Comparison of Functional Ankle Motion Measures in Modern Dancers

Danelle Dickson, P.T., D.P.T., Kendra Hollman-Gage, P.T., D.P.T., O.C.S., Sheyi Ojofeitimi, P.T., D.P.T., and Shaw Bronner, P.T., Ph.D., O.C.S.

Proofs to: danelle.dickson@gmail.com

Abstract

Ankle injuries are the most common lower extremity injury in dance and sports, often resulting in limitation of dorsiflexion or plantar flexion. Accurate assessment of any limitation in range of motion is an important factor in implementing effective preventative and rehabilitative regimens. Ankle range of motion has traditionally been quantified with goniometers. However, standard goniometry may not be an adequate method of assessing plantar flexion range of motion in dancers. An alternative technique using inclinometers to quantify ankle plantar flexion has been reported, but reliability and inter-instrument correlations for this method are limited. The dorsiflexion lunge distance method has been used to assess ankle dorsiflexion. Although shown to be reliable, this method has not been objectively correlated. The purpose of this study was to determine the most clinically appropriate tool for assessing functional ankle dorsiflexion and plantar flexion in dancers. The aims were to: 1. determine reliability of the weightbearing ankle dorsiflexion lunge method using inclinometer, goniometer, and distance; 2. assess the reliability of inclinometer and universal goniometer measurements of non-weightbearing active plantar flexion; 3. conduct inter-method and experienced versus novice rater correlations; and 4. determine if a relationship exists between dorsiflexion distance (cm) and dorsiflexion inclinometer angle (degrees) measurements. *Twenty-six modern dancers (age 20.2 ± 1.8 years) participated in the study. Four raters measured weightbearing dorsiflexion in a lunge position using a goniometer, two inclinometer placements, and a distance measurement. They also measured active ankle plantar flexion using an inclinometer placed on the anterior talonavicular joint and a goniometer placed at the lateral ankle. Intra- and inter-rater reliability and inter-method correlations were calculated with Intra-class Correlation Coefficients (ICC) and standard error of measurement (SEM). The relationship of dorsiflexion distance to angle was determined using grouped linear regression (p < 0.05). Dorsiflexion and plantar flexion intra- and inter-rater ICCs for inclinometer, goniometer, and distance ranged from 0.84 to 0.94. The SEM for angular measures ranged from 1º to 3º, and linear measures from 0.3 cm to 0.9 cm. Inter-method correlations ranged from 0.55 to 0.89. There were no differences between inclinometer and goniometer measurement dorsiflexion means. However, inclinometer plantar flexion values were greater than goniometric values (p < 0.001). Experienced raters recorded greater goniometric values compared to novice raters (p < 0.001). There was no consistent linear relationship between dorsiflexion lunge distance measure and inclinometer degrees. It is concluded that functional ankle DF in modern dancers is best quantified using an inclinometer (posterior placement) in the weightbearing lunge position. Non-weightbearing active ankle PF in modern dancers is best quantified with inclinometer placement on the dorsum of the foot. The distance method cannot be compared directly to angular measurement, is subject-specific, and cannot be used as a normative measure to compare DF range between subjects, populations, or age groups.*

Danelle Dickson, P.T., D.P.T., is the Clinical Director, Physical Therapy Sports and Assessment Center, Washington, DC. Kendra Hollman-Gage, P.T., D.P.T., O.C.S., is a Physical Therapist with Athletico, Ltd., Chicago, Illinois. Sheyi Ojofeitimi, P.T., D.P.T., is a Senior Research Associate, ADAM Center, Long Island University, Brooklyn, NY and Physical Therapist, Alvin Ailey, New York, New York. Shaw Bronner, P.T., Ph.D., O.C.S., is the Director of the ADAM Center, Long Island University, Brooklyn, New York, and Director, Physical Therapy Services at Alvin Ailey, New York, New York.

Correspondence: Danelle Dickson, P.T., D.P.T., 11700 Old Columbia Pike, Apt 1518, Silver Spring, Maryland, 20904; danelle.dickson@gmail.com.

Dancers frequently work at extremes of joint motion. They demonstrate greater active and passive range of motion (ROM) in selected joints than what has been reported for the general population.[1-3] Extreme ROM is important for the aesthetic look of dance and is needed to meet its functional requirements. This is especially true at the ankle. The aesthetics of dance dictate a pointed foot that is parallel to the tibial crest, whether in open (e.g., développé) or closed chain (e.g., en pointe or demi-pointe).[4] The demi-plié (hip and knee flexion and ankle dorsiflexion), a position of preparation and recovery for dynamic dance movements including jumps, pirouettes (turns on one limb), and jetés (leaps), requires sufficient ankle dorsiflexion (DF) ROM to initiate a jump or decelerate a landing.

Foot and ankle injuries have an average annual injury incidence of 34% to 57% in the dance population.[4-8] Impaired quantity and quality of ankle ROM can occur in conditions such as plantar fasciitis, Achilles tendinopathy, flexor hallucis longus tenosynovitis, and anterior and posterior impingement syndromes.[9] For dancers, even minimal loss of ankle ROM can lead to major compromise of their performance. Consequently, accurate assessment of functional ankle ROM is an important aspect of post-injury rehabilitation in this population.

Ankle DF and plantar flexion (PF) ROM have traditionally been quantified with goniometers and inclinometers.[10-12] Studies suggest goniometry may not be the optimal method of assessing ankle ROM in dancers.[13,14] Although inclinometers are easy to use and have demonstrated reliability,[15,16] no standardized patient position (knee bent or straight) or instrument placement (Achilles, anterior shin, or lateral calf) has been established for inclinometer weightbearing (WB) DF measurement.[10,17-22] Novella[13,23] developed a technique using inclinometry to quantify ankle PF in ballet dancers. Although promising, limited reliability and inter-instrument correlations have been reported for this method.[24] Bennell and coworkers[18] assessed DF using the DF lunge test. Researchers suggested a 1:2 or 1:5 ratio in describing the relationship between distance measure (cm) and angular displacement in this test but did not measure the change in degrees systematically across many subjects.[18,25,26] Although shown to be reliable, the DF lunge distance test has not been correlated with goniometer or inclinometer results in a meaningful way that allows for clinical interpretation.

The purpose of this study was to determine the most clinically appropriate method for measuring functional ankle PF and DF in dancers. We examined the following: 1. reliability of weightbearing ankle DF lunge measurement using inclinometer, goniometer, and distance methods; 2. reliability of non-weightbearing active PF using inclinometer and goniometer; 3. inter-method and experienced versus novice rater correlations; and 4. relationship between DF distance (cm) and DF inclinometer angle (degrees) measurements.

Methods

Subjects

A power analysis of sample size for a single-sample correlational study was conducted using nine pilot subjects. With an alpha level of $p = 0.05$, power of 0.90, and hypothesis that $r1 = 0.50$ and $r2 = 0.98$, it was determined that a one-tailed test required eight subjects, and a two-tailed test required ten subjects.

Twenty-six modern dancers, 6 males and 20 females (mean age 20.2 ± 1.8 years), participated in this study (Table 1). Subjects were university and pre-professional level dancers with a range of 4 to 16 years of dance training (mean 11.1 ± 4.5 years). Fifteen of the 20 female dancers had a range of 1 to 14 years of pointe training (6.5 ± 3.3). Inclusion criterion was enrollment in a pre-professional, university modern dance program, or membership in a modern dance company. Exclusion criterion was any lower extremity injury within the previous 3 months that required the dancer to stop dancing for more than 1 week. All subjects gave written informed consent in compliance with the guidelines of the researchers' University Internal Review Board.

Procedure

Dancers were scheduled for two sessions on 2 separate days, at least 48 hours apart, but within 7 days of the first session. Four raters conducted the measurements, two experienced physical therapists (mean 12.5 years of experience) and two student physical therapists (final year of study). Prior to data collection, all raters formally practiced the established protocol to familiarize themselves with the measurement procedures. One rater measured each subject's anthropometrics on Day 1 (Table 1). Height was measured in standing against a wall without shoes. Tibial length was measured in supine from the anterior aspect of the tibial tuberosity to the medial malleolus. The tibial midpoint was measured and marked on all subjects with a felt semi-permanent marker. All raters used this mark to align the inclinometer at the tibial midpoint during measurement. On Day 2, the same rater re-measured all midpoints. Leg length was measured also in supine, from the anterior superior iliac spine to the medial malleolus.[27] The left lower extremity was randomly, but uniformly, selected for all measurements. Foot length was measured in standing, from longest digit to posterior calcaneus. Hallux valgus was assessed and, if present, corrected manually to ensure parallel alignment with the tape measure for DF distance during all measurements.

Dorsiflexion Measurement

The DF stations consisted of a wall, a tape measure fixed to the floor to ascertain DF lunge distance (cm), a standard 12-inch universal goniometer (Baseline 360 ISOM™, Chattanooga Medical Supply, Inc., Chattanooga, TN), and a gravity inclinometer (Dasco Pro, Inc., Rockford, IL). Both instruments displayed

Table 1 Subject Anthropometrics and Characteristics

Parameters	Mean (SD)	Range
Age (yrs)	20.2 (1.8)	18 – 24
Dance training (yrs)	11.2 (4.5)	4 – 19
Point training (yrs)	6.5 (3.4)	1 – 14
Height (cm)	164.6 (7.3)	152.4 – 178.0
Tibia length (cm)	34.3(2.2)	30.8 – 39.5
Leg length (cm)	90.6 (4.7)	79.5 – 98.0
Foot length (cm)	24.7 (1.2)	22.2 – 27.5

SD, standard deviation; yrs, years.

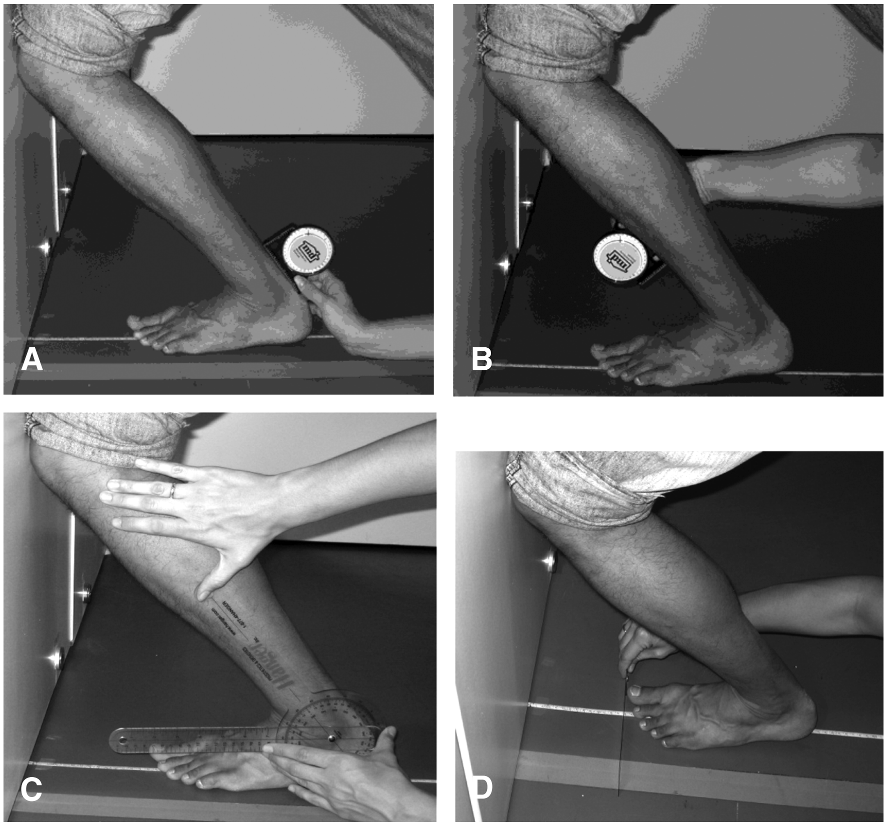


Figure 1 Active dorsiflexion lunge measurement. **A**, Positioning of the subject during the DF weightbearing measurement, and placement of the inclinometer at the posterior ankle on the Achilles tendon (post-DF). **B**, Placement of the inclinometer at the tibial midpoint (ant-DF). **C**, Placement of the goniometer at the lateral ankle. **D**, Distance measure of DF with tape measurement in centimeters

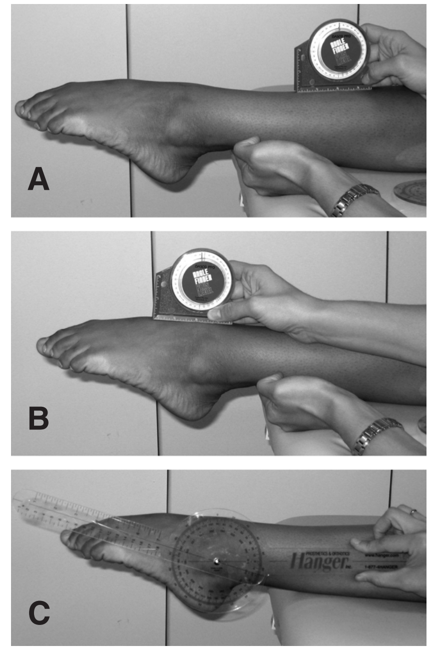


Figure 2 Active plantar flexion measurement: **A**, The tibial midpoint was elevated by the rater until the inclinometer read zero degrees, and **B**, Placement of the gravity inclinometer on the talonavicular joint. **C**, Placement of the goniometer, with the axis of rotation at the lateral malleolus, one arm parallel to the fibula and one arm parallel to the fifth metatarsal

one-degree increments. Subjects were instructed to stand facing the wall, assume a "lunge" position with the left knee touching the wall, and slide the left foot backward to the point of maximum tolerance while the left knee remained in contact with the wall and the left heel with the floor. All subjects wore thin anklet socks to decrease friction in sliding to the maximum lunge position. Raters verified that each subject's knee and heel were in contact with the appropriate surface before any measurements were taken. To allow for accurate assessment of the dancers' functional ROM, no attempt was made to maintain subtalar joint neutral. However, alignment of the knee over the second toe was verified from the starting position to the maximal lunge.

DF was measured in four ways: 1. posteriorly on the Achilles tendon with the distal edge of the inclinometer placed immediately above the calcaneal tuberosity (post-DF: Fig. 1A); 2. anteriorly at the previously marked tibial midpoint with an inclinometer (ant-DF: Fig. 1B); 3. at the lateral ankle using a goniometer with the fulcrum placed at the lateral malleolus, proximal arm aligned with the fibula, and distal arm parallel to the fifth metatarsal[28,29] (Fig. 1C); and 4. distance (cm) from the distal point of the great toe to the wall with a ruler (Fig. 1D). All measurements were recorded to the nearest degree or millimeter.

Plantar Flexion Measurement

The PF stations consisted of a plinth, a standard 12-inch goniometer, and a gravity inclinometer. Subjects lay supine on the plinth, with the left lower limb resting on the table and foot and ankle off the table. With the inclinometer placed at the previously marked tibial midpoint, the barefoot subjects were instructed to maximally PF their foot. The rater then elevated the test lower limb until the inclinometer read 0° (Fig. 2A). With the foot still pointed, a second reading was taken at the talonavicular joint on the dorsum of the foot (Fig. 2B). Each rater determined this position independently. For goniometric measurement the axis and arms were aligned as previously described (Fig. 2C).

Dorsiflexion Incremental Measurement

To examine the relationship between DF distance (cm) and inclinometer joint angle (degrees), one experienced physical therapist recorded inclinometer post-DF joint angle measurements at 2 cm increments from the wall, beginning with the great toe against the wall at the 0 cm mark and the final measurement at the maximum each subject could independently achieve. Inclinometer post-DF measurement was chosen for this test because the Achilles tendon was easier to access than the tibial midpoint, and the originators of the method used this placement in their previous studies.[25,30] All measurements were recorded to the nearest cm or degree.

Subjects rotated through each of the four raters on Days 1 and 2. At each session, two trials (A and B) of each measurement were assessed per subject. Two trials were selected for the sake of efficiency and because taking the average of two measures has been found to improve intra-rater reliability for ankle DF and PF.[12] To ensure that raters were blinded to previous data recordings, separate data sheets were used for each trial and day. To further ensure blinding, raters could not repeat trials consecutively for the same subject and were blinded to other rater measurements.

Data Analyses

The means of trials A and B were used for analysis. To allow for comparisons between goniometer and inclinometer data, inclinometer measurement was subtracted from 90° for DF and added to 90° for PF. Intra-rater repeatability was determined by comparing each rater's Day 1 to Day 2 measurements using Intra-class Correlation Coefficients (ICC: 3,k). Inter-rater reliability was determined by comparing means between raters using ICC (3,k). Inter-method correlations (inclinometer versus goniometer, inclinometer versus distance, and goniometer versus distance) were also determined using ICC (3,k). ICC values were considered low if ≤ 0.49, moderate if 0.50 to 0.69, high if 0.70 to 0.89, and very high if 0.90 to 1.00.[31] Means, standard deviations, 95% confidence intervals (CI), and standard error of measurement (SEM) were also calculated. Means of Day 1 and Day 2 trials were combined and repeated measures MANOVA was used to determine differences between experienced and novice raters for each measurement method. Data were analyzed in SPSS (Version 14.0, Chicago, IL)

To assess the clinical relevance of the distance measurement, the relationship between incremental distance (cm) and corresponding inclinometer joint angle were compared using grouped linear regression with covariance analysis in Prism (Version 5, GraphPad Software, Inc., La Jolla, CA). Individual regression lines were entered for each subject. Differences between the individual subject slopes and the grand slope were computed for the regression analysis, and the sums of squares (goodness of fit) of the two models were compared. To determine whether foot length improved the fit of the model, foot length plus incremental distance (cm) data were calculated and analyzed in the same way. The relationship between foot length and tibial length was also examined using a Pearson Product Moment correlation. Significance was set at $p < 0.05$ for all tests.

Results

Intra- and Inter-rater Reliability

Goniometer and inclinometer intra-rater reliability ICC for ankle DF ROM ranged from 0.87 to 0.90. SEM values ranged from 1° to 2°. Intra-rater reliability ICC for the distance method was 0.87, with an SEM of 0.90 cm. Goniometer and inclinometer ankle intra-rater PF ROM ICCs were 0.84 and 0.94, with SEM of 3° and 1°, respectively (Table 2).

Goniometer and inclinometer ankle DF inter-rater reliability ICC ranged from 0.84 to 0.96, with SEM between 1° and 2°. Inter-rater reliability ICC for ankle DF distance method was 0.95 and 0.99 for Day 1 and Day 2, with SEM of 0.5 cm and 0.3 cm respectively (Table 3). For PF ankle ROM, goniometer and inclinometer inter-rater reliability ICC ranged from 0.87 to 0.98, with SEM of 1° to 3° (Table 3). There were no significant differences between Days 1 and 2 values for the various measurement methods ($p > 0.05$).

Inter-method Correlations

For ankle DF, comparison of goniometer with inclinometer (Ant-DF and Post-DF) measurements revealed *high* correlations (ICC ranging from 0.76 to 0.88). Distance measurement demonstrated moderate correlations

Table 2 Intra-rater Reliability of Ankle Measurement

Motion	Instrument	Day	Mean (SD)	ICC (3,K)	95% CI	SEM
Ankle DF	Goniometer	1	34° (6)	0.90	0.85 – 0.93	2°
		2	34° (7)			
	Post-DF	1	34° (4)	0.87	0.81 – 0.91	1°
		2	34° (4)			
	Ant-DF	1	45° (5)	0.89	0.83 – 0.92	2°
		2	46° (5)			
	Distance	1	11.2 cm (2.5)	0.87	0.81 – 0.91	0.90cm
		2	11.4 cm (2.5)			
Ankle PF	Goniometer	1	70° (7)	0.84	0.77 – 0.89	3°
		2	70° (7)			
	Inclinometer	1	79° (6)	0.94	0.91 – 0.96	1°
		2	79° (6)			

Abbreviations: SD, standard deviation; ICC, Intraclass Correlation Coefficient; CI, confidence interval; SEM, standard error of measurement; PF, Plantar flexion; post-DF, posterior DF inclinometer; ant-DF, anterior DF inclinometer.

Table 3 Inter-rater Reliability of Ankle Measurement

Motion	Instrument	Day	Mean (SD)	ICC (3,K)	95% CI	SEM
Ankle DF	Goniometer	1	34° (6)	0.84	0.72 – 0.92	2°
		2	34° (7)	0.90	0.82 – 0.95	2°
	Post-DF	1	34° (4)	0.95	0.92 – 0.98	1°
		2	34° (4)	0.95	0.91 – 0.98	1°
	Ant-DF	1	45° (5)	0.96	0.92 – 0.98	1°
		2	46° (5)	0.94	0.90 – 0.97	1°
	Distance	1	11.2 cm (2.5)	0.95	0.91 - 0.98	0.5cm
		2	11.4 cm (2.5)	0.99	0.97 – 0.99	0.3cm
Ankle PF	Goniometer	1	70° (8)	0.89	0.80 – 0.95	2°
		2	70° (7)	0.87	0.76 – 0.94	3°
	Inclinometer	1	79° (6)	0.98	0.96 – 0.99	1°
		2	79° (6)	0.97	0.94 – 0.98	1°

Abbreviations: SD, standard deviation; ICC, Intraclass Correlation Coefficient; CI, confidence interval; SEM, standard error of measurement; PF, Plantar flexion; post-DF, posterior DF inclinometer; ant-DF, anterior DF inclinometer.

Table 4 Inter-method Correlations of Ankle Measurement

Motion	Instrument	Day	ICC (3,K)	95% CI
Ankle DF	Goniometer versus distance	1	0.61	0.25 - 0.79
		2	0.68	0.32 - 0.86
	Post-DF versus distance	1	0.55	0.32 - 0.69
		2	0.58	0.38 - 0.71
	Ant-DF versus Distance	1	0.68	0.50 – 0.77
		2	0.78	0.68 – 0.85
	Ant-DF versus goniometer	1	0.81	0.36 – 0.97
		2	0.88	0.60 – 0.96
	Post-DF versus goniometer	1	0.76	0.34 - 0.93
		2	0.79	0.30 - 0.95
Ankle PF	Inclinometer versus goniometer	1	0.83	0.71 - 0.87
		2	0.89	0.83 – 0.95

Abbreviations: SD, standard deviation; ICC, Intraclass Correlation Coefficient; CI, confidence interval; SEM, standard error of measurement; PF, Plantar flexion; post-DF, posterior DF inclinometer; ant-DF, anterior DF inclinometer.

Table 5 Comparison of Experienced Versus Novice Rater Ankle Range of Motion Measurement

Motion	Measurement	Rater	Mean (SD)	SE	95% CI
Ankle DF	Goniometer*	Experienced	37.7° (5.7)	0.7°	36.3° - 39.1°
		Novice	30.7° (4.4)	0.7°	29.3° - 32.1°
	Post-DF	Experienced	33.8° (3.9)	0.5°	32.8° - 34.9°
		Novice	33.9° (3.9)	0.5°	32.8° - 34.9°
	Ant-DF	Experienced	44.7° (5.1)	0.7°	43.4° - 46.1°
		Novice	45.8° (4.5)	0.7°	44.5° - 47.1°
	Distance	Experienced	11.3° (2.4) cm	0.3cm	10.6° - 11.9 cm
		Novice	11.3° (2.3) cm	0.3 cm	10.7° - 11.9 cm
Ankle PF	Goniometer*	Experienced	72.2° (7.2)	0.9°	70.4° - 74.0°
		Novice	68.0° (5.8)	0.9°	66.2° - 69.8°
	Inclinometer	Experienced	79.3° (5.7)	0.8°	77.8° - 80.9°
		Novice	79.0° (5.5)	0.8°	77.5° - 80.5°

Abbreviations: SD, standard deviation; ICC, Intraclass Correlation Coefficient; CI, confidence interval; SEM, standard error of measurement: PF, Plantar flexion; post-DF, posterior DF inclinometer; ant-DF, anterior DF inclinometer. *Experienced and novice raters significantly different, $p < 0.01$.

with the goniometer (ICC ranging from 0.61 to 0.68). There were moderate and high correlations between distance and post-DF (0.68 to 0.87), and moderate and high correlations between distance and ant-DF (0.68 to 0.78, Table 4). Inclinometer PF measurement demonstrated high correlations with the goniometer (0.83 to 0.89, Table 4). However, there were differences in mean angular displacements between the two instruments for both days ($p < 0.001$). The goniometer PF mean (combined for both days and the four raters) was

70° ± 7°, and the inclinometer mean was 79° ± 6°.

Experienced and Novice Raters

There were no differences between experienced and novice raters for post-DF, ant-DF, DF distance, or inclinometer PF ($p > 0.05$). However, experienced and novice raters differed for goniometer means ($p < 0.01$). Mean DF and PF goniometer values were lower for novices compared with experienced raters (Table 5). There were mean differences of 7.0° for DF and 4.2° for PF measurements.

Incremental Measurement

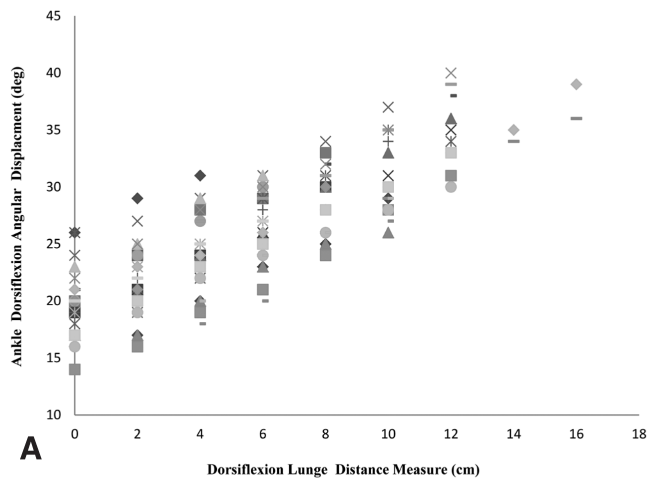
The overall slopes for distance versus inclinometer angle were significantly different [$F(25, 1) = 3.15$, $p < 0.01$]. A scatter plot of the incremental distance (cm) versus post-DF inclinometer angle demonstrated a 12º range of ankle DF angular displacement at the initial 0 cm measurement (Fig. 3A). The investigators found no statistically significant relationship ($r^2 = 0.50$, $p > 0.05$) between tibia and foot length. A scatter plot of tibia length versus foot length did not demonstrate a proportional relationship (Fig. 3B). Similarly, the overall slopes for distance plus foot length (cm) versus inclinometer were significantly different [$F(25,1) = 2.06$, $p < 0.01$]. A scatter plot of distance plus foot length (cm) versus inclinometer angle also failed to demonstrate a proportional relationship (Fig. 3C).

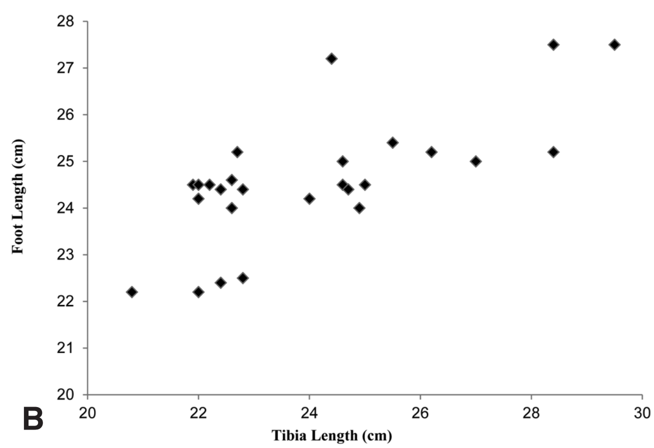
Discussion

This is, to the best of our knowledge, one of the first reports to combine analyses of reliability and inter-method correlation of the DF active ROM (AROM) lunge method and PF AROM measurements. The results of this study indicate that: 1. ankle DF ROM can be reliably measured in the lunge position using the goniometer, inclinometer, or distance method; 2. the inclinometer may be the most reliable tool for measuring ankle PF AROM in dancers; 3. clinician experience has an effect on accuracy of goniometric measurements; and 4. there was no consistent proportional relationship between DF lunge distance measurement and inclinometer angular displacement.

Functional Ankle Motion

Studies have reported excess ankle PF ROM at the expense of DF ROM in professional ballet dancers.[4,24] A recent study comparing university, vocational, and professional dancers found that ankle dorsiflexion ROM decreased with increasing dance proficiency.[24] These studies suggest that the improved PF ability in professional dancers may be due to stretching of the anterior ankle structures caused by years of performing en pointe or demi-pointe. Also, decreased DF ROM may be attributed to ankle





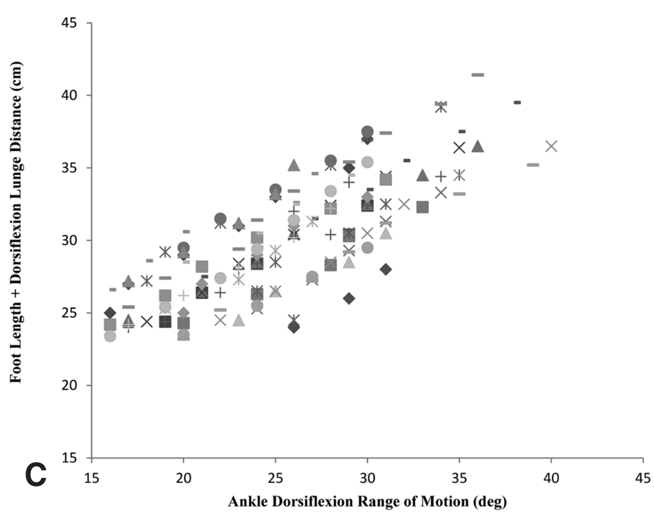


Figure 3 Incremental measurement scatter plots: **A**, Scatter plot of subject's incremental (cm) versus inclinometer (degrees) measurements; **B**, Scatter plot of foot versus tibial length (cm) relationship; **C**, Scatter plot of incremental distance plus foot length (cm) versus angle inclinometer (degrees) measurements. The symbols represent the individual data points of each subject.

impingement syndromes caused by the repeated forced DF that dancers undergo in demi-plié.[4,13,24] The modern dancers in this study exhibited greater ankle DF and less PF than has been reported in professional ballet dancers.[4,13] There are several plausible explanations for this. First, modern dancers can go their entire career without ever performing en pointe. While some modern dancers have trained en pointe, their training is often inconsistent. In this study, of the 15 dancers that indicated they had pointe training (Table 1), only 8 reported that training was continuous. Further, modern dance, unlike ballet, embraces more grounded movement such as hinges, primitive squats, and lunges that stretch the gastroc-soleus complex, thereby promoting increased ranges of DF. Finally, the dancers in this study were university and pre-professional level, with an average of 11 years of training and no professional experience. They have had less exposure to the choreographic demands of dance than their professional counterparts and, hence, are less likely to have developed the overuse injuries that predispose dancers to ankle DF limitation. Ankle ROM values of the dancers in this study were within the range previously reported for other ballet and modern dancers of similar age and skill level.[24,30,32]

Reliability

Studies show that goniometric ankle ROM measurements have good intra-rater reliability.[22,24,33,34] Reports on inter-rater goniometry reliability, however, are varied. Several studies have reported low to moderate inter-rater reliability for ankle DF,[12,22,35,36] while others reported *high* inter-rater agreement.[34,37,38] In this study, intra-rater correlations were *very high* for goniometric DF measurements, and inter-rater correlations were also *high* to *very high*, substantiating results of the latter three studies referenced above.

Few AROM PF goniometry reliability studies were found for comparison with this study.[12,24,34,39,40] This is most likely because PF restriction is of more concern to dancers than to other athletic or non-athletic populations. Previous reports on ankle PF goniometric intra-rater reliability ranged from 0.47 to 0.99,[12,24,34,39-41] and inter-rater reliability from 0.60 to 0.74.[34] Goniometric PF AROM intra- and inter-rater reliability in this study were both high, ranging from 0.84 to 0.89 (Tables 3 and 4). A plausible explanation for the higher than normal inter-rater reliability in this study is that our raters practiced the protocol to familiarize themselves with the measurement procedures. It is unclear if raters in previous studies did the same.

In addition to goniometry, the inclinometer has been shown to be a reliable tool for assessing ankle ROM.[15,18,24,42,43] Studies report higher ICC values and lower variability and measurement error than that typically observed with goniometry.[24,42] Bennell and colleagues reported ICCs of 0.97 to 0.98 and SEM of 1.1 to 1.4 for inter- and intra-rater ankle DF reliability.[18] McClinton and associates reported ICCs of 0.93 to 0.97 (knee bent posture) with SEM of 1.0 to 1.5 for between-day reliability of ankle DF measured with an inclinometer.[42] Russell and coworkers reported ankle PF intra-tester reliability ICC of 0.99, with a coefficient of variability (CV) of 1% (compared with 7% and 10% for goniometry), using one examiner.[24] The results of this study support these findings. Ant-DF, post-DF, and PF intra-rater inclinometer ICCs ranged from 0.87 to 0.94 with SEM of 1° to 2° (Table 3). Inter-rater reliability for these same methods ranged from 0.94 to 0.98 with SEM of 1° to 2° (Table 4). With ankle PF ROM, inclinometer measurement demonstrated higher correlations and lower SEMs than the goniometer for both intra- and inter-rater reliability.

The weightbearing lunge position is a common technique for assessing ankle DF ROM.[25,26,30,42,44,45] Goniometric, inclinometer, and distance measures have all been shown to be reliable methods of assessing ankle DF ROM in the DF lunge position.[18,26,42] Previous studies reported intra-rater reliability ICC of 0.66 to 0.98, and inter-rater reliability of 0.82 to 0.99 for the distance method.[18,26] The results of this study demonstrate *high* intra-rater ($r = 0.87$) and *very high* ($r = 0.95 – 0.99$) inter-rater correlations, substantiating previous reports.[18,26]

Intra-rater and inter-rater SEM for all methods in this study were less than 4° for angular measurements and less than 1 cm for linear measures. According to Jones and colleagues, a 3.6 cm accuracy is equivalent to a margin of error of 5.5°.[26] Using this conversion ratio, the distance method SEM of 0.90 cm was equivalent to a 1.4° margin of error. This margin of error compares well with that found in the goniometric and inclinometry measurements in this study.

Inter-method Correlations

Comparison of inclinometer and goniometer means revealed *high* correlations for ankle DF. Goniometric and inclinometer post-DF mean angular displacements were equal. However, there was a discrepancy of greater than 10º between ant-DF and goniometric or post-DF values. Post-DF and ant-DF placements are not truly parallel due to the increasing width of the leg from ankle to knee; therefore, the ant-DF placement is further away from the vertical, resulting in greater angular displacement. While the differing angular displacements have no effect on reliability calculations, the means of these two placements should not be compared. Goniometric and post-DF values were in agreement with measurements conducted using X-ray[24] and 3-D motion capture of functional DF in demi-plié.[32] Ant-DF measurement was more time consuming compared to post-DF, as it required an additional measurement to determine the tibial midpoint.

Comparison of inclinometer and goniometer PF measurement revealed *high* correlations. No other inter-instrument correlation studies of PF measurement were found. Russell and associates reported active non-weight-bearing inclinometer PF values that exceeded goniometric values by more than 10°.[24] In this study, inclinometry

PF values exceeded goniometric values by 9° (Table 3). Russell and associates concluded that goniometry and inclinometry appear to evaluate ankle plantar flexion differently.[24] Several reasons for the higher inclinometry values have been suggested. Goniometric assessment of ankle PF ROM requires estimation of the ankle joint axis and alignment of the goniometer arms with the fifth metatarsal and fibula, bony landmarks that are not easy to locate consistently.[24] Goniometric assessment, therefore, does not reflect single joint motion; rather, it includes ankle PF, subtalar, and midtarsal rotations. Inclinometry assesses talar position relative to the tibia without requiring selection of an axis of rotation.[13]

Incremental Measurement

A goal of this part of the study was to calculate a conversion ratio that would describe the relationship between the lunge distance measure (cm) and DF angular displacement. Bennell and coworkers suggested that a change in DF distance of 1 cm may represent 3º of angular displacement (i.e., 1:3 ratio).[18] This was determined by plotting the maximum DF angle against the maximum distance for each subject. Bennell and coworkers re-visited this distance-to-angle relationship in a study examining DF in female ballet dancers and controls, aged 8 to 11 years.[30] In that study, they implied a 2:1 ratio of distance (cm) to angle (degrees) when they reported that dancers had 25% and 12% greater DF than controls using the distance measure and inclinometer, respectively. Although comparison of goniometer and inclinometer to distance found acceptable reliability, there was no consistent relationship that allowed for calculation of a conversion ratio. This was primarily due to the influence of anthropometric measures, specifically tibia and foot proportions. Bennell and coworkers acknowledged that validity of the distance measurement relates to whether foot and tibia length are proportional between subjects.[18] The anthropometric factors of foot and tibial length introduced more variability, further complicating the effort to find a relationship between the distance measure and angular measures.

Subjects in this study exhibited a range of ± 5° of DF ROM at each cm interval, attributed to the differing foot to tibia ratio (Fig. 3A). This presents a clinical difficulty in terms of application and interpretation. The original premise of the distance test was its simplicity. If there were a simple centimeter-to-degree conversion (e.g., 1 cm to 3°), this would provide a relatively easy way for clinicians to interpret the measurement.

Experienced Versus Novice Raters

Clinical experience appeared to have no effect on inclinometry or distance measure, but had significant effect on goniometric ankle ROM measurements. Considering a standard error of 0.9° and a confidence interval range of ± 4°, a mean difference of 4.2° for PF measurements was within the range of acceptable error for functional goniometric measurements. However, a mean difference of 7.0° for DF, with a standard error of 0.7° and confidence interval range of ± 3°, was indicative of a true difference between experienced and novice raters. We have no way of determining whether the experienced or novice clinicians were closer to the "true value." This points to the potential difficulty in aligning accurately and then reading goniometers.

Limitations

There was incomplete rater blinding in this study. Secondary to time constraints and subject availability, instruments were not covered and read by an independent therapist. However, these circumstances mirror the exact situation one would find in a clinical setting where the evaluating therapist is expected to measure and accurately read the results of the instrument being used. Raters were not blinded to individual scores, but separate data sheets were used to record results for each rater, day, and subject trial to eliminate as much bias as possible. Raters could not repeat trials consecutively for the same subject, to further ensure blinding to previously collected data.

Fatigue of the rater's hand due to holding the test subject's lower limb during the PF measure may have affected the measurement when moving the inclinometer from the tibia to the talonavicular joint, causing a potential source of error. However, the raters stabilized their hand holding the lower limb on the table while moving the inclinometer hand and were free to start the measurement again if they felt their stabilization was compromised.

Only two trials were conducted for each measurement. A larger number of trials may have produced individual means closer to the group mean, but previous studies have produced reliable and valid results utilizing just two trials.[34,35,46]

There was the possibility of measurement error in reading the inclinometer resulting from placement over the two designated lower extremity positions. With all inclinometer measurements, the placement on the skin or bony surface introduces a measure of error due to surface irregularities. Every attempt was made to ensure the inclinometers were level at the time of reading. Correct placement of the axis of rotation of goniometers at the joint being measured has similar problems.

No attempt was made to maintain subtalar joint neutral during measurement. Although subtalar joint neutral position may be an optimal position to measure ankle ROM, it has demonstrated poor to fair inter- and intra-rater reliability.[34,47] The investigators felt that measurement of weightbearing DF with uncorrected subtalar joint neutral would yield the most accurate representation of functional DF movements (e.g., demi-plié) in dance. Dancers may perform barefooted or in ballet slippers with no foot support; therefore, some midfoot pronation often occurs during demi-plié.

The results of this study can only be generalized to university level and pre-professional modern dancers, but selection and placement of the instruments in a weightbearing posture has application to all patients. Future studies of inclinometer, goniometer, and lunge measurement should investigate larger sample sizes, along with comparisons to the general population. Additionally, investigations of the effects of different dance techniques, pathology at the ankle and knee, and sensitivity to change following intervention are warranted.

Conclusion

Functional ankle DF in modern dancers is best quantified using an inclinometer (posterior placement) in the weightbearing lunge position. Inclinometer posterior placement ankle DF values are within the range reported for goniometric, x-ray,[24] and motion capture measurements of ankle DF.[32] Non-weightbearing active ankle PF in modern dancers is best quantified with inclinometer placement on the dorsum of the foot. Inclinometer measurements in this study were reliable, the values correlated well with goniometric values, and it was the simplest and least time consuming of the three tools studied. These investigators do not recommend use of the distance method in a clinical setting to quantify ankle DF and PF in dancers. The centimeter values cannot be easily converted to an angular measure. Additionally, the measurements are subject-specific and cannot be used as a normative measure to compare DF range between subjects, populations, or age groups.

Acknowledgments

This research was conducted as part of the clinical affiliation requirements at the ADAM Center at Long Island University. The investigators are grateful to Dana Hash-Campbell from the Long Island University Dance Department and The Ailey School for their assistance in the recruitment of subjects and the dancers for their willingness to participate as subjects. The investigators wish to thank J. Adam Noah, PhD, for his assistance in statistical analysis and Lester Mayers, M.D., for his editorial comments.

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