Inter-site Reliability of Multisegmental Foot Kinematics Assessed with the Milwaukee Foot Model (MFM)

INTRODUCTION

Kinematic analysis of the multiple segments of the foot and ankle is becoming more prevalent in the research literature, with a number of different models having been reported over the past twenty years. The acceptance of these new models in the clinical and research arenas is contingent on validations which demonstrate sufficient fidelity to the behavior being analyzed and sufficient repeatability so as to be useful across a wide range of users.

The present study was designed to validate the use of the Milwaukee Foot Model (MFM) between two separate testing sites. The MFM is a four segment model which represents the lower leg and foot as the tibia, hindfoot (calcaneus), forefoot (metatarsals), and hallux. The MFM is unique in that it employs measurements from weightbearing x-rays to index the orientations of skin-mounted markers to the orientation of the underlying bony anatomy. These methods allow the model to account for bony deformities (e.g. hallux valgus, pes planus) and provide a crucial means of more reliably evaluating populations with pathology.

METHODS

This study was approved by the Institutional Review Boards of the Medical College of Wisconsin and Shriners Hospital, Chicago; all subjects provided informed consent prior to data collection. Six healthy young ambulators took part in the testing. Sample size was established based on power analysis.

Subjects underwent two data capture sessions in each of two different facilities. Motion data was acquired with a Vicon 524 at the Medical College of Wisconsin and Vicon MX at Shriners Hospital, Chicago. A single set of x-rays were collected for each subject including standing A/P and lateral views and a modified coronal plane view (Milwaukee view) to facilitate measurement of calcaneal rotation. For each x-ray, a footprint template was used to reposition the feet into the same weightbearing posture adopted during the static motion capture trial. Intersegmental angles were then measured from the weightbearing x-rays to develop the bone-based matrices defined by the MFM.

Data from the four sessions were processed using angular measurements from the x-ray session. Within each gait cycle phase, key summary measures (mean position and range of motion) were extracted and tabulated for statistical analysis.

RESULTS

Significant inter-site differences ranged from 0.74-4.64 degrees; of these, the majority of the measures (23 of 55, 42%) were in the hindfoot, followed by the tibia (16 of 55, 29%) and forefoot (15 of 55, 27%). Hallux motion showed minimal significant inter-site differences. In addition, most significant differences occurred during stance.

For the random effects, the largest measurement variability was observed between Subjects. The relative levels of variability for each effect were assessed given the maximum inter-subject variability observed (12.70 degrees, observed in transverse plane hindfoot ROM during midswing). Measures greater than 80% of this maximum were identified as high variability measures (HVMs), and measures lower than 20% of this maximum were identified as low variability measures (LVMs).

No measures of variability attributed to Residual, Session, and Site were HVMs; the majority of these measures were LVMs (86% of Residual measures, 93% of Session measures, 97% of Site measures). Measurement variability attributed to Subject was relatively higher, particularly in measures of the hindfoot in the transverse plane and the forefoot in the sagittal plane. These HVMs were present throughout the gait cycle without any clear bias toward stance or swing.

Analysis of total error due to the Site, Session, and Residual random effects (the “SSR spectrum”) finds that 80% of the variance in mean position measurements is below 3.36", and 80% of variance in ROM measurements is below 2.47" (Figures 1 and 2).

DISCUSSION

The relative small amount of variability imparted by inter-Site differences is a primary finding of this study. These findings suggest that the random effect of testing persons at two different sites leads to negligible differences in output. Similar findings of low inter-site variability suggest that differences between sessions are insignificant. While probability testing for variability due to Residual suggested that other sources of variability remained unidentified, the magnitude of variability imposed by these sources is quite small (86% of these measures were LVMs).

The largest sources of variability were found in inter-Subject measurements, and most of these were found at the hindfoot (internal/external rotation) and the forefoot (plantar/dorsiflexion). Variability in the forefoot segment may be explained by the definition of the segment as the plane spanned by the base and head of the fifth metatarsal and the head of the first metatarsal. Modeling the five metatarsals as a single segment does not account for inter-tarsal motion; whether further segmentation of the forefoot will reduce these levels of variability is unclear.

Conversely, the low variability of hindfoot motion measurements in all three planes can likely be explained by the segment definition methods (markers placed only on the calcaneus, with angular measurements from three x-rays to define the bone-based axes). The dependence of forefoot measurements on markers which span the metatarsals and of hallux measurements on the rigid triad likely explain the higher variability observed in these segments.

REFERENCES