MEASUREMENT OF TIBIOFEMORAL JOINT MOTION USING CINE-PHASE CONTRAST MRI

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INTRODUCTION

In cine-phase contrast (cine-PC) magnetic resonance imaging, velocity-dependent pulse sequences are used, and velocity information is extracted from the phase relationship of the MR signal. The utility of the application of this imaging method for determination of patellofemoral joint kinematics has been demonstrated previously (Sheehan, et al., 1998). In this abstract, preliminary results on the application of the technique to the measurement of tibiofemoral joint motion are reported.

METHODS

Cine-PC data was acquired while subjects performed a repetitive knee flexion/extension exercise within an MRI scanner (GE Signa LX.) The subjects lay face up, the thigh was raised via a ramp to flex the hip, and knee extensions were performed against the weight of the shank only. The ramp was adjusted until the knee was fully extended as the toe just touched the highest point of the imager's bore. The MR signal receiving coils were secured vertically, adjacent to each side of the knee, using a custom-made jig.

In the study protocol, the subject is instructed to flex and extend the knee through the available range of motion, at a frequency of 35 cycles per minute. This occurs by voluntary synchronization with the beat of a metronome. The MRI system collects a sequence of 24 frames of data through the cycle on a user-specified sagittal image plane. An optical trigger, positioned under the heel of the subject, is used to synchronize the acquisition of data with the motion.

Each resulting data frame yields four separate images on the selected plane; one is the usual anatomical cross-section (magnitude image), and the others are encoded with velocity information in each of three orthogonal directions. The experiment requires the subject to perform the cyclic exercise over a scan time of approximately 5.5 minutes.

Rectangular regions within the femur and tibia, as displayed in the first magnitude image, were user-selected for motion tracking. An integration algorithm (Zhu, et al., 1996) was used to process the velocity information and thereby compute the trajectory for each of these regions through the motion cycle. Coordinate axes were constructed from the two edges of each region, and 3D transformation matrices were computed relative to the fixed coordinate frame of the scanner. The longitudinal axis of the femur was defined based on anatomical landmarks in one image of the cine-PC data at which the knee was in full extension.

In addition to the cine-PC data acquisition, cine-MRI data was collected on a transverse plane through the femoral condyles. The knee flexion axis was defined in the image of this dataset for which the knee was fully extended.

An anatomical coordinate frame was defined in the femur based on the above axes. A transformation was calculated between the position of the tracked coordinate frame (from the cine-PC data) at full extension, and the anatomical frame. This transformation was then applied to the cine-PC coordinate frame at the other time points to calculate the position and orientation of the anatomical frame. The position and orientation of a coordinate frame aligned with the femoral frame at full knee extension yet fixed to the tibia was similarly calculated. The rotation matrix relating the tibial frame to the femoral frame was next calculated and decomposed using a 1-2-3 Euler angle sequence. The quantities computed represent flexion, varus/valgus, and axial rotations relative to the position at full extension.

RESULTS AND DISCUSSION

Four subjects (eight knees) were tested using the above methods. No knees had any history of injury or pathology. Figure 1 shows the resulting angles as averaged across the subjects, along with standard deviation margins.

The trajectories in flexion/extension are consistent across the subject knees (Fig. 1A.) Relatively little varus/valgus excursion is seen (Fig. 1B). The data show a significant coupled internal rotation with knee flexion (Fig. 1C), in accordance with the commonly observed 'screw home' phenomenon (Frankel and Nordin, 1980.)

SUMMARY

The data presented demonstrate the use of cine-PC MRI data to study tibiofemoral kinematics. Future studies will seek to assess the kinematic variations associated with pathological conditions.

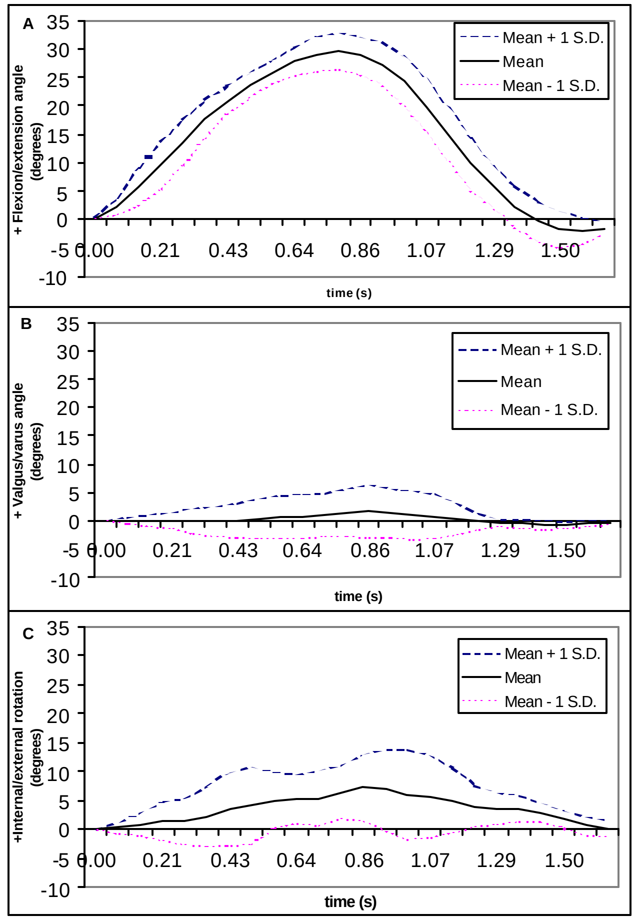

Figure 1: Mean plus/minus one standard deviation for joint angles measured in four subjects (eight knees)

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