Investigating Knee Shape Differences Due to Total Knee Arthroplasty

Mohsen Akbari Shandiz, Paul Boulos, Stefan K. Saevarsson, Carolyn Anglin.
University of Calgary, Calgary, AB, Canada.

Disclosures:

Introduction: One of the major goals of total knee arthroplasty (TKA) is to relieve pain due to arthritis of the knee and to restore function. Unfortunately approximately 18% of patients are not satisfied with the result of their surgery [1]. Reasons for this are largely unknown but TKA patients often comment that their knee does not feel “normal”. Shape changes may play an important role. We are unaware of any previous studies. Although the goal is generally to reproduce normal shape and kinematics as closely as possible, patients who receive a knee replacement usually have malaligned legs (varus or valgus), malshaped knees (worn cartilage, osteophytes) and may have improper kinematics (patellar maltracking, poor range of motion) that require alteration. Therefore, the knee will inevitably be changed as a result of the surgery. Furthermore, only a limited number of shapes and sizes of implants are available for each patient, necessitating compromises in the fitting of the components to the bones, and one or both cruciate ligaments are removed during the surgery. As a result, the implanted knee has a different shape and kinematics than the original natural knee. Implant designs are usually based on existing anatomy, without taking into consideration the changes that are made to the joint during surgery. The purpose of the present study was to measure and investigate changes in knee geometry due to arthroplasty, with a particular focus on the femoral groove, with the goal of improving implant design, selection and positioning. The resulting patient-specific planning can be incorporated into computer-assisted surgery systems or mechanical instrumentation to help reduce pain and restore more normal kinematics.

Methods: We acquired computed tomography (CT) scans of 9 subjects (4F, 5M, 70±10.6 yrs) before and at least one year after TKA, using a validated CT protocol that allows better visibility of the patella after TKA [2]. There was partial loadbearing of the leg by having the subjects press on a weighted pedal. In addition, we obtained sequential-biplanar calibrated radiographs at 0º, 45º and 90º knee flexion, from a sagittal view and 10º below sagittal; this allowed mediolateral shift and tilt within the groove to be determined following 2D-3D matching of the bones or components to the radiographs [3]. The preoperative CT scans were automatically segmented, with manual correction for the osteophytes, to create 3D models of the bones. 3D models of the implants, provided by the manufacturer, were automatically matched to the postop CT scans to determine the postop placement of the components [2]. Coordinate systems were assigned to the bones and components based on anatomical or component features [2]. All subjects had a rotating platform posterior-stabilized implant (Sigma Mobile Bearing; DePuy Inc., Warsaw, IN) with a resurfaced patella, and had good clinical results. The following geometric measurements were made: femoral component rotation, joint line height, hip-knee-ankle (HKA) angle, patellar thickness, patellar height and postop location of the patella in the femoral groove. Patellar height was measured from sagittal radiographs using the Insall-Salvati ratio [4]. The HKA angle was determined from the CT topograms, since the pedal aligned the patient’s leg appropriately. Patellar thickness was measured from the 3D bone model at the thickest part of the patellar bone. Joint line changes were determined by overlaying the postop 3D bone-plus-implant models onto the preoperative CT of the bones and determining the overlap or gap; this recently-developed technique accounts for the preop cartilage thickness [5]. Measurements were performed using ZIBAmira (v2011.2-rc6, Zuse Institute Berlin, Berlin) and ImageJ (NIH, Bethesda, MD).

Results: By overlaying the femoral component on the preop femoral bone (Fig. 1a), it can be seen that the knee shape changed in numerous ways as a result of the TKA, although in general, the intercondylar gap location was similar preop to postop. In 6/9 cases, the proximal portion of the preop femoral groove was more lateral, by varying amounts (green line in Fig. 1a = deepest point of the preop femoral groove; white = postop femoral groove; blue = postop patellar tracking). In all cases, the preop femoral groove extended more proximally. Postop patellar tracking followed the preop femoral groove more closely than the postop femoral groove. In all cases the patella tracked within 4.8 mm of the deepest point of the groove, so none would be classified as maltracking. Two of the postop patellae tilted greater than 5º in early flexion and a third tilted greater than 5º in later flexion. Each of these corresponded to cases where there was a visible difference between the preop and postop femoral grooves. There were 8 varus and 1 valgus knee; the average correction was 3.5º, bringing the knee closer to neutral alignment (Fig 1b, Table 1). Patellar height was unchanged (Fig. 1c, Table 1). Since the joint line was lowered in each case, by 1.7 mm on average in extension and 4.8 mm in flexion (Fig 1d, Table 1), the patella normally tracked slightly lower on the postop femoral component than the corresponding preop femur. There was a larger joint line shift on the medial side than the lateral side due to the varus knees preop. Patellar thickness increased by an average of 2.9 mm, excluding the preop cartilage (Fig. 1e, Table 1). The femoral component was internally rotated by 3.2º on average relative to the transepicondylar axis; tibial component rotation was not relevant due to the mobile bearing.

Discussion: Important differences in shapes were seen between pre-TKA and post-TKA knees. These differences are due to a combination of surgical technique, implant design, implant selection and component positioning. Comparing the knee shape of
each individual before and after TKA and analyzing the interrelationships amongst shape and kinematics, both based on these results and on musculoskeletal modeling, will allow us to make a direct evaluation of the effect of TKA on each individual. Detailed 6 degree-of-freedom tibiofemoral and patellofemoral data were also taken for these subjects as well as quality of life information. This pilot study was limited by a small number of subjects with a single implant design and surgeon. A larger study with multiple surgeons and implant designs, including patients with good and poor results, is planned. A previous study of 5 patients with poor results each revealed that component placement likely affected their clinical outcome [6]. The proposed extended study can be used to improve implant design, implant selection and component positioning. The resulting patient-specific planning can be incorporated into mechanical instrumentation or computer-assisted surgery systems with the goal of reducing pain and restoring more normal kinematics.

Significance: The shape of the knee joint changes substantially following knee replacement, both intentionally and unintentionally. Component placement impacts the tracking of the patella within the femoral groove as well as the joint line height, HKA angle and patellar thickness. These can influence the range of motion, pain and likelihood of patellar fracture. The larger study can be used to improve implant design, selection and positioning.

Acknowledgments: We gratefully acknowledge funding from Alberta Innovates Technology Futures and Alberta Innovates Health Solutions - Osteoarthritis Team Grant, as well as the provision of implant CAD models from Johnson & Johnson Medical Products, a division of Johnson & Johnson Inc., IIS No. 2012-6-DEP, image analysis support from Heiko Ramm (Zuse Institute Berlin), and clinical support from Dr. Stephen Miller.


![Image of knee joint measurements](image)

**Figure 1:** Geometrical measures of changes in joint shape

<table>
<thead>
<tr>
<th>Geometric Measure</th>
<th>Value</th>
<th>Pr-TKA</th>
<th>Post-TKA</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>HKA angle (°) (for 8 varus knees)</td>
<td>5.6 ± 2.2</td>
<td>2.1 ± 2.6</td>
<td>3.5 (0.0 to 0.8)</td>
<td></td>
</tr>
<tr>
<td>Patellar height (Insall-Salvati ratio)</td>
<td>1.1 ± 0.2</td>
<td>1.1 ± 0.2</td>
<td>-0.2 (0 to -0.2)</td>
<td></td>
</tr>
<tr>
<td>Patellar thickness (mm) (Pre-TKA refers to bone only, Post-TKA refers to component)</td>
<td>2.3 ± 1.8</td>
<td>2.4 ± 1.2</td>
<td>0.1 (0 to 0.2)</td>
<td></td>
</tr>
<tr>
<td>Joint line change (mm) at 90° flexion (+ = incursion in ligaments)</td>
<td>-1.7 ± 0.9</td>
<td>-3.7 ± 1.5</td>
<td>-2.0 (0 to 3.2)</td>
<td></td>
</tr>
<tr>
<td>Femoral component rotation (°) (for internal)</td>
<td>3.2 ± 1.2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**ORS 2014 Annual Meeting**
**Poster No: 1753**