INTRODUCTION

Total knee arthroplasty (TKA) is a well-established treatment for patients with severe knee osteoarthritis, with over 500,000 TKA procedures performed in North America each year [1]. Proper patellar mechanics are critical for surgical success [2]. While anterior knee pain (AKP) persists in a remarkable 12-26% of patients [3], the differences in patellar mechanics between patients with and without pain are unknown.

To fully assess the six degrees of freedom (6 DOF) of the patella, a three-dimensional imaging modality is required. Magnetic resonance imaging (MRI) has been used to assess post-TKA knee mechanics [4,5]; however, metal implants create unknown distortions in MRI; low-field MR produces poor bone boundary definition; the patient is required to remain stationary for a considerable time; and patellar mechanics in the reported techniques have not been validated.

Computed tomography (CT) offers the potential for fast, high resolution, three-dimensional visualization of the knee, allowing accurate assessment of pre- and post-TKA knee mechanics. Use of CT for postoperative assessment has been limited because of streak artifacts from the metal implant components (due to photon starvation and beam hardening effects), but methods may exist to mitigate the problem. Radiation dose has been a concern, but scanning in the extremities of older individuals leads to a relatively low risk. The objective of this preliminary study was therefore to develop a CT imaging protocol to clearly visualize the knee, in particular the patellar component, such that pre- and post-TKA patellofemoral (PF) and tibiofemoral (TF) mechanics as well as contact area can be measured.

METHODS

Our CT protocol involves acquiring CT scans of the pre- and post-TKA knee at multiple flexion angles. Given good visibility of the patella, we can register 3D CAD models of the femoral, tibial and patellar components to the CT images as well as determine PF and TF contact areas. The key factor is obtaining good visibility of at least two of the patellar pegs. Our approach to doing so is to raise the foot up to move the patella out of the main artifact band.

The most severe region of metal artifact occurs when the scan penetrates two sides of the femoral component: the anterior flange and the posterior condyles. When the patella is within the artifact region, the artifact severely obstructs patellar visibility. By raising the foot off of the CT bed while keeping the knee within the central field of view of the CT bore, we can move the patella out of the artifact region (Fig. 1A), allowing us to clearly distinguish key anatomic and geometric features.

To develop and validate the CT protocol, a fresh mid-tibia to mid-femur cadaveric knee specimen was mounted on a custom built metal-free rig that allows the knee to be positioned at any desired flexion angle, and the foot to be raised off of the CT bed (Fig. 1B).

Once the pre-TKA scans were complete, an orthopaedic surgeon implanted NexGen LPS components (Zimmer, Warsaw, IN), and the post-TKA scans were taken.

To validate the 6 DOF PF and TF mechanics of the bones and the implants: rigid-body markers, visible to an opto-electronic camera system (Spectra, NDI), were attached to the femur, tibia and patella, and 4 fiducial markers were anchored at anatomical locations for each bone. A digitizing probe was used to digitize the locations of the fiducial markers for each bone to create bone coordinate frames. Implant positions were also digitized at pre-determined geometric locations to create implant coordinate frames. At each flexion angle, the rigid-body marker locations were captured to track each bone and its respective implant component.

Coordinate frames for both the pre- and post-TKA bone mechanics are defined in our protocol using a point-picking technique to select key anatomical features within image analysis software (Amira®). To determine implant mechanics, we use a similar point-picking technique to select key component features (e.g. the tops of the patellar pegs) on each of the implants within the images. 3D CAD models of the knee components are registered to the selected key features using a point-to-point registration algorithm. Coordinate frames within each of these CAD models then define the relative implant mechanics. Implant contact areas are found by growing the CAD components by one voxel in all directions and calculating the intersecting voxels.

RESULTS

From our post-TKA CT scans, we were able to observe a clear distinction in the amount of metal artifact obscuring the patella with the foot flat (Fig. 2A) vs. foot raised (Fig. 2B). By manipulating the foot height, we are thus able to clearly visualize key features for each implant component, allowing us to precisely select implant features for image analysis, and giving us the potential for accurate CAD model registration and calculations of mechanics and contact area.

DISCUSSION

To our knowledge, there is no validated technique for measuring 6 DOF of patellar mechanics before and after TKA due to the difficulty in accurately visualizing the patellar component. We have proposed a CT protocol that allows the knee and its implant components to be clearly visible, such that PF and TF mechanics and contact area can be calculated. Furthermore, using CT provides the opportunity for morphological analysis and bone density property studies, including finite element analyses. 3D models of the knee can also be used in combination with fluoroscopic imaging for dynamic analysis of knee kinematics. Such analyses offer much clinical and research potential and could lead to changes in component design, surgical technique, preoperative planning, postoperative rehabilitation or patient selection.

REFERENCES


Figure 1: (A) Schematic showing the effect of raising the foot to move the patella out of the artifact region (shown in red) and (B) cadaveric knee specimen at 30° TF flexion mounted on the rig with the foot raised.

Figure 2: Sagittal and axial scans of the knee at 30° TF flexion with the foot flat (A), where the patella is inside the artifact region and hardly visible, and with the foot raised (B), in which the patellar component pegs are clearly visible, indicated by the red arrows.