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Can robotic technology mitigate the learning curve of total hip arthroplasty?

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Aims

Traditionally, acetabular component insertion during total hip arthroplasty (THA) is visually assisted in the posterior approach and fluoroscopically assisted in the anterior approach. The present study examined the accuracy of a new surgeon during anterior (NSA) and posterior (NSP) THA using robotic arm-assisted technology compared to two experienced surgeons using traditional methods.

Methods

Prospectively collected data was reviewed for 120 patients at two institutions. Data were collected on the first 30 anterior approach and the first 30 posterior approach surgeries performed by a newly graduated arthroplasty surgeon (all using robotic arm-assisted technology) and was compared to standard THA by an experienced anterior (SSA) and posterior surgeon (SSP). Acetabular component inclination, version, and leg length were calculated postoperatively and differences calculated based on postoperative film measurement.

Results

Demographic data were similar between groups with the exception of BMI being lower in the NSA group (27.98 vs 25.2; $p = 0.005$). Operating time and total time in operating room (TTOR) was lower in the SSA ($p < 0.001$) and TTOR was higher in the NSP group ($p = 0.014$). Planned versus postoperative leg length discrepancy were similar among both anterior and posterior surgeries ($p > 0.104$). Planned versus postoperative abduction and anteversion were similar among the NSA and SSA ($p > 0.425$), whereas planned versus postoperative abduction and anteversion were lower in the NSP ($p < 0.001$). Outliers > 10 mm from planned leg length were present in one case of the SSP and NSP, with none in the anterior groups. There were no outliers > 10° in anterior or posterior for abduction in all surgeons. The SSP had six outliers > 10° in anteversion while the NSP had none ($p = 0.004$); the SSA had no outliers for anteversion while the NSA had one ($p = 0.500$).

Conclusion

Robotic arm-assisted technology allowed a newly trained surgeon to produce similarly accurate results and outcomes as experienced surgeons in anterior and posterior hip arthroplasty.

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Introduction

Robotic arm-assisted surgery aims to reduce errors and improve accuracy for implant position in total hip arthroplasty (THA). In THA, implant positioning plays a pivotal role in good clinical outcomes and reduces long-term wear, therefore technology has been developed to help surgeons consistently achieve more accurate implant position. Computer-assisted navigation provides surgeons with knowledge to guide them intraoperatively, with some systems requiring CT, fluoroscopy-based, and imageless technology. Computer navigation provides patient-specific anatomical landmarks that provide information for optimal implant positioning. Computer navigation has been shown to accurately place components, but does not offer the same ability to conduct patient-specific preoperative planning as CT-based robotic systems.[1-5] Some evidence suggests that robotic arm-assisted

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THA is more accurate, however the cost and learning curve associated with robotic arm-assisted THA has yet to demonstrate long-term clinical benefits.[6-8]

Learning curves for surgical techniques and technologies have been evaluated in two main ways in the literature. One is to examine variables related to the surgical process such as operating time, blood loss, or technical success of the procedure. The other focuses on outcomes such as complications and patient-reported outcome measures. Previous studies have demonstrated significant learning curves with both anterior and posterior approach THA.[9,10] Important goals of technology-augmented surgery are to improve the accuracy and reproducibility of surgical procedures, while shortening the learning curve associated with difficult procedures. Robotic arm-assisted THA has been shown to improve accuracy of component placement and reduce outliers.[11,12] There is limited evidence to suggest that robotic arm-assisted THA improves clinical outcomes and reduces complications.[13,14]

Our study aims to assess a new, inexperienced surgeon's early experiences using both surgical process and patient outcome measures for robotic arm-assisted THA, compared to manual techniques by experienced surgeons. To our knowledge, this is the first study to assess surgical process and clinical outcomes in a single study comparing a newly trained arthroplasty surgeon to experienced senior surgeons who use no technology in their surgeries.

Methods

After institutional review board approval at all institutions, data were retrospectively reviewed for 120 patients at two institutions. The first 30 anterior and 30 posterior approach THAs performed by a newly graduated surgeon (BSW) were compared to a control group of 60 subjects (30 anterior and 30 posterior) performed by two different experienced surgeons (ES and MA). The newly trained arthroplasty surgeon did not perform a single THA case in practice outside of these 60 cases. The newly trained surgeon's prior experience with THA involved 240 posterior and 130 anterior approaches, as a fellow assisting senior surgeons. The senior anterior surgeon (MA) had been in practice 31 years and had performed over 5,000 anterior hip arthroplasties. The senior posterior surgeon (ES) had been in practice 18 years and has performed over 5,000 posterior hip arthroplasties. Surgeries were performed by the new surgeon using a robotic arm-assisted system, compared to standard THA by the two experienced surgeons. All patients underwent pre- and postoperative AP radiographs. Acetabular component inclination and version were calculated postoperatively with Elin Bild Roentgen Analyse (EBRA) software (Unit Geometry and CAD, University of Innsbruck, Austria). Clinical outcomes scores were assessed both preoperatively and postoperatively using Harris Hip Score (HHS).[15]

Preoperative imaging and templating. Both senior surgeons performed preoperative templating on all study patients using their radiology system (Sectra, USA) using standing place anteroposterior pelvic radiographs. Patients undergoing robotic arm-assisted THA also underwent a preoperative CT scan for preoperative planning. The preoperative CT scan of the pelvis and femur is used to create a 3D CAD model to provide optimal implant position. The new surgeon reviewed the plan prior to surgery to adjust optimal acetabular and femoral component placement. Targeted angles for the senior surgeons were 40° for inclination in all cases and between 20° to 25° for anteversion for all cases. Neutral leg lengths were the goal for the senior surgeons in all cases presented. For the newly graduated surgeon, specific goals were made using preoperative templating with the 3D CAD model (Stryker, USA) prior to each surgery.

Statistical analysis. Statistical analyses were performed with SPSS 25.0 software package (SPSS, USA). Mean and standard deviation (SD) are reported for continuous data while categorical data are presented as counts and percentages. Absolute error in acetabular component positioning and leg length restoration were calculated to account for values above and below planned targets. Outliers from acetabular component position and leg length discrepancy were identified by thresholds of 10° for acetabular inclination and anteversion and 10 mm for leg length discrepancy. Comparative analysis was performed using independent sample *t*-tests for continuous data and chi-squared test or Fisher's exact test for categorical data with statistical significance set at $p < 0.05$.

Results

A total of 120 patients were included in this study. This represented 30 patients in each approach (anterior vs posterior) and surgeon experience (new vs experienced) group. Demographic data are seen in Table I. There was no significant difference between age, sex, and BMI between the posterior experienced surgeon and posterior new surgeon groups. The anterior new surgeon group had a lower BMI ($p = 0.005$) than the experienced surgeon group. Age and sex were similar between anterior approach groups. Preoperative leg length discrepancy was greater ($p = 0.005$, Table I) in the anterior approach new surgeon group (mean 4.1, SD 3.9) compared to the experienced surgeon group (mean 2.53, SD 2.5)

Operative and clinical outcomes. Overall, there was no difference in operating time between the robotic arm-assisted new surgeon and the senior surgeon performing the posterior approach. The total time in the operating room was 15.2 minutes longer for the robotic arm-assisted new surgeon ($p = 0.0135$, Table II) for the posterior approach. Both operating time and total time in the operating room were significantly greater for the robotic arm-assisted new surgeon performing the anterior

Table I. Preoperative patient characteristics.

Variable	Posterior approach			Anterior approach		
	Senior surgeon	New surgeon	p-value	Senior surgeon	New surgeon	p-value
Mean age, yrs (SD)	65.3 (11.5)	66.0 (12.6)	0.805*	62.8 (6.9)	60.2 (14.4)	0.378*
Sex, n (%)			0.605†			0.246†
Female	20 (66.7)	14 (46.7)		15 (50)	21 (70)	
Male	10 (33.3)	16 (53.3)		15 (50)	9 (30)	
Mean BMI, kg/m^2 (SD)	31.5 (5.8)	30.8 (15.0)	0.605*	28.0 (3.7)	25.2 (3.9)	0.005*
Mean preoperative leg length discrepancy, mm (SD)	5 (3.8)	7.0 (5.5)	0.125*	2.5 (2.5)	4.1 (3.9)	< 0.001*
Mean preoperative Harris Hip Score (SD)	55.4 (12.3)	40.6 (11.9)	< 0.001*	53.8 (9.5)	47.4 (12.4)	0.036*

*Independant-sample *t*-test
†Chi-squared test
SD, standard deviation.

Table II. Operating time and clinical outcomes of total hip arthroplasty by surgical approach and surgeon experience.

Variable	Posterior approach			Anterior approach		
	Senior surgeon	New surgeon	p-value	Senior surgeon	New surgeon	p-value
Mean operating time, mins (SD)	80.0 (14.5)	83.6 (18.4)	0.390*	59.5 (5.8)	110.3 (27.5)	< 0.001
Mean total time in operating room, mins (SD)	125.5 (19.9)	140.7 (26.2)	0.014*	97.4 (5.9)	161.8 (36.1)	< 0.001*
Mean 6-week postoperative HHS (SD)	76.2 (17.4)	64.4 (16.0)	0.013*	86.1 (6.2)	64.1 (18.8)	< 0.001*
Mean change in HHS (SD)	20.8 (14.9)	25.1 (18.4)	0.345*	32.5 (10.7)	20.5 (14.8)	0.002*
Total complications, n (%)	0 (0)	1 (3.3)	0.500†	4 (13.3)	3 (10)	0.500†
		Delayed wound healing requiring antibiotics ×1		LFCN numbness ×3	LFCN numbness ×2	
				Serotonin syndrome ×1	Intraoperative greater trochanter fracture ×1	

*Independant-sample *t*-test
†Fisher's exact test
HHS, Harris Hip Score; LFCN, lateral femoral cutaneous nerve; SD, standard deviation.

approach (Table II). There were no differences in complication rates between the robotic arm-assisted new surgeon and experienced surgeon in either the posterior (p = 0.500) or anterior approach (p = 0.500) groups. In the posterior approach group with the new surgeon, one patient experienced delayed wound healing, requiring antibiotics. Both the senior surgeon and new surgeon experienced complications when performing the anterior approach. Ten percent of anterior approach patients (3/30) in the experienced surgeon group experienced postoperative lateral femoral cutaneous nerve (LFCN) numbness, while 6.7% (2/30) in the new surgeon group had postoperative LFCN numbness. The new surgeon had one instance of intraoperative greater trochanteric fracture when performing the anterior approach. Mean HHSs preoperatively and six weeks postoperatively were lower in the robotic arm-assisted new surgeon patients for both posterior and anterior approaches (Tables I and II). As can be seen in Table II, HHSs improved postoperatively in all surgeon and approach groups. Increase in HHS was similar in the new surgeon and experienced surgeon posterior approach groups (p = 0.345, Table II). The experienced surgeon anterior approach group experienced greater improvement in HHS postoperatively (p = 0.002, Table II).

Radiological outcomes. Radiological results can be seen in Table III. For the posterior approach acetabular component positioning was more accurate for both abduction (1.55° vs 5.2°; p < 0.001) and anteversion (1.12° vs 5.3°; p < 0.001) for the robotic arm-assisted new surgeon. Additionally, there were more > 10° anteversion outliers in the posterior experienced surgeon group (p = 0.012, Table III). There was no difference in accuracy in achieving planned leg length between the experienced and robotic arm-assisted new surgeon in the posterior approach groups. No difference in accuracy in achieving planned leg length, acetabular anteversion, or acetabular abduction were found between the experienced and robotic arm-assisted new surgeon performing anterior approach. There was also no difference in outliers between anterior approach groups.

Discussion

In our study, we found that the use of robotic arm-assisted THA for the new surgeon allowed for a decrease in outliers that have been previously reported in new surgeon manual THAs. The accuracy of placement is comparable with previous studies of robotic THAs; however, our study is the first to assess the use of a new surgeon accuracy using robotic arm-assisted THA compared to manual

Table III. Radiological outcomes of total hip arthroplasty by surgical approach and surgeon experience.

Variable	Posterior approach			Anterior approach		
	Senior surgeon	New surgeon	p-value	Senior surgeon	New surgeon	p-value
Mean leg length discrepancy, mm (SD)						
Planned	0 (0)	0.3 (3.9)	0.470*	0 (0)	0.8 (1.2)	0.690*
Postoperative	3.2 (2.7)	2.0 (2.7)	0.087*	2.7 (2.7)	3.1 (3.3)	0.580*
Difference	3.2 (2.7)	3.5 (3.5)	0.103*	1.7 (2.3)	2.7 (2.7)	0.126*
Outlier > 10 mm, n (%)	1 (3.3)	1 (3.3)	1.000†	0 (0)	0 (0)	1.000†
Mean acetabular component abduction, ° (SD)						
Planned	40 (0)	40 (0)	1.000*	40 (0)	39.9 (0.3)	0.340*
Postoperative	42.8 (4.9)	41.3 (1.6)	0.100*	41.0 (1.8)	40.4 (2.0)	0.205*
Difference	5.2 (2.1)	1.6 (1.4)	< 0.001*	1.6 (1.4)	1.3 (1.4)	0.420*
Outlier > 10°, n (%)	0 (0)	0 (0)	1.000†	0 (0)	0 (0)	1.000†
Mean acetabular component anteversion, ° (SD)						
Planned	24.5 (1.0)	24.0 (3.4)	< 0.001*	20 (0)	21.7 (2.5)	0.001*
Postoperative	29.9 (4.4)	23.3 (3.1)	< 0.001*	21.6 (1.7)	23.7 (3.6)	0.004*
Difference	5.3 (3.9)	1.1 (1.3)	< 0.001*	1.9 (1.3)	2.0 (2.6)	0.924*
Outlier > 10°, n (%)	6 (20)	0 (0)	0.012†	0 (0)	1 (3.3)	0.500†

*Independant-samples *t*-test
†Fisher's exact test
SD, standard deviation.

THAs performed by two experienced surgeons. In addition, this study is the first to report the use of robotic arm-assisted THA for a new surgeon for both the anterior and posterior approach.

Data from previous studies have shown improved accuracy in component placement when using robotic THA. A matched pair study found that navigated THA was more accurate than manual technique, with navigated THA accurate in 80% of cases compared to only 64% of manual cases.[16] Nodzo et al[11] evaluated the accuracy of robotic assisted intraoperative implant positioning measurements using postoperative CT scans and found that both the intraoperative acetabular and femoral component position were accurately correlated to postoperative CT measurements. Kamara et al[12] reviewed a single-surgeon case series to assess acetabular accuracy and found that 76% of manual THAs were within the surgeon's target zone compared to 97% of the robotic assisted THAs, demonstrating that adoption of robotic assisted THA provided significant improvement in acetabular component positioning during THA. Similarly, this study demonstrated a 97% accuracy rate for the new surgeon using robotic arm assistance. The robotic arm-assisted new surgeon's accuracy compared favourably to experienced surgeons using both anterior and posterior approaches for THA, suggesting that there is no significant learning curve for accuracy in acetabular component placement for a new surgeon using robotic arm assistance. Similarly, Kayani et al[17] did not find a learning curve associated with achieving accuracy using robotic arm-assisted technology; however, there was a 12-case learning curve for surgeons and their operating room staff that increased operating time.

The literature varies on increase in operating time with reports ranging from eight to 58 minutes longer for the use of intraoperative technology.[2,18] The reasons for increased intraoperative time is likely multifactorial. Additionally, it does not take into account the valuable preoperative planning and intraoperative insight that technology can provide for the surgeon. In this study, operating time was significantly greater for the robotic arm-assisted new surgeon performing anterior approach THA. Increased operating time for the new surgeon is consistent with literature demonstrating a learning curve for operating time of approximately 50 cases for anterior approach THA and 12 cases for using robotic arm technology.[17,19] Preoperatively, it was noted that HHS was lower for patients in both new surgeon groups compared to senior surgeons. Additionally, the new surgeon's patients had greater leg length discrepancy in the anterior approach group and trended towards greater leg length discrepancy in the posterior approach group. This suggests that patients in the new surgeon groups may have had worse preoperative deformity and thus may represent more challenging cases leading to longer operating time. For a new surgeon the use of technology, specifically robotic arm-assisted technology, can provide guidance for component position, and allow the surgeon to preoperatively alter component position. This preoperative knowledge provides confidence in the operating room, in combination with the use of technology to accurately place components and reduce outliers that might otherwise occur due to inexperience.

Redmond et al[20] found that although there was a learning curve associated with robotic arm-assisted THA, operating time decreased with experience and a decrease in acetabular component outliers, suggesting that while there is a learning curve with robotic arm-assisted THA the clinical benefits are better implant positioning and decreased outliers. There is a paucity of literature that correlates robotic assisted THA and clinical outcomes. Illgen et al[13] reported that the improved acetabular accuracy in robotic assisted THA significantly reduced dislocation rates when compared to manual THA. This study found no difference in surgical complications between the robotic arm-assisted new surgeon and the two experienced surgeons. Previously, studies have shown increased complications with the anterior approach until experience over 50 cases.[10,21] Our results suggest that robotic assistance mitigates the learning curve for early complications for a new surgeon. However, this study was likely underpowered to detect differences in complication rates. Bukowski et al[14] reported robotic assisted THA clinical outcomes at a minimum of one year and found that patients who underwent a robotic assisted THA had better clinical outcomes compared to a manual group. However, there have been no large multicentre studies that assess clinical outcomes after robotic assisted THA. This study found that robotic arm-assisted THA did not lead to a greater increase in HHSs compared to experienced surgeons using manual techniques.

For a new surgeon there is a learning curve intraoperatively and increased level of stress associated with initial cases. Intraoperative stress has been associated with reduced technical skills and altered operative performance.[17] In our study, robotic arm-assisted THA was an additional technological tool that was used in the operating room to help reduce stress by providing real-time haptic feedback intraoperatively. Intraoperatively the surgeon has an experienced technician to help navigate any system details and assist with intraoperative data capture. The use of robotic arm-assisted THA can provide various benefits for the surgical team and surgeon in addition to component position accuracy. However, while there are considerable benefits associated with robot arm-assisted technology it is also important for surgeons to recognize its limitations. For example, the new surgeon had an intraoperative greater trochanter fracture while performing the anterior approach. Greater trochanter fracture in an anterior approach is usually related to surgeon error in not adequately releasing capsule, and occurs in more inexperienced surgeons when preparing the femur. This is a portion of the surgical procedure that robotic arm assistance cannot aid the surgeon in performing, and therefore relies upon surgeon training and experience to avoid complications.

There are important limitations to this study. Firstly, this study reports the results between three different surgeons with varying intraoperative techniques, perioperative management, and postoperative protocols. Another limitation is the lack of long-term follow-up, which would allow the inclusion of survivorship data. Lastly, this study reports on a small cohort of patients, but the aim was to review the new surgeon data, therefore the first 30 cases of each approach were used, and the authors felt that this was the appropriate number of cases to define a "new surgeon."

The findings of this study may influence and provide better understanding about the use of robotic arm-assisted surgery. This study highlights the use of technology, specifically in the setting of a new surgeon, to help reduce outliers and improve component position accuracy. Robotic arm-assisted technology mitigated the learning curve for a newly trained surgeon, allowing the surgeon to produce similarly accurate results and outcomes as experienced surgeons in anterior and posterior hip arthroplasty.

Take home message

- Robotic arm-assisted technology mitigated the learning curve for a newly trained surgeon, allowing the surgeon to produce similarly accurate results and outcomes as experienced surgeons in anterior and posterior total hip arthroplasty.
- The new surgeon was able to avoid clinically important outliers in > 95% of their cases.

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- R. Ren: Conducted the statistical analysis, Collected and managed the data.
- C. Ojard: Collected and managed the data, Edited and wrote the manuscript.
- B. S. Waddell: Developed the idea, Designed and oversaw the study, Edited the manuscript, "New surgeon" in study.

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