Impact of Institutional Surgical Volume on the Operative Learning Curve for Robotic Assisted Total Knee Arthroplasty: An Analysis from the American Joint Replacement Registry

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INTRODUCTION: Robotic-assisted total knee arthroplasty (RA-TKA) has gained widespread attention for its potential to enhance surgical accuracy, overall alignment, and patient-reported outcomes. While surgeon-specific learning curves have been well-documented, less is known about how institutional surgical volume influences the collective learning curve for RA-TKA. Given that robotic adoption is typically a system-level decision that often requires significant team efforts, understanding how case volume affects institutional efficiency is critical. This study aimed to assess how institutional surgical volume influences the learning curve and operational efficiency of RA-TKA across the United States.

METHODS: A retrospective analysis was conducted using data from the American Joint Replacement Registry for all elective primary RA-TKA cases performed between January 1, 2017, and December 31, 2024. Institutions were stratified by monthly robotic case volume: low (<5 cases/month), medium (5–11/month), and high (≥12/month). Descriptive statistics were computed for patient demographics and institutional characteristics. Efficiency trends were evaluated using centered linear weighted moving averages (window=50 cases), while learning curve maturation was assessed using cumulative sum (CUSUM) analysis. Operative efficiency was defined as achieving a median operative time ≤90 minutes. Statistical comparisons were performed using Chi-square, one-way ANOVA, or Kruskal-Wallis tests as appropriate, with significance set at $p<0.05$.

RESULTS: A total of 156,347 RA-TKA procedures across 451 institutions were analyzed. Patient demographics across different institution categories are summarized in table 1. Low-volume centers (40.8%) had a mean operative time of 100.4 ± 32.8 minutes, medium-volume centers (26.4%) 91.6 ± 33.6 minutes, and high-volume centers (32.8%) 85.9 ± 30.5 minutes. Trend analysis using the moving average showed all groups improved operative times with subsequent cases, but only high- and medium-volume institutions consistently reached and maintained the 90-minute efficiency threshold (figure 1). CUSUM analysis revealed that high-volume institutions achieved and sustained operative efficiency after approximately 550 cases, compared to 650 cases in medium-volume centers (figure 1). Low-volume centers showed transient improvements but did not maintain sub-90-minute performance. Overall, 66.8% of high-volume institutions reached the efficiency benchmark, compared to 42.9% and 39.7% of medium- and low-volume centers, respectively.

DISCUSSION AND CONCLUSION: Our findings highlight that institutional surgical volume plays a critical role in shaping the learning curve for RA-TKA. While all volume tiers demonstrated learning curves with decreasing operative times, high-volume institutions not only reached the efficiency target faster but were also more likely to sustain it. This supports the idea that institutional experience fosters a more streamlined workflow, better-trained staff, and coordinated care pathways, all of which contribute to procedural efficiency. Notably, the number of cases needed to reach efficiency far exceeded previously published surgeon-specific learning curves, underscoring that institutional learning involves broader system-level processes. These results suggest that lower-volume centers may benefit from centralized support or collaborative strategies to accelerate proficiency. Future research should evaluate the effect of institutional training protocols and optimization initiatives on RA-TKA outcomes.

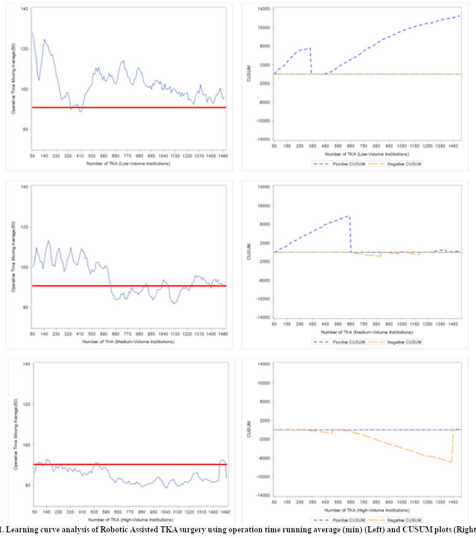

Figure 1. Learning curve analysis of Robotic Assisted TKA surgery using operation time running average (min) (Left) and CUSUM plots (Right).

	1. Low volume (N = 8,230)	2. Medium volume (N = 25,115)	3. High volume (N = 123,002)	Total (N = 156,347)	P Value
Age					
Mean (SD)	67.91 (9.43)	68.15 (9.23)	68.38 (9.13)	68.32 (9.16)	<0.001
Body Mass Index					
Mean (SD)	32.04 (6.66)	32.43 (6.41)	32.12 (6.39)	32.17 (6.41)	<0.001
N (N Missing)	6817 (1413)	23856 (1259)	115047 (7955)	145720 (10627)	
Hospital Length of Stay					
Mean (SD)	1.24 (1.49)	1.21 (1.37)	4.29 (1063.38)	3.63 (942.73)	0.87
N (N Missing)	8061 (169)	24794 (321)	120650 (2352)	153505 (2842)	
Charlson Comorbidity Index					
0-2	3,197 (38.85%)	10,184 (40.55%)	49,645 (40.36%)	63,026 (40.31%)	<0.001
3-4	3,625 (44.05%)	11,496 (45.77%)	55,778 (45.35%)	70,899 (45.35%)	
5+	1,408 (17.11%)	3,435 (13.68%)	17,579 (14.29%)	22,422 (14.34%)	
Sex					
Female	4,960 (60.29%)	14,785 (59.24%)	72,930 (59.57%)	92,675 (59.28%)	0.24
Male	3,267 (39.71%)	10,172 (40.76%)	49,505 (40.43%)	62,944 (40.26%)	
Missing	3 (0.04%)	158 (0.63%)	567 (0.46%)	728 (0.47%)	
Race/Ethnicity					
Non-Hispanic White	4,990 (67.67%)	16,964 (75.29%)	90,316 (81.79%)	112,270 (71.81%)	<0.001
Non-Hispanic Black	615 (8.34%)	1,580 (7.01%)	6,738 (6.10%)	8,933 (5.71%)	
Hispanic	652 (8.84%)	1,642 (7.29%)	6,501 (5.89%)	8,795 (5.63%)	
Other	1,117 (15.15%)	2,347 (10.42%)	6,867 (6.22%)	10,331 (6.61%)	
Missing	856 (10.40%)	2,582 (10.28%)	12,580 (10.23%)	16,018 (10.25%)	

Table 1. Patient demographics by institution classification