Osteophytes Increase Ligament Forces in the Medial Posterior Capsule and Posterior Oblique Ligament

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INTRODUCTION: Gap balancing techniques in total knee arthroplasty (TKA) aim to restore healthy knee function by adjusting implant alignment according to patient-specific anatomy and soft tissue tensions [1]. However, gap balancing assessments are typically performed prior to osteophyte removal. When osteophytes are later removed, ligament laxity is altered, and the planned implant alignment may no longer be appropriate for achieving the desired gap balance. Preoperatively identifying when the severity of osteophytes will affect ligament laxities, and hence the surgical plan, would help surgeon decide whether osteophytes need to be removed prior to gap balancing. As a preliminary step in achieving this goal, the objective of the present study was to utilize intraoperative data from cadavers to develop subject-specific computational models that quantified how ligament forces were impacted by osteophytes.

METHODS: Experiment: Two fresh-frozen cadavers with osteoarthritis (OA) underwent robotic-assisted TKA. B scores, which indicate OA severity [2], were 4.4 and 6.8 for Specimens 1 and 2, respectively (Table 1). After bone resection, a proprietary tensioner device was inserted into the joint to distract and measure load in the medial and lateral compartments of the knee to determine ligament laxity (Figure 1A). Distances between the femoral bone and tibial plateau were measured by the robotic system. Load and distance data were recorded at 5-pound force (lbf) increments from 0 to 40 lbf at 0, 10, 45, and 90° flexion for PCL-intact conditions. **Modeling:** Computational models, based on a custom kinematics driven framework [3,4], were developed for the two specimens. Computed tomography images were automatically segmented using a statistical shape and appearance model provided by Imorphics (Stryker, Manchester, UK) which generates the osteophytic and osteophyte-free femoral and tibial bone surfaces for each specimen. Ligaments were modeled as sets of nonlinear elastic springs. Ligament properties (stiffnesses, slack lengths, and nonlinear toe regions) were calibrated using the Covariance Matrix Adaptation Evolutionary Strategy (CMA-ES) to minimize differences between measured and predicted compartmental loads based on the sum of ligament reactions (Figure 1B). Calibration was performed at 10° and 90°, and at 0° for the posterior capsule (PCAP); validation was performed at 45°. **Analysis:** Calibrated ligament properties were then applied to bones with osteophytes (Figure 1C) and without osteophytes (Figure 1D) to determine differences in ligament forces.

RESULTS: Total osteophyte volumes were 2,151 and 19,777 mm^3 for Specimens 1 and 2, respectively (Table 1). For ligament calibration, root mean square errors ranged from 4.5 N (45° PCL intact, lateral load, Specimen 2) to 69.7 N (0° PCL intact, lateral load, Specimen 1). For Specimen 1, the largest differences in ligament forces between the bones with and without osteophytes occurred in the posterior oblique ligament (POL) at 0° (30 N) and 10° (26 N), and in the medial PCAP at 10° (32 N) (Figure 2A). For Specimen 2, the largest differences in ligament forces occurred in the superficial medial cruciate ligament (sMCL) at 90° (318 N), the POL at all flexion angles (116 to 221 N), and the medial PCAP at 10° (125 N) (Figure 2B).

DISCUSSION: Results indicate that differences in ligament forces for bones with and without osteophytes are dependent upon the location and size of the osteophytes. The increase in ligament forces were roughly correlated to the volume of the osteophytes, where Specimen 2's osteophytes were ~10 times the volume compared to Specimen 1. The POL and medial PCAP ligaments were affected in both specimens; not surprisingly, both ligaments wrap around the largest osteophytes on the femur's posterior medial condyle (Table 1). Future work will evaluate the sensitivity of this effect across additional specimens and, potentially, for statistically generated osteophytes of increasing volume for the same specimen.

SIGNIFICANCE/CLINICAL RELEVANCE: The severity of osteophyte growth will impact surgeons' ability to create an appropriate surgical plan preoperatively using gap balancing techniques. Quantifying the effect of osteophytes on ligament forces, and correspondingly the gap balances, will improve TKA outcomes by providing guidance on the effect of osteophyte presence and removal prior to gap balancing on patient-specific pre-operative surgical plans.

REFERENCES: [1] Golladay et al., *J Arthrop* (2019). [2] Bowes et al., *Ann Rheum Dis* (2021). [3] Zaylor, et al., *J Biomech* (2019). [4] Zaylor & Halloran, *J Biomech Eng* (2021).

Table 1: Characteristics of the two cadaveric specimens

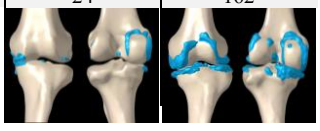
	Specimen 1	*Specimen 2*
Sex	Female	Female
Age	85	85
Body Mass Index (kg/m²)	25	21
Hip-Knee-Ankle Angle + varus, - valgus	7.2	7.0
B Score	4.4	6.8
Osteophyte Volumes (mm^3)		
Total	2,151	19,777
Femur		
Anterior Lateral	5	1,361
Anterior Medial	76	2,112
Lateral	36	1,039
Medial	393	3,067
Notch	31	377
Posterior Lateral	9	1,095
Posterior Medial	1,262	3,827
Tibia		
Anterior Lateral	0	1,373
Anterior Medial	186	1,282
Posterior Lateral	0	401
Posterior Medial	131	3,681
Spine	24	162
Segmented osteophytes colored blue		

Figure 1: (A) Illustration of experimental setup with tensioner device. (B) Computational model used for ligament calibration. (C) Application of calibrated ligament properties to bone with and without osteophytes.

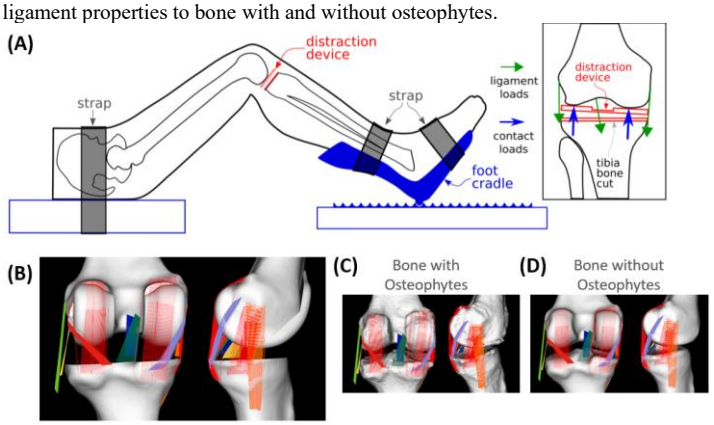


Figure 2: Differences in ligament forces for bone with osteophytes minus bone without osteophytes for (A) Specimen 1 and (B) Specimen 2.