Does Technology Increase the Risk of Manipulation Under Anesthesia? Evaluating the Role of the Learning Curve

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INTRODUCTION: Arthrofibrosis and stiffness remain among the most challenging complications following total knee arthroplasty (TKA). When conservative treatments fail to restore adequate range of motion, Manipulation Under Anesthesia (MUA) is commonly performed. Inadequate implant sizing, malalignment, imprecise positioning, and instability and suboptimal ligament balance are potential contributors to these complications. Robotic-assisted TKA (RA-TKA) has been developed to enhance surgical precision and address these technical limitations. Although associated with reduced use of constrained articular insert, potentially leading to increased postoperative range of motion, its association with higher surgical time and the potential influence on surgeon experience raises concerns regarding its impact on stiffness and arthrofibrosis. This study aimed to measure the association between surgical technologies and 90-day MUA rates, with a specific focus on the influence of the robotic learning curve and surgeon experience.

METHODS:

We conducted a retrospective case-control study of 25,611 unilateral primary TKA procedures performed between January 2016 and January 2025 and stratified based on manual instrumentation, computer-navigation, or robotic-assistance. Cases requiring MUA within 90 days postoperatively were matched 1:2 to controls using propensity scores based on age, body mass index, sex, race, smoking status, diabetes status, and implant constraint. Conditional logistic regression was used to evaluate the independent association between surgical technology and the risk of MUA.

To assess the impact of surgeon experience, a learning curve analysis was performed on the first 100 RA-TKA cases for each surgeon with at least 100 procedures using the same robotic platform. Segment-specific likelihood ratios (SSLRs) were calculated by case decile to estimate the relative probability of MUA compared to the baseline rate. LOESS-smoothed cumulative sum (CUSUM) plots and segmented logistic regression were applied to identify performance trends and breakpoints.

Lastly, to evaluate the effect of the learning phase on MUA risk, odds ratios (ORs) from conditional logistic regression models were compared between the full cohort and the cohort excluding learning phase cases

RESULTS:

A total of 25,611 primary TKA procedures were analyzed, including 14,080 manual (M-TKA), 7,712 computer-assisted (CA-TKA), and 3,819 RA-TKA cases. Following matching, conditional logistic regression showed a trend for higher but no statistically significant difference in the odds of MUA for either computer-assisted (OR = 1.11, 95% CI: 0.90–1.38, p = 0.33) or robotic-assisted TKA (OR = 1.24, 95% CI: 0.94–1.64, p = 0.12) compared to manual TKA.

Learning curve analysis of 10 surgeons (1000 procedures) revealed a significantly higher MUA rate in the first 10 robotic cases per surgeon (7.0%) compared to subsequent cases (OR = 0.32; 95% CI: 0.13–0.91; p = 0.02). Segmented regression identified a breakpoint at case 12, after which MUA rates stabilized and trended downward, indicating improved and more consistent surgical performance. This trend was further corroborated by CUSUM analysis and decile-based bar plots showing an early peak followed by a stable plateau.

After excluding each surgeon's first 12 robotic cases, the initially elevated risk of MUA was no longer observed, with an odds ratio of 0.98 (95% CI: 0.74–1.29), indicating no significant difference compared to manual TKA. The ratio of odds ratios between the full and post-learning cohorts was 1.27 (95% CI: 0.86–1.88), reflecting a 27% relative increase in MUA risk observed during the learning phase (p = 0.23).

DISCUSSION AND CONCLUSION: Our findings suggest that the initially elevated rate of MUA seen with RA-TKA may be confounded by the early phase of robotic adoption. Once this early phase is excluded, RA-TKA demonstrated comparable MUA risk to both manual and computer-assisted approaches. These results underscore the importance of focused training and robust credentialing processes during the adoption of robotic technology.

Variable		Overall	M-TKA	CA-TKA	RA-TKA
Patients (%)		25611 (100)	14080 (55)	7712 (30.1)	3819 (14.9)
Age (mean ± SD)		67.40 ± 9.1	68.20 ± 9	67.40 ± 9.1	65.27 ± 8.7
Bmi (mean ± SD)		31.89 ± 6.2	31.2 ± 6.2	31.8 ± 6.5	33.2 ± 6
Sex (%)	Female	14213 (55.5)	8994 (63.9)	5140 (66.6)	2075 (54.3)
	Male	9398 (36.7)	5086 (36.1)	2564 (33.2)	1748 (45.8)
Laterality (%)	Left	12249 (47.8)	6798 (48)	3842 (49.8)	1609 (42.1)
	Right	13362 (52.2)	7522 (52)	3870 (50.2)	2210 (57.9)
Race (%)	White or Caucasian	20942 (81.8)	11637 (84.1)	5966 (77.4)	3340 (87.5)
	Other	4669 (18.2)	2443 (17.9)	1746 (22.6)	479 (12.5)
Smoking (%)	Never	14210 (55.5)	8052 (57.5)	4794 (62.2)	1364 (35.7)
	Former/Former	11401 (44.5)	6028 (42.5)	2918 (37.8)	2455 (64.3)
Diabetes (%)	No	22795 (87.5)	12319 (87.9)	6893 (88.8)	3583 (93.8)
	Yes	3243 (12.7)	1761 (12.5)	1019 (13.2)	477 (12)
Cmorbidit (%)	PE	12712 (49.7)	9843 (69.9)	2308 (27)	559 (14.1)
	CR	4701 (18.4)	1444 (10.3)	1184 (14.3)	2193 (57.4)
	BCR	2890 (11.3)	842 (6.7)	1449 (21.4)	599 (15.8)
	CCR	5264 (20.7)	2951 (14.6)	2875 (37.3)	388 (9.8)

Figure 1. MUA Rate by Case Number Decile in Robotic-Assisted TKA

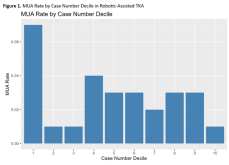


Figure 2. Learning Curve for Robotic-Assisted TKA: Estimated Probability of Manipulation Under Anesthesia (MUA) by Case Sequence

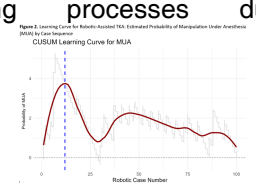
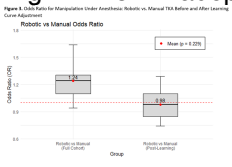


Figure 3. Odds Ratio for Manipulation Under Anesthesia: Robotic vs. Manual TKA Before and After Learning Curve Adjustment



Matched Full Cohort				
Variable		M-TKA	MTA	
Patients		10 (71.4 ± 9.7)	20 (69 ± 9.1)	0.772
Age (mean ± SD)		71.4 ± 9.7	69 ± 9.1	0.772
Bmi (mean ± SD)		31.89 ± 4.2	31.2 ± 6.2	0.772
Sex (%)	Female	10 (47.7)	19 (46.3)	0.849
	Male	9 (52.7)	19 (53.9)	
Race (%)	White or Caucasian	16 (76.2)	34 (82.9)	0.693
	Other	5 (23.8)	7 (17.1)	
Smoking (%)	Never	9 (42.9)	21 (51.2)	0.721
	Former/Former	12 (57.1)	20 (48.8)	
Diabetes (%)	No	1 (4.8)	3 (7.3)	0.790
	Yes	20 (95.2)	38 (92.7)	
Cmorbidit (%)	PE	10 (47.6)	19 (46.3)	0.957
	CR	5 (23.8)	10 (24.4)	
	BCR	2 (9.5)	4 (9.8)	
	CCR	4 (19.1)	8 (19.5)	

Matched Post-Learning Curve Cohort				
Variable		M-TKA	MTA	
Patients		10 (71.4 ± 9.7)	20 (71.4 ± 9.7)	0.751
Age (mean ± SD)		71.4 ± 9.7	71.4 ± 9.7	0.751
Bmi (mean ± SD)		31.89 ± 4.2	31.89 ± 4.2	0.751
Sex (%)	Female	10 (47.6)	10 (46.1)	0.228
	Male	9 (52.4)	15 (53.9)	
Race (%)	White or Caucasian	16 (76.2)	34 (82.9)	0.753
	Other	5 (23.8)	7 (17.1)	
Smoking (%)	Never	9 (42.9)	21 (51.2)	0.721
	Former/Former	12 (57.1)	20 (48.8)	
Diabetes (%)	No	1 (4.8)	3 (7.3)	0.910
	Yes	20 (95.2)	38 (92.7)	
Cmorbidit (%)	PE	10 (47.6)	19 (46.3)	0.775
	CR	5 (23.8)	10 (24.4)	
	BCR	2 (9.5)	4 (9.8)	
	CCR	4 (19.1)	8 (19.5)	