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Comparison of Postoperative Instability and Acetabular Cup Positioning in Robotic-Assisted Versus Traditional Total Hip Arthroplasty

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ABSTRACT

Background: Robotic-assisted total hip arthroplasty (R-THA) affords precision yet uncertain clinical benefits. This study compares dislocation rates and related revisions between R-THA and manual total hip arthroplasty (M-THA). Secondarily we evaluated cup position, patient-reported outcome measures (PROMs), and postoperative complications.
Methods: A three-surgeon cohort study was conducted on 2247 consecutive patients (1724 M-THA and 523 R-THA) who received a primary THA between January 2014 and June 2020 at a single hospital. Demographics, PROMs, emergency department visits, readmissions, and 90-day complications were collected via the Michigan Arthroplasty Registry Collaborative Quality Initiative. Chart review yielded instability occurrence with an average follow-up of 4 years. Multivariate regression analysis was performed, and a sample of 368 radiographs, including all dislocations, were assessed.
Results: There were significantly lower rates of dislocation in R-THA (0.6%) vs M-THA (2.5%; Multivariate odds ratio 3.74, $P < .046$). All cases of unstable R-THA were successfully treated conservatively, whereas 46% of unstable M-THA were revised for recurrent instability. Cup anteversion ($25.6^\circ \pm 5.4^\circ$ R-THA vs $20.6^\circ \pm 7.6^\circ$ M-THA) was greater, and cup inclination ($42.5^\circ \pm 5.3^\circ$ R-THA vs $47.0^\circ \pm 6.7^\circ$ M-THA) was lower in the R-THA group ($P < .05$). No significant differences were noted for demographics, PROMs, or other complications ($P > .05$).
Conclusion: R-THA resulted in less than one-fourth the dislocation rate compared to M-THA and no revision for instability. It was associated with no difference in PROMs or other early complications. The influence of R-THA on stability goes beyond simply cup positioning and deserves further study.

Total hip arthroplasty (THA) has been cited as the surgery of the century for its effectiveness at reducing pain and improving function [1]. Despite the success of THA for more than half a century, mechanical complications such as instability and aseptic loosening continue to occur secondary to component positioning, soft tissue balance, or component failure [2–4]. These complications have an established effect on not only patient outcomes but also economic productivity and overall health care costs.

Robotic-assisted total hip arthroplasty (R-THA) seeks to address these complications by offering increased technical precision and information for which the surgical team to act upon with a goal to limit variability. The precision, accuracy, and overall cost of robotic-assisted surgery continue to be a well-studied topic in current arthroplasty literature [5–13]. The initial added cost of R-THA has been a subject of debate, as recent literature has demonstrated excellent reproducible component positioning with conflicting data regarding benefit for outcomes and overall costs [14–17]. The current controversy with robotic-assisted surgery stems from limited literature that demonstrates improved early outcomes in small series but little longer term data.

The primary purpose of this study is to compare dislocation rates and their corresponding revisions between R-THA and

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Table 1
Univariate Comparison of Demographics Between Robotic and Nonrobotic Total Hip Arthroplasty.

Covariate	Statistics	Level	Robotic		*P* Value
			No (N = 1724)	Yes (N = 523)	
Sex	N (%)	Female	1006 (58.35)	293 (56.02)	.345
	N (%)	Male	718 (41.65)	230 (43.98)	
Age (y)	N		1724	523	**.030**
	Mean		65.63	64.47	
	Median		66	65	
Race	N (%)	Asian	8 (0.46)	3 (0.57)	.262
	N (%)	Black	397 (23.03)	100 (19.12)	
	N (%)	Caucasian	1179 (68.39)	388 (74.19)	
	N (%)	Native American	2 (0.12)	0 (0)	
	N (%)	Native Hawaiian-Pacific Islander	1 (0.06)	0 (0)	
	N (%)	Other	21 (1.22)	6 (1.15)	
	N (%)	Unknown	116 (6.73)	26 (4.97)	
Body mass index (kg/m^2)	N		1724	523	.731
	Mean		30.72	30.62	
	Median		30.1	29.9	
Diabetes mellitus	N (%)	No	1400 (81.21)	418 (79.92)	.486
	N (%)	Yes - type 1	3 (0.17)	0 (0)	
	N (%)	Yes - type 2	321 (18.62)	105 (20.08)	
Bleeding disorder	N (%)	No	1719 (99.71)	521 (99.62)	.740
	N (%)	Yes	5 (0.29)	2 (0.38)	
History of deep venous thrombosis or pulmonary embolism	N (%)	No	1612 (93.5)	485 (92.73)	.690
	N (%)	Unknown	1 (0.06)	0 (0)	
	N (%)	Yes	111 (6.44)	38 (7.27)	
Use of assistive device preoperatively	N (%)	No	974 (56.5)	303 (57.93)	.094
	N (%)	Unknown	15 (0.87)	0 (0)	
	N (%)	Yes	735 (42.63)	220 (42.07)	
American Society of Anesthesiologists score	N (%)	I	50 (2.9)	24 (4.59)	.281
	N (%)	II	759 (44.03)	221 (42.26)	
	N (%)	III	888 (51.51)	269 (51.43)	
	N (%)	IV	27 (1.57)	9 (1.72)	
History of lumbar surgery	N (%)	No	1618 (93.85)	479 (91.59)	.069
	N (%)	Yes	106 (6.15)	44 (8.41)	
Method of femoral component fixation	N (%)	Cemented	11 (1.35)	1 (0.19)	**.028**
	N (%)	Uncemented	801 (98.65)	521 (99.81)	

Bolded text indicates statistical significance ($P < .05$).

manual total hip arthroplasty (M-THA). Secondarily, the study investigated acetabular cup position, available postoperative patient-reported outcome measures, and 90-day postoperative complications.

Materials and Methods

We performed a retrospective cohort analysis of 2247 consecutive patients that received a primary THA by 3 adult reconstruction fellowship-trained specialist surgeons at a single suburban teaching hospital between January 2014 and June 2020 [18]. All surgeons were at least 2 years into their own adult reconstruction practice at the start of this timeframe, which should minimize learning curve concerns. At the midpoint of the study period, their average time in independent practice was 7 years. Inclusion criteria included patients undergoing primary THA within the study period. Exclusion criteria were revision THA, THA secondary to trauma or hardware failure, and hip hemiarthroplasty.

Two surgeons performed R-THAs while all three surgeons contributed to the M-THA cohort. One surgeon performed the vast majority of the R-THA as it became his standard procedure for all primary arthroplasty from 2017 onward. R-THAs were performed with a single system (MAKO, Stryker, Kalamazoo, MI) via a minimally invasive posterior approach to the hip in the lateral decubitus position. The express robotic workflow was utilized that does not rely upon navigated femoral implant assessment and simply helps place the cup and assess the length and offset with planned 3-dimensional template sizing. Similar posterior-based approaches were used for all M-THAs, and the acetabular component was placed before the femoral component. The combined version goal during broaching and trialing was 45-50 degrees in the majority of cases, along with stability during range of motion assessment. All surgeons typically used press-fit, uncemented implants with single-tapered stems unless otherwise indicated. Resident physicians were present in nearly all of the procedures. The majority of the robotic THAs were done with a senior resident while the manual THAs were evenly split between a postgraduate year 2 and postgraduate year 5. Teaching style and autonomy for the procedure was variable based on the seniority and skill of the resident, as well as senior staff involved. All surgeries were performed under spinal anesthesia unless otherwise contraindicated, and employed the same postoperative pain control regimen. Postoperatively all patients followed the same standardized rehabilitation protocol at that time. All clinical data, both inpatient and outpatient, was stored in the same electronic medical record for the entire study period.

Data collection was conducted following institutional review board approval. The study developed a patient list by utilizing registry data to ensure accuracy. Patient demographics, postoperative emergency department visits, readmissions, and 90-day complications were queried through the Michigan Arthroplasty Registry Collaborative Quality Initiative (MARCQI) prospective database. Registry data was entered by full-time abstractors assigned to such collections to ensure consistency. Patient-reported outcome measures were available in the registry beginning late 2017 onward, with a capture rate of over 95% during that period. As MARCQI data was limited to 90-day follow-up, further manual electronic medical record review was conducted to document the

Table 2
Univariate Comparison of Early Postoperative Outcomes Between Robotic and Nonrobotic Total Hip Arthroplasty.

Covariate	Statistics	Level	Robotic		P Value
			No (N = 1724)	Yes (N = 523)	
Operative time (minutes)			1724	523	**<.001**
	Mean		90.13	69.98	
	Median		88	68	
Postoperative hospital length of stay	N (%)		63 (3.65)	155 (29.64)	**<.001**
	N (%)	1	999 (57.95)	315 (60.23)	
	N (%)	2	491 (28.48)	36 (6.88)	
	N (%)	3	120 (6.96)	11 (2.1)	
	N (%)	4	29 (1.68)	4 (0.76)	
	N (%)	5	5 (0.29)	2 (0.38)	
	N (%)	6	5 (0.29)	0 (0)	
	N (%)	7	4 (0.23)	0 (0)	
	N (%)	8	4 (0.23)	0 (0)	
	N (%)	9	1 (0.06)	0 (0)	
	N (%)	10	3 (0.17)	0 (0)	
Dislocation	N (%)	0	1681 (97.51)	520 (99.43)	**.007**
	N (%)	1	43 (2.49)	3 (0.57)	
Readmission	N (%)	No	1618 (93.85)	497 (95.03)	.316
	N (%)	Yes	106 (6.15)	26 (4.97)	
Emergency department visit	N (%)	No	1541 (89.39)	473 (90.44)	.488
	N (%)	Yes	183 (10.61)	50 (9.56)	
Fracture	N (%)	No	1692 (98.14)	517 (98.85)	.271
	N (%)	Yes	32 (1.86)	6 (1.15)	
Deep venous thrombosis	N (%)	No	1714 (99.42)	521 (99.62)	.587
	N (%)	Yes	10 (0.58)	2 (0.38)	
Hematoma	N (%)	No	1711 (99.25)	521 (99.62)	.361
	N (%)	Yes	13 (0.75)	2 (0.38)	
Pulmonary embolism	N (%)	No	1717 (99.59)	522 (99.81)	.470
	N (%)	Yes	7 (0.41)	1 (0.19)	
Periprosthetic joint infection	N (%)	No	1711 (99.25)	521 (99.62)	.361
	N (%)	Yes	13 (0.75)	2 (0.38)	

Bolded text indicates statistical significance ($P < .05$).

incidence of hip dislocations, the number of dislocations, dislocation secondary to mechanical failure, and revision secondary to instability for all patients. This query was strengthened beyond the review of clinic notes by a newly available electronic medical record search function (EPIC Systems, Verona, WI). A global search utilizing the terms ‘dislocation’ and ‘dislocated’ was used to capture every encounter (ie, emergency department, radiology, and operative notes) that mentioned a dislocation event to minimize omitted documentation. The minimum follow-up was 6 months, with an average of over 4 years across the cohort. Incidence of lumbar fusion prior to THA was also recorded by reviewing all operative notes within our health system.

A representative, randomized sample of 368 anteroposterior pelvis post-THA radiographs, which included all dislocations, was assessed for acetabular implant positioning. Radiographs were obtained through the hospital picture archiving and communication system and analyzed using the ellipse method within our electronic templating system (Orthoview Digital Planning Software, Materialise, Belgium). All radiographs were assessed for cup anteversion and inclination by two orthopedic surgery residents to ensure reproducibility and precision of measurements. Cup inclination was measured using the profile of the ischial tuberosities to set the horizontal axis. Cup anteversion was measured using the OrthoView anteversion smart tool on the anteroposterior radiograph for angle computation. Any outlier measurements were corroborated and corrected by a senior resident.

Statistical Analysis

Continuous data are described using mean and median and are compared between the R-THA and M-THA groups using independent two-group t-tests or Wilcoxon rank-sum tests based on distribution. An average of the two measurements for cup anteversion and inclination was used for comparison between R-THA and M-THA. All categorical data are presented using counts and relative percentages and compared between the two groups using chi-square or Fisher’s exact tests based on cell counts. Multivariate logistic regression models controlling for gender, race, body mass index, age, preoperative American Society of Anesthesiologists score, surgeon, and history of lumbar surgery were used to determine any independent predictors of overnight admission, readmission, emergency department visit, 90-day complication, or subsequent dislocation event with results presented as odds ratio with 95% confidence interval and respective *P* values. All analyses were performed using SAS 9.4 (SAS Institute Inc, Cary, NC).

Results

A cohort with 2247 patients underwent primary THA within the study period. There were 1724 (76.7%) M-THAs and 523 (23.3%) R-THAs included in the analysis. Univariate analyses (Table 1) demonstrated both groups had comparable demographics with the exception of the lesser mean age in the R-THA group (64.47 vs 65.63 years, $P = .030$) and lesser incidence of femoral component cement fixation in the M-THA group (0.19% vs 1.35%, $P = .028$) (Table 1). Intraoperative and postoperative outcomes were mostly comparable, though R-THA patients were found to have significantly less operating room (OR) time (69.98 vs 90.13 minutes, $P < .001$), lesser average postoperative length of hospital stay (days) ($P < .001$), and lower periprosthetic dislocation rate without mechanical failure (0.57% vs 2.49%, $P = .007$) (Table 2). All robotic dislocations were successful with conservative treatment without recurrence (0 of 3), whereas 46% (20 of 43) of traditional dislocators were ultimately revised for recurrent instability. There were no significant

Table 3
Univariate Comparison of Patient-Reported Outcomes Between Robotic and Nonrobotic Total Hip Arthroplasty.

Covariate	Statistics	Robotic		*P* Value
		No (N = 1724)	Yes (N = 523)	
Preoperative PROMIS Global Score	N	521	407	.257
	Mean	46.66	47.78	
	Median	47	50	
Preoperative PROMIS Mental Health Score	N	512	401	.75
	Mean	50.22	50.04	
	Median	51	51	
Preoperative PROMIS Physical Function Score	N	512	400	.906
	Mean	40.62	40.67	
	Median	40	40	
Preoperative KOOS, JR. Score	N	521	406	.568
	Mean	46.66	47.78	
	Median	47	50	
2-16 Weeks PROMIS Global Score	N	474	383	.233
	Mean	72.68	71.4	
	Median	73	70	
2-16 Weeks PROMIS Mental Health Score	N	443	356	.874
	Mean	52.44	52.34	
	Median	53	53	
2-16 Weeks PROMIS Physical Function Score	N	441	357	.154
	Mean	46.98	46.17	
	Median	48	45	
2-16 Weeks KOOS, JR. Score	N	475	385	.568
	Mean	72.68	71.4	
	Median	73	70	
4-6 Months PROMIS Global Score	N	62	58	.814
	Mean	80	80.81	
	Median	81	85	
4-6 Months PROMIS Mental Health Score	N	64	58	.701
	Mean	52.3	52.95	
	Median	53	53	
4-6 Months PROMIS Physical Function Score	N	64	58	.921
	Mean	49.58	49.74	
	Median	51	51	
4-6 Months KOOS, JR. Score	N	62	58	.438
	Mean	80	80.81	
	Median	81	85	
1 Year PROMIS Global Score	N	57	44	.599
	Mean	83.26	81.36	
	Median	85	85	
1 Year PROMIS Mental Health Score	N	56	45	.174
	Mean	54.04	51.89	
	Median	53	53	
1 Year PROMIS Physical Function Score	N	56	45	.722
	Mean	49.75	50.31	
	Median	51	51	
1 Year KOOS, JR. Score	N	57	45	.667
	Mean	83.26	81.36	
	Median	85	85	

PROMIS, Patient-Reported Outcomes Measurement Information System.

differences between available R-THA and M-THA in preoperative or postoperative patient-reported outcomes measurement information system global health, mental health, and physical health (PROMIS-GH, PROMIS-MH, PROMIS-PH), as well as hip disability and osteoarthritis outcome score (HOOS, JR) (Table 3).

Multivariate logistic regression models (Table 4) demonstrated multiple significant correlations with postoperative outcomes. R-THA was found to be significantly correlated to lesser rates of primary periprosthetic dislocation ($P = .046$) and overnight admission ($P < .001$) in univariate analysis. Multivariate analysis subsequently controlling for surgeons further demonstrated improved stability in the R-THA group. In addition, a patient history of lumbar spine surgery was found to be significantly correlated with the increased incidence of periprosthetic dislocation, as well as overnight admission, readmission, postoperative emergency department visit, and all-cause 90-day complications, illustrating the anticipated concerns regardless of the arthroplasty technique.

Of the 368 sample radiographs included for cup position analysis, 141 had R-THA and 227 had M-THA. Univariate comparison of the measured acetabular component anteversion and inclination showed that following R-THA, cup anteversion was significantly greater ($25.6^\circ \pm 5.4^\circ$ vs $20.6^\circ \pm 7.6^\circ$) and cup inclination was significantly lesser ($42.5^\circ \pm 5.3^\circ$ vs $47.0^\circ \pm 6.7^\circ$) than M-THA ($P < .05$). Taking into consideration the classic Lewinnek [2] safe zone, 44.4% of the R-THA met the criteria. Of the R-THAs reviewed, 91.7% met inclination criteria, and 45.8% met version criteria. M-THA had 57.3% that met Lewinnek safe zone with 77.1% that met inclination, and 72.2% that met anteversion criteria. Of note, the robotic acetabular cup placement was usually templated for 22-25° anteversion by practice pattern. Regarding dislocations, we noted no difference in cup position compared to the random sampling of stable hips. In utilizing the same sample size, the surgeon's head size choices did not differ between cohorts. The head sizes ranged from 32 to 44 millimeters in diameter. There were 193 (80.4%) large

Table 4
Multivariate Analysis of Outcomes versus Demographics and Use of Robotic Assistance.

Outcome	Covariate	Level	Odds Ratio (95% CI)	*P* Value
Dislocations	Robotic surgery	No	3.74 (1.03-13.60)	**.046**
		Yes		
	Gender	Female	0.77 (0.42-1.39)	.381
		Male		
	Age		1.01 (0.98-1.05)	.347
	Race	Asian	0.00 (0.00-.)	.992
		Black	1.80 (0.39-8.38)	.453
		Caucasian	1.45 (0.34-6.18)	.613
		Native American	0.00 (0.00-.)	.997
		Native Hawaiian - Pacific Islander	0.00 (0.00-.)	.998
		Other	0.00 (0.00-.)	.986
	Body mass index		0.98 (0.93-1.03)	.441
	ASA	I	0.00 (0.00-.)	.977
		II	0.61 (0.08-4.83)	.636
		III	0.83 (0.11-6.44)	.860
		IV	-	-
	History of lumbar surgery	No	0.28 (0.13-0.59)	**<.001**
		Yes		
	Surgeon	Surgeon 1	0.61 (0.29-1.31)	.205
		Surgeon 2	0.65 (0.30-1.40)	.271
		Surgeon 3	-	-
Readmissions	Robotic surgery	No	0.90 (0.50-1.61)	.723
		Yes		
	Gender	Female	1.46 (0.99-2.15)	.056
		Male		
	Age		1.02 (1.00-1.04)	.067
	Race	Asian	6.89 (1.16-40.94)	**.034**
		Black	0.84 (0.32-2.19)	.715
		Caucasian	1.43 (0.61-3.37)	.415
		Native American	-	-
		Native Hawaiian - Pacific Islander	-	-
		Other	-	-
	Body mass index		1.02 (0.99-1.06)	.182
	ASA	I	0.14 (0.02-0.75)	**.022**
		II	0.20 (0.08-0.52)	**<.001**
		III	0.28 (0.11-0.70)	**.007**
		IV	-	-
	History of lumbar surgery	No	0.21 (0.13-0.33)	**<.001**
		Yes		
	Surgeon	Surgeon 1	0.84 (0.53-1.33)	.458
		Surgeon 2	0.51 (0.30-0.88)	**.015**
		Surgeon 3	-	-
Overnight admission	Robotic surgery	No	12.83 (8.09-20.35)	**<.001**
		Yes		
	Gender	Female	1.86 (1.35-2.57)	**<.001**
		Male		
	Age		1.03 (1.02-1.05)	**<.001**
	Race	Asian	621,544.4 (0.00-.)	.985
		Black	1.66 (0.75-3.64)	.208
		Caucasian	0.78 (0.39-1.55)	.473
		Native American	0.03 (0.00-0.62)	**.023**
		Native Hawaiian - Pacific Islander	195,375.1 (0.00-.)	.997
		Other	1.04 (0.19-5.72)	.960
	Body mass index		1.02 (0.99-1.05)	.116
	ASA	I	0.08 (0.01-0.73)	**.025**
		II	0.17 (0.02-1.38)	.098
		III	0.26 (0.03-2.06)	.202
		IV	-	
	History of lumbar surgery	No	3.25 (1.96-5.39)	**<.001**
		Yes		
	Surgeon	Surgeon 1	0.69 (0.40-1.22)	.203
		Surgeon 2	1.02 (0.56-1.86)	.943
		Surgeon 3	-	-
Emergency department visit	Robotic surgery	No	1.32 (0.88-1.97)	.182
		Yes		
	Gender	Female	1.35 (1.01-1.81)	**.043**
		Male		
	Age		1.02 (1.01-1.03)	**.006**
	Race	Asian	0.00 (0.00-.)	.984
		Black	1.92 (0.91-4.05)	.085
		Caucasian	1.55 (0.76-3.14)	.226
		Native American	0.00 (0.00-.)	.993
		Native Hawaiian - Pacific Islander	0.00 (0.00-.)	.995

(*continued on next page*)

Table 4 (*continued*)

Outcome	Covariate	Level	Odds Ratio (95% CI)	*P* Value
		Other	0.48 (0.06-4.02)	.498
	Body mass index		0.98 (0.96-1.01)	.162
	ASA	I	0.19 (0.04-1.03)	.055
		II	0.45 (0.18-1.15)	.096
		III	0.88 (0.35-2.20)	.784
		IV	-	-
	History of lumbar surgery	No	0.35 (0.23-0.53)	**<.001**
		Yes		
	Surgeon	Surgeon 1	1.06 (0.73-1.54)	.755
		Surgeon 2	1.26 (0.87-1.84)	.224
		Surgeon 3	-	-
All-cause 90-d complications	Robotic surgery	No	1.09 (0.77-1.54)	.631
		Yes		
	Gender	Female	1.46 (1.14-1.87)	**.003**
		Male		
	Age		1.02 (1.01-1.03)	**.004**
	Race	Asian	1.75 (0.34-9.06)	.503
		Black	1.53 (0.85-2.76)	.159
		Caucasian	1.37 (0.79-2.39)	.260
		Native American	0.00 (0.00-.)	.981
		Native Hawaiian - Pacific Islander	0.00 (0.00-.)	.986
		Other	0.26 (0.03-2.11)	.209
	Body mass index		0.99 (0.97-1.01)	.306
	ASA	I	0.13 (0.04-0.47)	**.002**
		II	0.28 (0.13-0.60)	**.001**
		III	0.49 (0.24-1.03)	.059
		IV	-	-
	History of lumbar surgery	No	0.28 (0.19-0.40)	**<.001**
		Yes		
	Surgeon	Surgeon 1	1.04 (0.76-1.41)	.819
		Surgeon 2	0.91 (0.66-1.26)	.585
		Surgeon 3	-	-

Bolded text indicates statistical significance ($P < .05$).
ASA, American Society of Anesthesiologists score.

head sizes (≥36 mm) in the M-THA cohort and 123 (84.2%) in the R-THA cohort, not a statistically significant difference.

Discussion

Recent literature has garnered considerable interest in defining where robotic-assisted surgery may provide sufficient advantages to justify the higher initial cost [19]. The purpose of this study was to add to the limited but expanding body of literature comparing R-THA and M-THA, primarily investigating dislocation and subsequent revision and secondarily evaluating immediate postoperative outcomes, patient-reported outcomes, as well as cup positioning.

Following both a univariate and multivariate regression model, this retrospective review of prospectively collected registry data found that R-THA demonstrated a lower rate of primary periprosthetic dislocation compared to M-THA. Interestingly, 46% of the M-THA dislocations went on to recurrent instability leading to revision surgery, and none of the R-THA dislocations required more than conservative management. Such costly episodes of subsequent care are important to consider in the overall value equation. For secondary findings, this investigation determined that R-THA had lower operative times and hospital lengths of stay with an advantage toward outpatient discharge. Finally, the radiographic randomized sample investigation found that R-THA exhibited greater anteversion and less inclination with a continued demonstration of accuracy but notably more cups outside of the historic Lewinnek safe zone. All other metrics, including patient-reported outcomes, were similar between the two groups.

With a moderately low complication rate after THA, mechanical complications like dislocation have created a premise for robotic-assisted surgery to aid in the controlled replication of anatomic implant positioning and limb length. Recent large database studies utilizing the Australian registry and Medicare Part A claims have found that computer navigation was associated with lower dislocation rates and revisions related to the acetabular component [20,21]. Much like earlier generation navigation systems, THA performed with robotic assistance has consistently demonstrated superior cup placement and mechanical alignment compared to conventional techniques [22–25]. There is limited data comparing a primary outcome of dislocation when investigating R-THA vs M-THA. Illgen et al. demonstrated a lower dislocation rate in R-THA, but this was not statistically significant (0% to 3%; $P > .05$) [23]. This current cohort is the first to demonstrate that R-THA had a 3.47 times lower dislocation rate compared to M-THA after controlling for gender, race, body mass index, age, preoperative American Society of Anesthesiologists score, surgeon, and history of lumbar surgery. For the surgeon performing the majority of the R-THA, there were limited robotic dislocations with many more in his manual cohort during this study period, which accounts for the multivariate finding still holding up for a stability benefit. Revision surgery for instability was not encountered with the robotic cohort while it approached almost half of the patients with manual dislocations. This was despite the fact that cup positions were similar on average, again showing contemporary dislocations are often within safe zones illustrating the multifactorial nature of the problem [26,27].

Another theme comparing R-THA and M-THA that has generated a lot of debate has been the notion that, similar to navigation, robotic-assisted surgery increases surgical time with questionable clinical benefits [28]. Domb et al. found that R-THA had a higher mean OR time compared to M-THA (110 vs 102 minutes; $P = .08$) [20]. This concept of longer OR time has been a common trend with the introduction of robotic arthroplasty surgery [29–32]. Our data with respect to surgical time illustrates that with experience, the extra time required for registration may be balanced with reaming and trialing efficiencies afforded by this haptic technology. The added intraoperative technology, once effectively incorporated into an optimized workflow, does not necessarily have to lengthen OR time and may actually yield more immediate episodes of care savings. While operative times are certainly multifactorial, our 20-minute shorter average robotic procedure duration suggests that time burden does not need to be a deterrent even in a teaching hospital when considering the adoption of robotic technology for THA.

Improper cup positioning has been correlated to a higher rate of periprosthetic dislocation, for which multiple methods of cup implantation have aimed to improve upon in recent years [2,33,34]. M-THA can demonstrate a 38%-47% rate of acetabular implant malpositioning [35,36]. Therefore, for many surgeons, the current intraoperative tools may be inadequate to reproducibly implant the acetabular component from case to case. This may be truer for those that do not regularly perform hip arthroplasty, as fellowship-trained, high-volume arthroplasty specialists tend to have less variation given continuous refinement of technique. Nonetheless, outliers still exist in every practice [37]. It is important to note that we did not evaluate offset or leg length. While we did have precise navigated offset and length data recorded in the majority of the robotic cohort, there was no comparable method to evaluate the manuals. Lack of ideal femoral rotation during positioning for standard radiographs can often underestimate the offset reproduction and vary even in the same patient depending on the date of image capture. CT would be ideal as the only way to truly acquire accurate numbers but was beyond the scope of our series.

A benefit many have noticed with R-THA is comparable postoperative radiographs in every patient. The reproducibility of technological assistance for cup placement across multiple platform options enables controlled positioning based on surgeon preference. Multiple authors have previously shown that superior cup positioning and offset, which were found with R-THA, compared to manual techniques [22–25,38]. While this is likely a contributing factor for the increased stability noted in our series, it is clearly not the only factor. Technology is only as good as the input data it is instructed to replicate. Rudimentary estimates of 'safe-zones' do not account for combined anteversion, biomechanical restoration, and the rapidly evolving concept of the hip-spine relationship or functional positioning. By utilizing our small random sample size, this cohort demonstrated that R-THA had significantly less inclination and more anteversion by choice. The safe zone criteria demonstrated similar findings as previous data that demonstrated improved precision in R-THA than M-THA [22–25]. More data available for surgeons to act upon may factor into decisions on head size and offset and which side of the implant construct to add or remove anteversion. The fact that our manual surgeries were more accurate at restoring a classic Lewinnek safe zone for anteversion than R-THA (57.3% vs 44.4%) illustrates the confines of antiquated boundaries. The decision to target 25° of anteversion in the majority of the R-THA naturally pushed beyond the upper limit of that definition, which may in itself be a protective factor to consider [26]. The precision to hit a target, whether that be a predetermined range or functional hip-spine adjustments, is a clear advantage of the current generation of technology assistance. The definition of what to target may be more elusive.

Although technology in hip arthroplasty allows for improved precision, this does not always translate into clinical relevance. R-THA may allow for safer minimally invasive surgery since direct visualization is not as essential, which may theoretically present as improved PROMs, though this has not always been borne out in the literature. Much like the debate over the optimal surgical approach to the hip, the treatment of what is equally recognized as soft tissue surgery is dependent on surgeon preferences with the tools available at that time. If the definition of success is patient-reported outcome measures, our current study once again found no difference in scores, which included hip-specific and global health PROMs. This was echoed in another large series by Singh et al who looked at both a robotic and navigation cohort compared to manual [39] but contradicted the findings from Domb et al [15]. This study utilized the Forgotten Joint Score that has been used in other studies to more effectively tease out subtle nuances in PROMs. While instability is an outcome of importance for patients, our patient-reported outcome scores did not reflect a difference at any time point. This metric may be better suited to evaluate more responsive differences since subtle postoperative differences from variation in intraoperative technology may demonstrate response bias that causes scale attenuation effects.

Limitations for the study must be acknowledged. While registry data are prospectively collected, a retrospective review of such data with subgroups presents room for an inherent bias. The fact that most R-THAs were performed by one surgeon may limit the generalizability of the data generated in the R-THA cohort in this study, although multivariate analysis accounted for the surgeon. Similarly, although the goal of the study was to compare overall dislocation rates over the 6-year study period and the dislocation rate of the pooled surgeon cohort matches other data in the literature for incidence of dislocation after posterior approach M-THA [40], another limitation is the absence of individualized dislocation rate by surgeon and year for the analysis. We did note a higher dislocation rate early in the study period. An attempt at subgroup analysis using just the latter half of the time period (2017-2020) with an improved steady-state dislocation rate still yielded a 2.8 times higher dislocation rate with M-THA, but then multivariate control was not possible given one surgeon's conversion to all R-THA. Due to the academic nature of the health system studied, residents within the case do add to the variability of the procedures performed. Since teaching methods vary based on the experience of the resident, as well as the teaching allowance of the senior staff, levels of resident involvement can vary by case. For example, the majority of the case could be done by a senior resident, whereas only select portions can be done by junior residents, potentially affecting outcomes and length of surgery. All surgeries within the cohort were done with the attending surgeon scrubbed and either closely supervising or actively performing the case. Operative time efficiency is likely correlated to the surgeon and would not be expected to be a result of the technology despite some technical efficiencies made possible by its usage. The reliance on the express robotic workflow without navigation of the femoral version also makes comparisons to other series heterogeneous if not well defined.

Combined anteversion during a THA is utilized as an objective marker for component placement and hip stability. Since postoperative radiographs do not provide a reliable mode of measurement for the femoral component version, this objective data could not be collected during the radiographic review. The so-called 'Ranawat sign', including combined anteversion, was used for intraoperative estimation in the majority of the cases, but even the robotic cohort did not use the technology for discrete femoral version, so this major variable remains unaccounted for in the analysis [41]. Particularly for cup positioning and head size, our evaluation represents only a randomly selected sample of controls along with those that had dislocation episodes, and our series did not have reproducible offset and leg length measurements that are equally known to influence stability. Although the retrospective review controlled for surgeons in the analysis, many M-THA surgeries utilized different implant systems than the robotic cohort, which introduces other factors that can contribute to primary dislocation. However, all implants were typical constructs widely equivalent in most registries, and no surgeon relied primarily upon anything more than standard heads and liners. Finally, although the cohorts demonstrated a statistically favorable ratio of 3:1, the secondary outcomes such as length of stay should be carefully interpreted since they are not appropriately powered to make clinically relevant conclusions, especially in light of other factors, including the push toward more ambulatory surgery in the middle of the study period. The length of follow-up available for analysis in the R-THA cohort is not as robust as the follow-up available for the M-THA cohort, and it is noted that although only three dislocations were noted in the R-THA cohort, the incidence of late dislocations is not picked up as readily in this particular dataset given this limitation in follow-up.

Conclusions

In this cohort study of prospectively collected registry data, R-THA demonstrated improved postoperative outcomes with regard to instability with one-fourth the risk. It adds to the literature that R-THA continues to produce reliable cup positioning that could contribute to this cohort's decreased dislocation rate. However, the multifactorial nature of instability points to the added value of additional information available for intraoperative surgical decisions that may ultimately be the primary benefit of such technology. Robotic assistance was found to not only protect against dislocation but also revision for subsequent recurrence, and also benefit for earlier and outpatient discharge home. The study demonstrates that even at an academic surgical program, R-THA does not have to increase the operative time. Robotic-assisted hip surgery continues to increase its adoption, and continued high-level studies are necessary to define its significant advantages.

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