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Original research

What is the Effect of Posterior Osteophytes on Flexion and Extension Gaps in Total Knee Arthroplasty? A Cadaveric Study

David C. Holst, MD [a], Gary W. Doan, MS [b], Marc R. Angerame, MD [c], Martin W. Roche, MD [d], Chadd W. Clary, PhD [b], Douglas A. Dennis, MD [b, e, f, g, *]

[a] Department of Orthopaedic Surgery, Duke University School of Medicine, Durham, NC
[b] Department of Mechanical and Materials Engineering, University of Denver, Denver, CO
[c] Illinois Bone and Joint Institute, Barrington, IL
[d] Holy Cross Orthopedic Institute, Ft. Lauderdale, FL
[e] Colorado Joint Replacement, Denver, CO
[f] Department of Orthopaedics, University of Colorado School of Medicine, Aurora, CO
[g] Department of Biomedical Engineering, University of Tennessee, Knoxville, TN

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ABSTRACT

Background: Posterior compartment knee osteophytes may pose a challenge in achieving soft-tissue balance during total knee arthroplasty (TKA). Obtaining symmetry of flexion and extension gaps involves balance of both bony and soft-tissue structures. We hypothesize that space-occupying posteromedial femoral osteophytes affect soft-tissue balance.
Methods: Five cadaveric limbs were acquired. Computed tomography scans were obtained to define the osseous contours. Three-dimensionally printed, specimen-specific synthetic posterior femoral osteophytes were fabricated in 10-mm and 15-mm sizes. TKAs were implanted. Medial and lateral compartment contact forces were measured during passive knee motion using pressure-sensing technology. For each specimen, trials were completed without osteophytes and with 10-mm and 15-mm osteophytes affixed to the posteromedial femoral condyle. Contact forces were obtained at full extension, 10°, 30°, 45°, 60°, and 90° of flexion. These were recorded across each specimen in each condition for three trials. Tukey post hoc tests were used with a repeated measures ANOVA for statistical data analysis.
Results: The presence of posteromedial osteophytes increased asymmetric loading from full extension to 45° of flexion, with statistically significant differences observed at full extension and 30°. A reduction in lateral compartment forces was noted. The 25%-75% bounds of variability in the contact force was less than 3.5 lbs.
Conclusions: Posteromedial femoral osteophytes caused an asymmetric increase in medial contact forces from full extension continuing into mid-flexion. The soft-tissue imbalance created from these osteophytes supports their removal before performing ligament releases to obtain desired soft-tissue balancing during TKA.

Introduction

Successful total knee arthroplasty (TKA) is reliant on achieving the goal of appropriately balanced and symmetric flexion and extension gaps. Unbalanced or asymmetric gaps may lead to accelerated polyethylene wear, unfavorable kinematics, chronic effusions, and persistent knee pain [1]. Instability, which is often a result of soft-tissue imbalance, has been identified as a leading cause for failure of modern TKAs in long-term analyses [2-4]. However, controversy exists over the best technique to achieve balanced gaps in TKA so as to avoid instability [5] and failure [6].

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* Corresponding author. Colorado Joint Replacement, 2535 S. Downing St. Suite 100, Denver, CO 80210. Tel.: 720-524-1367.
E-mail address: roseannjohnson@centura.org

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Multiple investigations have focused on sequential soft-tissue releases and their effect on coronal TKA balance and stability in cadaveric models [7-9], as well as their role in affecting flexion-extension gap balance [10]. Less attention has focused on the role played by osteophytes within the posterior compartment of the knee in affecting soft-tissue balance (Fig. 1). There have been some limited investigations that have demonstrated that structures within the posterior compartment of the knee affect the extension gap. For example, enlarged posterior condyles increase tension in extension, [11] and the amount of posterior condylar resection affects the size of the extension gap as well [12]. We have previously described a technique which allows early posterior osteophyte removal before performing appropriate soft-tissue balancing procedures [13] (Fig. 2a-c). However, there are limited studies investigating quantification of what effect posterior femoral osteophytes have on the soft-tissue envelope in TKA. One method of measuring soft-tissue strain and balance of the flexion and extension gaps is the use of pressure-sensing technology which quantifies joint contact forces as a surrogate for soft-tissue tension and balance [14,15,16,17,18,19]

The purpose of the present study is to evaluate the effect of posterior femoral osteophytes on tension and balance of flexion and extension gaps during TKA in a cadaveric model. Our study was meant to quantify knee contact forces at multiple flexion angles with and without the presence of posterior osteophytes of differing size. This was meant to determine what, if any, effect posterior osteophytes might have on soft-tissue balance as measured by the contact forces. The present study involves medial sided posterior osteophytes only for ease of conceptual analysis. We hypothesize that increasing sizes of posterior osteophytes would increase quantifiable strain on the soft tissues as measured by contact forces, and this effect would be present in both extension and flexion. We further hypothesize that the extension gap would be affected to a greater degree, owing to the intact posterior capsule being tensioned preferentially in extension, thereby increasing contact pressures with increasing extension angle.

Material and methods

Five male cadaveric lower extremity limbs (age: 71 ± 11, height: 72.7 ± 1.5”, body mass index: 22.4 ± 3.5) were acquired for testing. A computed tomography (CT) scan was performed on each specimen, and the femoral geometry of each specimen was segmented using ScanIP (Synopsis, Mountain View, CA). Ellipsoidal synthetic osteophytes were fashioned to replicate the morphology of clinically observed osteophytes and positioned with the center of the ellipsoid on the superior aspect of the posterior medial condyle. The geometry of the synthetic osteophytes was determined from a CT scan analysis of 20 osteoarthritic knees with known posterior femoral osteophytes (Fig. 3). The dimensions of the osteophytes in the analysis were measured superior-inferior from the superior apex of the osteophyte relative to the most superior point on the condylar articulating surface. The medial-lateral and anterior-posterior dimensions of the ellipsoids (osteophytes) were scaled to match the cadaveric condylar morphology and to avoid interference with the TKA posterior and intercondylar box resection planes. Osteophyte size ranged from 22 to 24 mm and 12 to 15 mm in the medial-lateral and anterior-posterior dimensions, respectively. Osteophytes were created with 10-mm and 15-mm superior-to-inferior radii and secured via mounting flanges extending into the intercondylar notch (Fig. 4). The synthetic osteophytes were created via 3D printing using a Fortus 450 3D printer (Stratasys, Inc, Edin Prairie, MN).

Posterior-stabilized TKAs (NexGen Knee System; Zimmer Biomet, Warsaw, IN) were performed by a fellowship-trained surgeon on all specimens via a medial parapatellar approach using a gap-balancing technique and a spacer block system [14]. After the femoral and tibial resections were performed, femoral and tibial trials were placed in the cadaveric knee. A VERASENSE sensor-enabled tibial spacer (OrthoSensor, Inc, Dania Beach, FL) was inserted into the tibial tray to assess the medial and lateral contact forces at the knee through the passive range of flexion. The use of the sensor-enabled tibial insert trial as a surrogate for soft-tissue tension in TKA has previously been described [15-20]. Measurements were taken at full extension, 10°, 30°, 45°, 60°, and 90° knee flexion while the tibia was supported in neutral tibial internal-external and adduction-abduction rotations and without the application of varus-valgus stress. Full extension was maintained by supporting the heel and allowing the weight of the leg to pull the knee into extension. Knee flexion angles were verified during each measurement with manual measurement using a goniometer.

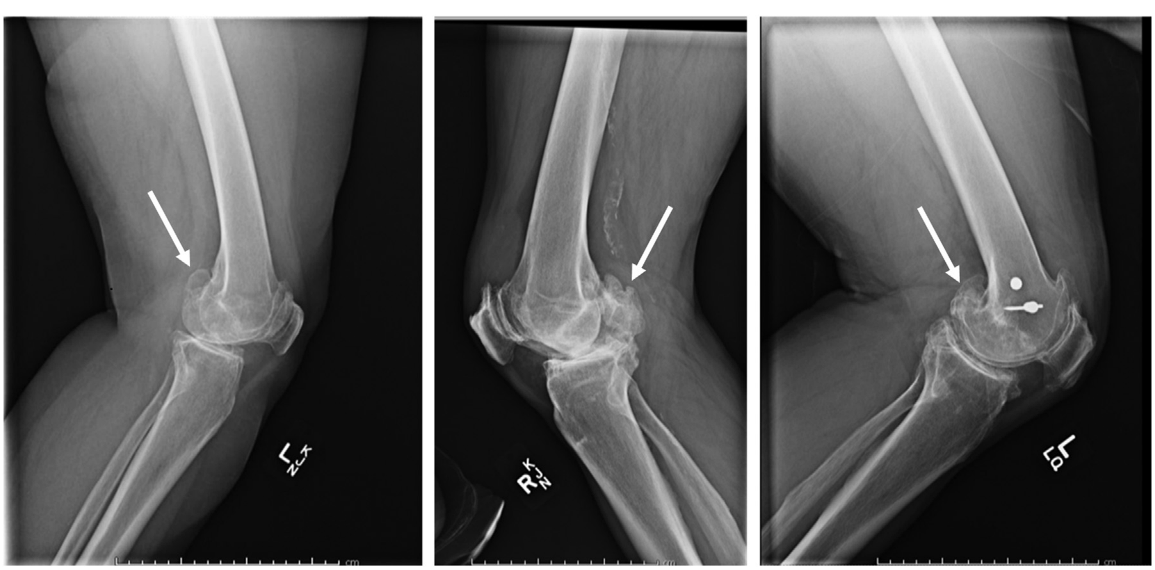

Figure 1. Three representative lateral knee radiographs with large posterior femoral osteophytes (arrows) from three separate patients, demonstrating the clinical entity related to the current study.

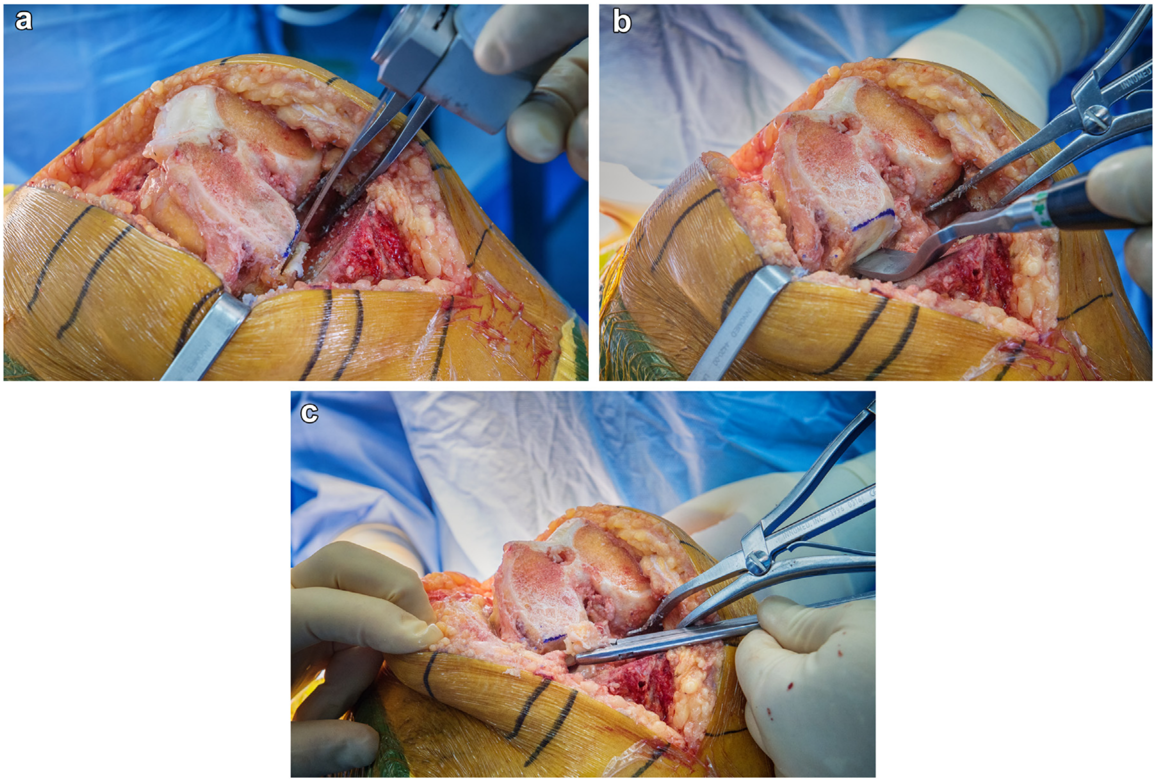

Figure 2. Intraoperative photographs demonstrating a preliminary 4-mm osteotomy of the posterior aspect of the medial femoral condyle (a) to allow access to the posterior compartment and subsequent posterior femoral osteophyte removal using a curved osteotome (b); (c) posterior femoral osteophyte removed.

Medial and lateral contact forces were manually recorded from the device display (Fig. 5). Contact force measurements were repeated three times at each flexion angle, and the sensor-enabled tibial insert trial was re-zeroed after every measurement sequence through the flexion range. All trials were performed by the same surgeon to reduce intraoperator variability, and the surgeon was blinded to the sensor readings during the evaluation to avoid unintentional bias.

After the initial tensioning evaluation, the femoral trial was removed, and the knee was positioned in maximum flexion. Sequentially, the 10-mm and 15-mm specimen-specific synthetic osteophytes were implanted over the posterior aspect of the medial femoral condyle and secured using a bone screw (Fig. 4). Care was taken not to perform further soft-tissue release during this procedure. The contact force assessments were repeated with each osteophyte in place, with three trials for each condition at each degree of flexion.

An initial analysis was conducted to assess potential uncertainty in condylar loading measurements because of the measurement process. Measurement variability was calculated as the difference between each individual medial and lateral contact force measurement and the average of the three repeated measurements for that condition. These differences were then averaged across all

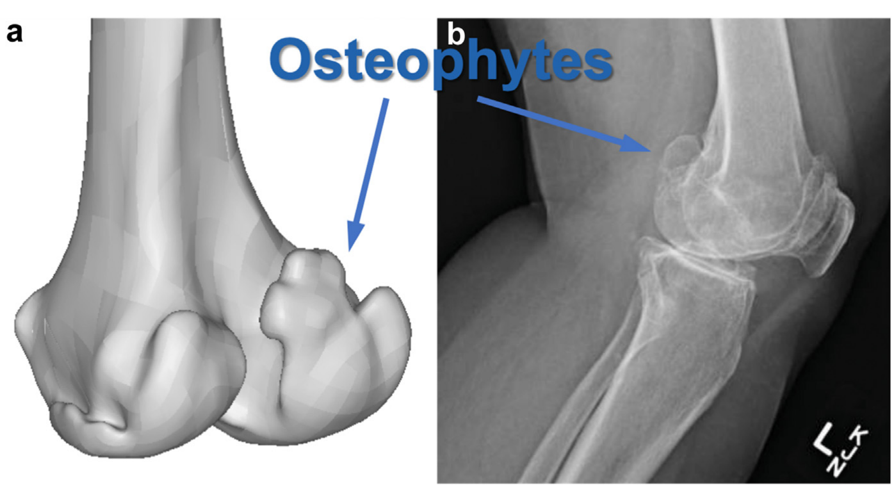

Figure 3. (a) A photograph of a CT scan-generated, three-dimensional reconstruction of a knee with a substantial posterior femoral osteophyte; (b) corresponding lateral radiograph.

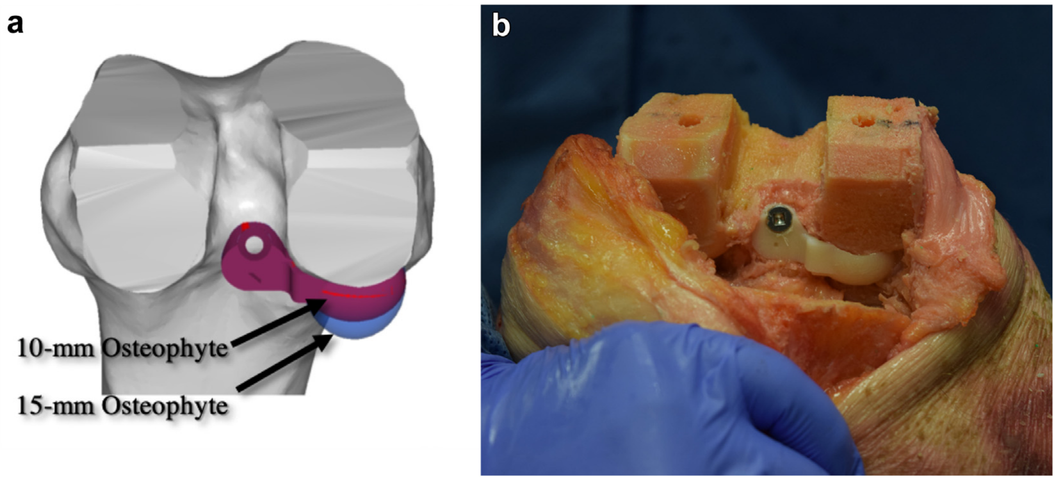

Figure 4. (a) Ten-millimeter (red) and 15-mm (blue) specimen-specific synthetic osteophytes; (b) synthetic osteophyte in situ.

specimens and osteophyte conditions for each flexion angle. The 25% and 75% uncertainty bounds at each flexion angle were calculated, and outliers were identified beyond ±2.7 standard deviations (SD).

Medial and lateral contact forces for each specimen were averaged across all three trials at each flexion angle, then across all five specimens, for each experimental condition (no osteophytes, 10-mm osteophyte, and 15-mm osteophyte). A repeated measures ANOVA with Tukey post hoc tests were used to detect statistically significant differences between the neutral condition and with each sized osteophyte through the flexion range, with a P value less than 0.05 as statistically significant (MATLAB, MathWorks, Inc, Natick, MA).

Results

The average measurement variability across all conditions was within ±0.7 lbs at each flexion angle for both the medial and lateral condyles, with 25% - 75% confidence intervals within ±3.5 lbs (Fig. 6). The measurement variability was within the reported measurement accuracy of the sensor-enabled tibial insert trial (±3.5 lbs) [21].

The gap-balancing technique resulted in nearly equal medial and lateral contact forces through the flexion range before the synthetic posterior femoral osteophytes were placed (Fig. 7). Medial and lateral mean contact forces were largest at full extension (43.5 ± 6.5 lbs and 42.7 ± 13.4 lbs, respectively) then ranged from 15.2 lbs to 26.5 lbs through the remainder of flexion. Variability in the contact forces after TKA was relatively uniform through flexion, with SD ranging from ±6.2 lbs to ±15.6 lbs, and the largest variability occurring medially at 90° flexion. The medial-lateral mean contact forces during the trials are given in Table 1.

Substantial increases in the percentage of medial vs lateral contact forces were observed in lesser degrees of flexion (Table 2). Implantation of the 10-mm osteophyte to the posterior aspect of the medial femoral condyle increased the medial mean contact force by 72% (31.3 ± 28.3 lbs) and reduced the lateral contact force by 43% (-18.3 ± 7.7 lbs) in full extension. A statistically significant increase in mean medial contact forces was seen at 0° ($P = .05$) and 30° ($P = .04$) of knee flexion. A coupled reduction in lateral contact force was also seen throughout the flexion range but was not statistically significant. Implantation of the 15-mm osteophyte did not

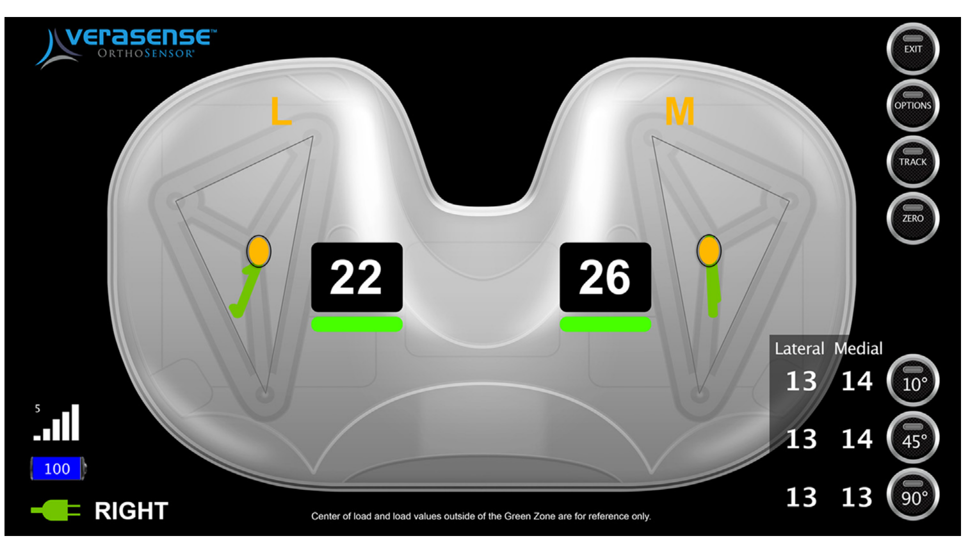

Figure 5. Screen shot from the VERASENSE display. Medial and lateral contact forces were recorded from the display during balance measurements with and without femoral osteophytes.

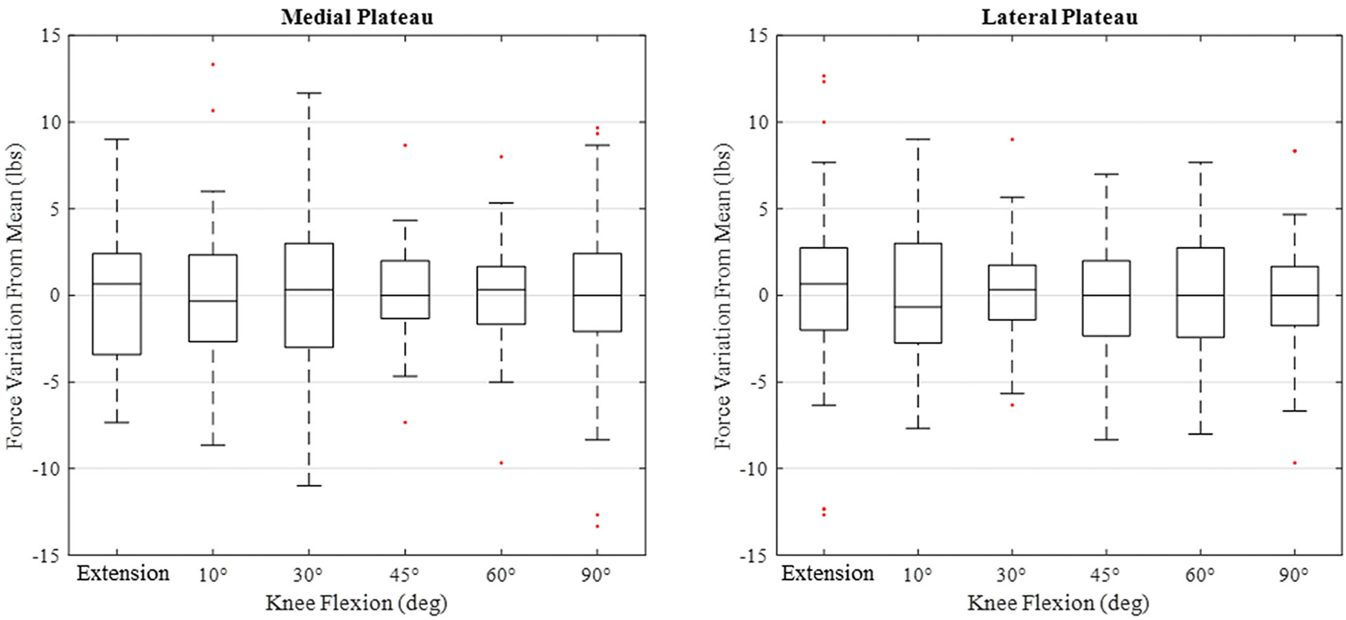

Figure 6. Variability in the contact force measurements across all 45 measurements taken at each flexion angle for the medial and lateral compartments. Boxes indicate 25%-75% while whiskers indicate ±2.7σ and red dots indicate outliers.

change the medial and lateral contact forces compared to the 10-mm osteophyte.

Discussion

This investigation demonstrates that the presence of posterior femoral osteophytes affects soft-tissue balance in a cadaveric TKA model as evidenced by difference in medial and lateral contact pressures. Specifically, the presence of a posterior medial femoral osteophyte created a greater medial contact pressure with the knee in relatively more extension. However, the effect persists into the mid-flexion range (30°) as well. The current methodology accounted for osteophytes on the posteromedial femur only, as this is clinically where we believe they are more frequently encountered (ie, varus knee).

Our data demonstrated asymmetric changes in the contact pressures that followed as expected: increased medial contact pressures and decreased lateral contact pressures. With an osteophyte on the posteromedial femur, the medial structures were preferentially tightened, resulting in a relative “unloading” of the lateral side of the knee, giving rise to the difference in contact pressures. We presume that this occurred because of a levering around the increased medial contact point, producing the observed effect of increased medial and decreased lateral contact pressures.

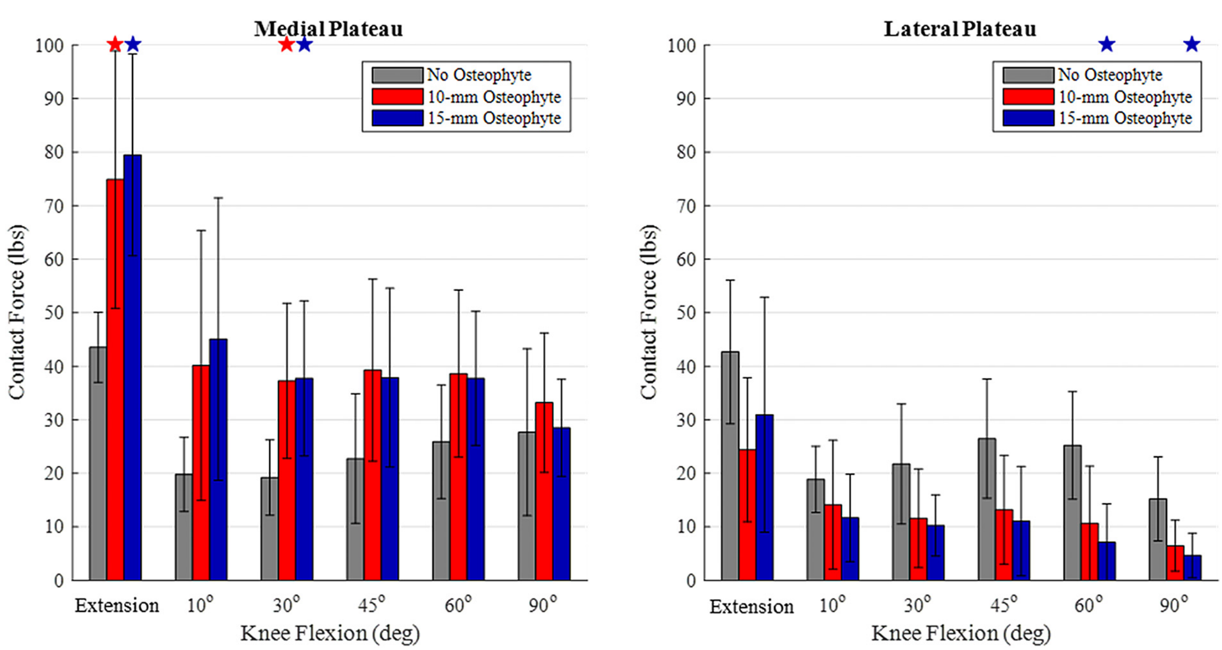

Figure 7. Averaged medial and lateral tibiofemoral contact forces with no and 10-mm and 15-mm osteophytes. Stars indicate statistical differences in joint load with the osteophytes present compared to the “no osteophyte” condition.

Table 1
Average medial and lateral contact forces during passive flexion after TKA with no osteophytes, with a 10-mm osteophyte, and with a 15-mm osteophyte.

Flexion	No osteophyte		10-mm osteophyte				15-mm osteophyte			
	Medial	Lateral	Medial		Lateral		Medial		Lateral	
	Mean ± Std (lbs)	Mean ± Std (lbs)	Mean ± Std (lbs)	*P*	Mean ± Std (lbs)	*P*	Mean ± Std (lbs)	*P*	Mean ± Std (lbs)	*P*
0	43.5 ± 6.5	42.7 ± 13.4	74.9 ± 24.0	.04	24.4 ± 13.5	.06	79.5 ± 18.8	0.01	30.9 ± 21.9	.34
10	19.8 ± 6.9	18.9 ± 6.2	40.1 ± 25.2	.15	14.1 ± 12.0	.46	45.1 ± 26.4	0.1	11.7 ± 8.2	.16
30	19.2 ± 7.0	21.7 ± 11.2	37.3 ± 14.5	.05	11.6 ± 9.2	.16	37.7 ± 14.5	0.04	10.3 ± 5.7	.09
45	22.7 ± 12.1	26.5 ± 11.1	39.3 ± 17.0	.12	13.2 ± 10.2	.09	37.9 ± 16.7	0.14	11.1 ± 10.2	.05
60	25.9 ± 10.6	25.2 ± 10.0	38.6 ± 15.6	.18	10.7 ± 10.7	.06	37.7 ± 12.5	0.15	7.1 ± 7.2	.01
90	27.7 ± 15.6	15.2 ± 7.9	33.2 ± 13.0	.56	6.5 ± 4.7	.07	28.5 ± 9.1	0.92	4.7 ± 4.1	.04

P values less than .05 indicate statistically significant differences in contact force with and without that osteophyte.

Intuitively, posterior osteophytes on the lateral side of the femur would likely have the inverse effect, although that was not specifically explored here.

We hypothesized that with increased size of the posterior osteophyte, a proportionally greater effect on the contact pressures would be demonstrated. This, however, was not observed, with no significant differences between the 10-mm and 15-mm simulated osteophytes conditions. It is possible that such a difference between size of osteophyte and magnitude of impact could be detected with a larger difference in osteophyte size or more trials or specimens to increase the investigation's power, but this difference proved elusive in the present study. It remains an open question as to the minimum size of osteophyte that would appreciably affect balance in the ways our study was designed to detect.

The threshold at which the size of posterior osteophytes' effect on soft-tissue balance becomes clinically relevant has not been defined. Recent clinical work elsewhere has demonstrated that smaller osteophytes have less of an observable effect than larger osteophytes, particularly in lower degrees of flexion [22]. Our study suggested that 10-mm and 15-mm osteophytes had no discernible difference in terms of the magnitude of their effect on balance. Methodologically, it became unfeasible to continue increasing the size of the manufactured osteophytes affixed to the posterior femur after a certain point. The selected sizes of 10-15 mm of the synthetic osteophytes are in keeping with investigations of the measurements of posterior femoral osteophytes [23]. Finally, it was the aim of our study to provide information regarding the effect posterior osteophytes have on TKA balance, but in our experience, osteophytes rarely occur in isolation. What effect additional osteophytes in the medial, lateral, or patellofemoral compartment might have or contribute to posterior osteophytes' presence remains a relevant question unaddressed by the present investigation.

The methodology used in this study involved a gap-balancing technique in which the extension gap was balanced before establishing the flexion gap and performing femoral cuts that determine femoral component rotation. The removal of posterior osteophytes and their effect on soft-tissue balance may be of increased significance to the surgeon performing the operation in this fashion. However, establishing equal and balanced extension and flexion gaps is a primary goal for any surgeon performing TKA, and we think that our findings have broader applicability to arthritic knees with substantial posterior osteophytes, and that attention should be given to these structures' effect on the surrounding soft tissues.

Table 2
Percentage change in medial-lateral contact forces during passive flexion after TKA with 10-mm and 15-mm osteophytes, as compared to the "no osteophyte" condition.

Flexion	10-mm osteophyte		15-mm osteophyte	
	Medial (%)	Lateral (%)	Medial (%)	Lateral (%)
0	72	−43	86	−28
10	103	−25	139	−38
30	94	−47	74	−53
45	73	−50	43	−58
60	49	−58	50	−72
90	20	−57	87	−69

There are a number of limitations to the present study. The investigation was performed on cadaveric specimens, and there could, therefore, be relevant differences between these conditions and live patients, potentially making our observations less or more relevant to the actual clinical realm. The total number of cadavers used was small (5), and this may have contributed to the inability to distinguish a difference in contact forces between the 10-mm and 15-mm osteophyte scenarios. It may also have contributed to the relatively wide SDs seen in our statistical analysis. While the entire investigation was performed in a matter of hours, the specimens used were freshly thawed cadaveric limbs, and there is a possibility that the tissue tension changed over the course of the testing. We believe that the consistency of our results through multiple specimens and multiple flexion angles serves as evidence against this. Furthermore, the nature of our methodology required that we implant osteophytes of different sizes in the cadavers in which no appreciable osteophytes were present. The soft tissues around the knee did not, therefore, accommodate and adapt to the presence over time, as may be the case in live patients. This could have led to an overestimation of the degree of effect the simulated osteophytes might have. The real-life situation might instead be manifested as laxity after osteophyte removal, as opposed to tightness, or increase in contact pressure, as shown in this cadaveric study. We did perform our analysis of osteophytes in the present scenario by affixing them *after* soft-tissue balancing was performed, as we felt it was not methodologically practical to place the osteophytes before balancing without disruption of the integrity of the posterior capsule, which we believe would have called into question the validity of findings in that case.

We believe this investigation may have importance for several reasons. First, this is, to our knowledge, an investigation with few, if any, of its kind. We are aware of very limited number of studies that attempt to demonstrate what effect posterior femoral osteophytes and their removal have on soft-tissue balance in TKA [22]. This is in spite of this being a commonly encountered entity in knees with hypertrophic arthritis, supporting the relevance of the investigation. We believe the study is significant methodologically as well. A database of existing femoral CT scans was queried to develop the relative shape, size, and location of posterior femoral osteophytes so as to reproduce them in a manner with high fidelity. In addition, the manufactured osteophytes were developed using 3D printing, giving a high degree of precision to the manufactured simulated osteophytes. We believe these factors give strength to our methods and, therefore, conclusions. The technology of contact force measurement with VERASENSE has been used in numerous other studies, [15-20] and we believe this is useful in quantifying a proxy for soft-tissue balance.

Conclusions

The findings of this study conclude that posterior femoral osteophytes affect soft-tissue tension as measured by joint contact forces. Failure to remove posterior osteophytes during TKA might result in persistent flexion contracture and, based on these results, perhaps lack of appropriate soft-tissue balance and symmetry.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Each author certifies that he or she has no commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article. D.A.D. has or may receive payments or benefits from DePuy, Corin U.S.A., Joint Vue, and Wolters Kluwer Health not related to this work. M.W.R. has or may receive payments or benefits from Orthosensor, Stryker, and Smith & Nephew not related to this work. C.W.C. has or may receive payments or benefits from DePuy not related to this work.

Statement of the location

All data was collected at the University of Denver, in Denver Colorado.

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