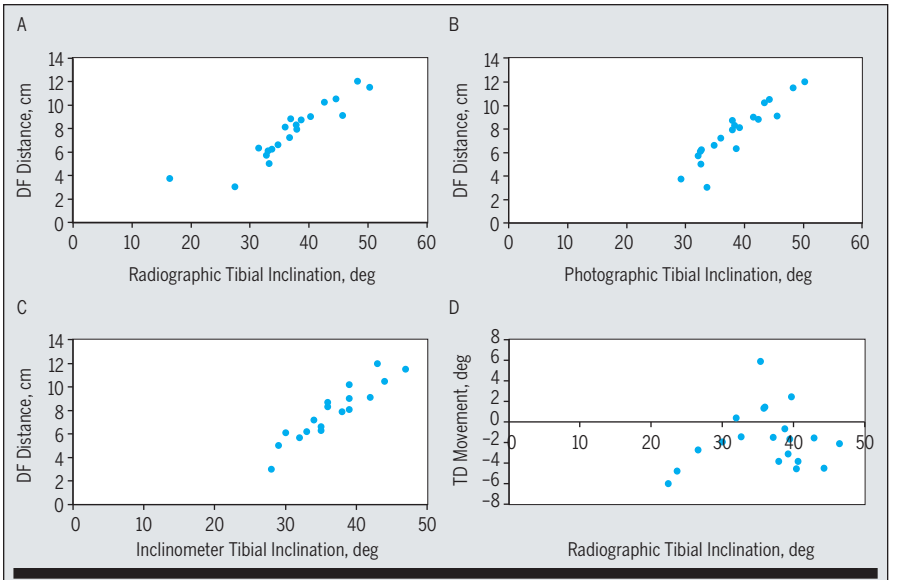


FIGURE 4. Correlation between (A) radiographic tibial inclination and horizontal lunge distance (r = 0.92, P<.001), (B) photographic tibial inclination and horizontal lunge distance (r = 0.92, P<.001), (C) inclinometer tibial inclination and horizontal lunge distance (r = 0.92, P<.001), and (D) tibial inclination and talar rotation on radiographs (r = 0.15, P = .52). Abbreviations: DF, dorsiflexion; TD, talar dome.

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radiographic measures, it is not known whether photographic and radiographic measures of dorsiflexion ROM would be similar if the tibial landmarks were estimated separately for each measurement.

While our data indicate excellent correlation between radiographic and inclinometer measures of tibial inclination at the end range of the WBLT, Bland-Altman calculations of 95% LA indicate a difference between tibial inclination measured on radiographs compared to an inclinometer of −7.84° to +5.92°. These data suggest that while there is a clear relationship between radiographic and inclinometer methods of measuring tibial inclination, the inclination values obtained will differ. A likely explanation for this is the curvature of the tibial shaft. The tibial shaft is often convex anteriorly, and we observed varying amounts of convexity between individuals. It is likely that the ball bearings placed on the medial tibia do not represent the convex shape of the anterior tibial border on which the inclinometer was placed. Thus, while inclinometer measures of tibial inclination can reliably be used clinically to measure dorsiflexion ROM during the WBLT,[2,22,24] the results will differ slightly from those that would be obtained from radiographs.

There was a strong correlation between WBLT horizontal distance and tibial inclination as measured on radiographs, photographs, and by an inclinometer. This is the first study to examine the correlation between horizontal lunge distance and tibial inclination measured on radiographs. Our data confirm the findings of Bennell et al,[2] who found a very strong correlation between weight-bearing lunge distance and tibial inclination measured using an inclinometer. These data indicate that horizontal distance during the WBLT is an accurate representation of talocrural dorsiflexion ROM.

Limitations should be considered when interpreting the results of this study. First, participant positioning, camera placement, and the location of landmarks may affect the reliability of the results. The digital single-lens reflex camera position was aligned to markers on the X-ray tube to ensure that the photograph captured the same view as the radiograph. Ball bearings (positioned to mark the bisection of the medial tibial border in the middle third of the leg) were used to measure tibial inclination on both the radiographic and photographic measures. The use of these landmarks for both measures would be expected to increase the agreement between photographic and radiographic measures, and contributed to photographs more accurately representing tibial inclination measured on radiographs than inclinometer measures. Second, a mean calcaneal lift of 0.3 cm at end-range dorsiflexion ROM was observed. This could have contributed a small amount of error to the calculation of tibial inclination. Third, while intrarater reliability of measuring talar rotation from radiographs was excellent, interrater reliability of this measure was poor. The orientation of the talus relative to the vertical was determined by selecting the most posterior aspect of the talus and the inflection between the talar dome and neck of the talus. Our data indicate that 1 individual is able to detect these points reliably, as was done to determine the relative contributions of the talus to the WBLT in the present study. Poor interrater reliability for 2 people detecting the same talar landmarks does not compromise the main outcomes of this study, and it is not expected that talar rotation on radiographs would likely be used in clinical practice. Fourth, subtalar joint movement occurs in multiple planes, and it is possible that frontal and transverse plane talar movement may have contributed to sagittal plane tibial inclination.

Individuals in this study were not required to have a limitation of dorsiflexion ROM to participate. This provided a sample with a large range of dorsiflexion ROM abilities (from 3.0 to 12.0 cm on the WBLT), which is expected to be representative of the general population. Many individuals had a dorsiflexion ROM that could be considered to be restricted, with 20% (n = 4) of participants having a horizontal distance of less than 6.0 cm on the WBLT and half of participants having a distance of less than 8.0 cm. While not identified in our data, the talocrural, subtalar, and tarsal joints and other soft tissues may move differently and contribute to tibial inclination differently in individuals with ankle pathologies and limited movement. Further research could explore the contributions to tibial inclination in different ankle pathologies with known dorsiflexion ROM limitations, such as chronic ankle instability and ankle osteoarthritis.[15,18]

CONCLUSION

Findings from this study indicate that ankle dorsiflexion during the WBLT primarily occurs at the talocrural joint, with only a small proportion of movement occurring more distally. Thus, measures of tibial inclination and horizontal knee projection distance during the WBLT represent talocrural dorsiflexion ROM in healthy individuals. Data indicate that tibial inclination measured from photographs (using the procedure outlined in this study) is an accurate representation of that measured on radiographs. Future research should validate the feasibility of using photographs to measure dorsiflexion ROM in a clinical environment, and confirm that WBLT measures accurately reflect talocrural dorsiflexion ROM in clinical populations, such as individuals with ankle osteoarthritis. ◉

KEY POINTS

FINDINGS: Tibial inclination during the weight-bearing lunge test (WBLT) accurately reflects movement at the talocrural joint. There are strong correlations between WBLT horizontal distance and tibial inclination, as measured by an inclinometer or with photographs, and talocrural dorsiflexion range of motion (ROM) on radiographs.

IMPLICATIONS: Tibial inclination and horizontal displacement during the WBLT predominantly measure talocrural joint motion. Digital photographs provide an

accurate method of measuring dorsiflexion ROM.

CAUTION: Further research is needed to explore the contributions to tibial inclination in different ankle pathologies with known dorsiflexion ROM limitations.

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