A New Geometric Ratio to Predict the Flexion Gap in Total Knee Arthroplasty: A Computational Study

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Introduction: Total knee arthroplasty (TKA) is the treatment of choice for end-stage osteoarthritis. Despite long-term survival rates of over 90% [1], TKA still suffers from short-term complications, such as knee instability, which is responsible for up to 20% of all revision surgeries [2]. Instability following TKA has been, in part, attributed to improper tensioning of knee ligaments during measured resection (MR) TKA; a common bony resection technique that depends on bony landmarks to place the femoral component, but neglects the geometry of the restraining medial collateral ligament (MCL). Thus, MCL might be tensioned improperly and knee stability could be compromised. We used a computational model of the knee to examine a new measurement “the MCL ratio” that accounts for both the femoral geometry and the attachments of the MCL to place the femoral component. Our objective was to determine whether the MCL ratio predicts the behavior of MCL and help to better balance the knee in TKA.

Materials and Methods: Six 3D hip to ankle cadaveric models were reconstructed from CT scans and used to build computational knee models using our previously-developed multibody dynamics framework [3]. A posterior stabilized implant design (Logic, Exactech, FL) was virtually installed using MR technique. Twenty fibers, representing knee ligaments, were added to the model and defined as a tension-only, nonlinear force element using mean structural properties reported in the literature. Ligament properties were standardized to reflect a clinically-acceptable, balanced knee at full extension [3]. Passive knee flexion was simulated; then, varus and valgus moments of ±20 Nm were applied to replicate intraoperative assessment of the knee during TKA [4]. The corresponding openings on the medial and lateral sides of the knee (i.e., the gaps) in response to the applied moments were measured. The MCL ratio; a ratio between the distances of the femoral insertions of the anterior fiber of the MCL to the posterior and distal cuts (Fig. 1), was calculated and compared to the medial and lateral gaps difference.

Results and Discussion: Despite similarly standardizing and balancing the six knees at full extension, three out of six knees were unbalanced in flexion and produced a difference between the medial and lateral gaps >2 mm (Fig. 2). This variability in gaps is likely due to high interpersonal geometric variation in the femoral condyles. The MCL ratio corresponded to this variability. Specifically, the closer the MCL ratio was to one, the less was the difference between the medial and lateral gaps (Fig. 2). The correspondence between the MCL ratio and the gap difference in flexion can be explained by the ability of the MCL ratio to capture the isometry of the MCL through flexion.

Translational Impact: A new geometric ratio that considered both the insertion location of the MCL relative to the femoral cuts corresponded to the difference in medial and lateral gaps in flexion and can, therefore, help personalize the bony cuts to achieve a balanced flexion gap in TKA.

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Fig. 1: MCL ratio; a ratio between the distance of the femoral insertions of the anterior fibers of the MCL to the posterior and the distal cuts. MCL ratio was 1 in knee 6 and was 1.5 in knee 3.

Fig. 2: Gaps in response to varus/valgus moments at 90° of flexion. The MCL ratio corresponded to the gap difference.