- Trabajo realizado por el equipo de la Biblioteca Digital de la Fundación Universitaria San Pablo-CEU

- Me comprometo a utilizar esta copia privada sin finalidad lucrativa, para fines de investigación y docencia, de acuerdo con el art. 37 del T.R.L.P.I. (Texto Refundido de la Ley de Propiedad Intelectual del 12 abril 1996)

Relationship Between the Subtalar Joint Inclination Angle and the Location of Lower-Extremity Injuries

Michael R. Pierrynowski, PhD*
Eric Finstad, BHSc(PT)*
Marta Kemecsey, BHSc(PT)*
Jade Simpson, BHSc(PT)*

This study hypothesized that individuals who have a history of knee pain during repetitive weightbearing activities have a higher subtalar joint inclination angle than those with a history of foot pain. Study participants were selected on the basis of results of a written questionnaire that asked about the site and cause of injury and pain frequency and intensity. Pain items were graded on a 7-point Likert scale. Subjects were mainly young (18 to 32 years of age), healthy university students who had a history of knee pain (knee group) or foot pain (foot group) during weightbearing activity. Both foot and lower-leg kinematic data were used to estimate the magnitude of each participant's subtalar joint inclination angle. These data were obtained while participants performed a series of open- and closed-kinetic-chain motions. The subtalar joint inclination angle was significantly greater for the knee group than for the foot group. The results of this study support the hypothesis that a higher subtalar joint inclination angle may predispose an individual to knee pain, and a lower subtalar joint inclination angle to foot pain. (J Am Podiatr Med Assoc 93(6): 481-484, 2003)

The subtalar joint is formed by separate articulations between the talus superiorly and the calcaneus inferiorly.[1] Although the motion between the talus and calcaneus is complex,[2] it typically has been considered a uniaxial joint with pronation and supination movements about the subtalar joint axis.[3] There have been many attempts to locate the subtalar joint axis within a person's foot using this mechanical linkage model. The cadaver studies of Inman[4] have been widely cited to suggest that the mean ± SD subtalar joint inclination angle relative to horizontal is 42° ± 9°, with lower and upper bounds of 20.5° and 68.5°.

*Human Movement Laboratory, School of Rehabilitation Science, McMaster University, Hamilton, Ontario, Canada.
Corresponding author: Michael R. Pierrynowski, PhD, Human Movement Laboratory, School of Rehabilitation Science, McMaster University, 1400 Main St W, Hamilton, Ontario, Canada L8S 1C7.

The most accepted estimate of average subtalar joint inclination angle (42°) results in an approximately equal amount of frontal plane foot rotation (inversion/eversion) and lower-leg transverse plane rotation (external/internal). If a person has a lower subtalar joint inclination angle, more inversion/eversion foot rotation is associated with a fixed amount of external/internal lower-leg rotation. Conversely, a person with a high subtalar joint inclination angle has more lower-leg transverse plane rotation than frontal plane foot rotation.[1] As a result of the mechanical relationship between the subtalar joint inclination angle and motion characteristics of the foot and lower leg (the "mitred-hinge" response),[1] it has been postulated that a higher subtalar joint inclination angle predisposes an individual to knee injuries whereas a lower subtalar joint inclination angle pre-

disposes an individual to foot injuries.[5] There have been no studies to date supporting or refuting this hypothesis.

To determine if there is an association between a higher subtalar joint inclination angle and knee injuries and between a lower subtalar joint inclination angle and foot injuries, individuals with a strong history of knee or foot pain that they attributed to lower-limb weightbearing activities were selected. It was hypothesized that individuals with a history of knee pain during repetitive weightbearing activities have a higher subtalar joint inclination angle than those with a history of foot pain.

Materials and Methods

Ethics approval was obtained from a combined university–hospital ethics review board and each participant provided informed consent prior to participation in the study. A power test during the initial study design stage revealed that at least 16 individuals per group would be required to obtain statistical significance. This was calculated using a commercially available software package (Axum, version 6.0; MathSoft, Inc, Cambridge, Massachusetts). Specifically, the sample size was calculated using an unpaired, two-sample, normally distributed data set in which the minimum detectable difference of interest was $9°$, the acceptable probability of rejecting a true null hypothesis was $\alpha = .05$, the desired probability of correctly rejecting a false null hypothesis was $\beta = .8$, and the variability within the study populations was $9°$.

Study participants were selected on the basis of the results of a written questionnaire regarding their lower-extremity injury history since the age of 18. The instrument asked about the injury site (foot, knee, hip, back, or other) and cause (specific repetitive weightbearing activities), as well as pain frequency and intensity using a 7-point Likert scale. In total, 61 individuals completed the questionnaire. Individuals were immediately excluded if the cause of their lower-extremity pain was not repetitive weightbearing activities (n = 4), or if they had had lower-extremity fractures or surgeries (n = 0), chronic diseases (n = 0), or acute lower-extremity strains or sprains (n = 4). Of the remaining 53 eligible participants, 32 were selected and allocated to a knee group (n = 16) or a foot group (n = 16) according to the predominance of pain patterns. Specifically, the site-specific pain intensity (1 = none, 7 = severe) and pain frequency (1 = never, 7 = always) were multiplied to derive a score from 1 (low) to 49 (high), and then sorted from high to low. The top 16 values for each site were selected for study inclusion. Individuals who

fell into both site groups were not selected (n = 7). Study participants were primarily university students working toward a second degree and consisted of 25 women and 7 men ranging in age from 23 to 32 years.

Four markers (infrared light–emitting diodes) were directly attached to the skin by semirigid forms (Orthoplast; Johnson & Johnson Orthopaedics, Raynham, Massachusetts) to estimate the magnitude of each participant's subtalar joint inclination angle. These markers were attached to the posterior surfaces of the right and left rearfoot, lower leg, and thigh. Three markers were placed posteriorly on a belt fitted snugly around the pelvis. Information from the thigh and pelvis markers was not used in this investigation. The three-dimensional position of each marker was measured at 50 Hz using a kinematic data-acquisition system (OPTOTRAK; Northern Digital Inc, Waterloo, Ontario, Canada) that was situated vertically behind the subject with the middle lens located 1 m above the floor. This system is able to locate markers to a precision of 0.01 mm in a volume of 1.0 m³. Participants completed a series of open- and closed-chain lower-extremity movements to determine the subtalar joint inclination angle. First, participants were requested to stand with the medial borders of their feet parallel and 8.5 cm apart, with their weight distributed equally between right and left limbs, in order to define the neutral position of the foot and lower leg. Second, while standing one-footed and holding a front-mounted railing, the participants consecutively plantarflexed/dorsiflexed, inverted/everted, zigzagged, and circumducted their ankle. Ideally, participants moved their subtalar and talocrural axes throughout a large percentage of the total range of motion. This trial was duplicated and repeated for the other ankle. The data were entered into a custom-written computer program that estimated the location and orientation of the right and left subtalar and talocrural axes relative to the neutral position of the foot and lower leg. The computer program was based on the published equations and then rigorously tested using van den Bogert's original code, simulated data, and data collected from known mechanical analogues of the foot.[3] Finally, these bilateral and repeated-measures subtalar joint inclination angles were arithmetically averaged to improve the point estimate of each participant's subtalar joint inclination angle.

The study used a two-group cross-sectional design to determine if a relationship existed between subtalar joint inclination angle and injury site. An unpaired, one-tailed t-test ($\alpha = .05$) was performed to determine if the knee group had a significantly greater subtalar joint inclination angle than the foot group. The author (M.R.P.) who estimated the subtalar joint incli-

nation angles and performed the statistical analyses was blinded to the grouping of the participants.

Results

The self-reported mean ± SD pain values (PV = pain frequency multiplied by pain intensity; $1 \leq PV \leq 49$) were 17.8 ± 5.1 and 19.3 ± 10.9 for the knee and foot group participants, respectively. The corresponding other-site PVs were 2.7 ± 2.1 and 4.2 ± 3.7 for the knee and foot groups, respectively. Individual pain values are displayed in Figure 1. The participants reported a strong history of either knee or foot pain attributed to repetitive weightbearing activities.

The subtalar joint inclination angle was significantly greater for the knee group (43.9° ± 5.5°) than for the foot group (36.8° ± 7.3°) ($t = 14.7$; $df = 15$; $P < .001$). The lower and upper values for the knee group were 33.7° and 50.8°, and for the foot group were 22.6° and 48.4°, respectively (Fig. 2).

Discussion

This study hypothesized that individuals who have a history of knee pain during repetitive weightbearing activities have a higher subtalar joint inclination angle than those with a history of foot pain. To test this hypothesis, 32 individuals with a predominant history of knee or foot pain had the inclination angle of their subtalar joint measured. The results suggest that a higher subtalar joint inclination angle may predispose an individual to knee pain, and a lower sub-
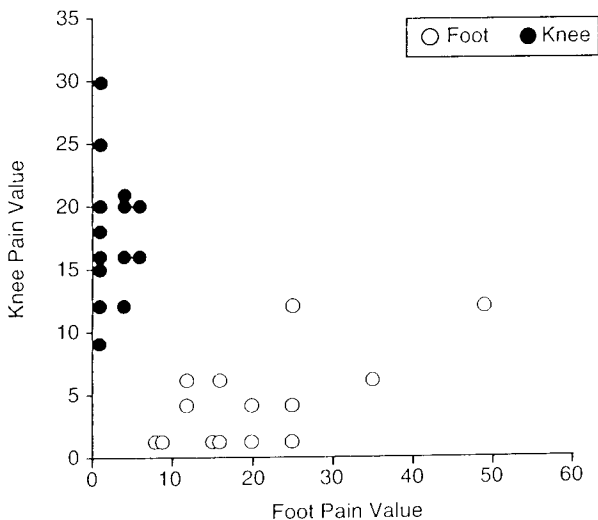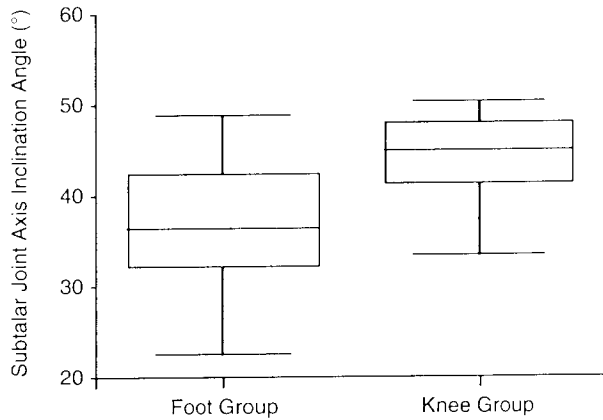

Figure 2. Box-and-whisker plots of the subtalar joint axis inclination angle by injury group. Each box represents the interquartile range, which contains 50% of values. A line across the box indicates the median. The whiskers are lines that extend from the box to the highest and lowest values.

talar joint inclination angle may predispose an individual to foot pain.

The subtalar joint inclination angle was estimated using a modification of the van den Bogert et al[3] protocol, which has been shown to be reliable with a reported 0.7° intrasubject standard error of measurement (SEM). Although this intrasubject SEM is small compared with the mean group difference (knee – foot = 7.1°), the intrasubject SEM was improved in this study by averaging each participant's right and left foot subtalar joint inclination angles, measured twice. Theoretically, the SEM of the subtalar joint inclination angle for all of the participants should be near 0.4° (van den Bogert's value divided by the square root of four measures), a value that allows us to confidently state that the knee group participants had higher subtalar joint inclination angles than the foot group participants.

There are several limitations to the subtalar joint inclination angle measurement protocol of van den Bogert et al.[3] First, specialized equipment is required to acquire the necessary data, and specialized software is used to calculate the subtalar joint inclination angle. This equipment and software are not widely available to clinicians. However, clinical protocols to measure the subtalar joint inclination angle are available,[6-9] although most have unknown reliability characteristics. Second, there is some controversy about whether the subtalar joint is truly a single rotational degree-of-freedom mechanical structure or one that incorporates other important mechanisms (such as a helical screw motion along the subtalar joint axis[3] or

Figure 1. Pain values (range, 1 to 49) by injury group for the 32 study participants. Note that several participant values are superimposed.

a universal joint[10]), or whether the rearfoot is better modeled as a flexible structure.[2] In all cases, the relationship between the foot's frontal plane inversion/eversion motion and the lower leg's transverse plane rotation would be altered if the subtalar joint mechanism was not fixed and uniaxial. The coupling of the foot and lower-leg motions used in this study was related to foot *versus* knee injuries. If the subtalar joint axis does not directly account for the relationship between frontal plane foot and transverse plane lower-leg motion, the rearfoot mechanism used in this study must be reexamined. However, because the study did find a strong relationship between these variables, a fixed and single-axis mechanism for the subtalar joint may be appropriate. Nevertheless, the influence of using different models of the rearfoot, and their prediction of the foot and lower-leg coupling motions, should be explored.

This study was limited to a sample of purportedly healthy individuals who reported that they had predominant knee or foot pain while participating in repetitive weightbearing activities. The fact that the subjects were generally healthy and not actively seeking treatment for their knee or foot pain is reflected in the data, as the subtalar joint inclination angle is not sufficiently sensitive or specific to separate the two groups. In essence, if one selects the most efficient threshold (subtalar joint inclination angle, 43.3°), one correctly identifies 87.5% (95% confidence interval [CI], 64.9%–97.8%) symptom-present membership (sensitivity) and correctly identifies 62.5% (95% CI, 38.9%–82.2%) symptom-absent membership (specificity).[11] Although these values seem discouraging, further studies examining the subtalar joint inclination angle and its relationship to injury site are needed to look for patterns that may help diagnosis and prediction of treatment prognosis. We speculate that individuals with unusually high or low subtalar joint inclination angles may be at risk for

site-specific injury. If this is true, informed clinicians could recommend specific interventions for individual patients.

References

1. LEVANGIE PK, NORKIN CC: *Joint Structure and Function: A Comprehensive Approach*, FA Davis Co, Philadelphia, 2000.
2. LEARDINI A, STAGNI R, O'CONNOR JJ: Mobility of the subtalar joint in the intact ankle complex. J Biomech **34:** 805, 2001.
3. VAN DEN BOGERT AJ, SMITH GD, NIGG BM: In vivo determination of the anatomical axes of the ankle joint complex: an optimization approach. J Biomech **27:** 1477, 1994.
4. INMAN VT: *The Joints of the Ankle*, Williams & Wilkins, Baltimore, 1976.
5. McCLAY I, BRAY J: The subtalar angle: a proposed measure of rearfoot structure. Foot Ankle Int **17:** 499, 1996.
6. KIRBY KA: Methods for determination of positional variations in the subtalar joint axis. JAPMA **77:** 228, 1987.
7. PHILLIPS RD, LIDTKE RH: Clinical determination of the linear equation for the subtalar joint axis. JAPMA **82:** 1, 1992.
8. MORRIS JL, JONES LJ: New techniques to establish the subtalar joint's functional axis. Clin Podiatr Med Surg **11:** 301, 1994.
9. WILLIAMS DS, McCLAY IS: Measurements used to characterize the foot and the medial longitudinal arch: reliability and validity. Phys Ther **80:** 864, 2000.
10. HINTERMANN B, NIGG BM, SOMMER C, ET AL: Transfer of movement between calcaneus and tibia in vitro. Clin Biomech **9:** 349, 1994.
11. KAIRISTO V, POOLA A: GraphROC for Windows Version 2.0, 1996. Available at: http://reimari.saunalahti.fi/~maxiw/. Accessed November 7, 2001.