Published in final edited form as:

Foot (Edinb). 2009 September 1; 19(3): 149–155. doi:10.1016/j.foot.2009.03.004.

Reliability and Validity of Measures of Hammer Toe Deformity Angle and Tibial Torsion

Kwon OY¹, Tuttle LJ², Commean PK³, and Mueller MJ⁴

¹ Department of Physical Therapy, College of Health Science, Yonsei University, South Korea

² Movement Science Program, Washington University, St. Louis, MO

³ Mallinckrodt Institute of Radiology, Washington University, St. Louis, MO

⁴ Program in Physical Therapy, Washington University, St. Louis, MO

Introduction

A hammer toe deformity is defined as dorsiflexion at the metatarsophalangeal joint (MTPJ), plantarflexion at the proximal interphalangeal joint (PIPJ) and either normal position or dorsiflexion at the distal interphalangeal joint (DIPJ) (Tollafild DR and Merriman LM 95). Hammer toe deformity is a common problem and source of discomfort in the forefoot. Hammer toe deformity may cause pain and callus formation under the head of the MTPJ. In people with diabetes who have diabetic peripheral neuropathy, motor neuropathy causes foot intrinsic muscle weakness contributing to hammer toe deformity (Greenman et al., 2005). Hammer toe deformity is frequently found in the diabetic foot and it has been shown to increase forefoot plantar pressure and the risk of ulceration (Mueller et al., 2003).

The measurements of foot deformity by goniometry have been criticized for poor validity and reliability (McPoil and Hunt, 1995). Buell et al. (Buell et al., 1988) reported a fair to good association between goniometric and radiographic measurements for the first MTPJ and Hopson et al. (Hopson et al., 1995) reported that all static measurement techniques for the first MTPJ were reliable. While reliability of goniometric measures has been studied (Menadue et al., 2006; Piva et al., 2006; Pua et al., 2008), no study has examined the reliability and validity of the 3D digitizer and CT methods for measuring the MTPJ angle of toes 2–4. Measurements from three dimensional images of the foot from computed tomography (CT) scans have been shown to be valid and reliable for measuring bony structures and the MTPJ angle in feet with hammer toe deformity (Commean et al., 2002; Mueller et al., 2003).

Tibial torsion is the rotational twist of the tibia in the transverse plane (Valmassy and Stanton, 1989) and is often evaluated in orthopedic clinics. Clinical measurement of tibial torsion is performed indirectly by goniometer or a foot printing method in the clinic (Hazlewood et al., 2007). Measurement of tibial torsion using CT, ultrasound, and magnetic resonance imaging has been described (Butler-Manuel et al., 1992; Hudson, 2008; Schneider et al., 1997). Stuberg et al. (Stuberg et al., 1991) reported the mean difference between goniometric and CT measures of tibial torsion was 5 degrees. We are not aware of any literature describing the use of a 3D digitizer to measure tibial torsion. Since CT scanning is difficult to use, expensive, and rarely

available in the clinical setting, it is worthwhile to establish the reliability and validity of clinical measurements such as goniometry and 3D digitizing.

Determining the reliability and validity of clinical measures of MTPJ angle in hammer toe deformity and the tibial torsion that may be associated with foot dysfunctions is critical for the study of hammer toe deformity as well as clinical decision making regarding treatment strategies that may include the use of orthotic devices, modifications of footwear, and corrective operative procedures in individuals who have hammer toe deformity and foot dysfunction. The purposes of this study are to determine: (1) reliability of using a 3D digitizer (Metrecom) and computed tomography (CT) to measure MTPJ angle for toes 2–4; (2) reliability of goniometer, 3D digitizer, and CT to measure tibial torsion; (3) validity of MTPJ angle measures for toes 2–4 using goniometry and 3D digitizer compared to CT (gold standard) and (4) validity of tibial torsion measures using goniometry and 3D digitizer (Metrecom) compared to CT (gold standard).

Methods

Subjects

Twenty-nine subjects participated in this study (16 females and 13 males). Twenty-seven feet (10 female feet, 17 male feet) with hammer toe deformity and a mean age of 36 ± 17 years were designated as the hammer toe group (HT). Thirty-one feet (22 female feet, 9 male feet) without hammer toe deformity and a mean age of 29 ± 8 years were designated as the non-hammer toe group (NHT). Subjects with noticeable metatarsal phalangeal joint hyperextension (beyond 20 degrees of extension) that was visible during standing and sitting were classified in the HT. Surprisingly, males were more likely to be in the hammer toe group than females (Table 1). This gender difference likely also contributed to a significant difference in weight, height, and foot length between the HT and the NHT groups ($p < 0.01$, Table 1). Individuals with a history of foot surgery, peripheral neuropathy, systemic disease, neurological disease, Morton's neuroma, severe foot deformity, foot ulceration, claustrophobia, cognitive impairment or malignant tumor were excluded from this study. Participants were recruited from among the staff and students at Washington University, and outpatients from the Department of Orthopedic Surgery at Barnes-Jewish Hospital, Washington University Medical Center. All subjects provided informed consent as approved by the Washington University School of Medicine Human Research Protection Office.

Goniometer Measures

Range of motion of the MTPJ was measured with the participant in a long sitting position with the ankle in 30 degrees of plantarflexion. An ankle board fixed at 30 degrees of ankle plantarflexion was used to maintain the same ankle position for all tests. The stationary arm of the goniometer was placed on the dorsal midline of the metatarsal bone of the joint to be measured and the axis was placed on the dorsal midline of the MTPJ to be measured. The moving arm of the goniometer was placed on the dorsal midline of the proximal phalanx bone of the MTPJ to be measured (Reese NB and Bandy WB, 2002). Repeated measures of MTPJ angle were not performed as goniometric measures have been shown to be reliable for the same examiner over time. (Menadue et al., 2006; Pua et al., 2008)

To measure tibial torsion, the participant was positioned in prone with the knee flexed to 90 degrees and the ankle positioned in neutral. The examiner first found the middle of the medial malleolus in the anterior-posterior direction at the level of the ankle joint and marked a dot at the midpoint using a pen. Next, the most prominent aspect of the lateral malleolus was marked with a dot using a pen. The examiner then drew a line on the plantar surface of the heel that connected the dots on the medial and lateral malleoli to mark the transmalleolar axis (Milner

and Soames, 1998; Staheli et al., 1985; Valmassy and Stanton, 1989). One arm of the goniometer was then aligned with the transmalleolar axis that had been drawn on the plantar surface of the heel and the other arm was aligned perpendicular to the long axis of the thigh and the angle between these two lines was recorded as the angle of tibial torsion (Stuberg et al., 1991) (Figure 1). The participant was asked to stay relaxed to minimize lower leg rotation during the measurements. To determine the intra-tester reliability of the tibial torsion measures, repeated measures with the same protocol were performed on two separate test days ranging from within 2–5 days. Repeated measurements of thirty-two feet were tested to determine reliability, 58 feet were tested total.

3D Digitizer Measures

Using a 3D digitizer (Metrecom; Faro Medical Technologies (US) Inc, 125 Technology Park, Lake Mary, FL), the examiner measured the MTPJ angle of toes 2–4 and the angle of tibial torsion. The MTPJ angle was measured with the participant in long sitting with the ankle in 30 degrees of plantarflexion and held in position with an ankle board. The examiner placed the tip of the 3D digitizer probe at the proximal and distal shaft of the metatarsal bone and the proximal phalanx (these points were marked with a pen) and the digitizer measured the positions of these points in space (Figure 2). Care was taken to apply light pressure with the probe to avoid movement of the toes and so that movement of the skin over the bone did not affect the values recorded. The MTPJ angle was calculated by trigonometry:

$$\text{Metatarsal bone angle } \Theta_M = \arctan(y_{m2} - y_{m1}) / (x_{m2} - x_{m1})$$

y_{m2} : y axis coordinate of proximal shaft of metatarsal bone

y_{m1} : y axis coordinate of distal shaft of metatarsal bone

x_{m2} : x axis coordinate of distal shaft of metatarsal bone

x_{m1} : x axis coordinate of proximal shaft of metatarsal bone

$$\text{Proximal phalanx bone angle } \Theta_P = \arctan(y_{p2} - y_{p1}) / (x_{p2} - x_{p1})$$

y_{p2} : y axis coordinate of distal shaft of phalanx bone

y_{p1} : y axis coordinate of proximal shaft of phalanx bone

x_{p2} : x axis coordinate of distal shaft of phalanx bone

x_{p1} : x axis coordinate of proximal shaft of phalanx bone

$$\text{Angle of MTPJ } \Theta_{MTP} = \Theta_M + \Theta_P$$

The angle of tibial torsion was measured with participants positioned in long sitting with the hip joint in a neutral position (no hip internal or external rotation and the femoral condyles were equidistant from the supporting surface). The lower leg was positioned with the tibial tuberosity pointing directly up. The tip of the 3D digitizer probe was placed at the midpoint of the medial malleolus and the most prominent aspect of the lateral malleolus (both points were

previously marked as described above) and the digitizer then measured the position of these points in space. The angle of tibial torsion was calculated by trigonometry:

$$\tan \Theta = (y_2 - y_1) / (x_2 - x_1)$$

$$\Theta = \arctan (y_2 - y_1) / (x_2 - x_1)$$

y_2 : y axis coordinate of medial malleolus

y_1 : y axis coordinate of lateral malleolus

x_2 : x axis coordinate of medial malleolus

x_1 : x axis coordinate of lateral malleolus

To determine the intrarater reliability of the 3D digitizer measures of MTPJ angle and angle of tibial torsion, repeated measures with the same protocol were performed on two separate test days, ranging from 2–5 days apart. Thirty-two feet were tested for reliability purposes and fifty-eight feet were tested total.

CT Measures

The MTPJ angle of toes 2–4 and the angle of tibial torsion were measured from CT data (Commean et al., 2002). CT scanning was performed with the subject in a long sitting position with the ankle positioned in 30 degrees of plantarflexion with an ankle board to ensure the same testing position as the goniometer and metrecom measures. The participant's hip was positioned in neutral (no internal or external rotation) and adhesive tape was used to stabilize the leg. The following CT parameters were used to acquire the scans for all subjects: 12 mm table increment per gantry rotation, 16×0.75 mm collimation, 220 mAs, 120 kVp, and a 512×512 matrix. The Sensation 16 has 16 parallel x-ray sources that were set to a collimation of 0.75 mm. Each subject was scanned from the knees to the toes. The CT data was archived on DVD in DICOM format. A PC workstation was used for image processing and measurement. All images were reformed and analyzed using Analyze 7.0 software (Biomedical Imaging Resource, Mayo Clinic, Rochester MN). The MTPJ angle was measured from the maximum intensity projection of the lateral view image of each tested toe (Commean et al., 2002) (Figure 3). Frontal view CT images at the tibial plateau and malleoli were used to measure the angle of tibial torsion by superimposing the two slices using the Analyze 7.0 software (Stuberg et al., 1991; Widjaja et al., 1985). The angle of tibial torsion was measured by drawing an axis line through the distal ankle and proximal tibial plateau. The axis line was drawn by bisecting a slice at the tibial plateau (along an estimated long axis of the tibial ellipse) and bisecting a slice at the medial and lateral malleolus (axis through the most prominent point of the lateral malleolus and estimated bisection line of the medial malleolus on a slice just above the distal tibial joint). The angle of tibial torsion was measured as the angle between the two axis lines on the superimposed image (Stuberg et al., 1991) (Figure 4). To determine intrarater reliability of the measures of MTPJ angle and tibial torsion, repeated measures with the same protocol were performed on 2 separate test days by the same examiner with 2–5 days between testing times. Nineteen feet were tested for reliability measures and 58 feet were tested total.

Statistical Analysis

Intraclass Correlation Coefficients (ICCs 3,1) were used to determine the intrarater reliability of MTPJ angle and tibial torsion measures. Pearson correlation coefficients, standard error of the measurement (SEM), and difference scores were used to determine correlation, bias and dispersion between the different measurement methods. The SEM was used to estimate the reasonable limits of the true score for a person with any obtained score; therefore it is useful

in the interpretation of the reliability of a single score. Taking 2 SEMs $\pm$ the obtained value gives a 95% confidence interval for the true value. A repeated measures analysis of variance with post hoc t-tests were used to determine if there were differences between measures of hammer toe deformity and tibial torsion using goniometry, a 3D digitizer, or CT. All statistics were run on the entire study sample (HT+NHT groups combined).

Results

The 3D digitizer and CT measures of MTPJ angle had high intrarater reliability (ICC: 0.95–0.96 and 0.99 respectively) (Table 2). Goniometric, 3D digitizer and CT measures of the angle of tibial torsion had good intrarater reliability (ICC (95% CI) = 0.75 (0.54–0.87), 0.85 (0.70–0.92), 0.98(0.94–0.99), respectively.) The SEM for 3D digitizer and CT measures of MTPJ angle ranged from 2.64–3.35 and 1.42–1.47 degrees, respectively, across toes 2–4. The SEM for goniometry, 3D digitizer and CT measures of tibial torsion were 2.15, 1.74, and 0.72 degrees, respectively.

Goniometric and 3D digitizer measures of MTPJ angle were highly correlated with CT measures (gold standard) of MTPJ angle ($r=0.84$ – 0.90 , $r=0.84$ – 0.88 , respectively) and tibial torsion ($r=0.72$, $r=0.83$, Table 3). Although the scores were highly correlated, there were consistent differences between measurement techniques. These differences are characterized next with the mean difference between repeated individual measures and group mean differences.

The mean and standard deviation of the individual difference scores between goniometric measures of MTPJ angle and 3D digitizer measures of MTPJ angle for toes 2–4 and for tibial torsion were $-5.93(8.04)$, $-5.92(7.79)$, $-2.19(8.89)$, and $1.93(3.28)$ respectively. The mean and standard deviation of the individual difference scores between goniometric measures of MTPJ angle and CT measures of MTPJ angle for toes 2–4 and for tibial torsion were $-9.63(7.48)$, $-10.44(6.91)$, $-6.44(7.09)$ and $1.18(3.60)$ respectively. The mean and standard deviation of the individual difference scores between 3D digitizer measures of MTP angle and CT measures of MTPJ angle for toes 2–4 and for tibial torsion were $-3.67(7.15)$, $-4.52(8.28)$, $-6.44(7.09)$ and $-0.76(2.88)$.

Results of the repeated measures ANOVA indicated a significant difference between the measurement techniques. Post hoc t-tests indicated that goniometry, 3D digitizer, and CT measures were all significantly different from each other for measures of MTPJ angle ($p<0.001$). The difference between the group means of goniometric measures and CT measures of MTPJ angle was 9.4 degrees for toes 2–4 ($p<0.001$). The difference between the group means of 3D digitizer and CT measures of MTPJ angle was 4.7 degrees for toes 2–4 ($p<0.001$). Post hoc t-tests indicated that goniometry measures were significantly different from CT measures and 3D digitizer measures of tibial torsion ($p<0.002$). CT measures and 3D digitizer measures of tibial torsion were not significantly different ($p=0.112$). The difference between the group means of goniometric measures and CT measures of tibial torsion was 1.1 degrees ($p=0.002$). The difference between the group means of 3D digitizer measures and CT measures of tibial torsion was 0.8 degrees ($p=0.112$, Table 4). Data for individual groups is contained in Table 4 for descriptive purposes.

Discussion

Measurements of MTPJ angle and tibial torsion are used in the clinic to characterize foot and toe deformity, but the measures of foot deformity have been criticized for poor validity and reliability (McPoil and Hunt, 1995). Quantitative measures of hammer toe deformity or tibial torsion generally are not required for a general clinical examination, but reliable and

quantitative measures would be useful to assess severity of deformity and benefit of treatment interventions (i.e. surgery or exercise). In this study, we found that the 3D digitizer and CT data provided reliable methods for measuring MTPJ angle and angle of tibial torsion, and that goniometric and 3D digitizer methods of measuring MTPJ angle and tibial torsion were highly correlated with CT data, but not interchangeable.

Hopson et al. (1995) reported that static measures of the 1st MTPJ are reliable, however, the first MTPJ provides landmarks for goniometry that are more easily accessible (medial side of the great toe and the axis can be placed directly over the MTPJ axis) than landmarks for toes 2–4. Two goniometric techniques for toes 2–4 have been described. In the first method, the goniometer is placed over the dorsal side of the foot. The stationary arm is placed on the dorsal midline of the metatarsal bone to be measured and the axis is placed at the dorsal midline of the MTPJ to be measured. The moving arm is placed on the dorsal midline of the proximal phalanx of the joint to be measured (Reese NB and Bandy WB, 2002). In the second method, the goniometer is placed over the plantar surface of the foot. The stationary arm is placed parallel to and over the plantar midline of the metatarsal and the axis is positioned over the midpoint of the plantar surface of the MTPJ to be measured (Minor MAD and Minor SD, 1985). It was difficult to align the goniometer with the metatarsal on the plantar surface of the foot, so we used the first method to measure MTPJ angle for toes 2–4 in this study. Our results are specific to this particular measurement method and should not be generalized to other methods. In addition, there is not a standardized ankle position that is used when measuring MTPJ angle, even though MTPJ angle is affected by ankle position. If the ankle is in a dorsiflexed position, the passive tension of the flexor digitorum longus muscle would increase and the MTPJ angle will decrease. In a plantarflexed position of the ankle, the increased passive tension of the extensor digitorum longus muscle will increase the MTPJ angle. Because of this effect of the ankle joint on the MTPJ angle, we chose to standardize the ankle position in 30 degrees of plantarflexion during our measures, which is the approximate mid position from dorsiflexion (10 degrees) to plantarflexion (45–50 degrees) range of motion.

Several methods for measuring tibial torsion via goniometry have also been described. Tibial torsion can be measured with the subject in long sitting, sitting with the legs hanging over the edge of the table, supine, or prone (Jakob et al., 1980; Staheli and Engel, 1972). Piva et al. (Piva et al., 2006) reported that reliability of tibial torsion with the subject in a prone position was moderate (ICC=0.70), which is why we chose to measure tibial torsion with the subject in prone. Our results investigating reliability using these methods were similar to their reported values (ICC=0.75). Using a goniometer, the examiner measures the angle between a line through the knee axis and a line through the ankle axis (Tomberlin JP and Saunder HD, 1995), but the determination of obvious relevant bony landmarks for reference points is relatively difficult during clinical measures (Milner and Soames, 1998). In our study, the test-retest reliability of goniometric measures for tibial torsion was lower (ICC=0.75, SEM=2.15 degrees) than the 3D digitizer (ICC=.85, SEM=1.74 degrees) and CT scan measures (ICC=.98, SEM=0.72 degrees). It is possible that the unobvious landmarks for reference points account for the difference in reliability measures. Hudson (Hudson, 2008) reported that goniometric techniques for measuring tibial torsion had good to excellent reliability (ICC 0.84–0.90) with the subject in a sitting position, while Milner and Soames (Milner and Soames, 1998) reported that four indirect techniques (sitting, supine, goniometer attached to 2 hinged arm, and prone position) for measuring tibial torsion showed low repeatability (agreement less than 50% of the time) and poor correlation with direct measurement ($r<0.50$). In our study, the test-retest reliability of goniometric measures of tibial torsion was high (ICC=0.75, SEM=2.15 degrees). It is unclear why our results differ from these previous studies, but it is possible that different measurement techniques and positioning (prone vs. sitting) could account for the differences between the results of our study and those of Hudson et al. The study by Milner

and Soames reports results on a very small sample (4 cadavers and 3 in vivo), so it is possible that their results are due to a small sample size.

Previous studies have demonstrated the accuracy and reliability of 3D digitizers for measures in the foot (Mueller et al., 1993) and we found the 3D digitizer to be reliable for measuring MTPJ (ICC = 0.95–0.96, SEM=2.64–3.35 degrees) angle and tibial torsion (ICC = 0.85, SEM=1.74 degrees). Care was taken to minimize any skin or soft tissue movement when pressing the digitizer probe to the metatarsal and the toe when measuring the MTPJ angle, but it is possible that skin and soft tissue movement could have affected the reliability of our measures. When measuring tibial torsion, the examiner marked the landmarks before using the digitizer probe, but as mentioned previously, detecting landmarks for tibial torsion measures can be challenging and could have affected the reliability of our measures.

Previous studies, including this one, have demonstrated that measuring MTPJ angle (Commean et al., 2002) and tibial torsion (Jakob et al., 1980) via CT scan is reliable and considered the gold standard. To our knowledge, this study is the first to attempt to validate clinical measures of MTPJ angle and tibial torsion angle by comparing goniometry and 3D digitizer methods with the gold standard CT measures. We found that goniometric measures of MTPJ angle and tibial torsion were highly correlated with CT measures of MTPJ angle and tibial torsion. The difference in group means between the goniometric measures and CT measures was 9.4 degrees for the MTPJ angle and 1.1 degrees for tibial torsion measures.

The mean difference between individual scores of goniometric measures and CT measures was -6.44 – -10.44 for the MTPJ angle and 1.18 for tibial torsion measures. Underestimation of the MTPJ angle by goniometric measures compared to CT measures was most likely due to soft tissue over the dorsum of the foot. Soft tissue on the dorsal side of the foot impedes close placement of the goniometer to the metatarsal bone and MTPJ. In addition, MTPJ angle can be influenced by ankle joint position. Passive tension of the extensor digitorum longus will be increased with ankle plantarflexion and decreased with ankle dorsiflexion. Because of this, an ankle board was used in all testing conditions to maintain a consistent ankle position. Although goniometric measures of MTPJ angle were highly correlated with the gold standard CT measures, underestimation of the MTPJ angle should be considered during goniometric measures. The results from this study indicate that goniometric measures of MTPJ angle are good indicators of the true MTPJ and tibial torsion angles, but that goniometric measures are not interchangeable with the gold standard CT measures of MTPJ angle and tibial torsion.

We found that 3D digitizer measures of MTPJ angle and tibial torsion were highly correlated with CT measure of MTPJ angle and tibial torsion. The difference in group means in MTPJ angle between 3D digitizer measures and CT measures was 4.7 degrees and was 0.8 degrees for tibial torsion. The mean difference between individual scores of 3D digitizer measures and CT measures was -3.67 – -6.44 for the MTPJ angle and -0.76 for tibial torsion measures. The mean difference between 3D digitizer and CT scan was less than the mean difference between goniometry and CT scan. The 3D digitizer measures may be closer to the CT values than the goniometry measures because the tip of the probe more closely approached the metatarsal and proximal phalangeal bone than the goniometer. 3D digitizer measures are good indicators of the actual MTPJ and tibial torsion angles but the measurement techniques should not be interchanged.

Several methods have been suggested for measuring tibial torsion using CT scans and results appear dependant upon selection of axes. The examiner must select an axis from several possible reference axes on the proximal and distal tibia. Laasonen et al. (Laasonen et al., 1984) measured tibial torsion in 5 different ways and reported that the most consistent values occurred based upon an estimated long axis of the tibial ellipse for the transverse axis of the

proximal tibia and an axis through the centers of the fibula and tibia on a slice just above the distal tibia-fibula joint. Based on this report, we selected a slice along an estimated long axis of the tibial ellipse for the proximal measure. However, we selected a distal axis through the most prominent point of the lateral malleolus and an estimated bisection of the medial malleolus on a slice just above the distal tibia-fibula joint to match the anatomical landmarks chosen for the goniometry and 3D digitizer measures (Figure 4).

There are several limitations in this study. First, we did not test the intrarater reliability of the goniometric measures of MTPJ angle. However, goniometric measures have been found to be reliable from the same examiner over time.(Menadue et al., 2006; Piva et al., 2006) Second, we measured tibial torsion in prone using a goniometer and measured tibial torsion in long sitting for the 3D digitizer and CT measures. It is possible that this difference in positioning contributed to a lower correlation between goniometric measures of tibial torsion and CT measures of tibial torsion. We chose to use a prone position for measuring tibial torsion with a goniometer because we were better able to control the position of the leg and were better able to align the proximal and distal axes to make the measures. Third, there are multiple methods in the literature for goniometric measures of MTPJ angle and tibial torsion. The data from this study should not be generalized beyond the measurement methods with the specific landmarks that we have described.

Measurements of MTPJ angle and tibial torsion are used in the clinic to measure toe and foot deformity, but little evidence supports the reliability or validity of these measures. We found that 3D digitizer and CT scan measures of MTPJ angle and goniometric, 3D digitizer and CT scan measures of tibial torsion are reliable. To our knowledge, this is the first study to demonstrate that goniometer and 3D digitizer measures of MTPJ angle and tibial torsion measures are highly correlated with the gold standard CT method indicating good validity of measures. While these measures are good indicators of the actual MTPJ angle and the angle of tibial torsion, these measurement methods cannot be interchanged. Clinically, when making measures of MTPJ angle or tibial torsion, the same measurement technique should be used when making repeated measures and one should not substitute a goniometric measure for a 3D digitizer measure and vice versa.

Goniometric and 3D digitizer methods to measure hammer-toe deformity and tibial torsion are reliable and validated with radiological measures. Additional research is needed to establish Interrater reliability. These measures can be used to study contributing causes of foot deformity and assess outcomes of treatment interventions.

Acknowledgments

The authors acknowledge the funding from the following sources that helped support this work: PODS I Award from the Foundation for Physical Therapy (Tuttle), RO1HD36895 (Mueller) and T32 HD007434-14 (Mueller, Tuttle); Sabbatical funding from Yonsei University (Kwon).

Reference List

- Buell T, Green DR, Risser J. Measurement of the first metatarsophalangeal joint range of motion. *Journal of the American Podiatric Medical Association* 1988;78:439–448. [PubMed: 3171958]
- Butler-Manuel PA, Guy RL, Heatley FW. Measurement of tibial torsion--a new technique applicable to ultrasound and computed tomography. *British Journal of Radiology* 1992;65:119–126. [PubMed: 1540801]
- Commean PK, Mueller MJ, Smith KE, Hastings M, Klaesner J, Pilgram T, Robertson DD. Reliability and validity of combined imaging and pressures assessment methods for diabetic feet. *Archives of Physical Medicine and Rehabilitation* 2002;83:497–505. [PubMed: 11932851]

- Greenman RL, Khaodhlar L, Lima C, Dinh T, Giurini JM, Veves A. Foot small muscle atrophy is present before the detection of clinical neuropathy. *Diabetes Care* 2005;28:1425–1430. [PubMed: 15920063]
- Hazlewood ME, Simmons AN, Johnson WT, Richardson AM, van der Linden ML, Hillman SJ, Robb JE. The Footprint method to assess transmalleolar axis. *Gait & Posture* 2007;25:597–603. [PubMed: 16904892]
- Hopson MM, McPoil TG, Cornwall MW. Motion of the first metatarsophalangeal joint. Reliability and validity of four measurement techniques. *Journal of the American Podiatric Medical Association* 1995;85:198–204. [PubMed: 7738816]
- Hudson D. A comparison of ultrasound to goniometric and inclinometer measurements of torsion in the tibia and femur. *Gait & Posture* 2008;28:708–710. [PubMed: 18555685]
- Jakob RP, Haertel M, Stussi E. Tibial torsion calculated by computerised tomography and compared to other methods of measurement. *Journal of Bone and Joint Surgery* 1980;British Volume 62-B:238–242.
- Laasonen EM, Jokio P, Lindholm TS. Tibial torsion measured by computed tomography. *Acta Radiol Diagn (Stockh)* 1984;25:325–329. [PubMed: 6485863]
- McPoil TG, Hunt GC. Evaluation and management of foot and ankle disorders: present problems and future directions. [Review] [16 refs]. *Journal of Orthopaedic & Sports Physical Therapy* 1995;21:381–388. [PubMed: 7655482]
- Menadue C, Raymond J, Kilbreath SL, Refshaug KM, Adams R. Reliability of two goniometric methods of measuring active inversion and eversion range of motion at the ankle. *BMC Musculoskelet Disord* 2006;7:60. [PubMed: 16872545]
- Milner CE, Soames RW. A comparison of four in vivo methods of measuring tibial torsion. *Journal of Anatomy* 1998;193:139–144. [PubMed: 9758144]
- Minor, MAD.; Minor, SD. Patient evaluation methods for the health professional. Reston Publishers; Reston, VA: 1985.
- Mueller MJ, Hastings MK, Commean PK, Smith KE, Pilgram T, Robertson DD, Johnson JE. Forefoot structural predictors of plantar pressures during walking in people with diabetes and peripheral neuropathy. *Journal of Biomechanics* 2003;36:1009–1017. [PubMed: 12757810]
- Mueller MJ, Host JV, Norton BJ. Navicular drop as a composite measure of excessive pronation. *Journal of the American Podiatric Medical Association* 1993;83:198–202. [PubMed: 8473991]
- Piva SR, Fitzgerald K, Irrgang JJ, Jones S, Hando BR, Browder DA, Childs JD. Reliability of measures of impairments associated with patellofemoral pain syndrome. *BMC Musculoskelet Disord* 2006;7:33. [PubMed: 16579850]
- Pua YH, Wrigley TV, Cowan SM, Bennell KL. Intrarater test-retest reliability of hip range of motion and hip muscle strength measurements in persons with hip osteoarthritis. *Archives of Physical Medicine and Rehabilitation* 2008;89:1146–1154. [PubMed: 18503813]
- Reese, NB.; Bandy, WB. Joint range of motion and muscle length testing. W.B. Saunders Co.; Philadelphia: 2002.
- Schneider B, Laubenberger J, Jemlich S, Groene K, Weber HM, Langer M. Measurement of femoral antetorsion and tibial torsion by magnetic resonance imaging. *British Journal of Radiology* 1997;70:575–579. [PubMed: 9227249]
- Staheli LT, Corbett M, Wyss C, King H. Lower-extremity rotational problems in children. Normal values to guide management. *Journal of Bone and Joint Surgery American Volume* 1985;67:39–47.
- Staheli LT, Engel GM. Tibial torsion: a method of assessment and a survey of normal children. *Clin Orthop Relat Res* 1972;86:183–186. [PubMed: 5047787]
- Stuberg W, Temme J, Kaplan P, Clarke A, Fuchs R. Measurement of tibial torsion and thigh-foot angle using goniometry and computed tomography. *Clin Orthop Relat Res* 1991;208–212. [PubMed: 1934735]
- Tollafild, DR.; Merriman, LM. Assessment of the lower limb. In: Merriman, LM.; Tollafild, DR., editors. *Assessment of the locomotor system*. Churchill Livingstone; 1995. p. 139–191.
- Tomberlin, JP.; Saunder, HD. Evaluation, treatment, and prevention of. Saunders Group; Chaska, MN: 1995.
- Valmassy R, Stanton B. Tibial torsion. Normal values in children. *Journal of the American Podiatric Medical Association* 1989;79:432–435. [PubMed: 2778678]

Widjaja PM, Ermers JW, Sijbrandij S, Damsma H, Klinkhamer AC. Technique of torsion measurement of the lower extremity using computed tomography. *Journal of Computer Assisted Tomography* 1985;9:466–470. [PubMed: 3989039]

Figure 1.
Aligning the transmalleolar axis with the axis of the tibia.

Figure 2.
3D digitizer, measurement of MTPJ angle

Fig 3. Lateral view maximum intensity projection through the third metatarsal. Angle BAD is measured to determine hammer toe deformity angle.

Fig. 4.

a) A slice from a CT scan at the level of the tibial plateau, b) A slice just above the distal tibial joint, medial and lateral malleoli, c) The two slices (a) and (b) from the tibial plateau and distal tibial joint have been superimposed, and d) Angle measurement of the tibial torsion performed on the superimposed image.

Table 1

Descriptive characteristics of the subjects

Characteristic mean (SD)	Group	
	HT	NHT
Age (years)	32(14)	29(8)
Gender		
Female feet (%)	10(27%)	22(71%)*
Male feet (%)	17(63%)	9(29%)*
Weight (kg)	78.3(14.2)	63.2(13.4)
Height (cm)	173.2(9.1)	164.4(9.6)*
Foot length(cm)	258.3(16.9)	243.7(23.3)*
BMI	26.4 (3.4)	23.2 (3.1)

HT, hammer toe deformity; NHT, non-hammer toe deformity

*
p<0.01

Table 2

Test-retest reliability of MTPJ angle measurement using 3D digitizer and CT scan

Group	Joint		3D Digitizer ICCs (95%CI) [SEM,°]	CT-scan ICCs (95%CI) [SEM,°]
HT + NHT	2 nd toe	MTP	0.96 (0.92–0.98) [2.92]	0.99 (0.98–0.99) [1.42]
	3 rd toe	MTP	0.95 (0.90–0.98) [3.35]	0.99 (0.99–0.99) [1.47]
	4 th toe	MTP	0.96 (0.92–0.98) [2.64]	0.99 (0.98–0.99) [1.42]

Table 3

Correlation between measurement techniques of MTPJ angle and tibial torsion

		3D digitizer	CT scan
2nd toe	Goniometer	0.84	0.86
	3D digitizer		0.88
3 rd toe	Goniometer	0.87	0.90
	3D digitizer		0.85
4 th toe	Goniometer	0.79	0.84
	3D digitizer		0.84
Tibial torsion	Goniometer	0.72	0.72
	3D digitizer		0.83

*
p<0.01

Table 4

Mean and standard deviation of MTPJ and tibial torsion angle according to measurement techniques

Group	Joint	Goniometer	3D digitizer	CT-scan
HT	2 nd toe MTP	51.2±11.1	55.3±13.9	58.6±11.9
	3 rd toe MTP	50.9±12.6	54.51±14.0	59.0±13.2
	4 th toe MTP	40.2±14.0	40.4±13.6	48.3±12.6
	Tibial torsion	33.4±4.9	31.7±5.1	32.7±6.15
NHT	2 nd toe MTP	28.8±6.0	33.3±8.0	40.2±10.0
	3 rd toe MTP	26.9±6.5	34.8±8.6	39.4±8.8
	4 th toe MTP	21.7±6.7	25.6±8.2	30.1±9.4
	Tibial torsion	33.3±3.8	31.2±3.9	31.6±4.0
HT+NHT	2 nd toe MTP*	39.2±14.2	45.2±14.6	48.8±14.2
	3 rd toe MTP*	38.1±15.5	44.0±15.0	48.5±14.7
	4 th toe MTP*	30.3±14.1	32.5±13.2	38.6±14.2
	Tibial torsion**	33.3±4.3	31.4±4.5	32.2±5.1

* all measurement values are significantly different from one another (P<.001)

** significant difference between goniometer and CT measurement values, but no significant difference between 3D digitizer and CT measurement values

Table 5

Mean (SD) difference between individual measures.

	Goniometry-3D Digitizer	Goniometry-CT	3D Digitizer-CT
2 nd MTPJ angle	−5.95 (8.04)	−9.63 (7.48)	−3.67 (7.15)
3 rd MTPJ angle	−5.92 (7.79)	−10.44 (6.91)	−4.52 (8.28)
4 th MTPJ angle	−2.19 (8.89)	−8.63 (7.58)	−6.44 (7.09)
Tibial Torsion	1.93 (3.28)	1.18 (3.60)	−0.76 (2.88)