Arthroplasty Today 11 (2021) 134–139

Contents lists available at ScienceDirect

Arthroplasty Today

journal homepage: http://www.arthroplastytoday.org/

Original research

Trends of Utilization and 90-Day Complication Rates for Computer-Assisted Navigation and Robotic Assistance for Total Knee Arthroplasty in the United States From 2010 to 2018

Ilya Bendich, MD, MBA *, Milan Kapadia, BS, Kyle Alpaugh, MD, Alioune Diane, BE, Jonathan Vigdorchik, MD, Geoffrey Westrich, MD

Adult Reconstruction and Joint Replacement. Hospital for Special Surgery. 535 East 70th Street, New York, NY 10021

ARTICLE INFO

Article history:
Received 18 June 2021
Received in revised form
8 August 2021
Accepted 12 August 2021
Available online xxx

Keywords:
Total knee arthroplasty
Computer navigation
Robotic-assistance
Technology-assisted arthroplasty
Utilization
Complications

ABSTRACT

Background: Computer-assisted navigation (CAN) and robotic assistance (RA) for total knee arthroplasty (TKA) are gaining in popularity. The purpose of this study is to update the literature on United States technology-assisted TKA trends of national utilization, regional utilization, and 90-day complication rates requiring readmission.

Methods: Patients who underwent primary, elective TKA between 2010 and 2018 were retrospectively identified in the PearlDiver All Payer Claims Database (PearlDiver Technologies Inc.). TKAs were classified as conventional, CAN, or RA based on International Classification of Diseases nineth or tenth revision and Current Procedural Technology codes. Annual rates and regional trends of each type of TKA were reported. Ninety-day complications requiring readmission for each group were captured. Multivariable logistic regression was used to identify odds ratios (OR) for all-cause readmission based on TKA modality.

Results: Of the 1,307,411 elective TKAs performed from 2010 to 2018, 92.8% were conventional, and 7.7% were technology-assisted (95.2% CAN and 4.9% RA). RA-TKA had the greatest increase in utilization (+2204%). The Western region had the highest utilization of technologies for TKA, while the Midwestern region had the lowest. Ninety-day postoperative complications requiring readmission were highest for conventional TKA and lowest for RA-TKA. RA-TKA (OR 0.68; 97.5% confidence interval 0.56-0.83, $P < .001$) and CAN-TKA (OR 0.93; 97.5% confidence interval 0.88-0.97, $P < .05$) had significantly lower odds of all-cause 90-day complications requiring readmission than conventional TKA.

Conclusion: Utilization of RA-TKA and CAN-TKA continues to rise across the United States. The use of these technologies is associated with a lower OR of readmission within 90 days postoperatively.

Introduction

Technology-assisted arthroplasty, which includes computer-assisted navigation (CAN) and robotic assistance (RA), has been available since the 1990s for total knee arthroplasty (TKA) [1,2]. Adoption of technology assistance for TKA has varied globally; over one-third of all arthroplasties performed in Australia use CAN, while fewer than one percent of arthroplasties performed in Sweden are technology-assisted [1].

In the United States, technology assistance for TKA has been on the rise, accounting for over 7 percent of all TKAs performed in 2014 [3]. Among American Association of Hip and Knee Surgeons attending the 2020 annual meeting, 77% of respondents indicated using technology in their surgical cases [4]. The most common reason cited for surgeons using technology-assisted arthroplasty was to increase precision [5].

Although both CAN and RA for TKA have demonstrated increased precision with component positioning and alignment, it is unclear if this translates into improved clinical outcomes [6,7]. Proponents of technology-assisted TKA cite improved early functional outcomes,

One or more of the authors of this paper have disclosed potential or pertinent conflicts of interest, which may include receipt of payment, either direct or indirect, institutional support, or association with an entity in the biomedical field which may be perceived to have potential conflict of interest with this work. For full disclosure statements refer to https://doi.org/10.1016/j.artd.2021.08.005.

* Corresponding author. 535 East 70th Street, New York, NY 10021. Tel.: 516-603-6561.

https://doi.org/10.1016/j.artd.2021.08.005

lower postoperative pain, and earlier discharge [8,9]. Critics of technology-assisted TKA cite increased operative time and cost without discernable long-term benefit [10]. Moreover, because technology-assisted TKA employs the use of pins for array placement, rare pin-site complications, such as fracture or infection, that otherwise would not be present in conventional TKA, may occur [11,12].

The primary objective of this study is to update the United States utilization trends of CAN and RA in TKA from 2010 to 2018. Prior studies have reported up to 2014 [3] or 2015 [13]. ICD-10 codes became available in 2015 [14], allowing for an update to the literature. An additional goal of this study is to compare 90-day readmission rates between conventional TKA (nontechnology assisted), CAN-TKA, and RA-TKA. Our hypothesis is that utilization of CAN and RA for TKA will rise every year throughout the United States and that there will be no difference in 90-day readmission among CAN-TKA, RA-TKA, or conventional TKA.

Material and methods

A retrospective study was performed using the PearlDiver All Payer Claims Database (PearlDiver Technologies Inc., Colorado Springs, CO). The database contains hospital and physician billing records in the form of Current Procedural Technology (CPT) and International Classification of Diseases (ICD) codes Ninth and Tenth Edition. Institutional review board approval was not needed because of deidentified patient reporting within the PearlDiver database.

Patients who underwent primary elective TKA were identified using ICD-9, ICD-10, and CPT codes (Appendix A). Patients undergoing primary TKA for nonelective reasons as outlined by the Medicare Total Hip (THA)/Total Knee (TKA) Complications [15], missing demographic data, and who had fewer than 90 days of claims records were excluded. In addition, patients undergoing unicompartmental knee arthroplasty (UKA) or revision TKA were excluded. Furthermore, any patients undergoing simultaneous bilateral TKA or staged bilateral TKA within 90 days were excluded. Patients were then separated into 3 groups: conventional TKA, CAN-TKA, and RA-TKA. These groups were defined based on ICD-9, ICD-10, and CPT codes. Comorbidities were calculated based on Agency for Healthcare Research and Quality (AHRQ) Elixhauser comorbidities [15] and Charleson Comorbidity Index [16]. Ninety-day complications requiring readmission were collected based on Medicare THA/TKA Complications Measures [17-19]. These included acute myocardial infarction, pulmonary embolism, sepsis, pneumonia, surgical site bleeding, mechanical complications, and periprosthetic fracture. All-cause complication requiring readmission at 90 days was also calculated.

Continuous variables were presented as means (standard deviation) and compared by independent samples Student's t test. Categorical variables were presented as frequencies and percentages and compared using the chi-square test or the Fisher exact test, when appropriate. Multivariate logistic regression was used to determine which patient characteristics and/or type of TKA modified risk of 90-day complication requiring readmission. Variables included in the logistic regression analysis are demographics, regionality, insurance type, and TKA modality used. Spearman's correlation and linear regression was used to identify annual trends among United States regions and type of TKA. All tests were 2-sided. Significance was defined as $P < .05$. Statistical analyses were performed using R 4.0.3 (R Foundation for Statistical Computing, Vienna, Austria; https://www.R-project.org/).

Between 2010 and 2018, 1,307,411 patients underwent primary, elective TKA procedures within the PearlDiver All Payer Claims Database. There were differences in baseline demographics between the conventional, CAN-TKA, and RA-TKA groups (Table 1). CAN-TKA had the lowest percentage of cases performed in the inpatient setting, while RA-TKA had the highest percentage (Table 1). RA-TKA had the shortest hospital length of stay (Table 1).

Results

Of all elective TKAs performed from 2010 to 2018, 92.8% were conventional, and 7.7% were technology-assisted. Among the technology-assisted cases, 4.9% of cases were RA, and 95.2% of cases were CAN (Fig. 1). From 2010 to 2018, the percentage of cases performed with technology assistance increased every year (Fig. 2). The use of CAN increased by 32% from 2010 to 2018, while the use of RA increased by 2204% over that same period. The largest year-over-year increase in RA-TKA utilization was between 2016 and 2017, during which there was nearly a three-fold increase. From 2017 to 2018, RA-TKA utilization increased over two-fold.

Utilization of technology assistance for TKA from 2010 to 2018 varied regionally, with the highest use in the West Coast and lowest in the Midwest (Fig. 3). All regions of the country had annual increases in the percentage of cases using technology assistance for TKA. From 2010 to 2018, the Midwest region had a 97.6% increased

Table 1
Patient demographics and characteristics.

Variable	Conventional TKA (n, Std Dev.)	Computer-assisted navigation TKA (n, Std Dev.)	*P*	Robotic TKA (n, Std Dev.)	*P*
	n = 1,213,038	n = 89,715		n = 4658	
Age (y)	65.8 ± 8.5	65.7 ± 8.5	[c]	65.2 ± 9.3	[b]
Sex (% female)	771,089 (63.6%)	56,640 (63.1%)	[c]	2715 (58.3%)	[c]
ECI	6.6 ± 3.8	6.5 ± 3.8	[c]	5.9 ± 3.6	[c]
CCI	1.2 ± 1.7	1.1 ± 1.7	[a]	0.7 ± 1.4	[c]
POC (% inpatient)	1,180,080 (97.3%)	87,235 (97.2%)	[a]	4618 (99.1%)	[c]
Length of stay (d)	2.9 ± 1.7	2.8 ± 2.7	[c]	2.1 ± 1.2	[c]
Payment (%)			[c]		[c]
Cash	1531 (0.1%)	106 (0.1%)		20 (0.4%)	
Commercial	743,931 (61.3%)	56132 (62.6%)		3040 (65.3%)	
Government	17,420 (1.4%)	1086 (1.2%)		71 (1.5%)	
Medicaid	31,754 (2.6%)	2612 (2.9%)		91 (2.0%)	
Medicare	408,580 (33.7%)	29161 (32.5%)		1413 (30.3%)	
Unknown	9822 (0.8%)	618 (0.7%)		23 (0.5%)	

CCI, Charles Comorbidity Index; ECI, Elixhauser Comorbidity Index; POC, Place of Care; TKA, total knee arthroplasty.
P values are for conventional TKA to computer-assisted navigation TKA or conventional TKA to robotic TKA.
[a] $P < .05$.
[b] $P < .001$.
[c] $P < .0001$.

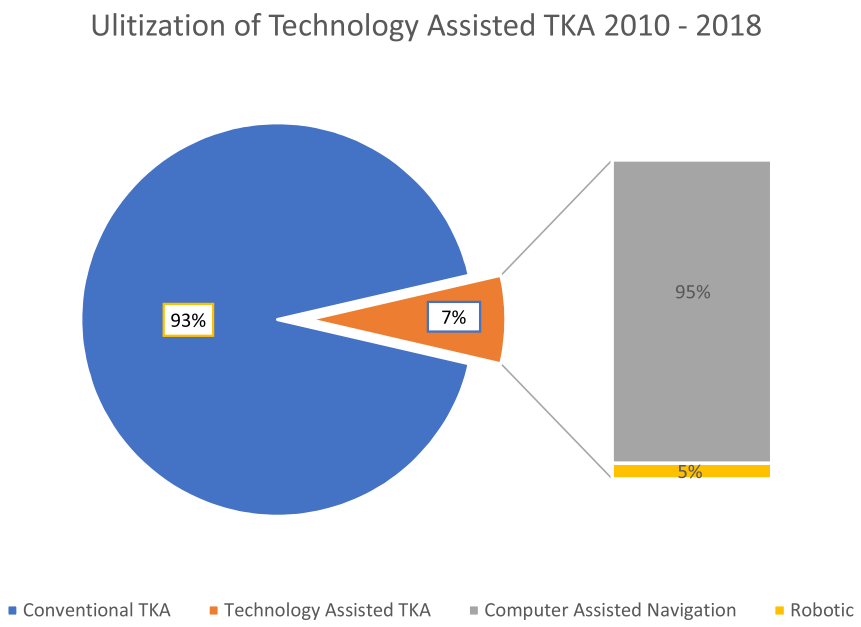

Figure 1. Utilization of conventional TKA, CAN-TKA, and RA-TKA modalities from 2010 to 2018.

utilization of technology assistance in TKA (74.0% increase in utilization of CAN and a 2432.4% increase in utilization of RA). From 2010 to 2018, the Southern region had a 49.4% increased utilization of technology assistance in TKA (25.3% increase in utilization of CAN and a 3601.5% increase in utilization of RA). From 2010 to 2018, the Northeast region had a 48.1% increase in utilization of technology assistance in TKA (23.5% increase in utilization of CAN and a 2488.8% increase in utilization of RA). From 2010 to 2018, the Western region had a 42.3% increased utilization of technology assistance in TKA (25.2% increase in utilization of CAN and an 874.8% increase in utilization of RA).

Ninety-day postoperative medical and surgical complications requiring readmission were highest for the conventional TKA group and lowest for the RA-TKA group (Table 2). The rate of all-cause readmission for conventional TKA was 0.27% and 0.98% higher than that for CAN-TKA and RA-TKA, respectively. The rates of 90-day all-cause readmissions were lowest for RA-TKA compared to conventional TKA at all time points of this study (Table 3). Rates of 90-day periprosthetic fracture and infection were similar between the groups. Based on multivariable logistic regression, RA-TKA (odds ratio [OR] 0.68; 97.5% confidence interval 0.56-0.83, $P < .001$) and CAN-TKA (OR 0.93; 97.5% confidence interval 0.88-0.97, $P < .05$) had

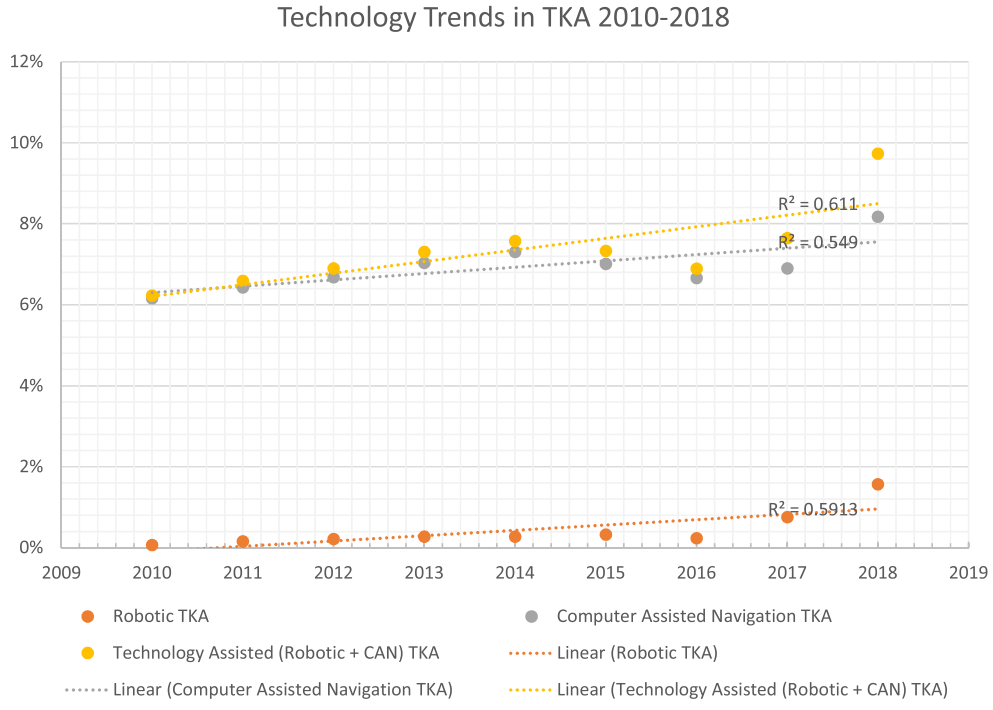

Figure 2. Trends over time of CAN-TKA and RA-TKA.

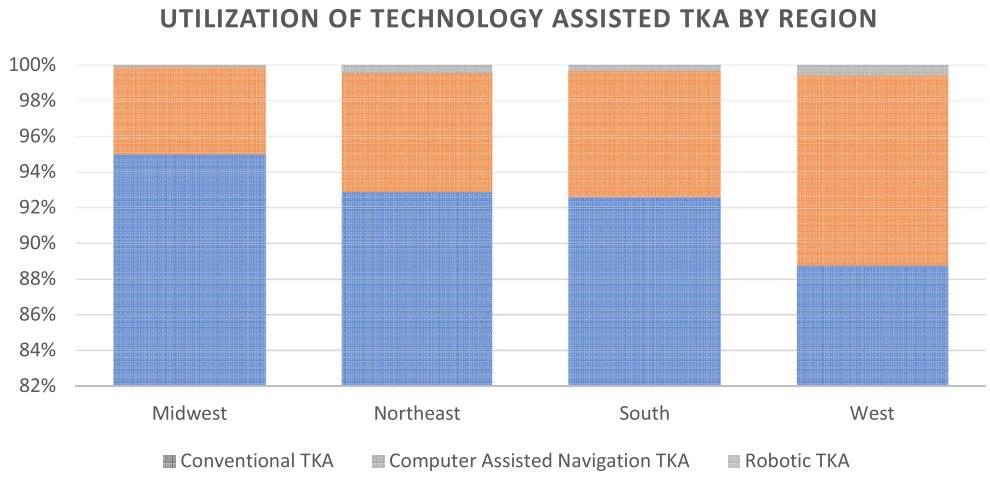

Figure 3. Technology-assisted total knee arthroplasty by region.

significantly lower odds of all-cause 90-day complications requiring readmission than conventional TKA.

Discussion

The purpose of the present study was to compare utilization as well as 90-day complications requiring readmission of conventional TKA, CAN-TKA, and RA-TKA using a large database of over 1,300,000 TKAs. There were several seminal findings. First, utilization of technology assistance for TKA has increased from 2010 to 2018, with a greater percentage increase of RA-TKA than CAN-TKA. Second, there were annual increases in technology utilization for TKA in every region of the United States, with the highest utilization in the West. Third, 90-day complication rates requiring readmission were lower in RA-TKA and CAN-TKA than those in conventional TKA.

Utilization of technology-assisted TKA in the United States increased from 2010 to 2018. RA-TKA outpaced CAN-TKA, with a large increase in RA-TKA utilization between 2016 and 2017. This may be partially due to the 2017 introduction of a robotic arm–assisted haptic feedback platform. Boylan et al. [13], using a statewide database of 188,050 knee arthroplasties, found an increase in utilization of CAN and RA for knee arthroplasty from 2.8% in 2008 to 8.6% in 2015. Similarly, Antonios et al. [3], using the Nationwide Inpatient Sample database, found an increase in CAN and RA utilization across the United States from 1.2% in 2005 to 7.0% in 2014. Our results are in line with these prior studies and indicate the rise of technology assistance has continued, with 9.7% of all TKAs performed in 2018 in the United States using either CAN or RA. Moreover, compared to the prior literature [13], which was unable to differentiate UKA from TKA, our data set allowed us to isolate TKA cases only.

While technology utilization is increasing across the United States, there are regional differences in adoption of technology. The Western region of the United States has the highest utilization of technology assistance for TKA (13.4% in 2018; 2.0% RA, 11.4% CAN), while the Midwestern region of the United States has the lowest utilization (7.1% in 2018; 1.0% RA, 6.1% CAN). Despite having the lowest utilization of technology assistance in 2018, the Midwestern region of the United States has the highest growth of CAN from 2010 to 2018 of 74% and an increase in RA utilization of over 2432%. Moreover, our results indicate that growth of RA is outpacing growth of CAN for TKA across the United States. Increases in regional growth from 2010 to 2018 for CAN have ranged from 25.2% (Western region) to 74.0% (Midwestern region), while over that same time period, RA has seen growth ranging from 874.8% (Western region) to 3601.5% (Southern region). Similar to our results, prior studies have also shown the Western region of the United States to have highest utilization of technology-assisted arthroplasty [3,20]. However, our results suggest technology assistance for TKA is growing more rapidly in other regions and

Table 2
Complications by method of TKA.

Complication	Conventional TKA (%)	Computer-assisted navigation TKA (%)	Robotic TKA (%)
	(n = 30, 900)	(n = 2077)	(n = 73)
AMI	0.17	0.15	0.24[a]
Mechanical	0.61	0.70[b]	0.45
PE	0.89	0.76[c]	0.49[a]
PNA	0.54	0.45[b]	0.26[a]
Sepsis	0.17	0.14	0.24
SSB/wound dehiscence	0.00	0.01[c]	0.00
Infection	0.34	0.27[b]	0.30
Periprosthetic fracture	0.05	0.07	0.06
All	2.55	2.32[c]	1.57[c]

AMI, acute myocardial infarction; PE, pulmonary embolism; PNA, pneumonia; SSB, surgical site bleeding; TKA, total knee arthroplasty.
P values are for conventional TKA to computer-assisted navigation TKA or conventional TKA to robotic TKA.
[a] $P < .05$.
[b] $P < .001$.
[c] $P < .0001$.

Table 3
Trends in all-cause readmissions from 2010 to 2018.

Year	Conventional TKA (%)	Computer-assisted navigation TKA (%)	Robotic TKA (%)
	(n = 30,900)	(n = 2077)	(n = 73)
2010	2.73	2.47	1.72
2011	2.63	2.42	0.80
2012	2.52	2.12	0
2013	2.53	2.22	1.35
2014	2.54	2.38	2.03
2015	2.57	2.81	1.21
2016	2.59	2.30	1.72
2017	2.40	2.12	1.72
2018	2.21	1.71	2.05
All	2.55	2.32	1.57

may soon catch up to that of the Western region of the United States. Moreover, given an approximately 8% increase in technology assistance utilization by American Association of Hip and Knee Surgeons members at the 2020 annual meeting compared to that of the 2018 meeting, we believe utilization of technology for TKA will continue to grow [4].

Although utilization of technology assistance for TKA introduces additional steps to TKA surgery and may pose increased theoretical risk to the patient, our study found a lower rate of 90-day readmission for patients undergoing technology-assisted TKA than for those undergoing conventional TKA. Prior authors [21] report a periprosthetic fracture rate up to 4.8% in technology-assisted TKA, with the mean time of fracture being 9.5 weeks postoperatively. In this study, we did not find a difference in periprosthetic fracture rates among conventional TKA, CAN-TKA, or RA-TKA up to 90 days. Furthermore, although technology-assisted TKA increased operative time, there was no evidence that infection rates were increased [22]. The results of our study also did not show a difference in prosthetic joint infection among conventional TKA, CAN-TKA, or RA-TKA up to 90 days. Unlike other studies in the literature [23], the present study did, however, find lower rates of 90-day complications requiring readmission for technology-assisted TKA than for conventional TKA. Our results are similar to that of Ofa et al. [24], who found lower rates of systemic complications and revisions up to 90 days after discharge among robotic TKAs than among conventional TKAs in an administrative database from 2010 to 2017. In our data set, the rate of all-cause readmission within 90 days postoperatively was 0.98% lower for RA-TKA than that for conventional TKA. These data imply that for every 102 patients treated with RA-TKA over conventional TKA, one readmission may be avoided. Based on these data, for RA-TKA to be cost-effective, the added cost of the technology for those 102 cases would have to be lower than the cost of a single readmission.

There are several strengths to this study. First, it includes over 1,300,000 TKAs. Then, our data set allowed for granularity of knee arthroplasty to select specifically for TKA and exclude UKA. Finally, this data set allowed for longitudinal analysis of 90-day complications. There are also a number of limitations to this study. First, it is a database study and, therefore, relies on accurate coding. Then, the complications included were ones that required readmission. It is possible that overall complications including ones that were managed in the outpatient setting may have a different pattern than what was found in this study. Furthermore, given the retrospective nature of this database study, there is always the risk of selection bias. Finally, the long-term benefits of CAN or RA for TKA are not established [25] and were not analyzed in this study.

Conclusion

Utilization of CAN-TKA and RA-TKA are both on the rise across the United States. The use of these technologies is associated with a lower OR of readmission within 90 days postoperatively.

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.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: J.V. is a paid consultant for Stryker, DePuy, Corin, and Medacta; has stock or stock options in Intellijoint and Corin; receives research support from Corin; and is in the BJJ Editorial Board and AAHKS Program Committee. G.W. received royalties from Stryker and Exactech; is in the speakers' bureau of or gave paid presentation for and is a paid consultant for Stryker, Exactech, and Ethicon; received research support from Stryker and Exactech; is a board member in Eastern Orthopedic Association and Knee Society.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.artd.2021.08.005.

References

[1] Hazratwala K, Brereton SG, Grant A, Dlaska CE. Computer-assisted technologies in arthroplasty: Navigating Your Way Today. JBJS Rev 2020;8(3):e0157.
[2] Jacofsky DJ, Allen M. Robotics in arthroplasty: a comprehensive review. J Arthroplasty 2016;31(10):2353.
[3] Antonios JK, Korber S, Sivasundaram L, et al. Trends in computer navigation and robotic assistance for total knee arthroplasty in the United States: an analysis of patient and hospital factors. Arthroplasty Today 2019;5(1):88.
[4] Abdel MP, Meneghini RM, Berry DJ. Current Practice trends in primary hip and knee arthroplasties among members of the American association of hip and knee surgeons: an update during the COVID-19 Pandemic. J Arthroplasty 2021;34(7):S24–7.
[5] Sherman WF, Wu VJ. Robotic surgery in total joint arthroplasty: a Survey of the AAHKS membership to Understand the utilization, Motivations, and Perceptions of total joint surgeons. J Arthroplasty 2020;35(12):3474.
[6] Sousa PL, Sculco PK, Mayman DJ, Jerabek SA, Ast MP, Chalmers BP. Robots in the operating room during hip and knee arthroplasty. Curr Rev Musculoskelet Med 2020;13(3):309.
[7] Harvie P, Sloan K, Beaver RJ. Computer navigation vs conventional total knee arthroplasty: five-year functional results of a prospective randomized trial. J Arthroplasty 2012;27(5):667.
[8] Kayani B, Konan S, Tahmassebi J, Pietrzak J, Haddad F. Robotic-arm assisted total knee arthroplasty is associated with improved early functional recovery and reduced time to hospital discharge compared with conventional jig-based total knee arthroplasty: a prospective cohort study. Bone Joint J 2018;100(7):930.
[9] Malkan AL, Roche MW, Kolisek FR, et al. Manipulation under Anesthesia rates in technology-assisted versus conventional-Instrumentation total knee arthroplasty. Surg Technol Int 2019;36:336.
[10] Kim Y-H, Yoon S-H, Park J-W. Does robotic-assisted TKA result in better outcome scores or long-term survivorship than conventional TKA? A randomized, controlled trial. Clin Orthopaedics Relat Res 2020;478(2):266.
[11] Kamara E, Berliner ZP, Hepinstall MS, Cooper HJ. Pin site complications associated with computer-assisted navigation in hip and knee arthroplasty. J Arthroplasty 2017;32(9):2842.
[12] Li C-H, Chen T-H, Su Y-P, Shao P-C, Lee K-S, Chen W-M. Periprosthetic femoral supracondylar fracture after total knee arthroplasty with navigation system. J Arthroplasty 2008;23(2):304.
[13] Boylan M, Suchman K, Vigdorchik J, Slover J, Bosco J. Technology-assisted hip and knee arthroplasties: an analysis of utilization trends. J Arthroplasty 2018;33(4):1019.
[14] Hirsch JA, Nicola G, McGinty G, et al. ICD-10: History and Context. Am J Neuroradiology 2016;37(4):596.
[15] Moore BJ, White S, Washington R, Coenen N, Elixhauser A. Identifying increased risk of readmission and in-hospital mortality using hospital administrative data. Med Care 2017;55(7):698.
[16] Quan H, Li B, Couris CM, et al. Updating and validating the Charlson comorbidity index and score for risk adjustment in hospital discharge abstracts using data from 6 countries. Am J Epidemiol 2011;173(6):676.
[17] Bozic KJ, Grosso LM, Lin Z, et al. Variation in hospital-level risk-standardized complication rates following elective primary total hip and knee arthroplasty. JBJS 2014;96(8):640.
[18] Grosso LM, Curtis JP, Lin Z, et al. Hospital-level 30-day all-cause risk-standardized readmission rate following elective primary total hip arthroplasty (THA) and/or total knee arthroplasty (TKA). Yale New Haven Health Serv Corporation/Center Outcomes Res Eval 2012.
[19] Simoes J, Grady J, Purvis D. Measure updates and specifications report: hospital-level risk-standardized payment measures–acute myocardial infarction–version 7.0, heart failure–version 5.0, pneumonia–version 5.0, elective primary total hip arthroplasty (THA), and/or total knee arthroplasty (TKA)–version 4.0. 2018. Heart Failure 2018.
[20] Hsiue PP, Chen CJ, Villalpando C, Ponzio D, Khoshbin A, Stavrakis AI. Trends and patient factors associated with technology-assisted total hip arthroplasty in the United States from 2005 to 2014. Arthroplasty Today 2020;6(1):112.
[21] Smith TJ, Siddiqi A, Forte SA, et al. Periprosthetic fractures through Tracking pin sites following computer navigated and robotic total and unicompartmental knee arthroplasty: a systematic review. JBJS Rev 2021;9(1):e20.

[22] Onggo JR, Onggo JD, De Steiger R, Hau R. Robotic-assisted total knee arthroplasty is comparable to conventional total knee arthroplasty: a meta-analysis and systematic review. Arch Orthopaedic Trauma Surg 2020;140(10):1533.
[23] 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.
[24] Ofa SA, Ross BJ, Flick TR, Patel AH, Sherman WF. Robotic total knee arthroplasty vs conventional total knee arthroplasty: a Nationwide database study. Arthroplasty Today 2020;6(4):1001.
[25] Antonios JK, Kang HP, Robertson D, Oakes DA, Lieberman JR, Heckmann ND. Population-based survivorship of computer-navigated versus conventional total knee arthroplasty. J Am Acad Orthopaedic Surgeons 2020;28(20):857.