Tibiofemoral Kinematics During the Stance Phase of Gait: Application of a New Imaging Technique

INTRODUCTION: Most of our knowledge of knee kinematics during gait is based on studies measuring knee motion using external skin markers. While these studies have dramatically improved our knowledge of human gait it remains a challenge to accurately determine the underlying bony motion non-invasively. [1] Recently, we validated the use of the dual-fluoroscopic imaging system (DFIS) for measuring knee kinematics during dynamic motion such as gait. [2] This study presents the first application of this method for measuring knee kinematics during treadmill gait in six degrees of freedom (6DOF).

MATERIAL AND METHODS: Seven subjects with bilateral healthy knees were recruited. First three-dimensional (3D) models were obtained by tracing bony contours of the tibia, fibula and femur on MR images in solid modeling software (Rhinoceros, Robert McNeal & Associates, Seattle, WA). The knees were then imaged using the DFIS while the subjects were walking on a treadmill at 1.5 mph. Thereafter, the 3D models and the pairs of fluorescent images were imported into the modeling software where a virtual fluoroscopic environment was created reproducing the position of the fluoroscopes during the scanning. The in-vivo positions of the tibia and femur were then reproduced by matching the projections of the tibial and femoral models to their outlines on the fluorescent images. For each gait cycle, the knee position was analyzed at every 10% of the stance phase from heel strike to toe-off. An anatomically based Cartesian coordinate system was used to measure the 6DOF knee kinematics of the knee.

RESULTS: Flexion and extension was obviously the major knee motion during the stance phase of walking (Fig. 1). The knee was extended at heel strike, flexed during loading response to about 8°, then begun to extend and remained in slight hyperextension (average 3.5°) throughout midstance until terminal stance when it started to flex again. The femur was observed to rotate externally twice during the stance phase. At heel strike the femur was in -1.6° of internal rotation which was followed by a 4.9° peak of external rotation during early midstance. Thereafter, the femur rotated internally to 0.5° at midstance and externally again towards toe-off. Valgus rotation was observed during stance phase and increased towards toe-off. The pattern of anterior-posterior motion was similar to that of flexion-extension. As the knee flexed, the femur shifted anteriorly on the tibia and during extension posteriorly. An initial lateral motion of the femur after heel strike reversed its direction during midstance and the femur kept moving medially thereafter.

DISCUSSION: In this study we investigated the 6DOF kinematics of the normal knee during the stance phase of gait using the DFIS. The knee showed consistent patterns in all rotations and translations. The rotational motion as well as anterior-posterior translation of the femur with respect to the tibia showed clear relationship with the flexion-extension path of the knee during the stance phase. These trends compare favorably to those reported in the current literature. [1] Additionally, we observed that the phenomenon of femoral rollback was reversed and the femur was noted to move posteriorly with extension and anteriorly with flexion. This phenomenon was also noted by others studying knee kinematics during gait using intracortical pins. [1] These data provide the basis for analysis of normal and pathological function of the knee joint during walking.

The presented technique has numerous advantages. It is accurate, non-invasive and does not require the placement of external devices or markers on the knee that could potentially interfere with its natural motion. Furthermore, the system can be assembled using any two commercially available fluoroscopes. In the future, this technique could provide information on the in-vivo motion of the knee, valuable for understanding various types of knee pathology and evaluating pathological changes and reconstructive procedures for ligamentous injuries.

REFERENCES: