Technique for Measurement of Foot and Ankle Kinematics

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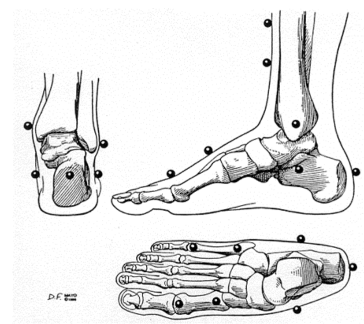
Introduction: A number of methods have been suggested for measurement of lower extremity kinematics. However, these models describe the foot as one rigid segment. Recently, efforts have begun to develop marker sets for use in foot and ankle motion analysis. The purpose of this study is to describe a technique for quantification of three-dimensional foot and ankle motion.

Clinical Significance: Measurement of foot and ankle motion is essential for understanding the pathomechanics of foot and ankle pathology.

Methods: The foot and ankle complex was divided into three functional segments: lower leg, hindfoot, and forefoot. A total of 11 markers are used to define the three-segment model (Figure 1). An eight camera ExpertVision™ System (Motion Analysis Corporation, Santa Rosa, CA) was used to collect reflective marker trajectory data at 60 frames/sec. Local coordinate systems were constructed for each segment. The motion of the distal segment orientation was expressed relative to the next proximal segment using Eulerian angle conventions. An initial standing reference position was collected to define the orientation of the embedded coordinate systems in a neutral position. The static reference position was captured in a weight-bearing stance with the mid-line of the posterior aspect of the calcaneus and the second toe on a line parallel to the line of progression with the tibia orientated vertically. All dynamic data was compared to the static reference position using the least squares position orientation algorithm. A minimum of 3 trials were collected from each of 10 subjects (31 ± 6 years of age).

3-Segment Foot Model



Results: The sagittal plane hindfoot motion (Figure 2a) indicates that the hindfoot moves into plantarflexion after foot contact then reverses and begins to dorsiflex until late stance when the hindfoot plantarflexes before toe off. Coronal plane hindfoot motion demonstrates an initial eversion with movement back into inversion. Transverse plane hindfoot motion shows internal rotation during first rocker, external rotation during second rocker, and internal rotation during third rocker. Sagittal plane forefoot motion (Figure 2b) demonstrates dorsiflexion until opposite foot strike when the forefoot again goes into plantarflexion. The dorsiflexion during mid-stance represents a flattening of the longitudinal arch as the body

Figure 2a. Hindfoot Motion

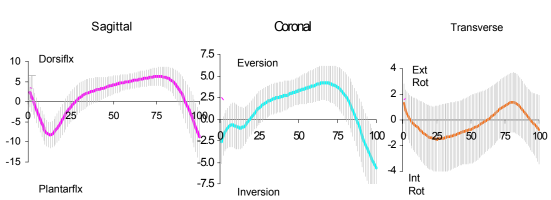
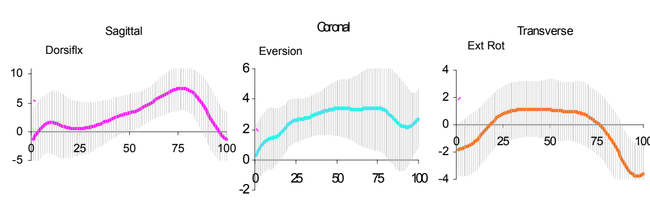


Figure 2b. Forefoot Motion



progresses over the stance foot. Coronal plane forefoot motion demonstrates progressive eversion. The transverse plane forefoot motion demonstrates external rotation and then internal rotation.

Discussion: A three-dimensional model for measuring normal foot and ankle motion has been developed. Hindfoot motion reported in this study agrees with published results. Motion of the forefoot segment also agrees with previously published studies .

A cadaveric study was conducted to compare the accuracy of skin mounted markers to the underlying bony anatomy. Dynamic testing was performed by rotating the ankle and foot from maximum dorsiflexion to maximum plantar flexion by loading the appropriate muscles. Additional dynamic testing was performed by rotating the ankle through the appropriate tendons from maximum inversion to maximum eversion. The accuracy test demonstrated that this marker system measured ankle and foot motion within three degrees root-mean-square error.

Consideration was given to adding a fourth rigid-body segment comprised of the halux to the foot model. A light-weight array carrying three 1 cm spheres was attached to the proximal halux approximately 1.5 cm distal to the first MTP joint. The motion of this array was compared to the underlying motion of the bony segments. Due to large variability found in the rotational measurements, the idea of adding a fourth segment to this foot model was dropped.

Additional considerations must be given to the assumption that each of the segments in this biomechanical model satisfy the rigid body assumption. While this assumption may be reasonable for the shank segment and the rearfoot (calcaneus) segment, there will be some relative motion of the metatarsals during gait. The motion of these joints compared to the total motion described for the forefoot segment is yet to be determined.

References:

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