

Brief Report

Reliability and validity of first metatarsophalangeal joint orientation measured with an electromagnetic tracking device

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Abstract

Objective. To establish the reliability and validity of measurements of sagittal plane orientation of the first metatarsophalangeal joint using the Flock of Birds™ electromagnetic tracking device.

Design. Different joint orientations were reproduced on cadaver specimens in a specially designed jig with skin and skeletal application of the sensors.

Background. The Flock of Birds™ provides a means for quantifying first metatarsophalangeal joint motion, however, the reliability and validity of such an application has not been determined.

Methods. Joint orientation was measured in five cadaver feet with skin and skeletal sensor application. A specially designed jig allowed simulation of clinical tests of range of motion. Sagittal plane orientation was determined from 3-D, anatomically-based, reference frames embedded in the first metatarsal and proximal hallux.

Results. Reliability of all measurements was high for skin and skeletal sensor application. There were no significant differences in joint orientation between either technique for any of the simulated motion tests.

Conclusions. The Flock of Birds™ provides reliable and valid measures of first metatarsophalangeal joint orientation with the sensors applied to the skin over the first metatarsal and proximal hallux.

Relevance

An electromagnetic tracking device is suitable for measuring sagittal plane motion of the first metatarsophalangeal joint. This motion can easily be expressed using 3-D, anatomically-based reference frames. © 1999 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Adequate motion of the first metatarsophalangeal joint (MTP) is an important component of normal ambulation. Sagittal plane motion of the MTP is usually measured using planar radiography [1], planar cinematography [2], or goniometry [3]. An alternative technique uses electromagnetic technology to monitor 3-D position and orientation of small sensors, attached to anatomical structures, with respect to a transmitter

[4]. Electromagnetic tracking devices can also be used for spatial digitization of anatomical landmarks. To our knowledge the only reported application to measurement of MTP orientation has been in an isolated hallux-first metatarsal preparation [5]. The Flock of Birds™ (FoB) electromagnetic tracking device (Ascension Technology, Burlington, VT, USA), has recently been shown to provide accurate position and orientation measurements in a controlled, non-biological context [6]. The purpose of the current investigation was to establish the reliability and validity of measurement of the sagittal plane orientation of the MTP using the FoB.

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2. Methods

In living subjects, sensors are adhered to the skin over bony landmarks. To determine the validity of the FoB, measurements with the sensors adhered to the skin were compared to measurements with the sensors anchored to the underlying bone in five fresh, frozen, cadaver foot specimens. Specimens were prepared by transecting the shank at the middle third, and fixating the tibia and fibula in a wooden jig that ensured vertical alignment of the shank. The jig allowed the application of an axial load of 267 N, and incorporated mechanical stops to control toe motion. A suture was placed in the tendon of the extensor hallucis longus, at the level of the inferior extensor retinaculum, to allow the MTP to be dorsiflexed by tendon loading. In two of the specimens, adequate motion could not be produced by tendon loading. The hallux sensor was placed on the mediadorsal aspect of the proximal phalanx, medial to the extensor hallucis longus tendon. The metatarsal sensor was placed on the mediadorsal aspect of the diaphysis, avoiding the abductor hallucis and the tendon of the extensor hallucis longus. After testing with the sensors applied to the skin, all tests were repeated using the same mechanical stop locations, with the sensors anchored to the underlying bone.

MTP orientation was measured during simulated clinical tests of passive range of motion during simulated weight-bearing (PRoM), heel rise over a fixed hallux (HEEL), and active range of motion during simulated weight-bearing (ARoM). PRoM trials were performed by setting the mechanical stop on the jig to the range of maximal dorsiflexion for each specimen. The hallux was moved to the mechanical stop while data were collected (100 Hz) with the FoB. Three trials were performed for each testing condition. ARoM trials were performed by loading the suture until the hallux contacted the mechanical stop. HEEL trials were performed by rotating the specimen over the hallux at the MTP to a predetermined stop on the jig, with the axial load removed. Marks on the specimens and jig ensured consistent beginning and ending points of motion. Data were smoothed using a fourth-order Butterworth digital filter with a 6 Hz cut-off frequency.

Dextral, anatomically-based, local coordinate systems were established for the first metatarsal and proximal hallux (Fig. 1) by digitizing four non-collinear points on each segment. A dextral global coordinate system was also established, with origin at the center of the transmitter. All anatomical landmarks to be digitized were carefully identified and marked using an instrumented caliper. Matrices were generated describing the orientation of the hallux local coordinate system relative to an initial coincident alignment with the metatarsal local coordinate system [7]. A Cardan angle system of three

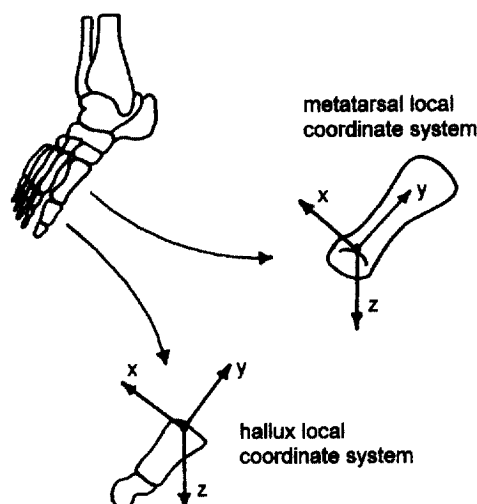


Fig. 1. Local anatomical coordinate systems used to express motion of the proximal hallux relative to the first metatarsal.

ordered rotations ($X-Z-Y$) was used to extract angular information of the proximal hallux relative to the first metatarsal from the resulting direction cosine matrices. Data analysis was restricted to the clinically relevant sagittal plane motion (X -axis). Unintentional data loss precluded the analysis of the HEEL data for one specimen. Reliability was assessed using intraclass correlation. Differences between measurement techniques were assessed using paired t -tests. The skeletal measurements were assumed to represent actual motion of the MTP. To minimize the incidence of Type II errors, an alpha level of 0.10 was utilized.

3. Results

Reliability of the three repeated trials across both measurement conditions was excellent (intraclass $r > 0.99$). The mean of the three trials was used in subsequent analyses. Mean MTP orientation values calculated for PRoM (skin 47.2, SD = 14.1°; skeletal 47.1, SD = 13.1°; $P = 0.85$), HEEL (skin 49.6, SD 7.2°; skeletal 49.7, SD = 6.7°; $P = 0.95$), and ARoM (skin 23.6, SD = 1.5°; skeletal 25.4, SD = 1.2°; $P = 0.11$) trials, were not significantly different between the two measurement conditions. Across all subjects, the differences in MTP orientation for the PRoM tests between the skin and skeletal sensors ranged from -2.3 to 1.8° , with a mean difference of 0.1° . The differences in MTP orientation for the HEEL tests between the two sensor applications ranged from -2.3 to 2.1° , with a mean difference of -0.1° . The differences in MTP orientation for the ARoM tests between the two sensor applications ranged from -3.1 to -0.9° , and averaged -1.8° . A negative value indicates that the skin-based measurements were less than skeletal values.

4. Discussion and conclusion

Although the FoB had been shown to be accurate in a non-biological setting [6], the reliability and validity for measurements of MTP motion made with the FoB had not been previously established. The reliability of measurements made with the FoB was excellent, and the differences between measurements made with skin and skeletal application of the sensors were small. Although none of the mean differences were statistically significant, the mean difference for ARoM (-1.8°) was considerably larger than for PRoM (0.1°) or HEEL (-0.1°). The ARoM test was included to examine the potential influence of skin movement due to tendon loading during contraction of the extensor hallucis longus. Movement of the skin relative to the bone due to loading of this tendon might explain the larger difference observed for the ARoM trials, and underscores the need for careful selection of sensor application sites.

Based on the high reliability and validity found in the current investigation, we feel the FoB may be confidently used for measurement of MTP kinematics. The FoB also offers the advantage of collecting

anatomically-based, three-dimensional, orientation data during dynamic activities. Care must be used, however, in selecting sensor application sites, to minimize artifact created by underlying muscles and tendons.

References

- [1] Joseph J. Range of movement of the great toe in men. *J Bone Joint Surg* 1954;36B(3):450–457.
- [2] Hopson MM, McPoil TG, Cornwall MW. Motion of the first metatarsophalangeal joint: reliability and validity of four measurement techniques. *J Am Podiatr Med Assoc* 1995;85(4):198–204.
- [3] Buell T, Green DR, Risser J. Measurement of the first metatarsophalangeal joint range of motion. *J Am Podiatr Med Assoc* 1988;78(9):439–448.
- [4] An KN, Jacobsen MC, Berglund LJ, Chao EY. Application of a magnetic tracking device to kinesiological studies. *J Biomech* 1988;21(7):613–620.
- [5] Ahn TK, Kitaoka HB, Luo ZP, An KN. Kinematics and contact characteristics of the first metatarsophalangeal joint. *Foot Ankle Int* 1997;18(3):170–174.
- [6] Milne AD, Chess DG, Johnson JA, King GJ. Accuracy of an electromagnetic tracking device: a study of the optimal range and metal interference. *J Biomech* 1996;29(6):791–793.
- [7] Craig JJ. *Introduction to robotics: mechanics and control*, 2nd ed. New York: Addison-Wesley Company, 1989.