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Total Knee Arthroplasty Hospital Costs by Time-Driven Activity-Based Costing: Robotic vs Conventional

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ABSTRACT

Background: Total knee arthroplasty (TKA) represents a major national health expenditure. The last decade has seen a surge in robotic-assisted TKA (roTKA); however, literature on the costs of roTKA as compared to conventional TKA (cTKA) is limited. The purpose of this study was to assess the costs associated with roTKA as compared to cTKA.

Methods: This was a retrospective cohort cost-analysis study of patients undergoing primary, elective roTKA or cTKA from July 2020 to March 2021. Time-driven activity-based costing (TDABC) was used to determine granular costs. Patient demographics, medical/surgical details, and costs were compared.

Results: A total of 2058 TKAs were analyzed (1795 cTKAs and 263 roTKAs). roTKA patients were more often male (50.2% vs 42.3%; $P = .016$), and discharged home (98.5% vs 93.7%; $P = .017$), and had longer operating room (OR) time (144.6 vs 130.9 minutes; $P < .0001$), and lower length of stay (LOS) (1.8 vs 2.1 days; $P < .0001$). roTKA costs were 2.17× greater for supplies excluding implant ($P < .0001$), 1.18× for total supplies ($P < .0001$), 1.12× for OR personnel ($P < .0001$), and 1.05× for total personnel ($P = .0001$). Implant costs were similar ($P = .076$), but 0.98× cheaper for post-anesthesia care unit personnel ($P = .018$) and 0.84× for inpatient personnel ($P < .0001$). Overall hospital costs for roTKA were 1.10× more than cTKA ($P < .0001$).

Conclusion: roTKA had higher total hospital costs than cTKA. Despite a lower LOS, the longer OR time with higher supply and personnel costs resulted in a costlier procedure. Understanding the costs of roTKA is essential when considering the value (ie, outcomes per dollars spent) of this modern technology.

Introduction

In the past decade, there were nearly 700,000 total knee arthroplasty (TKA) procedures performed annually in the U.S., and that number is expected to surpass 1.25 million annually by 2030 [1]. In the late 1980s, robotic systems began to be used in the operating room, with the first robotic-assisted TKA (roTKA) completed in 1988. Since then, the last decade has seen a surge in the number of roTKAs performed [2-4]. There are multiple factors contributing to the increase in popularity and utilization of roTKA including studies reporting improved accuracy in implant positioning and limb alignment, better short-term clinical outcomes, and increased patient-reported outcome measures (PROMs) with respect to the conventional manual technique [5-11]. While TKA is considered one of the most cost-effective surgeries in orthopedics, the cost to Blue Cross Blue Shield members was over $25 billion in 2017 alone [12]. With the technological emergence of roTKA, there is a need to better understand the costs associated with roTKAs to conventional manual TKAs (cTKAs).

In the United States, growth in health-care spending has outpaced growth in population, inflation, and the gross domestic product (GDP) [13]. In 2019, health-care spending represented 17.7% of the GDP for a total of $3.8 trillion, which equates to $11,582 per person [14]. This trend has caused the country to move toward value-based health care (VBHC), central to which is time-driven

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activity-based costing (TDABC). VBHC is defined as health outcomes achieved per dollar spent, and TDABC has been presented as a solution to the current cost crisis in health care [15-17]. It is a modern, bottom-up cost-accounting strategy that examines the costs of resources expended by the patient. It consists of 2 eponymous components: (1) the activity performed and (2) the time required to perform said activity [18]. Therefore, it is able to calculate the cost of resources a patient consumes as they move along a care process. This differs from traditional hospital cost accounting, which uses a top-down, bird's eye view approach that is less personalized and may be less accurate than TDABC, which is emerging as the gold-standard for arthroplasty cost-determination [18-21].

Owing to the increased utilization of roTKA over the last decade, previous studies have looked into the costs of roTKA using 90-day institutional or claims data [22-25]; however, costs between roTKA and cTKA have yet to be compared using granular patient-level data afforded by the cost-accounting methodology of TDABC. As repayment programs continue to promote VBHC, institutions must strive to more accurately understand the true costs of a procedure to appreciate the value it delivers. Therefore, the aim of this study was to determine and compare the TDABC hospital costs associated with roTKA to cTKA. Our hypothesis is that roTKA will be more expensive than cTKA.

Methods

Study design

After institutional review board approval (IRB) was obtained, we retrospectively identified prospectively-collected financial data at our single-specialty orthopedic institution for patients who underwent elective, primary, unilateral TKA procedures (both roTKA and cTKA) during the study period of July 2020 through March 2021. During this time, the robotic technology (Mako, Stryker, Kalamazoo, MI) was fully available for our 24 surgeons. Total in-hospital costs were identified for all cases, composed of personnel and supply costs including implants. Demographic factors including age, sex, body mass index (BMI), American Society of Anesthesiologists (ASA) classification, operating room (OR) time (defined as wheels in to wheels out), length of stay (LOS), and discharge disposition were also collected and compared. Episode-of-care (EOC) for this study was defined as the patient stay consisting of check in day of surgery to point of discharge. Fiscal data are presented as indexed values to protect hospital proprietary financial information.

Time-driven activity-based costing

EOC costs were determined with the use of a third-party, commercial medical cost-analysis database, Avant-garde Health (Boston, MA). Time-driven activity-based costing (TDABC) was used to determine granular patient costs, representing a modern, value-based cost accounting method created by Kaplan and Anderson [26]. TDABC has become the gold-standard for cost-determination studies, validated extensively in the orthopedic literature including knee, hip, shoulder, elbow, and ankle arthroplasty [18,20,26-30]. The EOC costs were calculated by taking the cost per minute of each personnel involved in the patient care process and multiplying it by the time spent caring for the patient and summing these values with the total supply costs including implants, medications, and consumables (inclusive of roTKA-specific consumables such as pins, drapes and arrays). Personnel costs were calculated for the OR, postanesthesia care unit (PACU), and inpatient stages of care. Process maps were used to determine TDABC for all cases included in the study. Fixed costs were regarded as constants, and indirect costs (eg, administrative) were excluded from the study.

Statistical analysis

Chi-squared and Student's t-tests were used to compare categorical and continuous data, respectively. To ensure hospital financial confidentiality, roTKA costs were indexed to cTKA costs. Statistical analyses were performed using SAS v9.4 (SAS Institute, Cary, NC). Significance was set at $P < .05$. No external funding was received for this work.

Results

Overall, 2058 TKAs were analyzed with 1795 cTKAs and 263 roTKAs (Table 1). Patients who underwent roTKA were less often female (49.8% vs 57.7%; $P = .016$) and had a lower BMI on average (30.7 vs 31.6; $P = .024$). OR time for roTKA was significantly longer by 13.7 minutes (144.6 minutes vs 130.9 minutes; $P < .0001$), but LOS was significantly shorter (1.8 days vs 2.4 days; $P < .0001$). Discharge disposition was significantly different between roTKA and cTKA, with more patients being discharged to home for roTKA than cTKA (98.5% vs 93.7%; $P = .017$). There were no significant differences between groups for age ($P = .85$) and ASA classification ($P = .18$).

Implant costs were not significantly different between roTKA and cTKA ($P = .076$; Table 2). Total supply costs were more expensive for roTKA by 1.18× ($P < .0001$). Excluding implants, supply costs were 2.17× more expensive for roTKA ($P < .0001$). Medication costs were similar between groups ($P = .79$). Total personnel costs were 1.05× more expensive for roTKA than for cTKA ($P = .0001$). While PACU and inpatient personnel costs were cheaper for roTKA (0.98×; $P = .018$ and .84×; $P < .0001$, respectively), OR personnel costs were 1.12× more expensive for roTKA ($P < .0001$). Overall EOC hospital costs for roTKA were 1.10x more expensive than cTKA ($P < .0001$). If all our cases were performed robotically (roughly 4000 annually), the extra costs would be equivalent to an additional 370 cTKA procedures.

Discussion

While robotic technology has been used in the field of orthopedic surgery for over 20 years [3], contemporary innovations and improvements in roTKA have received considerable attention from surgeons, payers, and hospitals. As overall health spending continues to rise, financial outcomes for the major Centers of Medicare

Table 1
Patient demographics.

Variable	cTKA (n = 1795)	roTKA (n = 263)	*P* value
Age[a]	67.9 (8.3)	68 (7.1)	.85
Female [b]	1036 (57.7%)	131 (49.8%)	.016
BMI[a]	31.6 (6.4)	30.7 (6)	.024
ASA[a]	2.4 (0.5)	2.3 (0.5)	.18
OR time (minutes)[a]	130.9 (22.5)	144.6 (16.8)	<.0001
Length of stay[a]	2.1 (1.1)	1.8 (0.8)	<.0001
Discharge disposition[b]			.017
Home	1681 (93.7%)	259 (98.5%)	
Inpatient rehab	11 (0.6%)	1 (0.4%)	
SNF	103 (5.7%)	3 (1.1%)	

ASA, American Society of Anesthesiologists classification; BMI, body mass index; cTKA, conventional total knee arthroplasty; OR, operating room; roTKA, robotic-assisted total knee arthroplasty; Rehab, rehabilitation; SNF, skilled nursing facility. Standard deviation or percentage is listed to the right in parentheses for values.

[a] *t*-Test was used.

[b] Chi-square test was used.

Table 2
Time-driven activity-based costs.

Cost category	cTKA (n = 1795)	roTKA (n = 263)	*P* value
Implant	—	1.03×	.076
Supply excluding implant	—	2.17×	<.0001
Supply (medications)	—	0.95×	.79
Supply cost total	—	1.18×	<.0001
Personnel PACU	—	0.98×	.018
Personnel inpatient	—	0.84×	<.0001
Personnel OR	—	1.12×	<.0001
Personnel cost total	—	1.05×	.0001
Total hospital cost	—	1.10×	<.0001

cTKA, conventional total knee arthroplasty; OR, operating room; PACU, post-anesthesia care unit; roTKA, robotic-assisted total knee arthroplasty.

& Medicaid Services (CMS) expense category for TKA is becoming increasingly scrutinized. Consequently, reimbursements for all TKAs have been decreasing, and new, lavish technologies may face resistance among institutions endeavoring to be financially solvent. As a result, previous studies have focused on the potential value roTKA may represent, describing favorable short-term patient outcomes and economical 90-day EOC costs when compared to cTKA [22,24,31]. The aim of the present study was to determine granular patient-level TDABC data for hospital EOC costs for roTKA and compare it to the corresponding cTKA costs at the same institution. Our results showed that overall hospital costs for roTKA were 10% more expensive than cTKA, due to increased OR personnel and supplies.

There have been several prior studies reporting on the costs of roTKA compared to cTKA, principally focused on 90-day global periods for the index TKA procedure. Using the 100% Medicare Standard Analytical Files (SAF), Cool et al. reported lower 90-day EOC costs for roTKA through decreased LOS and readmission rates [22]. Similarly, using the 100% Medicare SAF, Mont et al. reported lower 30-, 60-, and 90-day costs for roTKA through decreased postoperative health-care utilization (eg, inpatient rehabilitation, home health visits, emergency room services, and readmissions) [23]. Using a commercial payer database comprised of younger patients (OptumInsight Inc), Pierce et al. demonstrated lower 90-day EOC costs associated with roTKA through similar means reported by Mont et al. [24]. Using an institutional database from one surgeon with financial data sourced from hospital billing records and rehabilitation facility estimations, Cotter et al. reported lower 90-day EOC costs for roTKA [32]. Using a subset of their cohort with Medicare claims data, Grosso et al. showed no difference for inpatient and 90-day EOC costs between roTKA and cTKA [25]. The general consensus from these studies is that the high index procedure costs are offset by the greater savings in the postoperative period through decreased LOS and postoperative health-care utilization. Our findings are consistent with these previous findings in that the hospital index procedure costs were more expensive, and LOS was reduced with increased home discharge.

Due in part to increasing pressures to implement cost-saving initiatives and COVID-19 safety recommendations, there has been an accelerated advancement of outpatient/short-stay care for arthroplasty procedures. At our institution, this has resulted in an overall decrease in our patient LOS over time for all patients in our arthroplasty service line and a reduced disparity in LOS between roTKA and cTKA (1.8 vs 2.1 days). When compared to prior studies, this difference of a third of a day is lower than the reported nearly full-day difference [22,24]. The higher LOS for cTKA is most likely influenced by discharge to rehab facilities requiring at least 2 nights in the hospital. The authors believe this trend in shorter-stay care will persist and result in a continued decreased LOS for TKA, further decreasing the gap between roTKA and cTKA LOS. We also found a 4.8% difference in patients being discharged to home for roTKA vs cTKA. This disparity too may be decreasing in the near future as patient education and physician advocation for home discharge improves [33,34]. For total time spent in the OR, we found a roughly 14-minute difference between roTKA and cTKA. We believe this may be due to the ancillary components (eg, haptic feedback and constraints for soft-tissue protection) of the robotic-assisted process and less influenced by the surgeon learning curve, as time neutrality has been shown to occur after as little as 7 cases for high-volume surgeons [35,36]. Implant costs, which have been identified as a major cost driver in arthroplasty [28,37], were similar between roTKA and TKA. Total supply costs for roTKA were more expensive, likely due to the robot-specific consumables used in the OR. These additional costs are significant, and various strategies may emerge from providing institutions as a result. One idea may be to pass the cost onto the patient. If they felt strongly about roTKA over cTKA, they may be interested in the cost-sharing approach to maintain roTKA as a financially viable option. roTKA personnel costs were decreased for the PACU and inpatient stay, but the OR personnel costs augmented by the increased OR time outweighed these cost-savings. All these cost determinants resulted in a 10% increase in EOC cost for roTKA. These costs can also be seen in light of the marketing potential from patients seeking robotic technology, for which the theoretical increased surgical volume could help offset some of these extra costs.

Owing to the elusory nature of financial data in medicine, many of the previously mentioned roTKA studies relied on proxies for cost data. Common for big database commercial claims data, costs are measured and reported by proxy of charged amounts, representing what institutions bill to payers (often inflated to increase final reimbursement amount), and not the actual costs incurred by the facilities to provide the specified care. For 100% Medicare SAF data, costs were measured by proxy of the total payments made to Medicare providers, representing the reimbursements paid to hospitals (determined and funded by CMS) and not the actual costs incurred to provide the treatment. When using traditional accounting from hospital billing records, this method has been shown to conflate costs with indirect expenses not specific to patient care (eg, administrative overhead and hospital operating costs), which may misrepresent the true costs expended [18-20]. Contrarily, TDABC is a modern, value-based cost-accounting methodology born out of Harvard Business School to calculate the precise costs of health-care resources expended as each patient progresses through each stage of the care process [26]. TDABC has been validated in multiple studies as a benchmark for accurate cost-determination [18,20,26-30]. For TKA specifically, TDABC has been shown to be a more precise and accurate methodology than other traditional accounting strategies [18,19]. Through the robust cost-determining strategy of TDABC, our study demonstrated meticulous costing of roTKA indexed to cTKA and found roTKA to be a more costly procedure to perform for the hospital.

The strengths of this study include the relatively large sample size of 2058 procedures with 263 roTKAs in a relatively short time period at a single institution. To our knowledge, this is the first study to use the modern cost-accounting methodology of TDABC to uniformly compare the costs of robotic-assisted and conventional, manual TKA. Furthermore, our data come from 24 TKA-performing (both roTKA and cTKA) surgeons increasing the generalizability of our data. In addition, DeFrance et al. reported that nearly all studies (91%) comparing robotic-assisted arthroplasty involve financially conflicted authors that were more likely to report robotically-favorable results [38]. The current authors have no such financial conflict of interests related to the study and conceivably report less-biased results.

The present study contains several limitations, including those inherent to retrospective studies. Our institution is an orthopaedic-

only specialty hospital, which may limit the generalizability to academic or community institutions. The study period includes rapid changes to our arthroplasty service line due to COVID-19 regulations, including a novel emphasis on outpatient/short-stay procedures. However, these external constraints were consistent between roTKA and cTKA, which may limit confounding effects. Our study does not include the capital expenditure or maintenance of the physical asset, which may vary depending on the negotiated purchasing contract. At our institution, no capital outlay was required because of our earned out pricing structure—enabling us to avoid the immense upfront costs as capital is allocated across the case volume. Our study also does not include the cost of the preoperative computer-tomography (CT) scan or the robot-specific technician in the operating room, as the cost of the CT was outside the defined EOC and therefore excluded, and the robot-specific personnel cost is covered by the manufacturing company under contract. Furthermore, our study does not contain any postdischarge expenses, which certainly influences overall healthcare costs. These costs within the 90-day global period are particularly important when considering bundled repayment programs. However, postdischarge costs were outside the scope of our study. Our study does not capture any patient-reported outcome measures (PROMs) or functional scores to evaluate patient outcome data for these procedures. Comparing these outcomes to the dollars spent is essential for determining and comparing the value of this technology. Future research should focus on the long-term outcome comparisons of roTKA and cTKA. Despite the limitations of this study, we believe the results to be an important insight to robotic-assisted total knee arthroplasty costs and serve as a reference point for evaluating and targeting value-improving cost-containment strategies.

Conclusions

Robotic-assisted TKA is 10% more expensive than conventional TKA. The longer operative time with increased OR supply and personnel costs outweighed the cost-savings from a lower length of stay. Consumables specific to roTKA also contributed to higher costs and likely affect the overall margin of these procedures, which may limit the expansion of their utilization. Further studies are needed to evaluate the value (patient outcomes per dollars spent) of this modern technology.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

Ethical statement

IRB approval was obtained prior to research. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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