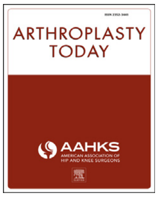
Arthroplasty Today 27 (2024) 101393

Contents lists available at ScienceDirect

Arthroplasty Today

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



Special Issue: Technological Advances in Arthroplasty. Edited by Stefano Bini, Peter L. Schilling, and Fabrizio Billi

Robot-Assisted Total Hip Arthroplasty Demonstrates Improved 90-Day Clinical and Patient-Reported Outcomes

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ARTICLE INFO

Article history:
Received 20 December 2023
Received in revised form
11 March 2024
Accepted 1 April 2024
Available online 11 May 2024

Keywords:
Total hip arthroplasty
Technology
Robot
Computer navigation
Outcomes
Patient-reported outcome measures

ABSTRACT

Background: The utilization of technology, including robotics and computer navigation, in total hip arthroplasty (THA) has been steadily increasing; however, conflicting data exists regarding its effect on short-term clinical and patient-reported outcomes. Therefore, this study sought to explore the association between different surgical technologies and postoperative outcomes following THA.

Methods: We retrospectively reviewed 9892 primary THA cases performed by 62 surgeons from a single institution from September 2017 to November 2022. Three cohorts were created based on the utilization of technology: conventional (no technology), navigation, or robotics. Patient demographics, clinical outcomes, and patient-reported outcome measures were collected over the first 90 days following surgery. This data was compared using analysis of variance and multivariate logistic regressions. In total, 4275 conventional, 4510 navigation, and 1107 robotic cases were included in our analyses.

Results: The robotic cohort achieved a perfect Activity Measure for Post-Acute Care (AM-PAC) score earliest (0.1 days, $P < .001$). After adjusting for potential confounding variables, use of robotic assistance was associated with greater odds of achieving a perfect AM-PAC score on postoperative day 0 (odds ratio 1.6, $P < .001$) and greater odds of having length of stay shorter than 24 hours (odds ratio 2.3, $P < .001$) compared to no technology use in THA. Hip dysfunction and Osteoarthritis Outcome Score, Joint Replacement and Patient-Reported Outcomes Measurement Information System Pain Interference scores showed the greatest improvement in the robotic cohort at both 6 weeks and 3 months following surgery.

Conclusions: The present study demonstrates favorable clinical and patient-reported outcomes in the first 90 days following surgery for patients undergoing robot-assisted THA compared to conventional and navigation-assisted THA.

Introduction

Total hip arthroplasty (THA) can reduce pain, restore function, and enhance the quality of life for patients suffering from a variety of degenerative, developmental, and traumatic hip joint disorders [1,2]. Nevertheless, the opportunity remains to reduce the already low incidence of mechanical complications related to bone preparation and component positioning, such as fixation failure, aseptic loosening, and instability [3]. Advancements in surgical techniques and technologies continue to transform the landscape of hip arthroplasty practices. While traditional manually-instrumented techniques often achieve excellent results, computer-assisted navigation and robotic assistance have been introduced to minimize failures and increase postoperative success.

Previous studies have described superior radiographic findings when intraoperative technology is utilized in THA [4–8]. Improved accuracy and precision of implant positioning have been postulated to contribute to enhanced long-term patient outcomes, reduced complications, and an overall improvement in the functional and radiographic success of THA [5]. However, the question remains whether observed improvements are indeed attributable to the use of technology or rather have occurred as a product of confounding factors such as improved surgeon practices, techniques, or hospital policies and procedures.

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https://doi.org/10.1016/j.artd.2024.101393

As surgical techniques are refined and perfected, there is an increasing demand for immediate and reliable solutions for advanced hip disease. Patients are becoming more adept at investigating their own diagnoses and anticipated outcomes, and both patients and surgeons seek to understand the elements of the THA procedure that contribute to improved outcomes during the initial recovery. Hospitals and payers are particularly focused on outcomes in the first 90 days, which are markedly impacted by both patient and surgical characteristics.

Currently, conflicting data exists regarding whether the use of intraoperative technology, in the form of computer-assisted navigation and robotic assistance in THA, does indeed provide improved short-term outcomes [9–11]. Sequential cohort studies of new surgical techniques can be influenced by confounding variables that demonstrate time-dependent improvements, such as surgical team and institutional processes. We sought to design a retrospective study that would minimize this bias by studying a large group of surgeons with nonuniform adoption of technology over the study period and by accounting for the year of surgery as a potential confounding variable. This allowed us to study the natural experiment of surgeon adoption and to control for improved institutional processes over the study duration as use of robotic and computer-navigated technology increased. We therefore reviewed our institutional database to examine the hypothesis that the use of specific intraoperative technologies during THA results in faster recovery and superior clinical and patient-reported 90-day outcomes when compared to traditional manually-instrumented techniques.

Material and methods

Study population

Following institutional review board approval, a retrospective cohort of 9892 patients was identified who underwent primary total hip arthroplasty (pTHA) at a large academic medical center from September 20, 2017—when the current system for electronic patient-reported outcome measure (PROM) data collection was introduced—to November 28, 2022.

This study population was divided into 3 cohorts based on intraoperative technology utilization: conventional (no technology utilized, n = 4275), computer navigation-assisted (n = 4510), and robotic-assisted (n = 1107). Sixty-two surgeons were included in the study: 59 in the conventional cohort, 18 in the robotic cohort, and 34 in the navigation cohort. Thirty-seven of the 62 surgeons performed surgeries in more than one cohort, and 12 surgeons performed surgeries in all 3 cohorts. Twenty surgeons performed both conventional and navigation-assisted THA; 4 performed both conventional and robotic-assisted THA; and one performed both robotic and navigation-assisted THA. In this large retrospective study, many surgeons used multiple surgical techniques for THA over the course of the study period in response to evolving research and practice trends. Patient data was extracted from the electronic medical record system (Epic Systems Corporation, Verona, WI). Patients were excluded if they received a hip hemiarthroplasty or revision hip arthroplasty. Indications for pTHA included osteoarthritis, inflammatory arthritis, and avascular necrosis. Cases with oncologic or fracture diagnoses were excluded. The mean age of the patients in the conventional cohort was 66.1 (range 12-97), while the mean ages in the navigation and robotic cohorts were 63.1 (range 13-97) and 63.6 (range 18-91), respectively. The conventional cohort had the largest mean body mass index (BMI) of 29.6 kg/m^2 (range 14.4-54.3), compared to 29.2 kg/m^2 (range 14.9-58.4) in the navigation cohort and 29.3 kg/m^2 (range 16.2-52.1) in the robotic cohort. There were no significant differences in sex ($P =$ .217) between the 3 cohorts. Additional demographic data can be found in Table 1.

Data collection

Chart review was conducted to collect patient demographics, surgical characteristics, clinical outcomes, and PROMs. Patient

Table 1
Patient demographics.

Variable	Conventional (n = 4275)	Navigation (n = 4510)	Robotic (n = 1107)	*P*-value
Mean age, years (range)	66.1 (12-97)	63.1 (13-97)	63.6 (18-91)	**<.001**
Mean BMI, kg/m^2 (range)	29.6 (14.3-54.3)	29.2 (14.9-58.4)	29.3 (16.2-52.1)	**.021**
Women, n (%)	2402 (56.2)	2599 (57.6)	611 (55.2)	.217
Race, n (%)				**<.001**
White	3312 (77.5)	3116 (69.1)	881 (79.6)	
Black	512 (12.0)	684 (15.2)	108 (9.8)	
Asian	72 (1.7)	112 (2.5)	19 (1.7)	
Other/unknown	379 (8.9)	598 (13.3)	99 (8.9)	
Smoking status, n (%)				.553
Never	2212 (51.7)	2410 (53.4)	580 (52.4)	
Former	1727 (40.4)	1726 (38.3)	454 (41.0)	
Current	320 (7.5)	363 (8.0)	65 (5.9)	
Insurance type, n (%)				**<.001**
Medicare	2353 (55.0)	1990 (44.1)	483 (43.6)	
Medicaid	326 (7.6)	600 (13.3)	90 (8.1)	
Commercial	1588 (37.1)	1895 (42.0)	531 (48.0)	
Other	8 (0.2)	25 (0.6)	9 (0.8)	
ASA classification, n (%)				**<.001**
1	205 (4.8)	402 (8.9)	83 (7.5)	
2	2323 (54.3)	2870 (63.6)	680 (61.4)	
3	1665 (38.9)	1175 (26.1)	334 (30.2)	
4	82 (1.9)	63 (1.4)	3 (0.3)	
Mean CCI ± standard deviation	3.7 ± 2.6	3.3 ± 2.6	3.3 ± 2.5	**<.001**
Diagnosis, n (%)				**<.001**
Osteoarthritis	4045 (94.6)	4313 (95.6)	1065 (96.2)	
Osteonecrosis	145 (3.4)	130 (2.9)	30 (2.7)	
Other	85 (2.0)	67 (1.5)	12 (1.1)	

All bold *P*-values are statistically significant ($P < .05$).

demographics collected included age, BMI, sex, race, smoking status, insurance type, American Society of Anesthesiology (ASA) score, Charlson comorbidity index (CCI) score [12], and preoperative diagnoses. Surgical characteristics collected included the type of technology used intraoperatively (no technology, imageless computer navigation, or computed tomography-based robotics), surgical approach, and year of surgery. Clinical outcomes collected immediately following surgery included length of stay in the hospital and discharge disposition. The Activity Measure for Post-Acute Care (AM-PAC) “6-Clicks” mobility score is a postoperative prediction tool that measures a patient’s ability to transfer and mobilize after surgery [13]. Once a patient is medically stable, a perfect AM-PAC score of 24 indicates sufficient functional independence to imply readiness for discharge home. The AM-PAC score is part of a holistic assessment of discharge readiness, such that patients with more assistance at home can be safely discharged without a perfect score. Daily AM-PAC scores were recorded for the duration of each patient’s hospital stay as well as the postoperative day on which patients achieved a perfect score. Readmissions within the first 90 days following surgery were recorded, along with reasons for readmission and the number of dislocations requiring revision within the first 90 days following surgery.

Two PROMs were collected: Hip dysfunction and Osteoarthritis Outcome Score, Joint Replacement (HOOS, JR.) and Patient-Reported Outcomes Measurement Information System (PROMIS) Pain Interference scores. These PROMs were administered preoperatively as well as at 6 weeks and 3 months postoperatively as part of clinical care. Systematic administration of PROMs began at our institution during the study period, meaning that not all patients had scores available from preoperative and both postoperative time points. Preoperative and 6-week postoperative HOOS, JR. were both completed by 1699 patients, and preoperative and 3-month postoperative HOOS, JR. were both completed by 1387 patients. There were 2037 patients who completed both a preoperative and 6-week postoperative PROMIS Pain Interference score and 1862 patients who completed both a preoperative and 3-month postoperative PROMIS Pain Interference score.

Data analyses

The primary outcomes of this study were the postoperative day on which a perfect AM-PAC score was achieved and improvements in HOOS, JR. and PROMIS Pain Interference scores. Secondary outcomes included length of stay, discharge disposition, readmissions within the first 90 days following surgery, reason for readmission, and the rate of dislocation requiring revision in the first 90 days following surgery. Surgical characteristics and clinical and patient-reported outcomes were reported as either a mean with a range or standard deviation or as the number of cases with the percentage of total cases.

Analyses comparing patient demographics, clinical outcomes, and PROMs (HOOS, JR. and PROMIS Pain Interference) between the 3 cohorts: conventional, navigation, and robotic—were performed using one-way analysis of variance testing. Separate analyses were conducted for the preoperative to 6-week postoperative and preoperative to 3-month postoperative intervals, as PROMs were not available for all study time points in all patients. Post hoc testing was performed using the Fisher’s least significant difference test. A multivariable analysis was performed using binary logistic regression to assess the odds of achieving a perfect AM-PAC score on postoperative day 0 in relation to multiple characteristics, including use of technology and surgical approach. Additional demographic variables, including age at surgery, BMI, race, insurance type, ASA score, CCI score, and preoperative diagnosis were included in the multivariable analysis to control for differences in these variables between cohorts. The year of surgery was also included as a control variable because, due to changes in surgical team processes and administrative policy, length of stay and trends in discharge disposition have changed over the 5 years that this study was performed. This variable was therefore included as a control to prevent new techniques from appearing artificially better than old techniques due to any evolving institutional norms. Additional multivariable analyses were performed to assess the odds of achieving length of stay shorter than 24 hours, the odds of readmission within 90 days following surgery, and the odds of dislocation requiring revision within 90 days following surgery in relation to technology use and surgical approach. The same variables (listed above) were included as controls in these analyses. Analyses were performed with the use of SPSS v25 (International Business Machines Corporation, Armonk, NY). The level of significance was set at a *P*-value of less than .05. This study was performed in accordance with the ethical standards of the institutional review board (study number i17-01,223_CR5) and the Helsinki Declaration.

Results

The mean lengths of stay in the hospital following surgery were longest for the conventional cohort (48.1 hours, range 7-728) and shortest for the robotic cohort (36.7 hours, range 6-469). The lengths of stay in each cohort were significantly different from each of the other cohorts, respectively ($P < .001$) (See Table 2). A multivariable analysis was performed to assess the association between the use of technology and the likelihood of having a length of stay less than 24

Table 2
Immediate postoperative outcomes.

Variable	Conventional (n = 4275)	Navigation (n = 4510)	Robotic (n = 1107)	*P*-value
Mean LOS, hours (range)	48.1 (7-728)	40.9 (4-1308)	36.7 (6-469)	**<.001**
Discharge disposition, n (%)				**<.001**
Home	3857 (90.2)	4212 (93.4)	1066 (96.3)	
Skilled nursing facility	366 (8.6)	246 (5.5)	29 (2.6)	
Other	52 (1.2)	52 (1.2)	12 (1.1)	
Mean day on which perfect AM-PAC score was achieved ± standard deviation	0.5 ± 0.8	0.5 ± 0.9	0.1 ± 0.5	**<.001**
Mean total score ± standard deviation				
POD0	18.9 ± 3.3	20.8 ± 3.2	21.1 ± 3.3	**<.001**
POD1	20.1 ± 3.8	21.2 ± 3.3	21.1 ± 3.2	**<.001**
Variable	Conventional (n = 3515)	Navigation (n = 3483)	Robotic (n = 450)	*P*-value
Perfect AM-PAC score reached on day, n (%)				**<.001**
POD0	394 (11.2)	858 (24.6)	162 (36.0)	
POD1	1039 (29.6)	1137 (32.6)	92 (20.4)	
POD2	288 (8.2)	312 (9.0)	18 (4.0)	
POD3	80 (2.3)	103 (3.0)	4 (0.9)	
POD4≤	37 (1.1)	49 (1.4)	4 (0.9)	
Never achieved	1677 (47.7)	1024 (29.4)	170 (37.8)	

LOS, length of stay; POD, postoperative day.
All bold *P*-values are statistically significant ($P < .05$).

hours. This regression accounted for potential confounding variables, including surgical approach, year of surgery, age at surgery, BMI, race, insurance type, ASA score, CCI score, and preoperative diagnosis. After adjusting for these variables, use of robotic assistance and navigation in pTHA were both associated with increased odds of achieving a length of stay shorter than 24 hours (odds ratio [OR] 2.3, $P < .001$ in robotics and OR 1.7, $P < .001$ in navigation) compared to no technology use in pTHA (see Table 3).

Of the 3 cohorts, robotics had the highest percentage of patients discharged home (96.3%), followed by navigation (93.4%) and conventional (90.2%). The discharge disposition in each cohort was significantly different from each of the other cohorts, respectively ($P < .001$) (see Table 2).

The mean day on which a perfect AM-PAC score was achieved was earliest in the robotic cohort at 0.1 days, followed by the navigation and conventional cohorts, which were both 0.5 days ($P < .001$ between robotic and each of the other cohorts, respectively). The mean AM-PAC score on postoperative day 0 was the highest in the robotic cohort at 21.1, followed by the navigation cohort at 20.8, and the conventional cohort at 18.9. The mean AM-PAC score on postoperative day 0 in the robotic cohort was significantly greater than in the conventional cohort ($P < .001$) but not significantly different from the navigation cohort ($P = .105$). The robotic cohort had the greatest percentage of patients achieve a perfect score on postoperative day 0 (36.0%), followed by the navigation and conventional cohorts (24.6 and 11.2%, respectively). All 3 cohorts were significantly different from one another in the number of patients that achieved a perfect AM-PAC score on postoperative day 0 ($P < .001$) (see Table 2).

A multivariable analysis was performed to assess the association between use of technology and the likelihood of achieving a perfect AM-PAC score on postoperative day 0, while accounting for the same potential confounding variables as stated above. After adjusting for these variables, use of robotic assistance and navigation in pTHA were both associated with greater odds of achieving a perfect AM-PAC score on postoperative day 0 compared to no technology use in pTHA (OR 1.6, $P < .001$ for robotics and OR 1.7, $P < .001$ for navigation) (See Table 4).

With the exception of 2017, the rate of readmissions was stable over the study period. Unexpectedly, there was a lower rate of readmission in 2017, which was a partial year with fewer cases included. The robotic cohort had the lowest rate of readmissions within the first 90 days following surgery (30 patients, 2.7%). This was significantly smaller than the 90-day readmission rate in both the conventional cohort (193 patients, 4.5%, $P = .007$) and the navigation cohort (182 patients, 4.0%, $P = .046$). In the multivariable analysis assessing the likelihood of readmission within 90 days following surgery, neither robotics nor navigation significantly impacted the odds of a 90-day readmission when compared to no technology use (OR 0.5, $P = .055$ for robotics and OR 1.0, $P = .767$ for navigation) (See Table 5).

The robotic cohort had no dislocations requiring revision within 90 days following surgery; the navigation cohort had 11 (0.2%); and the conventional cohort had 14 (0.3%). The 90-day rate of dislocation

Table 3
Multivariable analysis for length of stay <24 h odds ratio.

Variable	LOS<24 h odds ratio	*P*-value
Surgical technique		
Conventional	–	
Navigation	1.7 (1.5-1.9)	**<.001**
Robot-assist	2.3 (1.8-3.0)	**<.001**
THA approach		
Posterior	–	
Anterior	3.1 (2.8-3.5)	**<.001**
Lateral	1.2 (0.9-1.5)	.192
Year of surgery		
2017	–	
2018	0.9 (0.7-1.2)	.487
2019	1.0 (0.7-1.4)	.882
2020	2.3 (1.7-3.2)	**<.001**
2021	3.0 (2.2-4.2)	**<.001**
2022	3.4 (2.5-4.7)	**<.001**
Age at surgery	1.0 (1.0-2.0)	**<.001**
BMI	1.0 (0.9-1.0)	**<.001**
Race		
White	–	
Black	0.4 (0.3-0.5)	**<.001**
Asian	0.6 (0.4-0.9)	**.007**
Other	0.5 (0.4-0.6)	**<.001**
Insurance type		
Medicare	–	
Commercial	2.1 (1.8-2.4)	**<.001**
Medicaid	0.7 (0.6-1.0)	**.022**
Other	0.1 (0.0-0.9)	**.043**
ASA		
1	–	
2	0.5 (0.4-0.6)	**<.001**
3	0.2 (0.1-0.2)	**<.001**
4	0.1 (0.0-0.3)	**<.001**
CCI	0.9 (0.9-1.0)	**<.001**
Diagnosis		
Osteoarthritis	–	
Osteonecrosis	0.7 (0.5-1.0)	.060
Other	0.2 (0.1-0.4)	**<.001**

LOS, length of stay.
All bold *P*-values are statistically significant ($P < .05$).

Table 4
Multivariable analysis for perfect AM-PAC score achievement on POD0 odds ratio.

Variable	Perfect score POD0 odds ratio	*P*-value
Surgical technique		
Conventional	–	
Navigation	1.7 (1.2-2.1)	**<.001**
Robot-assist	1.6 (1.5-2.0)	**<.001**
THA approach		
Posterior	–	
Anterior	2.8 (2.4-3.2)	**<.001**
Lateral	1.1 (0.8-1.5)	.393
Year of surgery		
2017	–	
2018	0.8 (0.6-1.2)	.265
2019	0.9 (0.6-1.3)	.482
2020	1.5 (1.1-2.2)	**.018**
2021	1.8 (1.3-2.5)	**.001**
2022	2.2 (1.6-3.1)	**<.001**
Age at surgery	1.0 (1.0-1.0)	**<.001**
BMI	1.0 (0.9-1.0)	**<.001**
Race		
White	–	
Black	0.4 (0.3-0.5)	**<.001**
Asian	0.8 (0.5-1.2)	.318
Other	0.7 (0.6-0.9)	**.005**
Insurance type		
Medicare	–	
Commercial	2.0 (1.6-2.3)	**<.001**
Medicaid	0.8 (0.6-1.1)	.235
Other	0.5 (0.1-2.2)	.358
ASA		
1	–	
2	0.6 (0.5-0.8)	**<.001**
3	0.2 (0.1-0.3)	**<.001**
4	0.0 (0.0–)	.995
CCI	0.9 (0.9-1.0)	**<.001**
Diagnosis		
Osteoarthritis	–	
Osteonecrosis	0.8 (0.6-1.3)	.394
Other	0.4 (0.2-0.9)	**.026**

POD, postoperative day.
All bold *P*-values are statistically significant ($P < .05$).

Table 5
Multivariable analysis for readmission within 90 d odds ratio.

Variable	90-D readmission odds ratio (CI)	*P*-value
Surgical technique		
Conventional	–	
Navigation	1.0 (0.8-1.2)	.767
Robot-assist	0.5 (0.3-1.0)	.055
THA approach		
Posterior	–	
Anterior	0.7 (0.5-0.9)	**.003**
Lateral	0.7 (0.5-1.2)	.250
Year of surgery		
2017	–	
2018	1.9 (1.0-3.4)	.042
2019	1.6 (0.9-3.0)	.124
2020	1.8 (1.0-3.3)	.059
2021	1.8 (1.0-3.3)	.068
2022	1.6 (0.8-2.9)	.166
Age at surgery	1.0 (1.0-1.0)	.119
BMI	1.0 (1.0-1.0)	**.033**
Race		
White	–	
Black	0.8 (0.6-1.1)	.127
Asian	1.0 (0.4-2.1)	.956
Other	1.0 (0.7-1.4)	.966
Insurance type		
Medicare	–	
Commercial	0.8 (0.6-1.1)	.191
Medicaid	1.2 (0.8-1.7)	.440
Other	1.6 (0.4-7.1)	.508
ASA		
1	–	
2	3.9 (1.6-9.6)	**.003**
3	5.8 (2.3-14.5)	**<.001**
4	9.9 (3.4-28.8)	**<.001**
CCI	1.0 (1.0-1.1)	.063
Diagnosis		
Osteoarthritis	–	
Osteonecrosis	1.3 (0.8-2.3)	.285
Other	3.5 (2.1-5.8)	**<.001**

All bold *P*-values are statistically significant ($P < .05$).

Table 7
Multivariable analysis for dislocation requiring revision within 90 d odds ratio.

Variable	90-D dislocation requiring revision odds ratio	*P*-value
Surgical technique		
Conventional	–	
Navigation	1.0 (0.4-2.4)	.931
Robot-assist	0.0 (0.0–)	.993
THA approach		
Posterior	–	
Anterior	0.8 (0.3-2.0)	.602
Lateral	0.5 (0.1-4.0)	.525
Year of surgery		
2017		–
2018	0.8 (0.2-4.2)	.818
2019	1.3 (0.3-6.3)	.752
2020	0.7 (0.1-3.8)	.644
2021	0.3 (0.0-2.4)	.277
2022	0.3 (0.0-2.2)	.231
Age at surgery	1.0 (0.9-1.0)	.731
BMI	1.0 (1.0-1.1)	.278
Race		
White	–	
Black	0.2 (0.0-1.7)	.152
Asian	2.0 (0.2-15.6)	.524
Other	0.3 (0.0-2.3)	.249
Insurance type		
Medicare	–	
Commercial	1.0 (0.3-2.9)	.994
Medicaid	0.4 (0.0-3.2)	.363
Other	0.0 (0.0–)	.998
ASA		
1	–	
2	1.1 (0.1-9.4)	.902
3	1.8 (0.2-16.5)	.609
4	2.5 (0.1-52.0)	.564
CCI	1.1 (0.9-1.2)	.436
Diagnosis		
Osteoarthritis	–	
Osteonecrosis	1.5 (0.2-11.9)	.726
Other	6.4 (1.4-29.3)	**.016**

All bold *P*-values are statistically significant ($P < .05$).

requiring revision was not significantly different between any of the 3 cohorts ($P = .152$) (See Table 6). The multivariate analysis assessing the likelihood of suffering a dislocation requiring revision in the first 90 days following surgery produced similar results, in that the use of neither robotics nor navigation in pTHA significantly impacted the odds of a dislocation requiring revision in the 90 days following surgery when compared to no technology use in pTHA (OR 0, $P = .993$ for robotics and OR 1.0, $P = .931$ for navigation) (See Table 7).

Among patients who had both preoperative and 6-week postoperative HOOS, JR. scores, the mean improvement in HOOS, JR. at the 6-week postoperative interval was greatest in the robotic cohort (20.3). This was significantly greater than the improvement in the navigation cohort (16.4, $P = .020$), but was not significantly different from the improvement in the conventional cohort (17.8, $P = .151$). Among patients who had both preoperative and 3-month postoperative HOOS, JR. scores, the mean improvement in HOOS, JR. at the 3-month postoperative interval was also greatest in the robotic cohort (29.8); this was significantly greater than the improvements in both the conventional (24.6, $P = .015$) and navigation (23.8, $P = .005$) cohorts. For full reporting of scores at each time point, see Table 8.

Table 6
Short-term clinical outcomes.

Variable	Conventional (n = 4275)	Navigation (n = 4510)	Robotic (n = 1107)	*P*-value
90-D readmissions, n (%)	193 (4.5)	182 (4.0)	30 (2.7)	**.025**
Reason for readmission, n (%)				.304
Dislocation/instability	19 (0.4)	15 (0.3)	0 (0.0)	
Infection (+wound/ blood)	42 (1.0)	46 (1.0)	8 (0.7)	
Fracture	27 (0.6)	28 (0.6)	3 (0.3)	
Other	105 (2.5)	93 (2.1)	19 (1.7)	
90-D dislocations requiring revision, n (%)	14 (0.3)	11 (0.2)	0 (0.0)	.152

All bold *P*-values are statistically significant ($P < .05$).

Among patients who had both preoperative and 6-week postoperative PROMIS Pain Interference scores, the mean improvement in PROMIS Pain Interference scores at the 6-week postoperative interval was greatest in the robotic cohort (−6.9), which was significantly greater than the mean improvement found in the navigation cohort (−4.8, $P = .005$). The improvement between the preoperative and 6-week postoperative PROMIS scores in the conventional cohort was also significantly greater than that in the navigation cohort (−5.8 vs −4.8, $P = .009$). Among patients who had both preoperative and 3-month postoperative PROMIS Pain Interference scores, the difference between these preoperative and 3-month postoperative scores was that the robotic cohort again had the greatest improvement in PROMIS scores (−12.4), which was significantly greater than the improvement in both the conventional (−10.1, $P = .020$) and navigation (−9.8, $P = .007$) cohorts. For full reporting of scores at each time point, see Table 8.

Table 8
HOOS, JR. and PROMIS pain interference scores.

Variable	Conventional (n = 535)	Navigation (n = 1051)	Robotic (n = 113)	*P*-value
HOOS, JR. (preoperative)	48.5	48.9	47.1	.395
HOOS, JR. (6 wk)	66.3	65.3	67.4	.168
Delta HOOS, JR. (6 wk preoperative)	17.8	16.4	20.3	**.034**

Variable	Conventional (n = 586)	Navigation (n = 728)	Robotic (n = 73)	*P*-value
HOOS, JR. (preoperative)	49.0	48.9	44.5	**.029**
HOOS, JR. (3 mo)	73.6	72.7	74.3	.441
Delta HOOS, JR. (3 mo preoperative)	24.6	23.8	29.8	**.018**

Variable	Conventional (n = 657)	Navigation (n = 1248)	Robotic (n = 132)	*P*-value
PROMIS interference (preoperative)	64.5	64.5	67.6	**<.001**
PROMIS interference (6 wk)	58.7	59.7	60.7	**.003**
Delta PROMIS interference (6 wk preoperative)	−5.8	−4.8	−6.9	**.002**

Variable	Conventional (n = 783)	Navigation (n = 986)	Robotic (n = 93)	*P*-value
PROMIS interference (preoperative)	64.4	64.5	67.8	**<.001**
PROMIS interference (3 mo)	54.3	54.7	55.4	.429
Delta PROMIS interference (3 mo preoperative)	−10.1	−9.8	−12.4	**.025**

All bold *P*-values are statistically significant ($P < .05$).

Discussion

The existing literature yields conflicting evidence on the effect of technology utilization in THA on clinical and patient-reported outcomes. The aim of our study was to investigate the effect of computer navigation and robotic assistance in pTHA on clinical and patient-reported outcomes in the first 90 days following surgery. We found that both short-term clinical and patient-reported outcomes were superior when robotic assistance was utilized. Our primary outcome, the postoperative day on which a perfect AM-PAC score was achieved, was the earliest in the robotic cohort, demonstrating that patients who underwent pTHA with robotic assistance had faster immediate postoperative functional recovery compared to patients who underwent pTHA with navigation or traditional instrumentation. Our other primary outcome, HOOS, JR. and PROMIS Pain Interference scores, also showed the greatest improvement at both 6 weeks and 3 months after surgery in the robotic cohort. These findings demonstrate that patients also subjectively experienced greater improvement when robotic assistance was utilized in pTHA.

AM-PAC scores were examined in this study as a proxy for immediate functional recovery following surgery. When assessing patients who underwent THA with robotic assistance, the greatest percentage of these patients achieved a perfect AM-PAC score on postoperative day 0. In contrast, the greatest percentage of patients in the conventional and navigation cohorts achieved a perfect AM-PAC score on postoperative day 1. Of the 3 cohorts, the robotic cohort was found to have the highest mean AM-PAC score on postoperative day 0, and on average, achieved a perfect AM-PAC score the earliest. To our knowledge, this is the first study using AM-PAC scores to compare the recovery between types of intraoperative technology in THA. The AM-PAC score analysis favored the use of robotic assistance in pTHA, with higher early scores in this cohort indicating more rapid functional improvement among these patients. Further research is needed to confirm the generalizability of this finding to other groups of patients and surgeons. If confirmed by further research, a possible explanation for faster recovery of function with robotic assistance could be better restoration of hip center of rotation, leg length, and offset, resulting in decreased soft tissue strain, decreased pain, and improved functional recovery. Furthermore, robotic guidance may reduce soft tissue dissection and require less retraction, since direct simultaneous visualization of the entire acetabulum is not needed for accurate implant placement. Decreased soft tissue trauma could potentially lead to a faster functional recovery.

Other clinical outcomes that favored the robotic cohort included length of stay in the hospital following surgery and readmission rate in the first 90 days following surgery. Mean lengths of stay were the shortest in the robotic cohort, and the use of robotics increased the odds of having a length of stay less than 24 hours. Additionally, the number of readmissions within the first 90 days was lower in the robotic cohort compared to the conventional and navigation cohorts. In a PearlDiver database study comparing the use of robotic-assisted THA to conventional THA, Remily et al. also found shorter lengths of stay with robotic-assisted THA but found no difference in readmission rates between the robotic and conventional cohorts at 90 days [14]. A potential advantage of the PearlDiver database is its ability to capture readmissions outside the institution where surgery was performed. Compared to database studies, an advantage of our single-institution study was the ability to access patient medical records, allowing more accurate and complete reporting of reasons for readmissions. The study by Remily et al. did not report reasons for readmission.

Other studies have also failed to find a significantly lower readmission rate with the use of robotic assistance in THA [15,16]. An earlier study from our center by Singh et al. [15] did not find a lower readmission rate in the robotic cohort. Of note, the study did not control for the year that the surgery was performed, which can independently impact various clinical outcomes. That study was also performed over an earlier time period and included far fewer cases with technology assistance, including 135 robotic surgery patients vs 1107 robotic surgery patients in the current study. Robotic assistance was also newer to our institution over the earlier time period, and there may be a learning curve before technology use reduces readmission rates. In a separate study by Shaw et al., which also failed to show a difference in readmission rates between robotic and manual THAs, 2 surgeons performed the robotic THAs. The greater number of surgeons in our study using robotics in THA helped increase our power by generating more cases and increasing the external validity of our findings, making them more likely to generalize to the practices of other surgeons. Nevertheless, because some of our results do contrast with previous literature, further studies are necessary to confirm or refute our findings.

The rate of dislocation requiring revision surgery within the first 90 days following index surgery was lowest in the robotic cohort. Although this finding did not reach statistical significance with the numbers available, the observed decrease from a 0.3% dislocation rate in the conventional group to a 0% dislocation rate in the robotic cohort would be clinically important if confirmed in larger studies with increased power. Previous studies have demonstrated similar results when comparing the rate of dislocation between robotically assisted and manual THA [17,18]. Bendich et al. found decreased odds of dislocation requiring reoperation within 1 year in robot-assisted THA when compared to manual THA when a posterior approach is used [19]. In contrast, a meta-analysis of 17 studies by Ng et al. showed no difference in dislocation between robot-assisted and manual THA [20]. Bendich et al. included a larger robotic cohort with longer follow-up and, as a result, had greater power to find a difference in dislocation rates. As has been postulated in the literature, lower dislocation rates with the use of robotics could occur as the result of more accurate and precise cup placement. The current robotic platform does not simply enable more cups to be placed in the Lewinnek's safe zone [21], but it also allows individualized targeting of component position based on 3D anatomy and functional spinopelvic planning. Formal spinopelvic planning was introduced during the study period, but its impact cannot be assessed using the data available in the current study.

The present study demonstrated the greatest increase in HOOS, JR. scores among patients who underwent robot-assisted pTHA. The improvement in score at 6 weeks following surgery by over 20 points and just under 30 points at 3 months following surgery exceed the minimum clinically important difference for HOOS, JR. scores, which has been reported to be 18.0 in a recent study [22]. While the differences from preoperative to postoperative scores in the robotic cohort were clinically significant, the differences in HOOS, JR. score improvement between cohorts did not exceed the reported minimum clinically important difference. Similar to HOOS, JR. scores, patients in the robotic cohort also demonstrated the greatest improvement in PROMIS Pain Interference scores at both 6 weeks and 3 months following surgery. This notable improvement in PROMs in the short-term postoperative period provides further evidence that patients who underwent pTHA with robotic assistance achieved superior short-term outcomes compared to patients who underwent pTHA with navigation or no technology. As with AM-PAC scores, the improvements in patients' pain and perceived outcome in the robot-assisted cohort may be due in part to improved leg length discrepancy and offset, leading to less soft tissue strain. The reasons behind improved PROMs in the robotic cohort are unclear, and further investigation of the association between PROMs and technology in THA is warranted.

While prior studies have demonstrated good short-term patient-reported outcomes following robot-assisted THA, some did not directly compare these outcomes to those of manual THA [11,23]. Lu et al. assessed PROMs at 3 months postoperatively with Harris and Western Ontario and McMaster University Osteoarthritis index scores and found no significant differences between the robotic and manual THA groups [24]. Fontalis et al. assessed PROMs between robotic and conventional THA using the Oxford Hip Score, University of California at Los Angeles score, and Forgotten Joint Score and found no significant difference between the 2 cohorts for any of these scores. Conversely, Clement et al. found a statistically but not clinically significant improvement in the Oxford Hip Score in robotic THA when compared to manual THA, and the Forgotten Joint Score showed an improvement in robotic over manual THA that was both statistically and clinically significant [25]. From our center, Singh et al. also compared HOOS, JR. scores between robotic and conventional THA and found a significant improvement in the robotic cohort at 1 year. They did not measure improvement from baseline to 90 days in their study, although they did not find any significant differences in raw 3-month scores between their 3 cohorts (manual, navigation, and robotic). Their robotic cohort of 135 cases was slightly larger than our cohort of 73 robotic THA patients who completed both a preoperative and 3-month postoperative HOOS, JR. score, and this difference may have been due to different selection criteria between the 2 studies. Nevertheless, their slightly larger robotic cohort may have decreased their risk of type II error. The lack of consensus in the literature, along with the addition of our results, demonstrates the innate variability of different PROMs as an outcome measure. While our findings contribute to the existing literature by challenging many of the previous findings on the impact of robotic THA on short-term PROMs, further studies examining HOOS, JR. and PROMIS scores in robotic THA are necessary.

Limitations

This retrospective observational study has important limitations. Because this study is retrospective, it is subject to collection error. Additionally, the sample size of the robotic cohort, especially the subset with PROMs data, was relatively limited in comparison to the sample sizes of the navigation and conventional cohorts. Because this data was collected from a single institution, reported outcomes are limited to those that occurred within our institution. While the purpose of this study was to examine the outcomes of technology use in pTHA in the short term, the lack of long-term follow-up in this study limits the conclusions that can be drawn about the long-term impact of technology use in THA on clinical and patient-reported outcomes, along with implant durability. To address this, additional studies with greater follow-up are warranted to better understand the long-term benefit of technology use in THA on the patient. Despite these limitations, our results add to the existing literature by demonstrating improved short-term outcomes with the use of robotic assistance in pTHA, which will hopefully lead to further exploration into the potential benefits of robotic assistance in THA.

Conclusions

The use of robotic assistance in pTHA showed superior clinical and patient reported outcomes in the first 90 days following surgery when compared to the use of navigation or traditional instrumentation alone. These findings have not been consistently reported in the current literature on this topic and should inspire further investigation. Additional studies with greater follow-up are necessary to understand whether the short-term benefits of robotic use in THA found in this study are confirmed in other clinical settings and translate to a long-term impact on clinical and patient reported outcomes.

Conflicts of interest

M. Hepinstall is a speaker for Stryker, is a paid consultant and receives research support from Exactech and Stryker, and is a board/committee member of AAOS, AAHKS, CAOS, and ISTA. M. Meftah receives royalties from Innomed, is a paid consultant for Conformis and Intellijoint, has stock options in CAIRA Surgical and Constance, is an editorial/governing board member of Orthopedics, and is a board/committee member of ISTA. P. Meere receives royalties from Stryker, has stock options in Intellijoint and Stryker, and is an editorial board member of the Bulletin for Joint Diseases. All other authors declare no potential conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2024.101393.

CRediT authorship contribution statement

Alana Prinos: Formal analysis, Writing – original draft, Writing – review & editing. **Weston Buehring:** Data curation, Writing – original draft. **Catherine Di Gangi:** Data curation, Formal analysis. **Patrick Meere:** Writing – review & editing. **Morteza Meftah:** Writing – review & editing. **Matthew Hepinstall:** Conceptualization, Methodology, Project administration, Supervision, Writing – review & editing.

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