DYNAMIC SIX-SEGMENTAL FOOT MOTION USING ELECTROMAGNETIC TRACKING SYSTEM

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INTRODUCTION

Multi-segmental foot motion during walking has been mostly investigated using passive markers and the Video Motion Analysis System (1,2,3). These foot segments mainly are limited to the hindfoot and forefoot. Since the Electromagnetic Tracking System (ETS) was introduced to our biomechanical and clinical society, one study was conducted to determine the ankle joint kinematics (4). The goal of this study is to develop a newly designed anatomically based six-segmental foot model using the ETS, including the hindfoot, midfoot and forefoot kinematics, and to find out the reliability of intraobserver.

METHODS

The study was performed on six children with 12 normal feet. Their ages ranged from 9 to 15 years with a mean age of 12 years. The ETS consists of: a long range StarTrak transmitter (Polhemus Inc., Colchester, VT) with 12 sensors, electronics unit and the 6D Skill Technologies' Gait motion capture and software (Skill Technologies, Inc., Phoenix, AZ). There is a two-inch cubic transmitter used as the global reference frame within a maximum radius is 12 ft. Each sensor with half-inch cubic coils compute with 6 degrees of freedom in real-time. The motion is sampled at a rate of 120Hz. A fourth order Butterworth digital filter with a cut-off frequency of 6Hz is also used.

Six sensors were placed on each foot with double stick tape at the following locations: the tibia tuberosity, posterior calcaneus, navicular tuberosity, cuboid tuberosity, middle dorsal shaft of the 1st metatarsal bone and dorsal hallux. The children were initially asked to stand in a neutral postion, which is defined as a static standing with weight-bearing and their feet parallelling the y-axis of our global reference. Each sensor is used as a local reference frame for the segment to which it is attached and aligned with the global reference during calibration. After defining the neutral position, the subjects walked with 6 sensors on each foot along a 20 ft walkway at their natural speed. Data was captured over a 4 second period and three separate trials were completed for each subject. Four subjects were randomly selected for repeated tests during the same day and by the same satff. Correlation between two times measurements was calculated by Intraclass coefficient (ICC).

We always calculate angles by the distal sensor with respect to the proximal sensor. Hence the Cardan sequence is the angle around the medial/lateral axis first (dorsiflexion/plantarflexion as pitch angle), followed by the angle around the anterior/posterior axis (inversion/eversion as yaw angle), finally the angle around the vertical axis (internal/external rotation as roll angle).

RESULTS AND DISCUSSION

In the sagittal plane, mean peak dorsiflexion of the hindfoot at the mid stance is 10.4°. The navicular-1st metatarsal segment displays mean peak dorsiflexion of 4.9° before toe-off. The 1st metatarsal-hallux joint gives mean peak dorsiflexion of 43° at toe-off (Figure 1). In the coronal plane, mean peak inversion of the hindfoot is 5.2° and eversion is 2.9°, whereas the navicular-1st metatarsal segment, and 1st metatarsal-hallux joint yield smaller range of motion. In the transverse plane, the hindfoot displays dominated external rotation during 1st and 2nd rocker. The midfoot and forefoot expresses minimal internal rotation during stance phase yet external rotation during swing. In sagittal plane, ICC between two measurements are 0.62 for hindfoot, 0.40 for navicular-1st metatarsal segment, and 0.34 for 1st metatarsal-hallux joint. In the coronal plane, coefficients are 0.86, 0.52, and 0.79, respectively. In the transverse plane, coefficients are 0.94, 0.66, and 0.72, respectively.

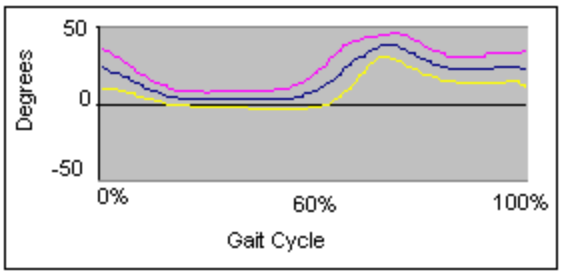

Figure 1. Dorsiflexion and plantarflexion of the 1st metatarsal-hallux joint in mean ± SD as a function of gait cycle.

CONCLUSIONS

Our foot model has a moderate to high reliability to determine hind and forefoot rotation. Movements derived from the navicular-1st metatarsal enhance our understanding of midfoot kinematics during walking. Further studies are needed to evaluate the interobserver variation across days.

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