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Original research

Impact of Robotic Assisted Surgery on Outcomes in Total Hip Arthroplasty

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A B S T R A C T

Background: The introduction of robotic technologies into the field of arthroplasty ushered in promises of increased precision and superior outcomes over conventional methods. However, the effect on outcomes in total hip arthroplasty (THA) remains debatable, particularly when considering the additional financial burden created by the addition of robotics. The purpose of this study is to examine total cost of care, length of stay (LOS), and postoperative complications in robotic-assisted vs conventional THA recipients.

Materials and methods: A retrospective review of the Mariner database was performed within PearlDiver Technologies for patients undergoing THA from 2010 to 2018 (n = 714,859). Patients with robotic-assisted procedures were matched with patients undergoing conventional THA at a 1:1 ratio based on age, sex, Charlson Comorbidity Index, smoking, and obesity status (n = 4630). LOS, total cost of care, readmission rates, and medical and surgical outcomes were examined.

Results: Robotic-assisted patients had shorter average LOS (3.4 vs 3.7 days, $P = .001$). The mean cost for robotic-assisted patients was $1684 and $1759 less at 90 days and 1 year, respectively (both $P = .001$). Readmission rates were higher for robotic-assisted patients at 1 year (7.8 vs 6.6%; $P = .001$), while surgical outcomes were not significantly different at all timepoints (all $P > .498$). Robotic-assisted patients demonstrated significantly higher blood transfusion rates (4.4 vs 3.2%; $P = .001$).

Conclusions: Robotic-assisted THA was associated with minimal decreases in LOS and costs as compared to conventional methods. However, robotics was associated with slightly higher readmissions and blood transfusions.

Introduction

Total hip arthroplasty (THA) remains as one of the most successful surgeries. The demand for THA is growing rapidly because of its cost-effectiveness and excellent results [1]. A recent shift toward outpatient procedure is an attempt to drive down hospital costs with the goal of delivering cost-effective THA without sacrificing quality [2,3]. The emergence of robotic-assisted surgery addresses this concern, with proponents citing improved component positioning and alignment [4–6]. Instability after THA is a common cause of revision surgery with acetabular component and stem malposition as major contributors. Despite reported success using robotic-assisted arthroplasty, dislocations persist. Recent literature obfuscates these findings, and further investigation is warranted to delineate the presence of any true difference between robotic and conventional THA outcomes.

Advancements in implant alignment should, in theory, lead to more natural biomechanics after THA with subsequent improvements in function and survivorship. Historically, literature examining robotic-assisted surgery has focused on improvements in pin placement and navigation-based bone cutting precision [7,8]. Current reports highlight superior clinical and functional results as compared to conventional THA [4,9]. Bohl et al. [9] found decreased dislocation and revision incidence among computer-assisted navigation. In contrast, multiple recent reports cite continued complications among robotic-assisted THA, leaving much room for its role in this new age of surgical advancement [10,11]. Moreover, the cost implications of robotic-assisted THA have not been thoroughly compared with those of conventional surgery in this

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age of increased outpatient procedures. A cost examination may provide a framework for comparative analysis between the 2 modalities.

The purpose of this study is to examine robotic-assisted vs conventional arthroplasty using a national database. Specifically, we ask: (1) Does robotic-assisted arthroplasty incur lower total costs of care, (2) lower length of stay (LOS), and (3) lower 90-day medical and up to 5-year surgical complications compared to conventional arthroplasty?

Materials and methods

Data source

A retrospective review of the Mariner database was performed with the PearlDiver supercomputer (PearlDiver Technologies, Fort Wayne, IN). This remote access, publicly available, all-payer database includes records from approximately 122 million patients spanning from 2010 to Q2 2018. This is one of the largest nationwide databases that tracks many patients in longitudinal fashion, mitigating risks of potential type II errors. These patients are derived from a number of payers (commercial, Medicare, Medicaid, Government, cash) throughout the United States and are identifiable through several fields, namely International Classification of Diseases Ninth Edition (ICD-9), ICD Tenth Edition (ICD-10), Current Procedural Technology (CPT) codes, and National Drug Code coding. As this database is deidentified and Health Insurance Portability and Accountability Act compliant, approval from the authors' local institutional board was not required.

Patient selection

The Mariner database was queried for patients undergoing THA procedures using codes from International Classification of Diseases (9th and 10th edition) and Current Procedural Terminology: ICD-9-P-8151, ICD-10-P-0SRB049, ICD-10-P-0SRB04Z, ICD-10-P-0SRB04A, ICD-10-P-0SRB039, ICD-10-P-0SRB03Z, ICD-10-P-0SRB03A, ICD-10-P-0SRB029, ICD-10-P-0SRB02Z, ICD-10-P-0SRB02A, ICD-10-P-0SRB019, ICD-10-P-0SRB01Z, ICD-10-P-0SRB01A, ICD-10-P-0SRB069, ICD-10-P-0SRB06Z, ICD-10-P-0SRB06A, ICD-10-P-0SRB0J9, ICD-10-P-0SRB0JZ, ICD-10-P-0SRB0JA, ICD-10-P-0SR9049, ICD-10-P-0SR904Z, ICD-10-P-0SR904A, ICD-10-P-0SR9039, ICD-10-P-0SR903Z, ICD-10-P-0SR903A, ICD-10-P-0SR9029, ICD-10-P-0SR902Z, ICD-10-P-0SR902A, ICD-10-P-0SR9019, ICD-10-P-0SR901Z, ICD-10-P-0SR901A, ICD-10-P-0SR9069, ICD-10-P-0SR906Z, ICD-10-P-0SR906A, ICD-10-P-0SR90J9, ICD-10-P-0SR90JZ, ICD-10-P-0SR90JA, and CPT-27,130 (n = 715,079). Thereafter, a separate cohort gathering all patients undergoing robotic-assisted surgeries was performed using the appropriate codes (ICD-10-P-8E0Y0CZ, ICD-9-P-1741, ICD-9-P-1749, CPT-S2900) (n = 6725). These 2 cohorts were then cross-referenced using the Boolean command "AND" function with the "SAME DATES FROM" time modifier, which only included patients possessing a code of the aforementioned list from both cohorts on the same day (n = 4641). These patients were then excluded from the original cohort by using the "NOT" function to avoid inadvertently comparing the same patients. This was followed then by using the propensity score match function, which compared robotic-assisted THA patients to patients undergoing conventional THA procedures at a 1:1 ratio based on age, sex, Charlson Comorbidity Index (CCI), smoking, and body mass index. After this process was performed, 2 cohorts of 4630 patients resulted.

Variables

General outcomes included index procedure hospital LOS; total cost of care at 90 days and 1 year; and readmission rates at 90 days and 1 year. Total cost of care was defined as the summative cost from hospital admission for specified procedure to either 90 days or 1 year after. This is the hospital cost reimbursed, not the charge billed to the payer. To date, the costs dictated by CPT code for surgical procedures are not inclusive of robotic-assisted modifiers or adjuncts. Surgical outcomes included revision surgery, aseptic loosening, dislocation, periprosthetic fracture, and prosthetic joint infection rates at 90 days, 1 year, and 5 years. Medical outcomes included various 90-day complication rates, including blood transfusions, cerebrovascular accidents, deep vein thromboses, myocardial infarctions, pulmonary emboli, and respiratory failures.

Patient demographics

Both cohorts had similar age (64 years), sex (female: 55.5%), body mass index (84.5% non-obese), CCI (0.8), rate of hypertension (76.5%), and rate of tobacco use (28.3%) ($P > .879$ for all) (Table 1).

Statistical analysis

Chi-square analyses were used when examining categorical variables, which were gender, obesity rates, tobacco use rates, and all complication rates. Student t-tests were used to compare continuous means, which included age, CCI, and LOS. All statistics were performed through the R software (Statistics Department of the University of Auckland) embedded within PearlDiver; significance was defined as $P < .05$.

Results

LOS, costs of care, readmission rates

Robotic-assisted patients demonstrated a shorter average LOS (3.4 vs 3.7 days; $P = .001$) (Table 2). Total costs of care were significantly different between groups, with robotic-assisted patients accruing lesser costs at 90 days ($13,892 vs $15,576; $P = .001$) and 1 year ($19,778 vs $21,537; $P = .001$). Readmission rates were similar at 90 days (2.9 vs 2.8%; $P = .806$); however, the readmission rates at 1 year were higher in the robotic-assisted THA cohort (7.8 vs 6.6%; $P = .001$).

Table 1
Demographics and baseline characteristics in robotic-assisted THA patients vs conventional THA patients.

N (%)	Robotic assisted THA patients (n = 4630)	Conventional THA patients (n = 4630)	P value
Age (SD)	64 (10.5)	64 (10.4)	.879
Sex			.999
Male	2062 (44.5)	2062 (44.5)	
Female	2568 (55.5)	2568 (55.5)	
Body Mass Index[a]			.999
Nonobese	1667 (84.5)	1667 (84.5)	
Obese	288 (14.6)	288 (14.6)	
Morbidly obese	[b] (0.5)	[b] (0.5)	
Charlson Comorbidity Index (SD)	0.8 (1.6)	0.8 (1.6)	.999
Hypertension	3543 (76.5)	3543 (76.5)	.999
Tobacco use	1309 (28.3)	1309 (28.3)	.999

SD, standard deviation.
[a] Cases not reporting obesity status were excluded (n = 2666).
[b] Data with <11 patients censored in accordance with PearlDiver confidentiality agreement.

Table 2
Outcomes in robotic-assisted THA patients vs conventional THA patients.

N (%)	Robotic assisted THA patients (n = 4630)	Conventional THA patients (n = 4630)	*P* value
Lengths of stay (SD)	3.4 (1.7)	3.7 (1.4)	**.001**
Cost of care[a]			
90 d	$13,892 ($15,454)	$15,576 ($16,633)	**.001**
1 y	$19,778 ($22,011)	$21,537 ($24,050)	**.001**
Readmissions rates			
90 d	133 (2.9)	129 (2.8)	.806
1 y	360 (7.8)	308 (6.6)	**.037**
Revision rates			
90 d	60 (1.3)	57 (1.2)	.852
1 y	91 (2.0)	93 (2.0)	.941
5 y	130 (2.8)	142 (3.1)	.498

SD, standard deviation.
Bold indicates statistical significance.
[a] Mean figure given with standard deviation in parentheses.

Surgical outcomes

Revision rates at all timepoints were found to be similar (all $P > .498$). Subgroup revision analysis results for aseptic loosening, dislocation, periprosthetic fracture, and prosthetic joint infection rates were also similar (all $P > .112$) (Table 3).

Medical outcomes

Ninety-day blood transfusion rates were significantly higher in the robotic-assisted group (4.4 vs 3.2%; $P = .001$). All other complication rates (cerebrovascular accidents, deep vein thromboses, pneumoniae, pulmonary emboli, and respiratory failures) were found to be similar (all $P > .158$).

Discussion

Current trends are seeing many orthopedic surgeons shifting care toward an outpatient model with the goal of delivering cost-effective treatment without sacrificing quality [3]. The recent emergence of robotic-assisted arthroplasty has attempted to achieve this goal, but superiority over conventional arthroplasty remains debatable. This study used a large, national database to investigate the role robotic-assisted THA has on surgical outcomes, length of hospital stays, revision rates, readmission, and total costs of care. We found robotic-assisted THA was associated with decreased LOS and costs. Despite higher 1-year readmissions among robotic-assisted surgeries, no difference in surgical outcome measures was found.

This study is not without limitations. This study was performed using a national database and is highly dependent on data retrieval accuracy as well as determination of granular variables such as costs of care and reporting of collections and not accounts billed. However, this possible limitation is mitigated by the routine performance of audits from external parties. Second, we must recognize the potential presence of selection bias that may occur when choosing patients for technology-assisted procedures. These patients tend to be younger, have fewer comorbidities, and are of

Table 3
Complications in robotic-assisted THA patients vs conventional THA patients.

N (%)	Robotic assisted THA patients (n = 4630)	Conventional THA patients (n = 4630)	*P* value
Surgical complication rates			
Aseptic loosening			
90 d	12 (0.3)	13 (0.3)	.999
1 y	34 (0.7)	39 (0.8)	.638
5 y	77 (1.7)	81 (1.8)	.810
Dislocations			
90 d	66 (1.4)	69 (1.5)	.862
1 y	83 (1.8)	90 (1.9)	.645
5 y	105 (2.3)	121 (2.6)	.312
Periprosthetic fractures			
90 d	80 (1.7)	70 (1.5)	.459
1 y	98 (2.1)	90 (1.9)	.606
5 y	127 (2.7)	122 (2.6)	.797
Prosthetic joint infections			
90 d	60 (1.3)	43 (0.9)	.113
1 y	67 (1.5)	54 (1.2)	.272
5 y	82 (1.8)	86 (1.9)	.815
Medical complications (90 d)			
Blood transfusions	204 (4.4)	147 (3.2)	**.001**
Cerebrovascular accidents	32 (0.7)	26 (0.6)	.510
Deep vein thromboses	74 (1.6)	67 (1.5)	.611
Pneumoniae	50 (1.1)	36 (0.8)	.159
Pulmonary emboli	50 (1.1)	36 (0.8)	.159
Respiratory failures	29 (0.6)	36 (0.8)	.455

Bold indicates statistical significance.

higher income brackets [9]. An attempt to mitigate this bias was made by propensity-score matching the collected sample with conventional THA patients. This database comprises over 122 million deidentified patient information and can therefore not account for surgeon or institution volume differences for robotic THA. However, the strengths of the study lie in its ability to track a large number of patients longitudinally over the course of several years, allowing for analysis of entire episodes of care. Irrespective of this studies' limitations, it provides a thorough analysis of the role robotic-assisted surgeries have on cost and outcomes at various timepoints.

Interestingly, our investigation demonstrated that robotic-assisted THA was associated with lower cost than conventional THA. The associated decreased LOS among the robotic-assisted cohort may have contributed to the overall cost differences, as seen in multiple related reports [12,13]. However, the LOS differences may not demonstrate a clinically significant difference in light of current THA hospital and discharge protocols. Possibly given the recent trends toward robotic-assisted procedures, literature examining cost differences as compared to conventional arthroplasty is limited. Aligning with our study results, Maldonado et al. [14] found robotic-assisted THA to be more cost-effective than conventional over 5 years, saving $945 and $1810 for Medicare and private insurance costs, respectively. In contrast, Kirchner et al. [15] examined 758 robotic-assisted THAs with 758 conventional THA patients, finding the former to incur an additional $1788 during the inpatient stay. Given the uncertainty in the cost-effectiveness of robotic-assisted surgery, an analysis using higher level of evidence may be warranted. In a recent survey given by American Academy of Hip and Knee Surgeons, [3] cost was among the primary deterrents in adopting robotic-assistance in total joint arthroplasty. Only 6.9% of members agreed that robotic-assisted surgeries were cost-effective. Similarly, few members cited decreased revision rates and surgical complications with robotic surgery as compared to conventional methods. Our study furthers the aforementioned survey by suggesting most postoperative complications do no differ between the 2 modalities.

In our study, surgical outcome measures of instability, aseptic loosening, periprosthetic fracture, and infection did not significantly differ at 90 days and 1 year between the 2 cohorts. These findings align with multiple recent reports. A retrospective report by Kamara et al. [16] examined radiographic and clinical outcomes among 3 types of THA: robotic, fluoroscopically guided, and manual. Complication incidence was found to be similar ($P = .54$), despite the robotic-assisted group demonstrating significantly lower variation in various radiographic parameters such as inclination and anteversion, in addition to having a significantly higher percentage of successful safe zone placement (all $P < .01$). In a systematic review, Chen et al. [17] concluded that robotic-assisted THA may be superior to conventional methods in terms of component positioning and rates of intraoperative complications. However, long-term postoperative complications could not be examined in the included studies. The utilization of robotics appears to consistently reproduce radiographic parameters in THA at a higher rate than its conventional counterparts, but this improvement may not result in superior surgical outcomes. Interestingly, our study found higher rates of blood transfusion among the robotic-assisted cohort. Limited studies assess transfusion requirements in robotic-assisted THA; however, Caldora et al. [18] found lower rates of blood transfusions in robotic-assisted vs conventional methods. Given the multiple factors that contribute to increased blood transfusion requirement such as operative time and patient-specific factors, further research may be warranted to associate robotic-assisted surgery and transfusion requirement.

Robotic-assisted surgery is associated with a slight decrease in LOS and costs as compared to conventional methods; however, no surgical complication differences were found. The prospect of robotics may be considered a cost-effective procedure, increasingly relevant as more orthopedic surgeons opt for outpatient procedures. However, a thorough cost-analysis is necessary to truly delineate cost benefits in THA.

Conflicts of interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Dr. Ronald Delanois is a board or committee member in the MD Baltimore City Medical Society and received research support from Flexion Therapeutics, Orthofix, Inc., Stryker, Tissue Gene, and United Orthopedics.

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