Association of Technology Usage and Decreased Revision TKA Rates for Low-Volume Surgeons Using an Optimal Prosthesis Combination

An Analysis of 53,264 Primary TKAs

Michael McAuliffe, MBBS, Ibrahim Darwish, MD, Jon Anderson, MBBS, Alex Nicholls, MBBS, Sophie Corfield, PhD, Dylan Harries, PhD, and Christopher Vertullo, MBBS

Background: Technology (navigation and robotics) usage during total knee arthroplasty (TKA) is often supported by literature involving high-volume surgeons and hospitals, but the value of technology for lower-volume surgeons is uncertain. This study aimed to determine if there was a relationship among surgeon volume, technology usage, and revision rate when using an optimal prosthesis combination (OPC).

Methods: Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) data were obtained from January 1, 2008, to December 31, 2022, for all primary TKA procedures performed for osteoarthritis using an OPC by a known surgeon ≥5 years after their first recorded procedure. The interaction between surgeon volume and conventional-instrumentation (CV) versus technology-assisted (TA) TKA was assessed. The cumulative percent revision (CPR) was determined by Kaplan-Meier estimates. Cox proportional-hazards methods were used to compare rates of revision by surgeon volume and by the interaction of volume and technology. Subanalyses were undertaken to examine major and minor revisions separately, and to assess the influence of technology on revision rates relative to those of a surgeon undertaking 100 TKA/year.

Results: Of the 53,264 procedures that met the inclusion criteria, 31,536 were TA-TKA and 21,728 were CV-TKA. Use of technology reduced the all-cause revision rate for surgeons with a volume of <50 TKA/year and the rate of minor revisions for surgeons with a volume of <40 TKA/year. No interaction between surgeon volume and the rate of major revision surgery was found. With CV-TKA by a surgeon with a 100-TKA/year volume as the comparator, all-cause and major revision rates were significantly elevated for surgeons undertaking <50 and <100 TKA/year, respectively. In contrast, analysis of TA-TKA showed no difference in rates of all-cause or major revisions for surgeons undertaking <100 TKA/year compared with 100 TKA/year.

Conclusions: TA-TKA was associated with a decrease in the revision rate for lower-volume surgeons but no significant alterations in revision rate for higher-volume surgeons. Preferential use of TA-TKA by lower-volume surgeons should be considered.

Level of Evidence: Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

Technology-assisted total knee arthroplasty (TA-TKA) includes the use of computer navigation (CN) and robotic-assisted (RA) platforms. There is a global trend of increasing use of such adjunctive TKA technologies[1]. Technology utilization is rising in the U.S.[2-4], although conventional-instrumentation (CV)-TKA still predominates[2]. TA-TKA has also increased consistently in Germany[5]. The Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) recently reported that 65.8% of TKAs in Australia utilized adjunctive technology[6].

This trend is largely premised on increased implant positioning accuracy[3,7-10]; however, it has increased TKA delivery costs[11-13]. A substantial body of published clinical evidence suggests that there is no significant improvement in patient outcomes when comparing TA-TKA with CV-TKA[7,10,14-18].

Disclosure: No external funding was received for this work. The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJS/I215).

The American Academy of Orthopaedic Surgeons (AAOS) clinical guidelines recommend with a "strong" level that there is no evidence of improved outcomes, function, or pain, and no difference in complications, after CV-TKA compared with CN-TKA[19].

Many factors affect patient outcomes after TKA, including surgeon volume[20,21]. TA-TKA performed in higher-volume surgical centers may have improved cost-effectiveness compared with CV-TKA[11,12]. However, there is limited evidence regarding the effect of TA-TKA on the clinical outcomes of TKAs performed by lower-volume surgeons. It is possible that this technology is more effective at reducing the revision rate after procedures performed by less-experienced, lower-volume surgeons.

We hypothesized that TA-TKA (RA-TKA or CN-TKA) usage by lower-volume surgeons would have a beneficial effect on implant survivorship.

Materials and Methods

The AOANJRR is approved by the Commonwealth of Australia as a Federal Quality Assurance Activity (F2022L00986) under Part VC of the Health Insurance Act 1973 (HIA) and Part 10 of the Health Insurance Regulations 2018. All AOANJRR studies are conducted in accordance with ethical principles of research (the Helsinki Declaration II).

The AOANJRR has well-documented data collection and validation procedures that ensure high-quality data encompassing almost all arthroplasties performed in Australia since mid-2002[6]. Revisions involving the insertion, removal, and/or replacement of any components fixed to bone, except for the patellar prosthesis, are defined as major. All other revisions are defined as minor[6,22,23].

Data were obtained from the AOANJRR for all primary TKAs performed for osteoarthritis (OA) between January 1, 2008, and December 31, 2022. This period was chosen because prior to 2008 provision of the operating surgeon's code for a procedure was an opt-in process, potentially underestimating procedure volumes for surgeons who were operating prior to 2008. Furthermore, only surgeons whose first procedure was recorded since January 1, 2008, were included. Of the 1,452 surgeons with TKA procedures recorded by the registry, 962 had their first procedure recorded since January 1, 2008. TKA procedures in the first 5 years of a surgeon's practice were also removed from the study cohort to diminish the influence of learning curves and experience. Additionally, only procedures that used an optimal prosthesis combination (OPC) were included in the analysis, to limit confounding factors associated with the prosthetic construct. OPCs were defined as those with a minimally stabilized or medial-pivot design, fixed mobility, a cross-linked polyethylene (XLPE) insert, a cemented tibial component, and resurfacing of the patella. Only procedures in which computer navigation, robotic assistance, or conventional instrumentation was used were included. Procedures using image-derived instrumentation (IDI) were excluded, as they have a higher revision rate in the AOANJRR. The TKA was classified as technology-assisted if either computer navigation or robotic assistance was used. Of the 962 surgeons whose first procedure was performed since January 1, 2008, 677 had procedures eligible for inclusion in this analysis. After removing the procedures performed in their first 5 years of practice, 457 surgeons contributed cases and 53,264 of the 886,536 primary TKA procedures performed since January 1, 2008, met the criteria for inclusion in the study (Table I). These included 31,536 TA-TKAs and 21,728 CV-TKAs (Table II).

Since a given surgeon's procedure volume could change over time, each procedure was analyzed on the basis of the volume of the surgeon (the number of primary TKA procedures for any diagnosis and using any prosthesis) in the year (365 days) before that particular procedure was undertaken.

Statistical Analysis

The primary outcome for this study was the time from primary TKA to the first revision (major or minor) for any reason. Secondary outcomes were the time to major revisions and minor revisions. For each outcome, Kaplan-Meier estimates of survivorship were used to report the time to revision, with censoring at the time of death or closure of the data set at the end of December 2022. The unadjusted cumulative percent revision (CPR) was calculated as the complement, in probability, of the Kaplan-Meier estimates, and its 95% confidence interval (CI) was calculated using unadjusted point-wise Greenwood estimates.

Rates of revision by technology usage and by surgeon volume were compared using hazard ratios (HRs) estimated under Cox proportional-hazards models adjusting for age and gender, as well as under a model including age, gender, technology usage (TA or CV), and surgeon volume. For the latter model, age and surgeon volume were treated as continuous variables, and potential nonlinear effects were modeled using restricted cubic splines. Additionally, a model containing an interaction between technology usage and surgeon volume was

TABLE I Application of the Inclusion and Exclusion Criteria*

Criterion	No. Included	No. Excluded
Primary TKA	886,536	0
Primary diagnosis OA	867,113	19,423
Used an OPC	154,383	712,730
Performed by a known surgeon	148,040	6,343
Surgeon performed first procedure after 2007	83,785	64,255
IDI not used	76,366	7,419
Performed at least 5 years since the surgeon's first procedure	53,264	23,102

*Each inclusion or exclusion criterion also applies to all subsequent rows. OPC = optimal prosthesis combination, and IDI = image-derived instrumentation.

TABLE II Characteristics of Primary TKAs (for a Primary Diagnosis of OA) According to Technology Assistance*

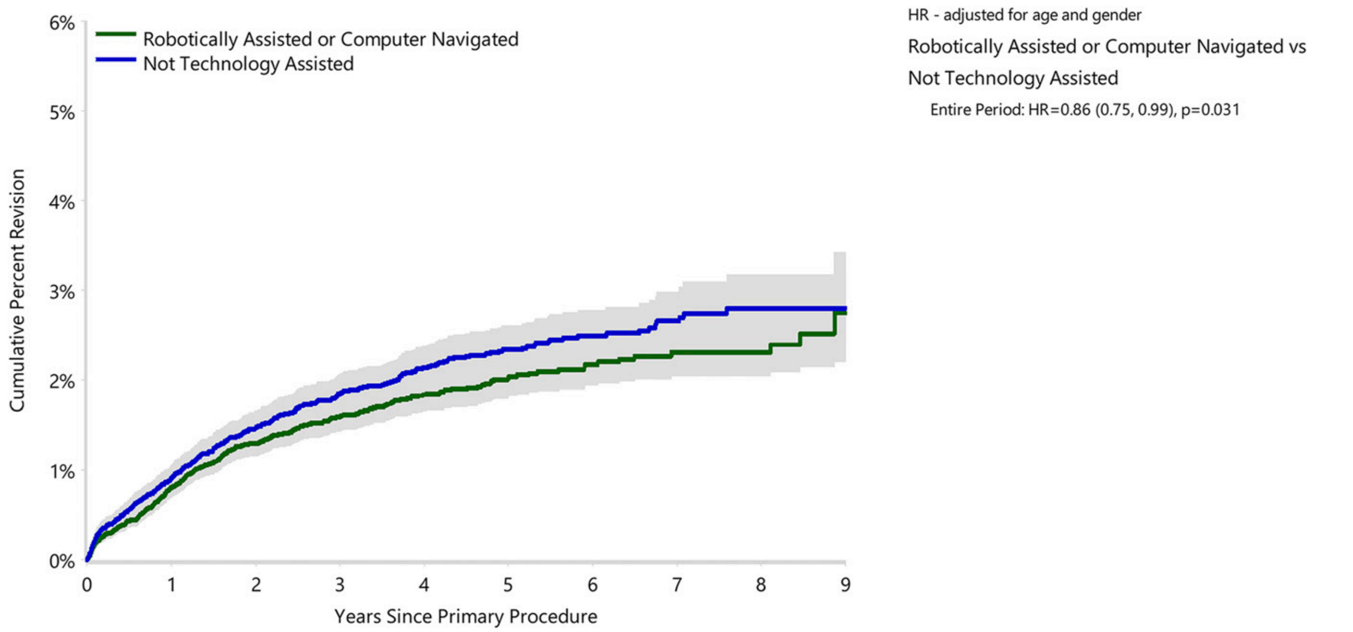
Variable	Robotically Assisted or Computer-Navigated	Not Technology-Assisted	Total
Years since surgeon's first procedure			
Mean ± SD	9.2 ± 2.7	9.3 ± 2.6	9.2 ± 2.7
Median (IQR)	8.8 (6.9, 11.3)	9 (7, 11.4)	8.9 (6.9, 11.4)
Minimum	5	5	5
Maximum	14.9	14.9	14.9
Surgeon's prior number of cases			
Mean ± SD	697.2 ± 482	657.6 ± 456.3	681 ± 472.1
Median (IQR)	565 (342, 924)	542 (317, 894)	557 (331, 910)
Surgeon volume			
Mean ± SD	98.2 ± 54.4	92 ± 44.7	95.7 ± 50.8
Median (IQR)	87 (57, 131)	91 (56, 119)	89 (57, 125)
Age group			
<55 yr	1,845 (5.9%)	1,133 (5.2%)	2,978 (5.6%)
55-64 yr	8,314 (26.4%)	5,335 (24.6%)	13,649 (25.6%)
65-74 yr	13,203 (41.9%)	9,192 (42.3%)	22,395 (42.0%)
≥75 yr	8,174 (25.9%)	6,068 (27.9%)	14,242 (26.7%)
Sex			
Male	12,666 (40.2%)	9,094 (41.9%)	21,760 (40.9%)
Female	18,870 (59.8%)	12,634 (58.1%)	31,504 (59.1%)
ASA class†			
ASA 1	1,383 (4.4%)	984 (4.6%)	2,367 (4.5%)
ASA 2	16,343 (52.0%)	10,921 (50.7%)	27,264 (51.5%)
ASA 3	13,346 (42.5%)	9,437 (43.8%)	22,783 (43.0%)
ASA 4	349 (1.1%)	201 (0.9%)	550 (1.0%)
ASA 5	1 (0%)	1 (0%)	2 (0%)
BMI category in kg/m^2‡			
Underweight (<18.50)	49 (0.2%)	29 (0.2%)	78 (0.2%)
Normal (18.50-24.99)	3,028 (10.2%)	1,816 (9.4%)	4,844 (9.9%)
Pre-obese (25.00-29.99)	8,856 (29.9%)	5,899 (30.6%)	14,755 (30.2%)
Obese Class 1 (30.00-34.99)	9,234 (31.2%)	5,895 (30.6%)	15,129 (31.0%)
Obese Class 2 (35.00-39.99)	5,277 (17.8%)	3,447 (17.9%)	8,724 (17.9%)
Obese Class 3 (≥40.00)	3,131 (10.6%)	2,195 (11.4%)	5,326 (10.9%)
Total	31,536	21,728	53,264

*SD = standard deviation, IQR = interquartile range, ASA = American Society of Anesthesiologists, BMI = body mass index. †Excludes 298 procedures with unknown ASA class. ‡Excludes 4,408 procedures with unknown BMI category.

examined for each outcome. HRs comparing TA-TKA with CV-TKA as a function of surgeon volume and comparing higher and lower surgeon volumes with a volume of 100 TKA/year for TA-TKA and CV-TKA procedures separately were calculated to summarize the effect of each factor. The number of eligible procedures during the study period determined the available sample size.

Further analysis adjusting for American Society of Anesthesiologists Physical Status Classification (ASA) and body mass index (BMI) at the time of the primary procedure was performed to assess potential confounding effects. The AOANJRR commenced collection of ASA and BMI values in 2012 and 2015, respectively. For the purposes of this analysis, missing ASA and BMI data were assumed to be missing completely at random, and the analysis was restricted to procedures with complete data for these covariates.

The assumption of proportional hazards was checked analytically for each model. If the interaction between the predictor and the log of time was significant in the standard Cox model, then a time-varying model was developed. Time points were selected on the basis of the greatest change in hazard, weighted by a function of events. Time points were iteratively chosen until the assumption of proportionality was met, and HRs were then calculated for each selected time



Number at Risk	0 Yr	1 Yr	2 Yrs	3 Yrs	4 Yrs	5 Yrs	6 Yrs	7 Yrs	8 Yrs	9 Yrs
Robotically Assisted or Computer Navigated	31536	23919	17366	12618	8751	5690	3506	2213	1251	350
Not Technology Assisted	21728	18204	14361	11095	8282	6000	3983	2365	1183	377

Fig. 1
Cumulative percent revision of primary TKA (for a primary diagnosis of OA) with and without technology assistance. The shading represents the 95% CI.

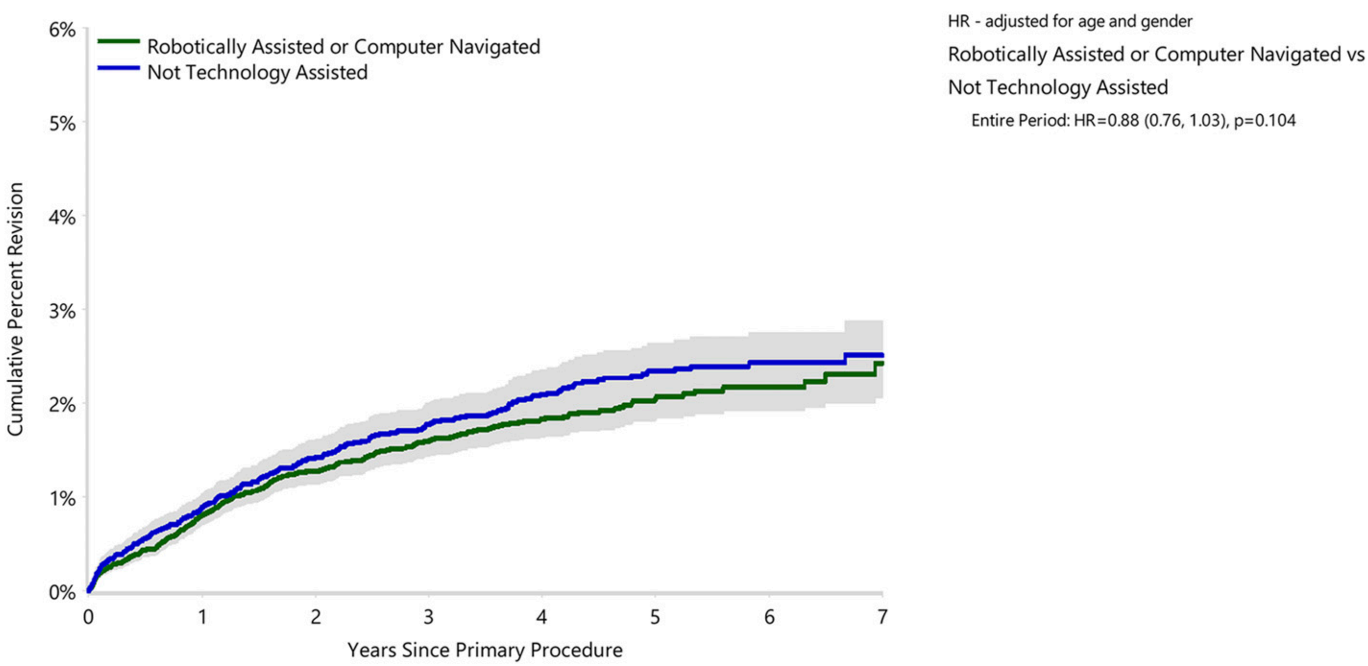


Fig. 2
Cumulative percent revision of primary TKA (for a primary diagnosis of OA) with and without technology assistance in patients with known ASA and BMI. The shading represents the 95% CI.

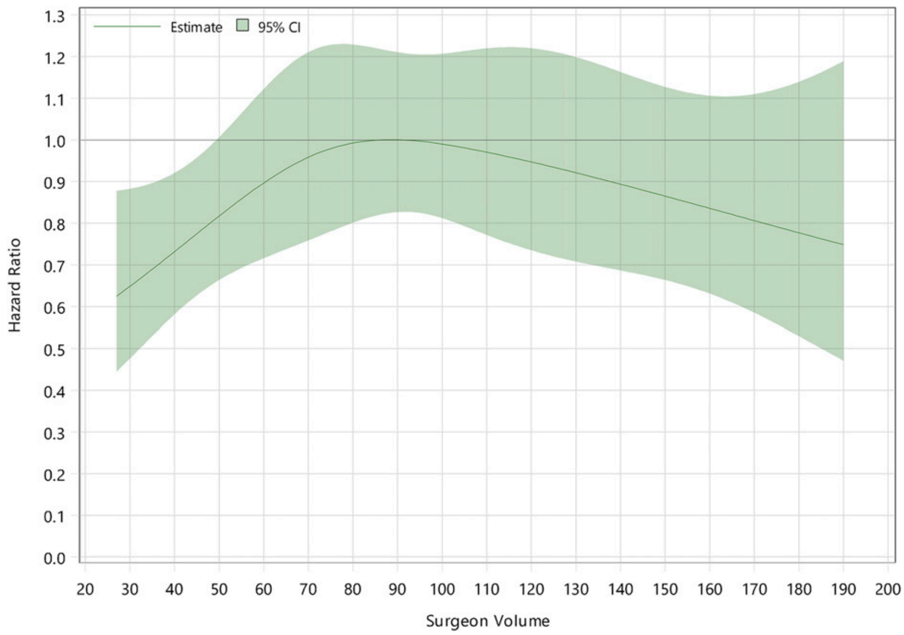


Fig. 3
Hazard ratio for all-cause revision of primary TKA (for a primary diagnosis of OA) with, relative to without, technology assistance, graphed according to surgeon volume.

period. In the current study, if no time period is specified, the stated HR was calculated over the entire follow-up period. All tests were 2-tailed at the 5% level of significance. Statistical analysis was performed using SAS (version 9.4; SAS Institute).

Results

When evaluating the all-cause revision rate and adjusting for age and gender only, TA-TKA had a lower revision rate compared with CV-TKA procedures (HR = 0.86 [95% CI, 0.75 to 0.99], p = 0.031) (Fig. 1). However, this reduction in revision rate with the use of TA-TKA was no longer significant when analyzing the subset of 48,819 procedures with known ASA and BMI data (Fig. 2). The revision rate also did not differ significantly between TA-TKA and CV-TKA in this subset when adjusting for additional variables (age, gender, ASA, BMI, surgeon volume) (HR = 0.89 [95% CI, 0.77 to 1.03], p = 0.128).

When the effect of technology usage was allowed to vary with surgeon volume, through the inclusion of an interaction between these 2 factors, the relative difference in revision rate between TA-TKA and CV-TKA was largest among procedures performed by lower-volume surgeons (Fig. 3, Table III). Surgeons with a volume of <50 TKA/year demonstrated a lower revision rate with TA-TKA compared with CV-TKA. At higher surgeon volumes, there was no evidence of a difference in the revision rate.

Figure 4 shows all-cause revision as a function of surgeon volume, with a 100 TKA/year surgeon as the reference. For TA-TKA, there was no significant difference between the revision rate of procedures performed by surgeons with a volume of <100 TKA/year and procedures performed by 100-TKA/year surgeons. Conversely, when CV-TKA was utilized, there was a significantly higher rate of revision for surgeons undertaking <50 TKA/year compared with 100-TKA/year surgeons. The revision rate of TA-TKA was found to steadily decrease, with variable significance, as surgeon volume increased above 100 TKA/year. For CV-TKA procedures, however, there was no evidence of a difference in revision rate between surgeons performing >100 TKA/year and 100-TKA/year surgeons.

Taken together, the model allowing an interaction of technology usage with surgeon volume and the comparison of lower with higher-volume surgeons suggest that TA-TKA is associated with a decreased revision rate for lower-volume surgeons. However, it should be noted that there was not strong evidence for this interaction, given the p value of 0.158 for the

TABLE III Hazard Ratios for All-Cause Revision with Versus without Technology Assistance, According to Surgeon Volume

Surgeon Volume	HR (95% CI)*	P Value
50 cases	0.82 (0.66, 1.01)	0.057
75 cases	0.98 (0.78, 1.23)	0.854
100 cases	0.99 (0.81, 1.21)	0.921
125 cases	0.93 (0.72, 1.21)	0.609
150 cases	0.86 (0.66, 1.13)	0.283
175 cases	0.79 (0.56, 1.12)	0.189

*Revision of primary TKA for a primary diagnosis of OA. Adjusted for age and gender.

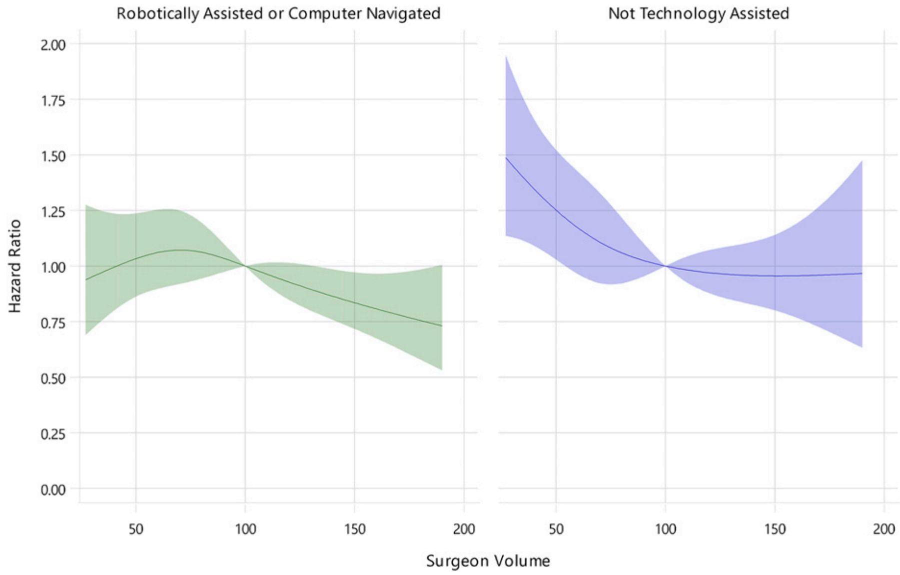


Fig. 4

Hazard ratio for all-cause revision of primary TKA (for a primary diagnosis of OA), with and without technology assistance, versus a surgeon volume of 100 TKA/year. The shading represents the 95% CI.

total model, and the observed data were thus also compatible with the absence of an interaction between technology assistance and surgeon volume.

Our analysis examining variation in the effect of TA-TKA usage with surgeon volume demonstrated that TA-TKA decreased the rate of minor revision surgery for surgeons performing <40 TKA/year (Fig. 5). The model also suggested a decrease in the minor revision rate with TA-TKA for some surgeons undertaking >100 TKA/year, but the estimated HR was relatively imprecise.

Table IV describes the HR for minor revision associated with specific surgeon volumes. As for all-cause revision, there was no strong evidence to suggest an interaction between technology usage and surgeon volume (p = 0.298).

Figure 6 demonstrates that, regardless of technology utilization, there was no significant difference in the rate of minor

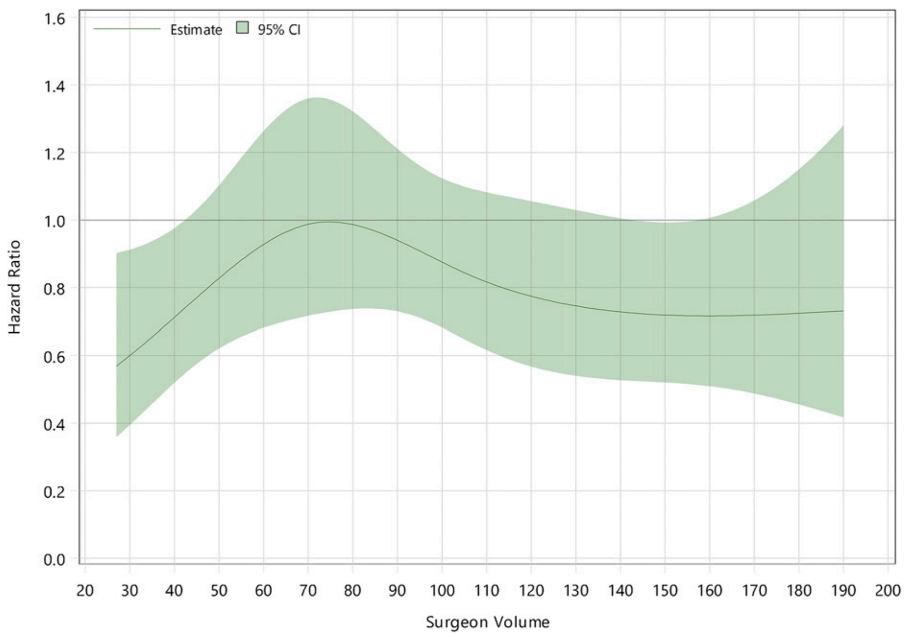


Fig. 5

Hazard ratio for minor revision of primary TKA (for a primary diagnosis of OA) with, relative to without, technology assistance, graphed according to surgeon volume.

TABLE IV Hazard Ratio for Minor Revision with Versus without Technology Assistance, According to Surgeon Volume

Surgeon Volume	HR (95% CI)*	P Value
50 cases	0.83 (0.62, 1.10)	0.196
75 cases	0.99 (0.73, 1.36)	0.971
100 cases	0.88 (0.68, 1.12)	0.296
125 cases	0.76 (0.55, 1.04)	0.089
150 cases	0.72 (0.52, 0.99)	0.045
175 cases	0.72 (0.47, 1.10)	0.128

*Revision of primary TKA for a primary diagnosis of OA. Adjusted for age and gender.

revision surgery when higher and lower-volume surgeons were compared with a 100 TKA/year surgeon.

Figure 7 compares major revisions between TA-TKA and CI-TKA as a function of surgeon volume. No significant effect of technology use on the major revision rate was found at any surgeon volume, as all CIs contained an HR of 1.0.

Figure 8 shows the HRs of major revisions by surgeon volume, with a surgeon undertaking 100 TKA/year as the reference. The findings are similar to those for all-cause revision. With TA-TKA, high-volume surgeons tended to have a lower rate of major revision compared with surgeons with a volume of 100 TKA/year. Without technology usage, a similar pattern was seen for some of the high-volume surgeons, although with lower precision. With CV-TKA usage, lower-volume surgeons had a higher rate of major revision than a 100-TKA/year surgeon. For TA-TKA, there was no significant difference in the rate of major revision surgery for lower-volume surgeons compared with 100-TKA/year surgeons.

Discussion

The key finding of this study is that TA-TKA was associated with a lower revision rate than CV-TKA for lower-volume surgeons.

TA-TKA with an OPC was associated with a lower rate of revision in an unadjusted analysis of the whole study cohort. However, when results were adjusted for age, gender, ASA, BMI, and surgeon volume in a large subset for whom such data were available, no significant benefit of TA-TKA was demonstrated. This raises the question of whether the potential benefits of technology assistance are more apparent in certain subgroups, rather than being spread evenly across the cohort.

Our study results support our hypothesis that TA-TKA may be most beneficial for lower-volume surgeons. We found a lower rate of all-cause revision with the use of TA-TKA than CV-TKA for surgeons whose annual volume at the time of the TKA was <50 TKA/year. This was predominantly due to a lower rate of minor revisions for TA-TKA, compared with CV-TKA, performed by surgeons with an annual case volume of <40 TKA/year. No clear difference in the revision rate was found between TA-TKAs and CV-TKAs performed by higher-volume surgeons. This suggests that the maximum value of these technologies to the health-care system would result from its preferential use by lower-volume surgeons. More commonly, it is high-volume surgeons at large teaching centers who are heavily involved in technology usage, study, and promotion[24,25]. However, lower-volume surgeons are an important group because they account for a considerable percentage of TKAs. A recent Canadian study investigating volume-outcome relationships defined low-volume surgeons as those performing <70 TKA/year, with this cohort accounting for 33% of the caseload (56,265 TKAs) over a 15-year period[26]. Comparable studies have

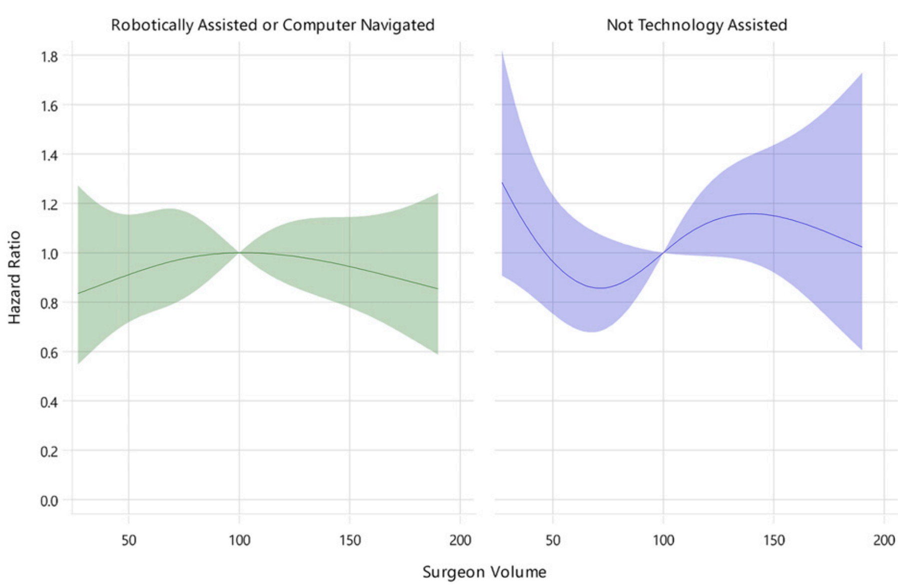


Fig. 6
Hazard ratio for minor revision of primary TKA (for a primary diagnosis of OA), with and without technology assistance, versus a surgeon volume of 100 TKA/year. The shading represents the 95% CI.

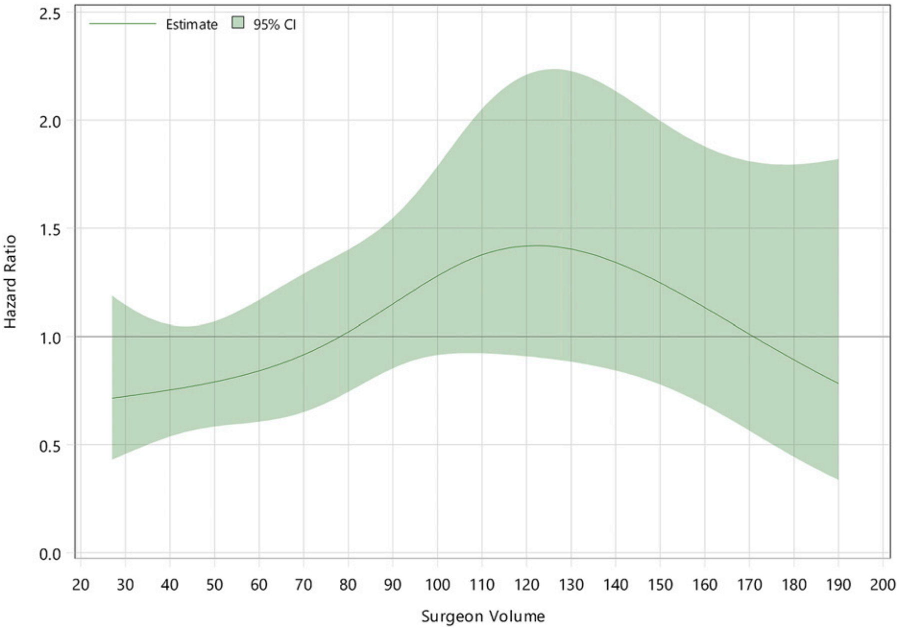


Fig. 7
Hazard ratio for major revision of primary TKA (for a primary diagnosis of OA) with, relative to without, technology assistance, graphed according to surgeon volume.

previously reported similar findings[20,27,28]. The focused application of technology in this surgeon group has the potential to produce considerable health-care system benefits. These findings should be carefully considered by health-care administrators when considering technology usage.

We utilized a comparator of 100 TKA/year to examine whether TA-TKA allowed lower-volume surgeons to achieve results similar to those of their higher-volume colleagues, and whether further benefit was gained with technology at higher volume levels.

Surgeons performing <50 CV-TKA/year had a significantly higher rate of all-cause revision compared with the 100-CV-TKA/year surgeon, and those performing <100 CV-TKA/year had a significantly higher rate of major revision compared with the 100-CV-TKA/year surgeon. However, when performing TA-TKA, lower-volume surgeons had rates of all-cause and major revision comparable with those of higher-volume surgeons, and the variation in revision rates with volume decreased. Thus, technology made the results of lower-volume surgeons

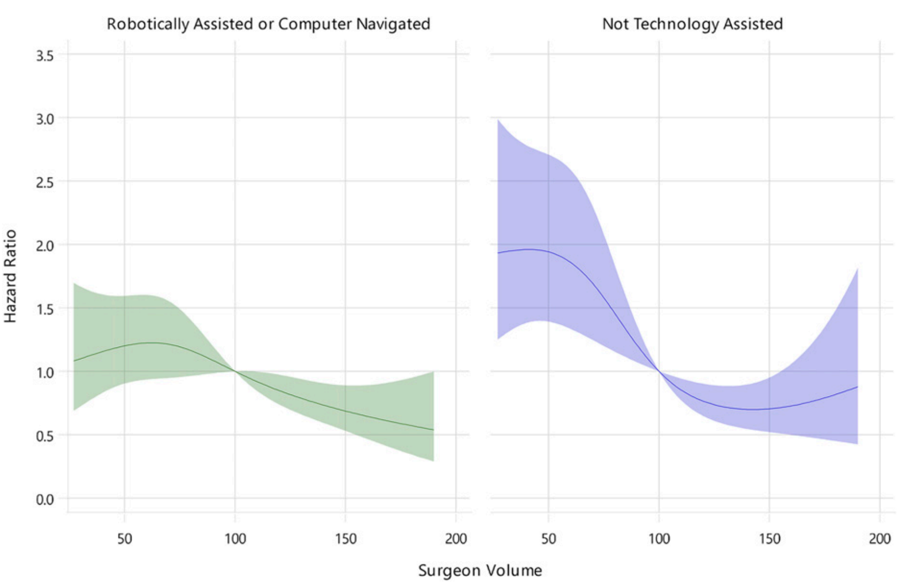


Fig. 8
Hazard ratio for major revision of primary TKA (for a primary diagnosis of OA), with and without technology assistance, versus a surgeon volume of 100 TKA/year. The shading represents the 95% CI.

more homogeneous and comparable with those of their higher-volume peers. These conclusions are consistent with our hypothesis that lower-volume surgeons would attain value from utilizing TA-TKA.

Furthermore, as surgeon volume increased above 100 TKA/year there was a reduction in all-cause and major revision with both CV-TKA and TA-TKA. The significance of the difference in revision rate compared with the 100-TKA/year surgeon depended on the TKA volume/year, and the significance was more consistent with TA-TKA than with CV-TKA. The comparatively better revision rates at higher volumes are unsurprising, as surgeon volume has been previously linked to improved outcomes[27,29-35]. TA-TKA also appeared to be associated with more consistency in surgical outcomes for higher-volume surgeons.

The more homogeneous revision outcomes across surgeon volumes for TA-TKA compared with CV-TKA using the 100 TKA/year comparator would be consistent with the fact that the technology platforms are based on standardized algorithms that should act to keep surgical outcomes within a certain range.

The potential benefits of TA-TKA may be due to multiple associated factors. Although these factors may vary between platforms, they may include implant alignment and sizing guidance, more precise resections, intraoperative feedback about resections, detailed soft-tissue balance, and limb and local knee alignment information. As lower-volume surgeons showed greater outcome variation than higher-volume surgeons with TA-TKA, they may be a good group in which to undertake future studies aimed at determining which of the technology factors offer maximum value in diminishing the revision rate. These factors could then be optimized in future technology iterations.

Our findings are consistent with prior literature in which limited outcome differences are seen with TA-TKA compared with CV-TKA[7,15-18,36,37]. Many of these studies are from high-volume surgeons and centers, which is consistent with our finding that this surgeon group derives limited benefit from TA-TKA.

Our results also suggest that the benefits of TA-TKA are limited overall. TA-TKA carries substantial associated costs. If this technology is to be embraced across all surgeon volumes, then it is important to demonstrate clear improvements in patient-reported outcome measures and overall reductions in the revision rate that meet cost-effectiveness thresholds.

Our study had several limitations. First, we combined CN and RA in the TA-TKA cohort. Purely robotic technology may deliver consistent improvements in the revision rate across wider surgeon volumes. However, the AOANJRR 2023 report notes no difference in the early revision rate for RA-TKA compared with CV-TKA[6]. Second, although our study has a large patient cohort, there was heterogeneity within the technology systems and the OPCs which may have affected outcomes. However, we attempted to minimize the influence of prosthetic variables by studying only OPCs, and the prosthetic variability was present in both the CV-TKA and TA-TKA cohorts. Third, although the study cohorts were large, and are a pragmatic representation of real-world practice, when considering the models in totality we were not able to exclude the possibility that technology usage and surgeon volume do not interact. It thus also remains plausible that any benefits associated with TA-TKA do not vary with surgeon volume. Fourth, hospital volumes may represent unrecognized confounders between the groups. Fifth, ultimately registry-based studies can only show association, not causation. It would be important to confirm these findings in well-designed prospective trials that focus on lower-volume surgeons.

In conclusion, we have demonstrated that TA-TKA shows the potential to improve the revision rate after TKA surgery, particularly when utilized by surgeons whose practice volumes are <50 TKA/year. ■

Michael McAuliffe, MBBS[1,2,3]
Ibrahim Darwish, MD[4]
Jon Anderson, MBBS[5,6]
Alex Nicholls, MBBS[4]
Sophie Corfield, PhD[1]
Dylan Harries, PhD[1]
Christopher Vertullo, MBBS[1]

[1]Australian Orthopaedic Association National Joint Replacement Registry, Adelaide, South Australia, Australia

[2]Queensland University of Technology, Brisbane, Queensland, Australia

[3]CJM Centre, Ipswich, Queensland, Australia

[4]Sydney Orthopaedic Research Institute, Sydney, New South Wales, Australia

[5]Brisbane Orthopaedic and Sports Medicine Centre (BOSMC), Brisbane, Queensland, Australia

[6]School of Human Movement and Nutrition Sciences, University of Queensland, St Lucia, Queensland, Australia

Email for corresponding author: ibrahim.darwish093@gmail.com

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