The Relationship Between Navicular Drop and First Metatarsophalangeal Joint Motion

Joanne S. Paton, MSc*

This study was conducted to determine whether navicular drop, as a representative measure of foot pronation, was associated with first metatarsal joint motion in 24 healthy subjects aged 21 to 40 years. The magnitude of first metatarsophalangeal joint motion was identified using a custom-built weightbearing goniometer designed to measure maximal hallux dorsiflexion in stance. The weightbearing measure of navicular drop was recorded using an adapted digital caliper. Statistical analysis demonstrated a significant negative correlation ($P < .05$) between the two variables. Furthermore, simple regression analysis suggested that 33.2% of the variation in maximal hallux dorsiflexion could be explained by different navicular drop values. (J Am Podiatr Med Assoc 96(4): 313-317, 2006)

To achieve effective forward progression of the center of mass during the propulsive phase of gait, approximately 65° to 75° of hallux dorsiflexion is necessary.[1-5] This occurs in two stages. The first 20° to 30° is a hinge-type rotation about the axis of the first metatarsophalangeal joint.[6, 7] The second stage of hallux dorsiflexion is achieved through plantarflexion of the first ray and activation of the windlass mechanism.[1, 6] The windlass mechanism was first described by Hicks,[8] who likened its effect to a cable being wound one-quarter of a turn onto the drum of a windlass, with the drum of the windlass being the head of the metatarsal, the handle that does the winding being the proximal phalanx, and the cable that is wound onto the drum being the plantar aponeurosis.

Several theories have been postulated to explain how the second stage of hallux dorsiflexion might be restricted and to determine the mechanism of injury and subsequent foot pathology. One possible explanation considers an association between foot pronation and hallux dorsiflexion capacity,[8-12] generated from the common understanding that excessive foot pronation will result in increased tension in the plantar fascia, increased dorsiflexion force under the first metatarsal head, and thus a reduced ability of the hallux to dorsiflex.

The only study to date investigating this relationship was conducted by Harradine and Bevan.[10] In their study, the maximum available hallux dorsiflexion was recorded using a digital goniometer in static stance, with the subjects wearing shoes. The procedure was repeated with 3°, 5°, and 8° valgus wedges placed under the rearfoot within the shoe in an attempt to replicate the function of an excessively pronated foot. It was concluded from the results that an initial increase in rearfoot pronation produced a statistically significant decrease in hallux dorsiflexion ($P < .05$). This study used valgus wedging to artificially replicate three magnitudes of pronation; therefore, the findings may not be representative of the full continuum of foot pronation seen in the general population.

To my knowledge, there is no study quantifying the association between navicular drop and hallux dorsiflexion in subjects displaying differing degrees of pronation. Therefore, the purpose of this study was to determine whether navicular drop (as a measurement of subtalar and midtarsal joint pronation) affects first metatarsophalangeal joint motion. The null hypothesis of this study was that first metatarsophalangeal joint dorsiflexion in stance is independent of navicular drop.

*Faculty of Health and Social Work, University of Plymouth, SF30 Peninsula Allied Health Centre, College of St Mark and St John, Derriford Rd, Plymouth PL6 9BH, England.

Methods

Subjects

A convenience sample of 24 subjects (5 men and 19 women) was recruited for the study (mean age, 33 years; age range, 21–40 years). Subjects were excluded from the study if they presented with any of the following: a history of surgery or serious injury to the foot, an inflammatory joint disorder, a neuromuscular disorder, current foot pain, limited range of motion in the first metatarsophalangeal joint during nonweightbearing, or increased flexibility in the ankle and subtalar joints. Ethical approval was provided by the Staffordshire University ethics committee, Stoke-on-Trent, England. The nature and purpose of the measurement procedure were fully explained to each subject before written consent was obtained.

Methods and Procedure

All of the measurements were performed on the same day. The environment in which the measurements were taken was standardized throughout the session, the heating and lighting were set at comfortable constant levels, and noise was kept to a minimum. The examining table was positioned at eye level for the clinician, and it was maintained at this level for all of the measurements. A single clinician with 10 years' experience performed all of the measurements; the readings were shielded and read by an independent observer.

A standardized procedure was performed for each subject that included positioning of the subject, clinician, and independent observer; alignment and use of the instruments; and the order in which the reference marks were made and the measurements taken. The order in which the subjects attended the measurement session was unspecified. The subject stood in a relaxed bipedal stance while the clinician measured the distance between the medial malleolus using a tape measure; the subject then stood on a small elevated platform while the clinician located the navicular and drew the reference mark. Only the right foot was used, and each measurement was repeated four times, with the mean and range values calculated for each set of four measurements.

Measurement of First Metatarsophalangeal Joint Motion

Most research on first-ray motion and hallux dorsiflexion to date has centered on the total range of motion available at the first metatarsophalangeal joint. The reported range of motion varies from 50° to 90°, with 65° to 75° thought to be adequate for normal gait.[1-4, 12-15] This wide variation in the measurement range reflects not only the variation that exists between individuals but also the lack of a standard measuring technique.

The technique used in this study is described by Roukis et al[16] and uses a weightbearing goniometer consisting of two segments of wood. A solid brass hinge lies between the two segments to allow sagittal plane motion of the distal segment on the proximal segment. A protractor is then attached to record the degree of sagittal plane motion (Fig. 1). The subject stands on the proximal segment, with the center of the metatarsophalangeal joint over the hinge. The distal segment of the goniometer is then dorsiflexed until resistance is felt but before visual plantarflexion of the first metatarsal, and the angle is recorded.

The Roukis goniometer was deemed the most suitable for the study for the following reasons: it was constructed specifically to measure closed-kinetic-chain dorsiflexion of the first metatarsophalangeal joint, it uses a consistently repeatable zero starting position, it is believed to successfully isolate the metatarsophalangeal joint, it is independent of the inclination angle of the first ray, and it avoids the error of introducing reference marks drawn on the skin so that the final measurement is not affected substantially by soft-tissue motion.

The subject was positioned in the base of stance on the measurement rig and was asked to relax and look straight ahead. The measurement of maximal hallux dorsiflexion was described and performed once to demonstrate it to the subject before recording the measurements.

The magnitude of manual force used to dorsiflex the first metatarsophalangeal joint was estimated after the experiment was performed by using a spring

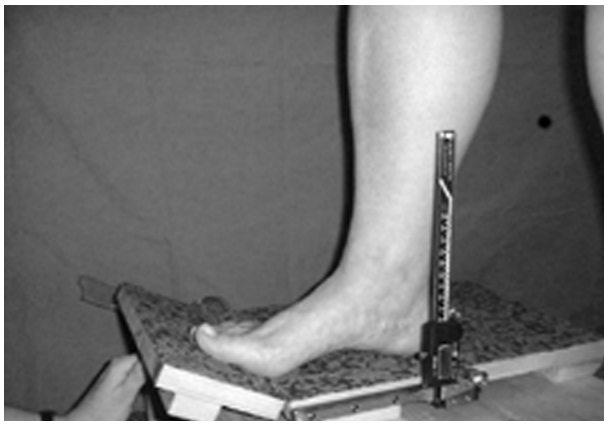


Figure 1. Hallux dorsiflexion measuring rig (medial view).

balance. The magnitude of the manual force applied to the distal portion of the goniometer to induce angular motion at the metatarsophalangeal joint was approximately 16 N (determined using a spring balance). The distance from the hinge of the goniometer to the point of application of the force was 0.11 m and represents the length of the moment arm. Using this information, an estimate of the dorsiflexion moment placed on the first metatarsophalangeal joint by the goniometer can be computed. The magnitude of the moment applied is defined as the product of the force and length of the moment arm. Therefore, the approximate dorsiflexion moment applied to the hallux by the goniometer was 1.76 N.

Navicular Drop

Navicular drop measures the distance the navicular tuberosity moves in stance as the subtalar joint moves from its neutral position to a relaxed position. The most common method of taking the measurement was first described by Brody[17] and involves making a mark on the skin to identify the tuberosity of the navicular. Then, using a blank card held at right angles to the foot against the navicular, with the base of the card flat on the supporting surface, the height of the navicular is marked on the card. The participant is asked to stand in a relaxed position; again, the height of the navicular is marked on the card. The difference between the two marks is recorded as the navicular drop value.

In an effort to improve repeatability, the technique described by Brody[17] was adapted for the study. The subject was asked to stand in the relaxed calcaneal stance position, and a dot was marked on the skin corresponding to the navicular tuberosity. A modified digital caliper was then used to measure navicular drop (Fig. 2). With the subject standing in the subtalar joint neutral position, the caliper arm was placed over the mark and the caliper was set to zero. Subtalar joint neutral was located by palpating for talonavicular congruency and by observing when the curves superior and inferior to the lateral malleolus were equal. The subject then assumed his relaxed calcaneal stance position, and the caliper arm was again placed over the mark. The difference between the two measurements could then be recorded from the digital scale and was defined as the navicular drop value. During the procedure the subject was maintained in the base of stance on the measurement rig and was asked to relax and look straight ahead. The method used to measure navicular drop was described and demonstrated to the subject before the recording took place.



Figure 2. Digital caliper adapted to measure navicular drop.

Results

The navicular drop measurement for the 24 subjects ranged from 1.68 mm to 11.50 mm (mean, 5.48 mm). The maximum hallux dorsiflexion measurement for the same group of subjects ranged from 8° to 36° (mean, 22.78°). Analysis of the 24 subjects using the Pearson product moment correlation identified a statistically significant negative correlation at $P < .05$ between maximum hallux dorsiflexion and navicular drop (Pearson $r = –0.474$; $P = .02$). The relationship between the two variables was investigated further in 23 patients using simple regression analysis.

The relationship between navicular drop and maximal hallux dorsiflexion is presented graphically, and the R^2 value is displayed for the pair of variables, in Figure 3. The null hypothesis that navicular drop has no effect on maximal hallux dorsiflexion can be rejected at the 5% level of significance ($P = .004$). An examination of R^2 reinforces the view that navicular drop provides part of the explanation for subject variation in maximal hallux dorsiflexion ($R^2 = 0.332$). Using simple regression analysis, 33.2% of the variation in maximal hallux dorsiflexion can be explained by different navicular drop values. The P value for the F statistic is smaller than .05, indicating R^2 at the 5% level of significance ($F = 10.421$; $P = .004$).

Discussion

Navicular drop is negatively correlated with hallux dorsiflexion at the 5% level of significance. It is highly probable, therefore, that the measurement of navicular drop has an effect on hallux dorsiflexion because navicular drop is a measure of sagittal plane and frontal plane movement of the midfoot. As the navic-

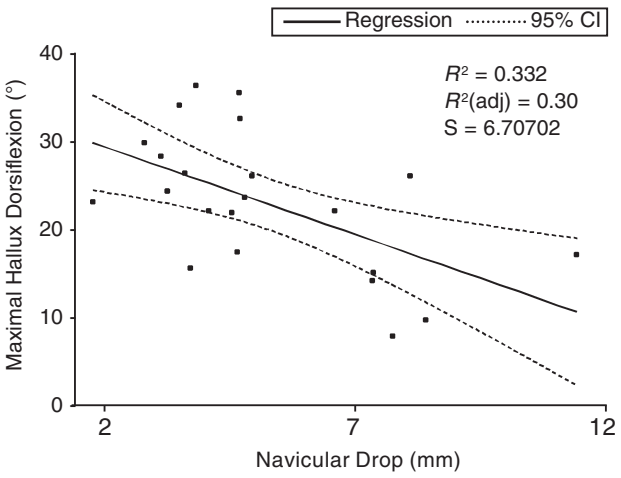


Figure 3. Regression plot of maximal hallux dorsiflexion *versus* navicular drop. Adj indicates adjusted; CI, confidence interval; and S, standard deviation about the line.

ular drop displayed by a subject increases, the angle of hallux dorsiflexion decreases.

These findings are in agreement with most of the related research. Jack (1953), cited in an article by Payne,[18] found that the windlass mechanism failed to operate in unstable flat feet displaying joint collapse at the talonavicular and naviculocuneiform joints. Roukis et al[16] demonstrated that a proportionate decrease in the range of motion of the first metatarsophalangeal joint in stance occurs with dorsiflexion of the first ray, and Harradine and Bevan[10] state that eversion of the rearfoot lowers the maximal hallux dorsiflexion available when measured in the static setting. All agree that lowering of the height of the navicular or, conversely, dorsiflexion of the first ray decreases the passive range of motion of the hallux in stance.

Because a small subject group was used, this is a preliminary study. The information presented shows only a trend that deserves further investigation. Although there is no evidence to suggest that the measures under investigation are sex-related, any generalization of results made to the larger population must take into consideration the nearly 4:1 ratio of women to men in the sample population and acknowledge that this imbalance may have introduced bias to the results.

Although the study design aimed to maximize the repeatability of the measurements used, limitations persist. The repeatability of the navicular drop measurement depends on the examiner's ability to reproduce subtalar joint neutral as the zero measuring position. Another potential source of error in the study was the end position of hallux dorsiflexion, which was subjectively determined by the examiner to occur with an increase in resistance to dorsiflexion and with first-ray plantarflexion. In future studies, a precisely measured dorsiflexion force at a precisely measured distance from the first metatarsophalangeal joint axis on the Roukis goniometer should further improve the accuracy of measurement of the dorsiflexion moment required to dorsiflex the hallux at the first metatarsophalangeal joint.

Conclusion

The aim of this study was to investigate the suspected association between navicular drop as a measure of foot pronation and hallux dorsiflexion in stance. The results indicate that navicular drop is negatively correlated with hallux dorsiflexion at the 5% level of significance. Although causation cannot be inferred, the results suggest that navicular drop has a linear effect on hallux dorsiflexion. As navicular drop increases, the range of hallux dorsiflexion seems to decrease. The results of this study seem to support the theory that excessive pronation results in increased tension in the plantar fascia and increased dorsiflexion force under the metatarsal head and thus reduces the ability of the hallux to dorsiflex.[19]

References

1. Root ML, Orien W, Weed JH: *Normal and Abnormal Function of the Foot*, Clinical Biomechanics Corp, Los Angeles, 1977.
2. Kilmartin TE, Wallace WA, Hill TW: Orthotic effect on metatarsophalangeal joint extension: a preliminary study. JAPMA **81:** 414, 1991.
3. Joseph J: Range of movement of the great toe in men. J Bone Joint Surg **36:** 450, 1954.
4. Sgarlato TE: *A Compendium of Podiatric Biomechanics*, California College of Podiatric Medicine, San Francisco, 1971.
5. Hopson MM, McPoil TG, Cornwall MW: Motion of the first metatarsophalangeal joint: reliability and validity of four measurement techniques. JAPMA **85:** 198, 1995.
6. Valmassy R: *Clinical Biomechanics of the Lower Extremity*, CV Mosby, Boston, 1996.
7. Hetherington VJ, Carnelt J, Patterson B: Motion of the first metatarsophalangeal joint. J Foot Surg **28:** 13, 1989.
8. Hicks JH: The mechanics of the foot: part II. The plantar aponeurosis and the arch. J Anat **88:** 25, 1954.
9. Fuller EA: The windlass mechanism of the foot: a mechanical model to explain pathology. JAPMA **90:** 35, 2000.
10. Harradine PD, Bevan LS: The effect of rearfoot eversion on maximal hallux dorsiflexion: a preliminary study. JAPMA **90:** 390, 2000.
11. Sarrafian SK: Functional characteristics of the foot and plantar aponeurosis under tibiotalar loading. Foot Ankle **8:** 4, 1987.

12. Bojsen-Moller F, Lamoreux L: Significance of free dorsiflexion of the toes in walking. Acta Orthop **50:** 471, 1979.
13. Phillips RD, Law EA, Ward ED: Functional motion of the medial column joints of the foot during propulsion. JAPMA **86:** 474, 1996.
14. Buell T, Green DR, Risser J: Measurement of the first metatarsophalangeal joint range of motion. JAPMA **78:** 439, 1988.
15. Hetherington VJ, Johnson RE, Albritton JS: Necessary dorsiflexion of the first metatarsophalangeal joint during gait. J Foot Surg **29:** 218, 1990.
16. Roukis TS, Scherer PR, Anderson CF: Position of the first ray and motion of the first metatarsophalangeal joint. JAPMA **86:** 538, 1996.
17. Brody DM: Techniques in the evaluation and treatment of the injured runner. Orthop Clin North Am **13:** 541, 1982.
18. Jack EA: Naviculo-cuneiform fusion in the treatment of flat foot. J Bone Joint Surg Br **35:** 75, 1953. Cited by: Payne CB: Is excessive pronation of the foot really pathologic? Australas J Podiatr Med **33:** 7, 1999.
19. Dananberg HJ, Phillips AJ, Blakman HE: "A Rational Approach to the Nonsurgical Treatment of Hallux Limitus," in *Advances in Podiatric Medicine and Surgery*, Vol 2, Mosby–Year Book, St Louis, 1996.