Introduction

Understanding the *in vivo* kinematics of the lower extremity is of considerable interest to current research in biomechanics and, consequently, design optimization and implementation of total knee replacements (TKRs). One of the primary goals in some TKR designs is to replicate the kinematics generally observed in healthy knees. Therefore, it is of great importance to understand how and why normal knees move in characteristic patterns. Studies have shown that the cruciate ligaments contribute a passive force under elongation; whereby from flexion-to-extension a passive force of the posterior cruciate ligament (PCL) is generated that pulls on the lateral condyle causing posterior motion, enacting a screw home mechanism. Current studies make light of this ACL/PCL interaction in normal knee kinematics by 1) using 1D linear spring models and 2) introducing wrapping algorithms to account for surface geometry of nearby bones; however, this oversimplifies the motion.

Materials and Methods

Five healthy patients volunteered to take part in this study. All subjects gave informed consent to participate in this study. The study has been approved by an institutional review board. Patient-specific bone models were created from the computed tomography (CT) scans for each patient’s femur and tibia. Next, all patients performed a weight-bearing deep knee bend under fluoroscopic surveillance. Using a 3D-to-2D registration procedure the 3D patient surface models were overlaid onto the fluoroscopic images (Fig 1). Relative rotations of the femur to the tibia were calculated at every 20 degrees of flexion using the 3D motion captured from the fluoroscopy. Using the CT scans and MRI scans, the origin and insertion points were marked on the femur and tibia models for the ACL and PCL. Using the rotational matrices the origin and insertion points were tracked over the entire deep knee motion. Finally, a 3D dimensional surface model of the ACL and PCL was fit to the origin and insertion points taking into account contact with both surface models (Fig 2). This model was manually manipulated at each step using the bone models, origin, and insertion as constraints. A line fitting algorithm was used to determine the lengths of the ACL and PCL during the entire motion. This was compared to the linear technique for measuring the lengths.

Results

The ACL ligament is seen to be at a maximum length of 37.7 ±4.8 mm at maximum extension of the knee while the PCL ligament maximum length of 44.586 ± 3.7 mm occurs at maximum flexion of the knee. The ligaments tend to act in opposite directions because as one elongates the other ligament is retracting (Fig 3). Comparing our measurement technique with a linear method, the lengths show significant differences both in pattern and magnitudes (Fig 4).

Discussions

While methods exist for measuring the length of the cruciate ligaments, none have used an anatomically correct model to determine the overall length during any knee motions. While this may not be the first attempt to measure the lengths, our belief is that the lengths are more representative than any current techniques. The current limitation for this procedure is the time taken to manually manipulate the ligaments; however techniques are being created to automatic accomplish this step. Hopefully with the new measurement techniques better kinematic mathematical models can be created. Furthermore that this technique will give advancements into the designs of cruciate sacrificing knee implants to design better cams and reduce wear on all tibial polyethylene.

Significance

This study was done to introduce soft tissue modeling in order to design a new technique for measuring ligament lengths during patient activities. This new technique should provide advancements in implant design and mathematical knee modeling to further our understanding of the forces and stresses for any types of patients.