Pre-operative Complexity Scoring Accurately Predicts Total Knee Arthroplasty Operative Time

Joseph Koressel, MD[1]
Max Shin, BS[2]
Matthew K. Stein, MD[1]
Matthew Sloan, MD[1]
Neil P. Sheth, MD[1]

[1]Department of Orthopaedic Surgery University of Pennsylvania

[2]Perelman School of Medicine University of Pennsylvania

Introduction

Primary total knee arthroplasty (TKA) is projected to grow to 935,000 procedures in the United States by 2030.[1] Medicare reimbursement rates for TKA have decreased by approximately 1.7% per year since 2000 after adjusting for inflation.[2] The total cost of providing quality care in total joint arthroplasty continues to rise at a rate that is not commensurate with Medicare reimbursement rates.[3] Decreasing TKA profit margins, when compared to operating room (OR) costs which are estimated to be as high as $80/min, highlight the need for increasing OR efficiency.[4]

Proper surgical scheduling may decrease the risk of unexpectedly long OR days and result in enhanced OR efficiency. Surgical schedulers generate OR schedules, despite unfamiliarity with specific considerations inherent to the procedures that are being scheduled. Schedulers rely on institution metrics, such as the average surgical time for the last ten cases of a specific common procedural terminology (CPT) code, when predicting case duration and number of cases to be performed on a given OR day. However, schedulers are often unaware of patient complexity variations that may impact actual surgical duration.[5] All TKA procedures, regardless of complexity, share a single CPT code. Conversion TKA, which does not have a separate CPT code, has an increased mean operative time when compared to standard TKA (102.1 minutes versus 71.7 minutes); this time discrepancy must be considered when scheduling procedures.[6] Streamlined communication between surgeon and scheduler can more accurately reflect the OR time needed for a case, and potentially result in more cases being performed on a given OR day.

Delays in surgical execution have been associated with increased costs by up to 39%, and the mismatch between reimbursement and case complexity further requires enhanced OR efficiency.[7] Multiple patient factors have been associated with increased OR time in primary TKA, including younger age, male gender, increased ASA score, smoking, general anesthesia, and obesity.[8-10] However, previous studies have not evaluated surgery specific factors that influence surgical time, such as degree of knee deformity or presence of hardware, that may be accurately assessed by the operating surgeon but cannot be estimated by a large database. We anticipate that subjective surgeon assessment, influenced by multiple technical and anatomic patient factors, will accurately estimate increased OR time and subsequently promote efficient scheduling of both complex and routine surgical cases. This study evaluated the correlation between a single surgeon's pre-operative complexity scoring system and the resulting TKA procedure time, and secondarily the effect of the primary surgical assistant training level on surgical time. We hypothesized that a subjective orthopedic severity score will predict the intra-operative time required for performing a TKA. As a secondary endpoint, we hypothesized that surgery performed with a more inexperienced surgical trainee/assistant will increase surgical time.

Methods

This study qualified as a quality improvement initiative that did not meet the definition of human subjects' research and was exempt by the institutional review board. This was a retrospective review of one attending surgeon's patients at a single hospital within a large academic health system. All patients who underwent primary, unilateral TKA between February 2014 and November 2019 with an assigned, subjective pre-operative complexity score were included in this study.

A total of 674 patients were identified. A final cohort of 551 patients were included in the study. Patients were excluded due to: absence of a pre-operative complexity score (n = 99), inadequate anesthesia documentation (n = 1) and lack of tourniquet use during TKA (n = 23). All TKAs were performed through either the medial parapatellar or midvastus approach. The patient's age, gender, pre-operative body mass index (BMI), American Society of Anesthesiologists (ASA) status, and co-morbidities were documented in the pre-operative anesthesia note. The patient's type of anesthesia, spinal versus general endotracheal, was recorded in the operative anesthesia procedure note. The tourniquet time for each procedure was recorded at the end of each procedure. At the time of TKA, the average patient age was 62.3 years (range, 17.2-86.3 years) and the average BMI was 31.9 (range, 15.6-53.3). Patient demographics are summarized in Table 1.

Tourniquet time, defined as the procedure time from incision to start of arthrotomy closure, was the primary dependent variable and was recorded for all TKAs by the operative surgeon in the final operative report. The criteria used for the pre-operative complexity score (Table 2) was determined and documented in the patient progress note by the operative surgeon at the pre-operative outpatient visit. Scores recorded as "1+" or "2+" in the pre-operative progress note were analyzed as scores of 2 and 3, respectively.

Descriptive statistics were calculated for all variables (frequencies, ranges, means, confidence intervals). Spearman's correlation was used to determine the correlation between complexity score and tourniquet time. Shapiro-Wilk normality test was used to determine whether parametric or non-parametric tests of hypothesis were appropriate for analysis of complexity score, surgical specific variables, and patient specific variables as a function of tourniquet time. For variables with two groups, either *t*-test or Mann-Whitney U test were used as appropriate depending on the normality test. For variables with more than two groups, either ANOVA or Kruskal-Wallis test were used as appropriate depending on the normality test. All data analysis was performed using STATA 16 software (StataCorp LLC, College Station, TX). The level of significance was set to $p \leq 0.05$.

Table 1. Summary of Patient Demographics

		n	%
Age (<65)		320	58
Gender (Male)		166	30
BMI			
	<30	223	40
	30-35	164	29
	35-40	86	15
	>40	78	14
Current Tobacco Use			
	no	443	80
ASA			
	1 or 2	318	57
	3 or 4	233	42
Spinal Anesthesia		411	74
General Anesthesia		140	26
DMII		92	16
Bleeding Disorder		7	1.2
HTN		343	62
COPD		27	4.9

BMI: Body mass index. *ASA:* American Society of Anesthesiology Physical Status. *DMII:* Diabetes mellitus type II. *HTN:* Hypertension. *COPD:* Chronic obstructive pulmonary disease.

Results

Pre-operative complexity score was positively correlated with tourniquet time (p < 0.001, rho = 0.196) (Figure 1). A complexity score of 1 had a mean tourniquet time of 59 minutes (CI, 56.8 to 61.2); a score of 2 had a mean time of 64.2 minutes (CI, 62.2 to 66.3); and a score 3 had a mean time of 76 minutes (CI, 66.6 to 85.4) (p < 0.001) (Figure 2). Other factors associated with increased tourniquet time were age (p < 0.001), male gender (p < 0.001), positive smoking status (p = 0.004), general anesthesia (p = 0.021), conversion TKA (p = 0.011), and obesity (p = 0.048) (Table 3).

Patient specific factors not associated with increased tourniquet time included: ASA status (p = 0.352), type 2 diabetes mellitus (p = 0.573), hypertension (p = 0.477), bleeding disorder (p = 0.929), and chronic obstructive pulmonary disease (COPD) (p = 0.819). The training level of the assistant during the surgical case also did not correlate with a longer tourniquet time (p = 0.492).

Discussion

Pre-operative, subjective surgical scoring can help predict surgical case duration in TKA. We found that pre-operative subjective complexity scoring by the operative surgeon correlated with primary TKA operative time. Surgeons incorporate patient and technical factors into OR time estimates, which are not readily recognized by surgical schedulers. Our study highlights the utility of a pre-operative complexity score as a method to streamline communication between the surgeon and surgical scheduler, accurately predict and communicate case length, and enhance OR efficiency.

Appropriate scheduling and accurate case length prediction optimize OR time utilization and minimize the number of long operative days. Surgeons have been shown to endure an average 51 minutes of wait time between cases (turn-over time) and up to 29.5 hours of turn-over time per month.[11] The evolution in OR scheduling from a first-come first-serve basis to historical averaging has maximized OR throughput and minimized resource underutilization.[12,13] Bartek et al. used machine learning to predict case-time duration and found increased accuracy with machine learning; prediction within 10% of actual case duration was seen in 39% of cases.[14] Wu et al. developed a predictive model for determining surgical time in revision total hip arthroplasty and found that that the operative surgeon's predicted surgical time improved the accuracy of the model to a greater extent than historical averages.[15] Additionally, Eijkeman's et al. performed a similar study in general surgery and showed that surgeons' estimates provided the most important predictors of total OR time.[16] However, there is evidence that historical averages of primary TKA are stronger predictors of surgical time than surgeon prediction.[17] Another issue is that CPT codes for a specific procedure are not all inclusive; CPT codes do not distinguish between the unequivocally more challenging conversion TKA from a standard TKA, but instead rely on complexity qualifiers

Table 2. Criteria for Patient Complexity Score

Score	Description
1	Anticipated operative time <60 minutes
2	Anticipated operative time 60-120 minutes due to technical challenges (obesity, deformity, prior hardware) or patient disease
3	Anticipated operative time >120 minutes due to severe technical challenges (deformity, prior hardware)

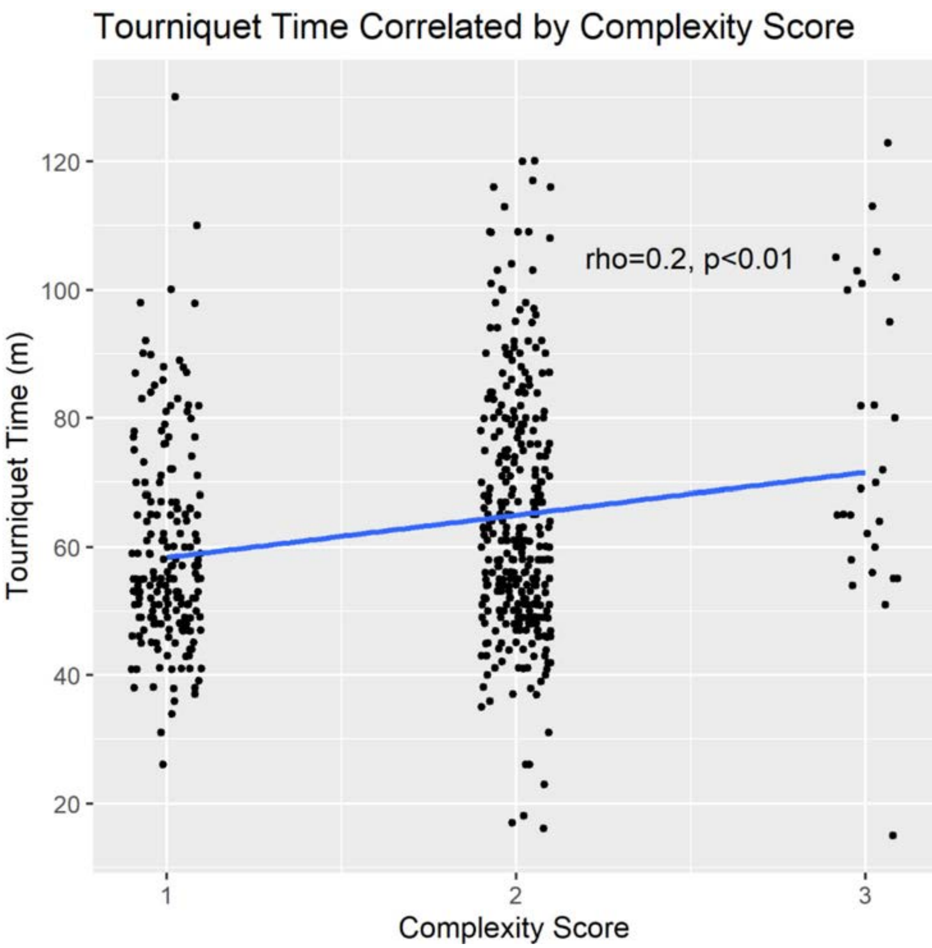

Figure 1. Tourniquet time in minutes as a function of complexity score. All individual patients are represented as an individual point. Spearman's coefficient (ρ, rho) and p value are displayed. Linear regression line displayed in blue.

that are non-specific.[18] Our study demonstrates that variation exists among patients undergoing the same procedure and may be anticipated by the operative surgeon. A pre-operative subjective score does not predict exact surgical times, but rather classifies surgeries into a relative time range based on specific case complexity.

The assigned complexity score and conversion TKA were the most significant predictors of operative duration when compared with other patient and operation-derived metrics. Additional predictors of operative duration were gender, age, smoking status, obesity, and anesthesia type, although these factors demonstrated a small effect size and did not account for surgery specific differences. Several studies have identified similar patient specific factors associated with OR time. These patient specific factors included younger age, male gender, smoking status, and obesity.[8–10] While the literature describes the relationship of these associated predictors of OR time, OR efficiency has been based on peri-operative and intra-operative improvements. Attarian et al. used inter and intra-operative workflow analysis to invoke peri-operative changes that led to a 29% increase in total joint arthroplasties per OR per day.[19] The standardized OR setup and parallel task completion were found to decrease total OR time per case.[20] Decreasing OR time per case continues to be at the focal point of improving OR efficiency, but accurately anticipating surgical case length may impact OR efficiency to a greater extent.

In academic hospitals, the training level of the assistant may result in greater OR time variation, as fellows, physician sssistants, and senior or junior residents regularly act as the primary assistant for a single surgeon. We anticipated that training level of the assistant would be a significant predictor of OR time, however, this did not hold true. Contrary to our

Table 3. Patient factors in relation to tourniquet time

		Tourniquet time (m)	95% CI min	95% CI max	p-value
Age					<0.001
	<65	66.2	64.1	68.4	
	>65	58.3	56.2	60.4	
Gender					<0.001
	Male	68.6	65.5	71.8	
	Female	60.5	58.8	62.2	
Complexity Score					<0.001
	1	59	56.8	61.2	
	2	64.2	62.2	66.3	
	3	76	66.6	85.4	
BMI					0.0479
	<30	61	58.5	63.5	
	30-35	62.3	59.7	64.8	
	35-40	65.5	61.6	69.5	
	>40	67.2	62.5	71.9	
Current Tobacco Use					0.004
	Yes	66.5	63.2	69.7	
	No	62.1	60.3	63.8	
ASA					0.352
	1 or 2	62.6	60.5	64.7	
	3 or 4	63.5	61.2	65.8	
Anesthesia					0.021
	Spinal	62	60.2	63.7	
	General	65.8	62.6	69	
DMII					0.573
	Yes	63.6	59.9	67.3	
	No	62.8	61.1	64.5	
Bleeding Disorder					0.929
	Yes	61.4	49.4	73.4	
	No	63	61.4	64.5	
HTN					0.477
	Yes	63.2	61.3	65.1	
	No	62.5	60	65.1	
COPD					0.819
	Yes	62.8	55.8	69.8	
	No	63	61.4	64.6	
Assistant					0.492
	Physician's Assistant	61.7	53.6	69.7	
	Resident	61.9	59.9	63.9	
	Fellow	64.4	61.9	66.9	
Conversion TKA					0.03
	Yes	74	63	85	
	No	62.6	61.1	64.2	

CI: Confidence interval. *BMI:* Body mass index. *ASA:* American Society of Anesthesiology Physical Status. *DMII:* Diabetes mellitus type II. *HTN:* Hypertension. *COPD:* Chronic obstructive pulmonary disease. *Conversion TKA:* Conversion total knee arthroplasty.

findings, the literature supports training level of the assistant as having a significant impact on OR time. In general surgery, seniority of surgical resident has been found to significantly reduce surgical time.[21,22] Yamaguchi et al. performed a NSQIP database study of lumbar spinal fusions and found that not only was orthopaedic resident involvement significantly associated with increased OR time, but also with length of stay and development of surgical site infection.[23] Orthopaedic surgical procedures with orthopaedic resident involvement are consistently associated with increased OR time throughout the literature.[24–26] An explanation of our finding is that the single surgeon in this study pre-operatively defined the role of the assistant based on their experience level preventing an excessive increase in procedure time. Pre-operatively setting expectations and having consistent help over a six-week clinical resident rotation allows for gradual independence and minimal variation in case length. If our study was expanded to include all arthroplasty surgeons within our institution, a positive correlation between resident involvement and OR time would most likely have been observed.

This study represents initial data derived from a novel method for estimating OR length and has inherent limitations. The criteria underlying the three-point scoring system, which relies on the experience of a single, arthroplasty fellowship trained attending, is not exact and limits the reproducibility of the score. However, the subjective nature of the score allows the operative surgeon to consider an array of unmeasurable factors that influence OR time, both intrinsic and extrinsic to the patient, as contributors to the score. A subjective score may be an all-encompassing and potentially most useful predictor of OR time. This may be even more apparent in revision TKA where surgical complexity is significantly greater. Further study of the complexity score in both primary and revision TKA may demonstrate more significance.

Furthermore, this scoring system has not been validated in the literature. We present this scoring system, utilized in practice to coordinate OR schedules, as a proof of concept with potential for more ubiquitous utilization. A subjective scoring system would necessitate individualization at the surgeon level; a single system may not be conducive to validation and widespread use. We allow a surgeon's experience to drive predicted surgical time, theoretically incorporating several patient factors that general assessment tools cannot.

Our findings demonstrate that a subjective complexity scoring system assigned by the operative surgeon is correlated with OR time. The results of this work suggest exploring OR utilization and efficiency by implementing the pre-operative complexity scoring system in the scheduling algorithm. Additionally, studies involving multiple arthroplasty attendings may determine if this system can be ubiquitously adopted. While initial implementation among other surgeons may be met with tepid enthusiasm, constant use, personalization of the scoring system, and working with a consistent team would improve the ability to estimate case duration. This study demonstrates that the operative surgeon can anticipate which cases will take longer, a resource that can be used to streamline pre-operative scheduling and enhance OR efficiency.

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