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Variability in Coronal Knee Laxity Measured During Computer-Assisted Total Knee Arthroplasty

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Abstract

Principal component analysis on 376 TKA knees presented the distinctive patterns and variabilities in the coronal knee angular laxity throughout the range of motion, measured post-implantation during computer-assisted total knee arthroplasty. The variability in the laxity curves were dominated by the first mode of variation (varus/valgus offset of the laxity envelope) and the second mode of variation (varus/valgus crossing pattern). Further analysis revealed that surgeon-specific impact was associated with the first mode of variation for the laxity curve, and both first and second mode of variation for the size of the laxity envelope. The results shed a light on the characteristics and variabilities of post-implantation soft-tissue laxity under surgical reality and may be used to further understand the clinical implications of intraoperative soft-tissue management.

1 Introduction

Appropriate management of the soft tissue envelope intraoperatively is critical to the success of total knee arthroplasty (TKA). Knee laxity has been studied in vitro and in vivo using calibrated force and special fixture devices, which may not be suitable to apply intraoperatively [1-4]. Moreover, the tests often represent healthy rather than arthritic knees. The results reported by the studies therefore may not reflect knee laxity observed in the operating room.

With the advances of modern computer-assisted orthopedic surgery (CAOS), many surgeons start to use the system provided tools for measuring ligamentous balance intraoperatively. However, it still remains unclear on what constitutes the ideal varus/valgus laxity. Beyond advancing soft-tissue laxity knowledge in the lab setting, a quantitative characterization of the variability in intraoperatively measured postoperative laxity may offer the first step to the understanding of the scope of current clinical targets that motivate the surgeons.

This study applied a statistical tool (principal component analysis, PCA) to quantify the patterns and variability in the coronal laxity of the knee after TKA implantation, measured intraoperatively using a contemporary CAOS system.

2 Materials and Methods

Technical records of primary TKA cases performed by 4 surgeons (A-D) using a contemporary CAOS system were reviewed. All cases performed since the release of a Kinematic Test Module in the CAOS system were included in this study. Each case contained results from intraoperatively measured coronal laxity varus/valgus via stress tests across the range of motion (ROM). The angular laxity data with trial implantation of the prosthesis was extracted from the records, representing minimum and maximum laxity boundary measured at 5° interval from 5° to 120°. Each individual laxity curve was checked to ensure completeness of data during ROM, with cases with missing data excluded from the analysis.

PCA analysis was performed to identify discriminating features and variability of the laxity curves. The specific metrics analyzed were: 1) modes of variation (PCs, representing a set of independent modes that describe the pattern variation of the laxity curves); 2) the percentage of variances explained with each PC (reflecting the amount of variability in the dataset that is captured in that PC); 3) the coefficient associated with each PC for each TKA case. In additional to the assessment of laxity curve on the pooled data set, surgeon-specific impact on the variability were also assessed by assessing the differences in PC coefficients. Statistical significance was defined as $p < 0.05$.

3 Results

Three hundred and seventy-six CAOS TKA cases were analyzed. The specific numbers of case from each surgeon performed were 76, 186, 54, and 60 for surgeons A-D, respectively. The first four modes of variation (PCs) explained 93% of variance in the laxity curve, with the first two PCs accounting for 83% of the variance. Each PC demonstrated distinctive pattern. PC1 described an overall varus/valgus offset in the laxity curve, while PC2 represented a varus/valgus crossing pattern with increased flexion, accompanied by a change in the size of the laxity envelope (Fig 1A). Similar modes of variation were found in the size of the laxity envelope (Fig 1B).

The coefficients for PCs 1 and 2 were compared across the 4 surgeons (Fig 2A). Significant differences were found in the varus/valgus offset of the laxity curves (PC1) but not in the shape of the laxity curve (PC2). For the size of the laxity envelope, differences were revealed in its magnitude (PC1) and variation throughout the ROM (PC2) (Fig 2B).

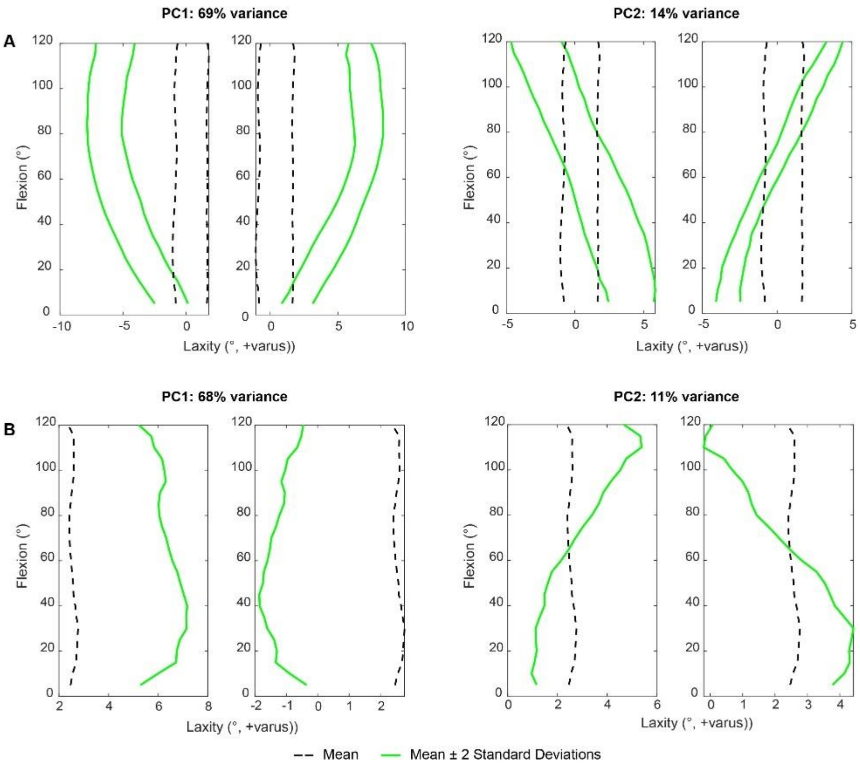

Figure 1. Mean and perturbed (± 2 Std Dev) results on PC1 and PC2 for A) angular laxity curve, and B) size of the laxity envelope. %variance each PC explained was also listed.

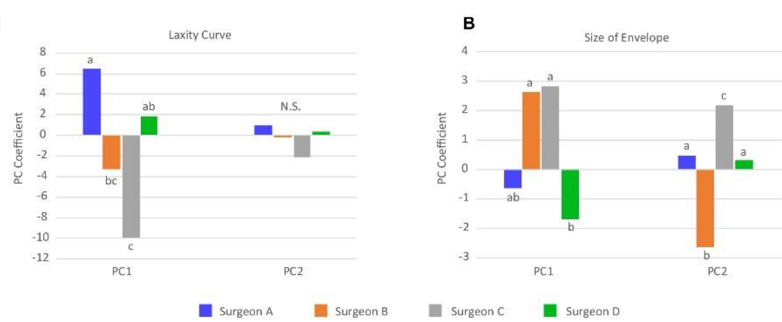

Figure 2. Mean PC coefficients for the first two modes of variation (PCs), compared between surgeons for A) laxity curve and B) size of the laxity envelope. Lower case letters identify statistically different groups.

4 Discussion

This study provides statistical insights into the clinically observed passive laxity tested intraoperatively after implantation. The PCA data revealed the two dominating distinctive patterns (PCs 1 and 2) and its variability in the laxity curves and the size of the envelope. As intraoperatively measured post-implantation laxity might be influenced by the nature of manual tests, the impact was found to be primarily on the magnitude of the laxity curve and its envelope size (PC1). This finding aligned with the widely accepted belief that the manual force surgeon applied during the intraoperative stress test is the major source of variation. Acknowledging the limited information and control on the force applied during individual manual stress test, the separation between the magnitude and the shape of the laxity curve through each independent modes of variance (PCs) allowed investigation of the specific patterns (shapes) of post-implantation kinematics the surgeons targeted in general.

This study reported similar PC patterns as previous investigation on intraoperatively measured post-implantation kinematics [5]. In addition to offering the proven benefit on accurate bony resection [6], studying intraoperatively measured knee laxity by the CAOS system may improve the understanding of ligament balancing and enhance knowledge of what constitutes appropriate soft tissue balance. The PCA results may be used to correlate with clinical results from the same patient cohort to identify specific balancing approaches and goals that may provide optimal outcome.

5 References

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