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Inter-Observer Precision and Physiologic Variability of MRI Landmarks Used to Determine Rotational Alignment in Conventional and Patient-Specific TKA

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ABSTRACT

Preoperative planning for patient-specific guides (PSGs) in total knee arthroplasty (TKA) requires identification of anatomic landmarks on three-dimensional imaging studies. The aim of this study was to assess the accuracy and precision with which landmarks commonly used to determine rotational alignment in TKA can be identified on magnetic resonance imaging (MRI). Two orthopedic surgeons and two musculoskeletal radiologists independently reviewed a sequential series of 114 MRIs of arthritic knees. The magnitude of interobserver variability was high, suggesting an inherent risk of inconsistency when these landmarks are used in PSG fabrication. Additionally, there was a high degree of physiologic variation among patients, indicating that assuming standard relationships among anatomic landmarks when placing TKA components may lead to rotational malalignment relative to each patient's native anatomy.

Total knee arthroplasty (TKA) is one of the most commonly performed operations by orthopedic surgeons, yet it has an overall dissatisfaction rate of almost 20% and a long term revision rate of 10% at 10 years [1,2]. One possible etiology of poor functional outcome and aseptic failure is malalignment of components either relative to target ranges or to the patient's native anatomy. While Parratte et al found no relationship between coronal alignment within 3° of neutral and survivorship of TKA at 15 years, numerous biomechanical, finite model analysis, and clinical studies have demonstrated an increased risk of failure and revision in cases of excessive varus or valgus malalignment [3–6]. Furthermore, malrotation of components in the axial plane has been implicated in patellar maltracking and anterior knee pain and may be a cause of poor functional outcome in patients with TKAs [7,8].

Traditional TKA relies on standard intramedullary and extramedullary cutting guides to dictate placement of components. These guides have been associated with a high degree of inaccuracy, with numerous studies reporting that over 20% of TKAs performed with conventional cutting guides fail to restore coronal alignment to within 3° of neutral [9–11]. More accurate coronal alignment has been demonstrated with computer-assisted orthopedic surgery (CAOS), which utilizes intraoperative navigation to guide cuts based on tracking markers that have been registered into a computer [12,13]. However, CAOS has been associated with a high degree of rotational and sagittal plane malalignment [14–18]. Also, a recent systematic review of navigated TKA found no improvement in revision rates, survival, and functional outcomes in the short to medium term despite the additional cost and increased operative time [15].

Patient-specific guides (PSGs) were developed as a way to combine the ease of use of standard guides with the customization of computer-assisted techniques. Custom cutting guides are templated and fabricated on the basis of preoperative computed tomography (CT) or magnetic resonance imaging (MRI) scans of the patient's knee, in essence moving navigation from the operating room to the preoperative period. This technology has been shown to reduce operative time and number of equipment trays needed and may enable the surgeon to customize implant placement in cases involving anatomic deformities [19]. Another theoretical benefit of PSGs is improved component alignment in all planes due to the ability to precisely determine component position preoperatively. However, studies evaluating whether PSG techniques improve either coronal or rotational alignment have been contradictory [9,20–23]. Also, no clinical outcomes data have supported the use of PSGs over traditional instrumentation and justified the additional costs of the preoperative CT or MRI scans and PSG fabrication [19].

The achievement of consistent rotational alignment in TKA and PSG generation is dependent on two factors: (1) standard relationships among anatomic landmarks of the distal femur and proximal tibia and (2) accurate identification of those landmarks on three-dimensional imaging. We hypothesized that conventional assumptions of anatomic

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relationships may lead to rotational malalignment and that anatomic landmarks commonly used in TKA would not be identifiable on MRI with a high degree of reproducibility.

Materials and Methods

We performed a radiographic retrospective study to evaluate the physiologic variability of anatomic landmarks used in templating TKAs and the interobserver and intraobserver reliability of identifying those landmarks on MRI. One hundred fourteen patients obtained knee MRIs at our institution as preoperative preparation for a patient-specific Biomet Signature TKA (Biomet, Warsaw, Indiana). This was a consecutive series of patients with osteoarthritis or inflammatory arthritis in a native knee evaluated by one of the two senior surgeons. These patients were part of a prospective cohort study performed to compare the radiographic clinical outcomes of the use of patient-specific cutting guides versus standard instrumentation at our institution. The option of PSG versus standard instrumentation was presented to the patients and selection was based on patient preference. Patients in the PSG cohort were willing to have an MRI and a 6-week delay in their surgery for image processing. One hundred fourteen patients selected patient-specific cutting guides, while 134 selected standard instrumentation. One hundred fourteen was calculated as the minimum sample size based on the desired precision of ± 0.10 for a 95% confidence interval [24]. This cohort included 54 males and 60 females with an average age of 64 years (range 46 to 90 years). All patients were scanned in the supine position with the knee extended in a dedicated extremity transmit-receive coil. All study cases were scanned on 1.5 or 3.0 T Siemens MRI scanners (Siemens Healthcare, Munich, Germany) with axial fast spin echo T2-weighted fat-saturated imaging. The scanning protocol included axial, sagittal and coronal images of the knee, as well as axial images of the ipsilateral ankle and femoral head and neck for the purpose of version evaluation. Only the axial imaging of the knee was considered for this study.

Four reviewers (two orthopedic surgeons and two musculoskeletal radiologists) reviewed each MRI in duplicate, with 2 weeks between each review and in a fashion that blinded the reviewers to patient identifiers. For the distal femoral measurements, the TEA was drawn between the lateral epicondylar prominence and the medial sulcus of the medial epicondyle, as described by Berger et al [8]. If the two landmarks were not on the same slice, then the slice with the best-defined sulcus was selected and the position of the lateral epicondyle was extrapolated from adjacent slices. The slice number was recorded. The posterior condylar line was drawn between the posterior-most cartilage surfaces of the medial and lateral femoral condyles on the same slice as the TEA. The angle subtended by these lines, the posterior condylar angle (PCA), was measured with the Cobb angle tool, with positive numbers denoting external rotation of the TEA relative to the posterior condylar line and negative numbers denoting internal rotation (Fig. 1).

Two sets of measurements were obtained for the proximal tibia. For the first measurement, the slice with the best-defined tibial tubercle was identified and the medial third was marked (Fig. 2). This point was translated proximally to the most inferior slice containing the full PCL footprint, and the apex of the PCL sulcus was identified on this slice (Fig. 3). A line was drawn between these two points, and the angle between this line and the posterior border of the tibia (the line drawn between the most posterior medial and lateral aspects of the tibial plateau) was then measured (Fig. 4). For the second measurement, the tip or midpoint of the tibial tubercle was identified on the slice with the best-defined tibial tubercle (Fig. 2), then this point was translated proximally to the slice with the proximal tibial shaft just distal to the tibial plateau. The geometric center of the tibia was identified according to Berger et al's protocol [8], as the center of the best fit ellipse around the proximal tibial shaft (Fig. 5), and the angle subtended by a line between the tip of the tubercle and the geometric center and the posterior border of the tibia was measured (Fig. 6).

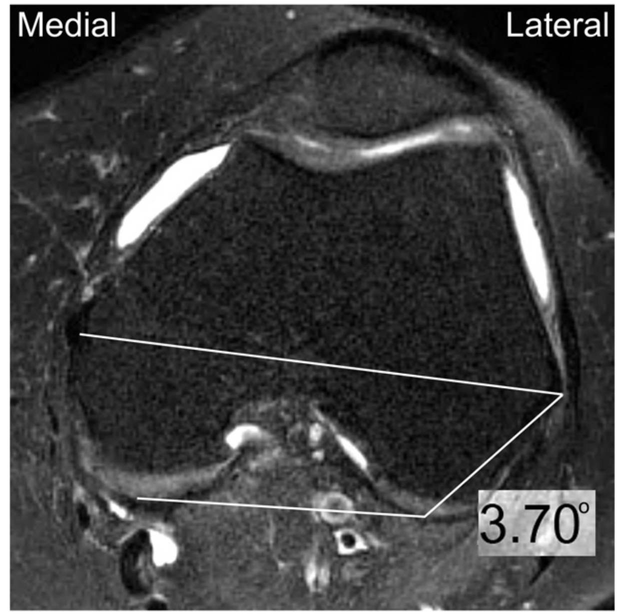

Fig. 1. The transepicondylar axis (TEA) was drawn between the lateral epicondylar prominence and medial epicondylar sulcus, and the posterior condylar angle (PCA), or angle between it and the posterior condylar line, was measured on this T2-weighted, fat-saturated axial MRI slice.

Statistical Analysis

Statistical analysis for reliability was performed by computing interobserver and intraobserver intraclass correlation coefficient (ICC) for each set of measurements. We computed ICC by comparing the variability of different ratings of the same subject to the total variation across all ratings and all subjects, using maximum likelihood estimation based on two-way mixed-effects ANOVA models [25,26]. For interpretation of ICC, 1 was considered perfect reliability, 0.81–1 very good, 0.61–0.80 good, 0.41–0.60 moderate, and <0.4 poor [27].

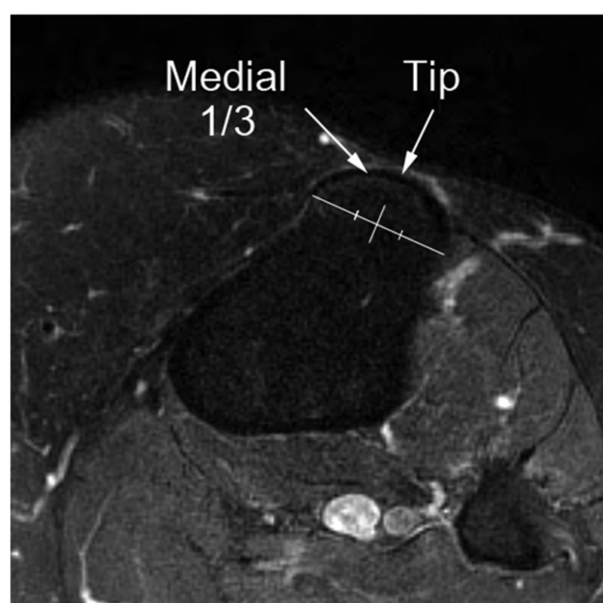

Fig. 2. Both the tip and the medial third of the tibial tubercle were marked on this image.