Ensuring optimal balance among the soft tissues of the joint during total knee arthroplasty (TKA) is imperative to maximize functional outcomes. These tissues, which include the medial collateral ligament, lateral collateral ligament, posterior cruciate ligament (if spared), arcuate-popliteal complex, iliotibial band, posterior lateral capsular fibers, and semimembranosus, operate together to dictate the unique intra-articular kinematics and loading patterns of individual patient gait. Intraoperatively, great care is taken to confirm balance and appropriate alignment prior to final implantation of components. Some of these measures rely on the subjective assessment of the surgeon, and other measures require expensive equipment such as navigation systems; however, none of these effects of cementing on ligament balance during total knee arthroplasty

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abstract

Complications related to joint imbalance may contribute to some of the most predominant modes of failure in total knee arthroplasty (TKA). These complications include instability, aseptic loosening, asymmetric component wear, and idiopathic pain. Fixation may represent a step that introduces unchecked variability into the procedure and may contribute to the incidence of joint imbalance-related complications. The ability to quantify in vivo loading in the medial and lateral compartments would allow for the ability to confirm balance after fixation and prior to wound closure. This retrospective study sought to capture any variability and imbalance associated with cementing technique. A total of 93 patients underwent sensor-assisted TKA. All patients were confirmed to have quantifiably balanced joints prior to cementation. After cementing and final component placement, the sensor was reinserted into the joint to capture any cementation-induced changes in loading. Imbalance was observed in 44% of patients after cementation. There was no difference in the proportion of imbalance due to surgeon experience (P = .456), cement type (P = .429), or knee system (P = .792). A majority of knees exhibited loading increase in the medial compartment. It was concluded that cementation technique contributes to a significant amount of balance-related variability at the fixation stage of the procedure. The use of the sensor in this study allowed for the correction of all instances of imbalance prior to closure. More objective methods of balance verification may be important for ensuring optimal surgical outcomes. [Orthopedics. 2017; 40(3):e455-e459.]

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The sensor system used in this study was composed of 2 parts: the wireless sensor and the real-time interface visually displaying sensor output. In this image, the medial and lateral compartments of the sensor are being compressed to show the corresponding loading values on the interface screen.

measures evaluate the effects of dynamic ligament tension during trialing and final cementation. As such, complications associated with imbalance that may arise from unfavorable and unconfirmed cementation-induced kinetics currently represent one of the most prominent reasons for revision.

Recently, it has been shown that the added thickness of the cement mantle at final fixation can significantly affect the mechanical axis, flexion-extension gap, and gap balance. However, no study to date has evaluated potential changes in quantified loading force after cementation. Therefore, the purpose of this retrospective study was to identify any changes in quantified joint balance after cementation in a group of patients who had confirmed soft tissue balance prior to final implant cementation and fixation.

MATERIALS AND METHODS

Patient Population

Retrospective intraoperative data were collected for 93 TKAs (93 patients). All data evaluated were anonymized, and this study was exempt from institutional review board approval. All data originated from a consecutive series of procedures performed by 2 surgeons (K.W., M.R.) at the same hospital between April and August 2014. Both surgeons were fellowship-trained in TKA; the first surgeon had been practicing for nearly 1 year and the second surgeon for 24 years. Three different knee systems were implanted in the patient cohort: Vanguard (Zimmer Biomet, Warsaw, Indiana), Triathlon (Stryker, Kalamazoo, Michigan), and NexGen (Zimmer Biomet). Navigation (Stryker) was used to guide all bony cuts to ensure appropriate alignment during each procedure.

Bone Cement

Two types of cement were used: Simplex P Bone Cement (Stryker) for the NexGen and Triathlon systems, and Palacos R Bone Cement (Zimmer Biomet) for the Vanguard system. Simplex cement is a medium viscosity-type adhesive, and Palacos cement is a high viscosity-type adhesive. The average mix/set time was approximately 2 minutes for both surgeons and both cement types. Operating room temperature was standardized at 72°F during all procedures. For the femur, cement was placed on both the bone and the component, and for the tibia, cement was placed on only the bone. Both components were cemented simultaneously.

Quantification of Joint Loading

To measure the pre- and postcementation loading patterns, both surgeons incorporated the use of intraoperative kinetic sensors into each procedure (OrthoSensor Inc, Dania Beach, Florida). The wireless sensor was geometrically identical to the shape and thickness of the polyethylene tibial trial for each knee system used in this study. As such, the sensor replaced the polyethylene insert during the trialing phase.

After all bony cuts and metallic trials were placed, the sensor was inserted. With the sensor seated in the tibial baseplate, the capsule was closed, and the knee was taken through a range of motion to evaluate dynamic loads. Throughout the range of motion, the sensor transmitted the force loading data to a display screen and indicated the pounds of pressure in both the medial and lateral compartments, as well as the location of intra-articular peak loading (Figure 1). Soft tissue corrections were made with the sensor in place to fine-tune any residual soft tissue imbalance.

Evaluation of Balance

Prior to cementation, each patient was corrected to a state of quantified joint “balance” as described previously in the literature. This definition of balance (mediolateral compartmental loading differential <15 lb through range of motion) was chosen for its correlation with favorable patient-reported outcomes scores. Absolute loading and sagittal plane balance was dictated by a stable posterior drawer test and confirmed limited femoral excursion on the tibial plateau, as shown by the sensor.

After the surgeon had achieved quantified balance for each patient, recorded the loading values, and deemed the joint to be clinically acceptable during dynamic testing, the final components were cemented into place. With the cemented components in place, the sensor was inserted into the tibial baseplate, and the sensor again replaced the polyethylene insert for final recording of postcementation loading. Because the sensor exactly replicated the geometry and thickness of the final implanted polyethylene insert, the postcementation loading values represented an accurate depiction of passive loading in vivo.

In the event the joint exhibited a return to imbalance during cementation, the abnormal pressures were evaluated for symmetry or asymmetry in extension, midflexion, and flexion (10°, 45°, and 90°, respectively). In the case of symmetrical imbalance in extension, the distal femur was further impacted. If both flexion and extension exhibited imbalance, the tibial baseplate was further impacted. All asymmetric presentations of imbalance were defined as an increase in medial or lateral compartmental pressures during flexion,
extension, or both flexion and extension. Angular impaction was used to fully seat the implant, and any extruded cement was removed with a curette. All surgeries were closed when balance was confirmed after the cementation process.

**Statistical Analysis**

All descriptive and statistical analyses were performed using SPSS version 23 software (SPSS Inc, Chicago, Illinois). Cross tabulation (either with Fisher exact test or Pearson chi-square test depending on the number of variables) was used to determine significance in the proportion of cementation-induced imbalance for multiple independent variables. These variables included surgeon experience, cement type/viscosity, and knee system. Significance for all analyses was defined as \( P < .05 \).

**RESULTS**

Of the 93 knees in this study (all of which were balanced prior to final fixation), 44% exhibited imbalance after cementation (\( P < .001 \)) (Figures 2-3). The average change in loading between pre- and postcementation, reported as the absolute sum of the change across the joint, was 28.3±24.8 lb of force (standard unit output of sensor). The average absolute change in the medial compartment was 17.8±18.1 lb. The average change in the lateral compartment was 10.5±12.7 lb.

In the imbalanced patient group, 84% of knees exhibited asymmetric imbalance in the medial compartment in extension. The proportions of cement type used in all procedures were 72% for Simplex and 28% for Palacos. The proportions of knee systems used were 28% for Vanguard, 47% for Triathlon, and 25% for NexGen. Surgeon 1 (M.R.; 24 years of practice) performed 85% of cases and surgeon 2 (K.W.; nearly 1 year of practice) performed 15% of cases. With respect to the incidence of imbalance after cementation, there was no significant difference in cement type and viscosity (\( P = .429 \)), surgeon experience (\( P = .456 \)), or knee system used (\( P = .792 \)).

**DISCUSSION**

By using intraoperative sensors, the participating surgeons in this study captured pre- and postcementation loading values. Data from 93 balanced TKA procedures were collected and evaluated; nearly half (44%) of the procedures demonstrated imbalance after cementation. The average absolute change in loading across the joint was 28.3±24.8 lb of pressure, indicating a high degree of variability inherent in postcementation loading values.

Residual imbalance of this type may invariably lead to patient-reported pain, limited range of motion, or a sense of instability; gross imbalance can lead to asymmetric loading patterns, accelerated polyethylene wear, or aseptic loosening.1-4 In a medical environment that is expected to become saturated with TKA candidates in the near future, it is imperative that any origins of imbalance and unfavorable outcomes are explored for future mitigation.14 As such, this retrospective study sought to quantify any imbalance that may arise from the addition of the cement mantle during final fixation of TKA components—the cementation phase of the procedure representing a possible source of kinetic variability.

Most notable in this investigation was the nonsignificance associated with cement viscosity (\( P = .429 \)) and surgeon experience (\( P = .456 \)). Despite 2 different viscosity types and 2 different levels of surgeon experience, neither variable exhibited significant differences in the incidence of postcementation imbalance.

The authors used the quantified sensor output to observe unfavorable effects
of cement on loading that may be due to either (1) induced homologous thickness of the components and thus an increased tension in soft tissues or (2) altered varus-valgus alignment due to incomplete or malaligned impaction. Okamoto et al\textsuperscript{15} showed that soft tissue laxity greater than 1 mm decreased the risk of flexion contracture. As such, a decrease in ligament laxity can likely be induced by increasing cement mantle thickness, which would manifest as increased loading values. Catani et al\textsuperscript{16} showed that considerable coronal and sagittal variation in alignment may occur during final implant impaction, even after navigation was used to make bony cuts. The observations made in the current study are in agreement, with 44% of knees exhibiting asymmetric imbalance despite the use of navigation in all procedures. In addition, 84% of imbalanced knees exhibited heavier loads on the medial side, which could be explained by the right-handed mallet swing of both surgeons and unnatural pronation thus required by the wrist (Figure 4), leading to incomplete impaction of the mediofemoral component.

In most of the cases included in this series, sensor data indicated that tibial malimpaction was not implicated in abnormal loading values. This may be due to the vertical-inferior impaction angle and the increased ability to visually inspect the implant-bone interface (Figure 5). By contrast, femoral malimpaction was implicated in the majority of abnormal loading patterns, likely due to the partially hidden orientation of the implant-bone interface. It also was found that in cases of medial overload, applying a valgus moment contributed further to unfavorable medial loading, and thus the knees were best held in a varus moment to compress the femur medially.

Limitations
There were several limitations to this study. The precise thickness of cement or the consistency of the cement when applied was not known in every case. Calculating the thickness may have given the authors the ability to further elucidate the ratio of pounds of pressure to cement thickness.

The study also would have been made stronger with the inclusion of data from many sources rather than from only 2 surgeons. However, the distinct difference in surgeon experience provided an important point of comparison in experience-based imbalance.

Another limitation was not having a left-handed surgeon included in the surgeon group to allow for analysis of different impaction positions. Because both surgeons were right-handed, the authors suspected that to be a possible origin of increased medial loading. However, it would have been important to also assess the role of hand dominance within a left-handed sample. In addition, a standard impactor was used, and thus the use of an offset impaction to mitigate valgus moment of a right-handed surgeon was not evaluated.

Assessing loads prior to full curing of cement also was a limitation. Due to cement contraction on curing, the loading values may be different if collected at that point. However, one might assume that contraction of the cement would be homologous through the mantle and thus any loading changes would be proportional between the 2 joint compartments. Finally, the sample size was relatively small.

CONCLUSION
As the number of primary TKAs performed each year continues to rise, the number of preventable revisions also will increase. Therefore, careful attention should be given to the state of joint balance by surgeons and surgical assistants. Cementation techniques are not standardized and may lend significant variability through various steps associated with the fixation process. The need to quantify intraoperative balance is improved with sensor data, and the use of sensors has demonstrated the ability to minimize errors that may contribute to unfavorable postoperative outcomes.

REFERENCES
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