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Foot and Ankle Motion Analysis Using Dynamic Radiographic (Fluoroscopic) Imaging

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FOOT AND ANKLE MOTION ANALYSIS USING DYNAMIC RADIOGRAPHIC (FIUOROSCOPIC) IMAGING

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INTRODUCTION

The goal of this work was to develop fluoroscopic instrumentation for use with an integrated segmental foot and ankle model suitable for kinematic and kinetic assessment of *in vivo* bony motion during gait. While new knowledge about foot kinematics in healthy persons has provided quantitative insight and allowed detailed characterization of segmental patterns, these techniques do not include radiographs and rely on assumptions about the underlying bony anatomy (GCMAS) [1]. In contrast, the fluoroscopic system developed for the current study supports direct characterization of *in vivo* bony dynamics.

CLINICAL SIGNIFICANCE

Quantification of *in vivo* tarsal kinematics and kinetics via fluoroscopy eliminates errors associated with skin marker motion as a surrogate for underlying bony dynamics. Fluoroscopic imaging also offers significant increases in system resolution and accuracy as well as a means of assessing foot and ankle dynamics under a variety of conditions not possible with skin marker approaches (e.g. orthotics, in-shoe motion, etc). Application of fluoroscopic techniques may lead to further improvements in pre-treatment assessment, post-treatment follow up and longer term rehabilitation.

METHODS

Preliminary trials were conducted with 3 normal adult subjects during barefoot walking, while wearing athletic shoes, and while wearing a pair of orthopedic single rocker shoes. Motion, fluoroscopic and ground reaction force (GRF) data were collected as subjects walked across a 6m walkway. The system is comprised of a Vicon MX Motion Capture System, an embedded AMTI OR6-5-1 force plate, and a single gantry OEC 9000 fluoroscopy system (RIS, Hamburg, PA). Fluoroscopic images are recorded during the stance phase of gait (heel strike to toe off) at 120 fps using a Basler Aviator (avA1000km) digital camera, and XCAP (Buffalo Grove, IL) imaging software. The fluoroscopic system is synchronized with the Vicon system via a TTL pulse captured through the A/D panel. 6 standard 16mm reflective markers were placed on the tuberosity of the calcaneus, superior head of 2nd metatarsal, medial/lateral malleoli, and medial/lateral femoral epicondyles. The marker system defined the foot progression angle, defined the tibia coordinate system (image intensifier too small to capture enough of the tibia to do fluoroscopically), and was used for geometric referencing (GR) of *in vivo* bony landmarks (required to use in conjunction with GRF). Synchronized fluoroscopic images were mathematically de-warped; global coordinates of ankle bony landmarks were then determined, and dynamics characterized.

DEMONSTRATION

Three adult subjects were tested following institutional review approval and informed consent. Foot and ankle marker trajectories were simultaneously tracked and compared using the synchronized Vicon and fluoroscopy systems. This phase of the project supported analysis of marker and bony motion at the calcaneal tuberosity. Particular interest was directed towards the hindfoot (calcaneus and talus) in the quantitative fluoroscopic analysis. Tracking included estimates of center of mass locations of the calcaneus and talus. For the kinetic analysis, joint reaction forces and moments were determined at the subtalar and talocrural joints. Kinematics and kinetics of the talocrural joint compare favorably to data reported in other studies [2]. There is little information available for similar comparison of subtalar dynamics.

An illustration of a typical barefoot fluoro image is provided in Fig 1. Global coordinate algorithms were used to determine bony foot and ankle orientations (Eq 1-3). Geometric referencing allowed expression of calcaneal and talar locations within the foot progression plane. GR also allowed accurate referencing of GRF to the bony anatomy.

FIGURE 1: Typical fluoroscopic image captured of a barefoot trial.

$$POIX = HX + \left[\frac{POIx' - Hx'}{ppm}\right] \cos\theta + \left[\frac{POIz' - Hz'}{ppm}\right] \sin\theta \qquad (1)$$

$$POIY = HY + \left|\left[\frac{POIx' - Hx'}{ppm}\right] \cos\theta + \left[\frac{POIz' - Hz'}{ppm}\right] \sin\theta\right| \tan\beta \qquad (2)$$

$$POIZ = HZ + \left[\frac{POIx' - Hx'}{ppm}\right] \sin\theta + \left[\frac{POIz' - Hz'}{ppm}\right] \cos\theta \qquad (3)$$

Where: POI(X,Y,Z) = point of interest global coordinates; H(X,Y,Z) = heel marker global coordinates; POI(x',z') = point of interest image coordinates; H(x',z') = heel marker image coordinates; ppm = pixels/millimeter conversion; θ = angle between X and x'; and β = foot progression angle.

SUMMARY

Fluoroscopic imaging of the foot and ankle during gait allows detailed characterization of the underlying bony motion as well as assessment of orthotic and footwear effects. Inclusion of external markers allows assessment of various segmental models with respect to marker motion and tracking fidelity. Incorporation of ground reaction force data extends the system's kinetic capacity to estimate interarticular forces and moments.

REFERENCES

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