Original research

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

Christopher J. Fang, MD a, John C. Mazzocco, BS b, Daniel C. Sun, MD a, Jonathan M. Shaker, MS a, Carl T. Talmo, MD a, David A. Mattingly, MD a, Eric L. Smith, MD a, b

a Department of Orthopaedic Surgery, New England Baptist Hospital, Boston, MA, USA
b Department of Orthopaedic Surgery, University of Louisville, School of Medicine, Louisville, KY, USA

ARTICLE INFO

Article history:
Received 4 August 2021
Received in revised form 15 October 2021
Accepted 14 November 2021

Keywords:
Arthroplasty
TKA
Robotic
TDABC
Costs

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-fold greater for supplies excluding implant (P < .0001), 1.18-fold for total supplies (P < .0001), 1.12-fold for OR personnel (P < .0001), and 1.05-fold total personnel (P < .0001). Implant costs were similar (P = .076), but 0.98-fold cheaper for post-anesthesia care unit personnel (P = .018) and 0.84-fold for inpatient personnel (P < .0001). Overall hospital costs for roTKA were 1.10-fold 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.

© 2021 The Authors. Published by Elsevier Inc. on behalf of The American Association of Hip and Knee Surgeons. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

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
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 TKAs (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 institutional 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 times more expensive for roTKA (\( P < .0001 \)). Medication costs were similar between groups (\( P = .79 \)). Total personnel costs were 1.05 times more expensive for roTKA than cTKA (\( P = .0001 \)). While PACU and inpatient personnel costs were cheaper for roTKA (0.98 vs 1.0; \( P = .018 \) and .84 vs \( P < .0001 \)), respectively), OR personnel costs were 1.12 times more expensive for roTKA (\( P < .0001 \)). Overall EOC hospital costs for roTKA were 1.10 times 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** | 67.9 (8.3) | 68 (7.1) | .85 |
| **Female** | 1036 (57.7%) | 131 (49.8%) | .016 |
| **BMI** | 31.6 (6.4) | 30.7 (6) | .024 |
| **ASA** | 2.4 (0.5) | 2.3 (0.5) | .18 |
| **OR time (minutes)** | 130.9 (22.5) | 144.6 (16.8) | <.0001 |
| **Length of stay** | 2.1 (1.1) | 1.8 (0.8) | <.0001 |
| **Discharge disposition** | | | .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.

* t-Test was used.

* Chi-square test was used.
decreasing the gap between roTKA and cTKA LOS. We also found a persist and result in a continued decreased LOS for TKA, further in the hospital. The authors believe this trend in shorter-stay care will utilization. Our period through decreased LOS and postoperative health-care utilization. The general consensus from these studies is that the high index procedure costs were more expensive, and economical 90-day EOC costs when compared to cTKA 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 this 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 advocacy 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.

References

[1] Sloan M, Premkumar A, Sheth NP. Projected volume of primary total joint arthroplasty in the U.S., 2014 to 2030. J Bone Joint Surg Am 2018;100:1455.
[2] Kayani B, Haddad FS. Robotic total knee arthroplasty. Bone Joint Res 2019;8:478.
[3] Lang JE, Mannava S, Floyd AJ, et al. Robotic systems in orthopaedic surgery. J Bone Joint Surg Br 2011;93-B:1296.
[4] St Mart J-P, Goh EL. The current state of robotics in total knee arthroplasty. EFORT Open Rev 2021;6:270.
[5] Park SE, Lee CT. Comparison of robotic-assisted and conventional manual implantation of a primary total knee arthroplasty. J Arthroplasty 2007;22:1064.
[6] Bellemans J, Vandenneucker H, Vanlaeue J. Robotic-assisted total knee arthroplasty. Clin Orthop Relat Res 2007;464:111.
[7] Hampp E, Chughtai M, Scholl L, et al. Robotic-armed assisted total knee arthroplasty demonstrated greater accuracy and precision to plan compared with manual techniques. J Knee Surg 2019;32:239.
[8] Moon Y-W, Ha C, Do K-H, et al. Comparison of robot-assisted and conventional total knee arthroplasty: a controlled cadaver study using multiparametric quantitative three-dimensional CT assessment of alignment. Comput Aided Surg 2012;17:86.
[9] Sultana A, Samuel L, Khlopas A, et al. Robotic-assisted total knee arthroplasty more accurately restored the posterior condylar offset ratio and the Insall-Salvati index compared to the manual technique: a cohort-matched study. Surg Technol Int 2019;34:409.
[10] Song E-K, Seon J-K, Yim J-H, Netravali NA, Bargal WR. Robotic-assisted TKA reduces postoperative alignment outliers and improves gap balance compared to conventional TKA. Clin Orthop Relat Res 2013;471:118.
[11] Zhang J, Nduw NS, Ng N, et al. Robotic-assisted total knee arthroplasty is associated with improved accuracy and patient reported outcomes: a systematic review and meta-analysis. Knee Surg Sports Traumatol Arthrosc 2021. https://doi.org/10.1007/s00167-021-08464-4.
[12] Planned knee and hip replacement surgeries are on the rise in the U.S. Blue Cross Blue Shield; 2019. https://www.bcbs.com/the-health-of-america/planned-knee-and-hip-replacement-surgeries-are-the-rise-the-us.
[13] OECD. Organization for economic co-operation and development. Stat Health Status. 2017. http://stats.oecd.org/Index.aspx?DatasetCode=HEALTH_STAT. [Accessed 30 June 2021].
[14] CMS. Centers for Medicare & Medicaid Services. National health expenditures 2019 highlights. https://www.cms.gov/Research-Statistics-Data-and-System/Statistics-Trends-And-Reports/NationalHealthExpendData/NHE-Fact-Sheet. [Accessed 15 June 2020].
[15] Porter M. What is value in health care? N Engl J Med 2010;363:2477.
[16] Porter M, Lee T. The strategy that will fix health care. Harv Bus Rev 2013;91:24.
[17] Porter M, Teisberg M. Redefining health care: creating value-based competition on results. Health Aff (Millwood) 2007;26:1366.
[18] Palus JA, Brehmer TS, Pellegrini VD, Drew JM, Sachs BL. The cost of joint replacement. J Bone Joint Surg Am 2018;100:326.
[19] Akhavan S, Ward L, Bozik KJ. Time-driven activity-based costing more accurately reflects costs in arthroplasty surgery. Clin Orthop Relat Res 2016;474:8.
[20] Fang CJ, Sherk JF, The cost of joint replacement of knee arthroplasty. J Knee Surg 2020. https://doi.org/10.1055/s-0040-1718603.
[21] Andreasen SE, Holm HB, Jørgensen M, Gromov K, Kjærsgaard-Andersen P, Husted H. Time-driven activity-based cost of fast-track total hip and knee arthroplasty. J Arthroplasty 2017;32:1747.
[22] Cool CL, Jacobsf DJ, Seeger KA, Dodhi N, Mont MA. A 90-day episode of care cost analysis of robotic-assisted total knee arthroplasty. J Comp Eff Res 2019;8:327.
[23] Mont MA, Cool C, Gregory D, Coppolecchia A, Dodhi N, Jacobsf DJ. Health care utilization and payer cost analysis of robotic assisted total knee arthroplasty. J Knee Surg 2018;30:60, and 50 days. J Knee Surg 2021;34:328.
[24] Pierce J, Needham K, Adams C, Coppolecchia A, Lavernia C. Robotic arm-assisted knee surgery: an economic analysis. Am J Manag Care 2020;26:E205.
[25] Grosso MJ, Li WT, Hozack WJ, Sherman M, Parvizi J, Courtney PM. Short-term outcomes are comparable between robotic-arm assisted and traditional total knee arthroplasty. J Knee Surg 2020. doi:10.1055/s-0040-1718603.
[26] Online ahead of print.
[27] Kaplan RS, Anderson SR. Time-driven activity-based costing. Harv Bus Rev 2004;82:131.
[28] Carducci MP, Mahendararaj KA, Menendez ME, et al. Identifying surgeon and institutional drivers of cost in total shoulder arthroplasty: a multicenter study. J Shoulder Elbow Surg 2021;30:113.
[29] Carducci MP, Gasbarraro G, Menendez ME, et al. Variation in the cost of care for different types of joint arthroplasty. J Bone Joint Surg Am 2020;102:104.
[30] Menendez ME, Lawier SM, Shaker J, Bassoff NW, Warner JJ, Jawa A. Time-driven activity-based costing to identify patients incurring high inpatient cost for total shoulder arthroplasty. J Bone Joint Surg Am 2018;100:2050.
[31] Fang CJ, Shaker JM, Ward DM, Jawa A, Mattingly DA, Smith EL. Financial burden of revision hip and knee arthroplasty at an orthopedic specialty hospital: higher costs and unequal reimbursements. J Arthroplasty 2021;36:2680.
[32] Hamilton DA, Oponu UC, Nowak C, Chen C, Darwiche H. Differences in immediate postoperative outcomes between robotic-assisted TKA and conventional TKA. Arthroplast Today 2021;8:57.
[33] Cotter EJ, Wang J, Ilgen RL. Comparative cost analysis of robotic-assisted and jig-based primary total knee arthroplasty. J Knee Surg 2020. https://doi.org/10.1055/s-0040-1713895.
[34] Online ahead of print.
[35] Keswani A, Tasi MC, Fields A, Lovy AJ, Moucha CS, Bozik KJ. Discharge destination after total joint arthroplasty: an analysis of postdischarge outcomes, placement risk factors, and recent trends. J Arthroplasty 2016;31:1155.
Fang C, Lim SJ, Tybor DJ, Martin J, Pevear ME, Smith EL. Factors determining home versus rehabilitation discharge following primary total joint arthroplasty for patients who live alone. Geriatrics (Basel) 2020;5:7.

Sodhi N, Khlopas A, Piuzzi N, et al. The learning curve associated with robotic total knee arthroplasty. J Knee Surg 2018;31:17.

Kayani B, Konan S, Huq SS, Tahmassebi J, Haddad FS. Robotic-arm assisted total knee arthroplasty has a learning curve of seven cases for integration into the surgical workflow but no learning curve effect for accuracy of implant positioning. Knee Surg Sports Traumatol Arthrosoc 2019;27:1132.

Fang CJ, Shaker JM, Stoker GE, Jawa A, Mattingly DA, Smith EL. Reference pricing reduces total knee implant costs. J Arthroplasty 2021;36:1220.

DeFrance MJ, Yayac MF, Courtney PM, Squire MW. The impact of author financial conflicts on robotic-assisted joint arthroplasty research. J Arthroplasty 2021;36:1462.