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Biplane Fluoroscopic Analysis of the Hindfoot Using Model-Based Tracking Techniques: A Static Phantom Study

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BIPLANE FLUOROSCOPIC ANALYSIS OF THE HINDFOOT USING MODEL-BASED TRACKING TECHNIQUES: A STATIC PHANTOM STUDY

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INTRODUCTION

Dynamic assessment of skeletal kinematics is necessary for understanding normal joint function, in addition to effects of injury or disease [1, 2]. Conventional methods of motion analysis track skin-mounted optical markers with cameras to determine joint motion of the underlying bones. While these methods are simple, easy to implement and appropriate for various clinical and research related applications, they have been found to suffer from error due to movement (artifact) of the skin on which the markers are placed [3]. Due to the numerous bones and articulating surfaces within the foot and ankle, several rigid body assumptions are made to divide the foot into multiple segments for motion analysis. This method does not allow for obtaining inter-tarsal kinematics or kinetics of the hindfoot. A technique that locates the talus during gait analysis would allow for more advanced subtalar motion assessment and a more accurate estimate of hindfoot kinetics.

Fluoroscopy allows direct visualization of underlying bones by obtaining a sequence of x-ray images of a joint as it undergoes motion. This technology offers a valuable complement to conventional optical methods of motion analysis by providing a means of dynamic weight-bearing intra-articular motion measurements that are otherwise difficult to achieve. It has been used to track bone motion in animals, and in the human shoulder and knee [1, 2, 4]. Our group has previously reported hindfoot kinematics obtained from a single gantry in a population of adults, both shod and barefoot [5]. The ability of fluoroscopic analysis to have direct visualization of bony structures reduces the inaccuracies due to skin markers and enables analysis of the shod and orthotically braced foot [1].

Model-based fluoroscopy identifies bony position and orientation by comparing a three dimensional (3D) bone model to the acquired biplane fluoroscopic images. The 3D model is created from computed tomography (CT) or magnetic resonance (MR) images by identifying and segmenting the anatomy of interest. The accuracy of the model-based method was found to be within 0.8 mm of translation and 2.5° of rotation of the gold standard measurements performed with implanted bony markers [2]. The goal of this study was to develop a unique biplanar system that uses model-based tracking methods to perform *in vivo* analysis of the hindfoot.

METHODS

A biplane system was constructed centered along a 7 m raised walkway with an embedded 46.4 by 50.8 cm force plate (AMTI OR6-500 6-DOF, Watertown, MA). Two x-ray sources (OEC 9000, GE, Fairfield, CT), and two images intensifiers (15" diam., Dunlee, Aurora, IL) were mounted to the walkway with a 60 degree angle between the sources. High-speed cameras (N4, IDT, Pasadena, CA) were attached to each image intensifier. Cameras had 52mm lenses (Nikon, Melville, NY). The images were captured and digitized directly to a controller PC via Motion Studio 64 (Version 2.10.05, IDT, Pasadena, CA). The source-to-detector and source-to-object-center distances were 112 cm and 76 cm, respectively.

Open source software, X-Ray Reconstruction of Moving Morphology (XROMM, Brown University, Providence, RI) was used for image intensifier distortion correction. Two calibration frames of 1.20 mm thick perforated steel with 3.18 mm diameter holes spaced 4.76 mm apart in a staggered pattern were cut to fit the face of the image intensifiers (part no. 9255T641, McMaster-Carr, Robinson, NJ). The distortion correction algorithm in XROMM compares the spacing between the holes of the calibration frame in the fluoroscopic image with the true spacing and calculates a transformation matrix for correcting the images [4]. A foot/ankle phantom (XA241L, Phantom Lab Inc) was placed on the force plate in the middle of the irradiated area. Static images were collected with the x-ray sources set at 100 kV and 2.5 mA, with an estimated 10 µSv of radiation per trial.

RESULTS AND DISCUSSION

A unique biplane fluoroscopy system designed for hindfoot analysis was built, configured, tested and approved through the State and medical IRB for subject/patient testing. In order to quantify the cross-scatter contamination in the biplanar system, a study was performed [6]. Contamination was found to be relatively low when imaging distal extremities. Image intensifiers introduce distortion on the order of 10% that is corrected prior to motion analysis to minimize 3D tracking errors [1]. Images of the calibration frames were corrected for geometric distortion using the XROMM distortion correction algorithm to create a transformation matrix. This matrix was then applied to images of the static foot/ankle phantom. Figure 1A shows the raw distorted image of the phantom foot while figure 1B shows the foot after the application of the distortion correction algorithm. The undistorted image is smaller due to the edges of the image being reduced to their exact size. Further research is needed using dynamic phantom studies, along with continued patient pilot studies to further validate the biplanar system and model-based tracking software to implement full biplanar kinetic capability.

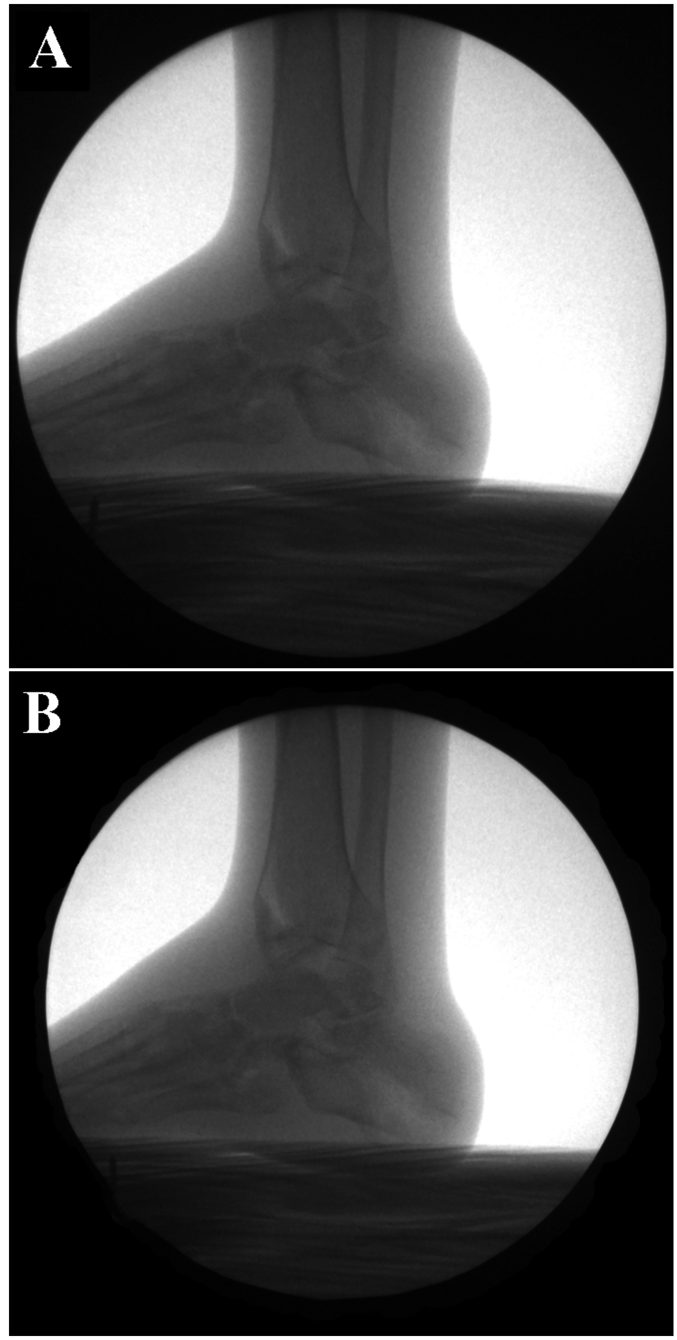

Figure 1: Correction of fluoroscopic distortion. A: Raw, distorted image of static phantom foot. B: After distortion correction algorithm applied.

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