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The Learning Curve Associated With Robotic-Assisted Total Hip Arthroplasty

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ABSTRACT

There are no reports examining the learning curve during the adoption of robotic assisted THA. The purpose of this study was to examine the learning curve of robotic assisted THA as measured by component position, operative time, and complications. The first 105 robotic-assisted THAs performed by a single surgeon were divided into three groups based on the order of surgery. Component position, operative time, intra-operative technical problems, and intra-operative complications were recorded. There was a decreased risk of acetabular component malpositioning with experience ($P < 0.05$). Operative time appeared to decrease with increasing surgical experience ($P < 0.05$). A learning curve was observed, as a decreased incidence of acetabular component outliers and decreased operative time were noted with increased experience.

Multiple factors have the potential to influence the short- and long-term outcomes of total hip arthroplasty (THA) including patient characteristics, surgical technique, and implant features. Optimal component positioning is one surgeon-controlled factor, which plays a large role in preventing complications including hip dislocations, accelerated bearing wear, poor biomechanics, leg length discrepancy, and revision surgery [1–3]. Currently, hip instability and mechanical loosening account for over 40% of revision hip arthroplasties; and both conditions may be directly related to component positioning [4].

The ideal orientation of the acetabular component continues to be debated. Lewinnek et al defined a safe zone for acetabular components as 15° ± 10° of anteversion and 40° ± 10° of inclination. This safe zone was based on hip stability; however, higher rates of bearing surface wear have been seen when the acetabular component inclination is greater than 45° [5]. This has led some authors to modify the safe zone for acetabular inclination to 30–45° [2]. Other authors have put forth a combined anteversion safe zone, which takes femoral anteversion into account for determination of the safe zone [6]. Two large studies have recently been published documenting a significant percentage of malpositioned acetabular components at high volume institutions [2,7]. Depending on the safe zone used, only 38–47% were in the ideal position.

Appropriate femoral component selection and positioning are essential for satisfactory reconstruction. Improper femoral component placement may lead to leg length inequality, altered offset, and instability. Limb length inequality can be a source of patient dissatisfaction, and is the second most common cause of litigation in reconstructive surgery [8].

Multiple techniques have been put forward over the last two decades to optimize component positioning including: computer navigation, mechanical navigation, intra-operative fluoroscopy, and robotic assistance [9–12]. Many of these guidance techniques have shown the ability to decrease component malposition; however, these techniques often present intra-operative challenges [11,13,14]. Technical complexity, increased operating room time, and expense have been offered as reasons not to adopt navigation [15].

Robotic assisted THA is a new technology, which has the potential to improve acetabular component position compared to a conventional technique [10]. Robotic assisted THA utilizes a computed tomography (CT) based navigation system; and a robotic arm, which assists in acetabular reaming and component placement. Like all surgical procedures, robotic assisted THA likely has a learning curve; and to our knowledge, no study exists examining the learning curve of robotic assisted THA. The purpose of this study was to examine the learning curve of robotic assisted THA as measured by component position, operative time, and intra-operative complications.

Materials and Methods

Subjects

Using a prospectively constructed database, we performed a review of the first 105 robotic assisted THAs performed by the senior

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author (BGD). From June 2011 to August 2013 patients undergoing robotic assisted THA via a posterior approach were included. Patients were excluded if they had missing or rotated postoperative anteroposterior radiographs. The patients were divided into three groups of 35 for comparison purposes. Group A consisted of the first 35 patients undergoing robotic assisted THA by the senior surgeon. Group B consisted of patients 36–70, and Group C consisted of patients 71–105. Component positioning, operative time, intra-operative technical problems, and complications were compared between the groups. Age, gender, and body mass index (BMI) were recorded on all patients. Institutional review board approval was obtained prior to initiation of this study.

Surgical Technique

All patients underwent preoperative CT scans of the affected hip and knee. A standard preoperative template was utilized to determine component sizing and positioning; this served as a comparison for a three dimensional computer based model built from the CT scan. The senior surgeon templated component placement using the three dimensional CT scan data prior to each case. A standardized mini-posterior operative approach was utilized for all robotic assisted THAs. All patients were placed in the lateral decubitus position. An incision 10–12 cm was utilized to perform a mini-posterior approach to the hip. The hip was dislocated and a screw was placed in the greater trochanter for femoral registration. The robotic assisted THAs were performed using the MAKO robotic hip system (MAKOplasty total hip application; MAKO Surgical Corporation, Fort Lauderdale, FL, USA), which is a robotic-assisted computer navigation system that uses RIO (Robotic Arm Interactive Orthopedic System) for reaming the acetabulum and acetabular component placement. Following femoral registration the neck osteotomy is navigated and created. The femur was then prepared for an uncemented implant. The acetabulum was then exposed and registered using three pins and an array in the iliac crest. Pelvic tilt and rotation are accounted for by the navigation system and the robotic arm was used to prepare the acetabulum and impact the acetabular component. For this study, all acetabular components were planned at 40° of inclination and 20° of anteversion. The hip was trialed for stability. During the study period no acetabular components required a change in position due to stability. Intraoperative feedback of leg length, offset, and femoral version was provided by the navigation system.

Implants

All robotic assisted THAs used the Restoris Trinity acetabular component (Corin Group PLC, Cirencester, UK). The femoral components utilized either the Restoris Metafix (Corin Group PLC, Cirencester, UK) or Smith & Nephew Anthology (Smith & Nephew, London, UK) stem depending on preoperative templating.

Radiographic Measurements

At the two-week postoperative visit all patients received a supine AP pelvic radiograph, which was used to measure acetabular inclination and anteversion. Pelvic radiographs with the symphysis rotated greater than 10 mm from the coccyx were discarded, and a radiograph from the three-month follow-up visit was used for measurement. The measurements were obtained using Trauma-Cad software (build number 2.2.535.0, 2012, Voyant Health, Petach-Tikva, Israel). This software allows measurement of cup inclination and version on the AP pelvis. The accuracy of this software for inclination and version measurements has been validated [16]. Leg length discrepancy (LLD) was measured by drawing a bi-ischiatic line using the inferior aspect of the obturator foramen and measuring a perpendicular line to the lesser trochanters. The difference between the distance, in millimeters (mm), to the lesser trochanters was the LLD. The femoral head size was used to calibrate all postoperative radiographs. If the obturator foramen were asymmetrical a line between the radiographic tear-drops was used. If the lesser trochanters were poorly visible the patient was not included in LLD measurements. All radiographs were interpreted by an independent observer who was blinded to groups. Previous radiographic measurements have been evaluated using this technique for intra-observer and inter-observer reliability and shown to have satisfactory correlation ($r > 0.82$ and $P < 0.001$) [10].

Operative Time

Operative time was recorded in minutes (min) from incision until the time closure began. The average operative time was calculated for each group. If operative time for a patient was not recorded the patient was not included in the average.

Intra-Operative Technical Problems and Complications

Technical problems, such as, failure of the robotic or navigation systems were recorded intra-operatively and tabulated. Intraoperative delays secondary to the robotic system were also recorded. Intra-operative complications were recorded. Post operative complications were not included.

Statistical Analysis

The average acetabular inclination, anteversion, and LLD were calculated along with the standard deviation (SD) and range for each group. Calculation of the number of hips that were in the safe zones of Lewinnek et al (inclination, 30°–50°; anteversion 5°–25°) and Callanan et al (inclination 30°–45°; anteversion, 5°–25°) was done for all groups [2,17]. The average operative time along with the SD was calculated with available data. An analysis of variance (ANOVA) was used to compare means and standard deviations for acetabular inclination, acetabular anteversion, LLD, operative time, complications, age, and BMI. A chi-squared analysis was used to compare the frequencies of outliers and gender between groups.

Results

Patient demographics are displayed in Table 1 for age, BMI, and gender. The average age for patients undergoing THA for groups A, B, and C was 60.2, 60.4, and 56.2 respectively with no difference between groups. BMI for groups A, B, and C was 29.2, 28.3, and C 30.8 respectively with no difference between groups. Gender was different between groups with 20 males in group A, 9 in group B, and 16 in group C ($P < 0.05$).

There was no difference for mean acetabular inclination, acetabular anteversion, or leg length discrepancy as experience increased ($P > 0.05$). Table 2 displays acetabular inclination averages, ranges, and standard deviations for the three groups. Table 3 displays acetabular anteversion averages, ranges, and standard deviations for the three groups. Average acetabular inclination was 40.7° ± 3.4, 39.9° ± 2.5, and 39.3° ± 3.0 for groups A, B, and C respectively. Average acetabular anteversion was 16.5° ± 3.8, 17.4° ± 3.4, and 16.7° ± 3.9 for groups A, B, and C respectively.

Outliers

The cumulative number of outliers was two for the Lewinnek safe zone and six for the Callanan safe zone. Fig. 1 displays acetabular component positioning in relation to previously documented safe zones for the three groups. Outliers are depicted. The risk of having an acetabular component outside of Lewinnek's safe zone was not

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Table 1
Demographics for Group A (Cases 1–35), Group B (Cases 36–70), and Group C (Cases 71–105).

Demographics			
Age		Average	STD
	Group A	60.2	8.7
	Group B	60.4	10.3
	Group C	56.2	10.3
	P-value	0.130	
BMI		Average	STD
	Group A	29.2	5.1
	Group B	28.3	3.8
	Group C	30.8	5.5
	P-value	0.110	
Gender		Male	Female
	Group A	20	15
	Group B	9	26
	Group C	16	19
	P-value	0.027	

Table 3
Acetabular Component Version for Group A (Cases 1–35), Group B (Cases 36–70), and Group C (Cases 71–105).

Version	Group A	Group B	Group C
Count	35	35	35
Average	16.5	17.4	16.7
Low	6.0	9.8	7.0
High	28.0	21.5	27.0
STD	3.8	3.4	3.9
P-value	0.56		

different between groups ($P = 0.60$). The risk of having an acetabular component outside of Callanan's safe zone decreased after group A and was statistically significant ($P = 0.02$).

No patient in this study had a leg length discrepancy greater than 10 mm (Fig. 2). The number of patients with a leg length discrepancy less than five millimeters for groups A, B, and C were 91%, 91%, and 94% respectively. There was no difference for leg length discrepancy between groups, and Table 4 displays LLD averages, ranges, and standard deviations for the three groups.

Operative Time

Operative time is shown in Fig. 3. The average operative time for groups A, B, and C was 79.8 ± 27 min, 63.2 ± 14.2 min, and 69.4 ± 16.3 min respectively ($P = 0.02$).

Technical Problems and Complications

Overall there were eight (8%) intra-operative technical problems and 1 (1%) intra-operative complication. The complications are listed in Table 5. In group A there were three technical problems: one loosened femoral array, one loosened pelvic array, and one cup that appeared erroneous according to the navigation system. In group B there was one complication, a femoral calcar fracture treated with a cerclage wire. There were two technical problems: one loosened femoral array, and one intra-operative delay. In group C there were three technical problems, all a loosened femoral array. There was no difference in the overall number of intra-operative technical problems and complications between groups ($P = 1.0$).

Discussion

Improper component placement during total hip arthroplasty leads to complications such as: instability, accelerated bearing wear, leg length discrepancy, and revision surgery [8,18,19]. Recent reports have documented a significant frequency of malpositioned acetabular components, even at high volume reconstruction centers [2,7]. The burden of component malposition is substantial, with 22.5% of revision THAs being secondary to hip instability [4]. This results in $504 million in charges and $201 million in payments annually for the United States Medicare population. Acetabular components placed with inclination angles greater than 45° show increased bearing surface wear, which may account for a significant number of revisions for aseptic loosening [19]. Metal on metal prosthesis has also been shown to be intolerant of acetabular components with higher inclination angles [20]. One tool to decrease component malposition in total hip arthroplasty is the use of robotic assistance [10]. The adoption of new technology is associated with a learning curve, and to our knowledge, this is the first look at one surgeon's experience with robotic assisted THA. In this study there did appear to be a learning curve for operative time, and the risk of an acetabular component outside of Callanan's safe zone decreased with experience. Based on our experience a learning curve of approximately 35 cases was sufficient to decrease operative time and reduce the risk of outliers.

Robotic assisted THA has shown to be more accurate in the placement of the acetabular component in comparison to traditional techniques [10]. In that study, Domb et al. found that acetabular components were placed in Lewinnek's safe zone for inclination and anteversion in 100% of patients, and in the safe zone defined by Callanan in 92% of patients. This compared to 80% of acetabular components within Lewinnek's safe zone, and 62% of acetabular components in Callanan's safe zone without navigation. Nawabi et al. have also confirmed more accurate acetabular component positioning using robotic assisted THA in comparison to traditional techniques [21]. The current study also demonstrated precise component positioning with 103/105 acetabular component in Lewinnek's combined safe zone, and 99/105 for the more restrictive Callanan safe zone. The standard deviation for acetabular inclination and anteversion in all three groups also demonstrates the precision of this technique. There was a decreased risk of acetabular component malpositioning with experience. We believe this learning curve is secondary to improved surgical technique as it relates to bony registration, and improved handling of pelvic and femoral arrays intra-operatively.

Logically, operating room time decreases as a procedure becomes more familiar to the surgeon. This has been shown in previous studies examining the learning curve during hip and knee arthroplasty. Masonis et al. evaluated their experience adopting direct anterior total hip arthroplasty and noted a decrease in operative time after the first 100 cases [22]. Decreased operative time has also been seen as surgeons become familiar with navigated total knee arthroplasty [23,24]. Conversely, in one study on computer-assisted navigation for hip resurfacing, no increase in operative time was noted compared to conventional methods [25]. In our study there was a trend toward shorter operating room time in the final 70 cases, which was statistically significant. Group C showed a slightly increased operative time in comparison to Group B which may have been secondary to a

Table 2
Acetabular Component Inclination for Group A (Cases 1–35), Group B (Cases 36–70), and Group C (Cases 71–105).

Inclination	Group A	Group B	Group C
Count	35	35	35
Average	40.7	39.9	39.3
Low	33.0	32.5	33.0
High	47.0	43.8	44.0
STD	3.4	2.5	3.0
P-value	0.18		

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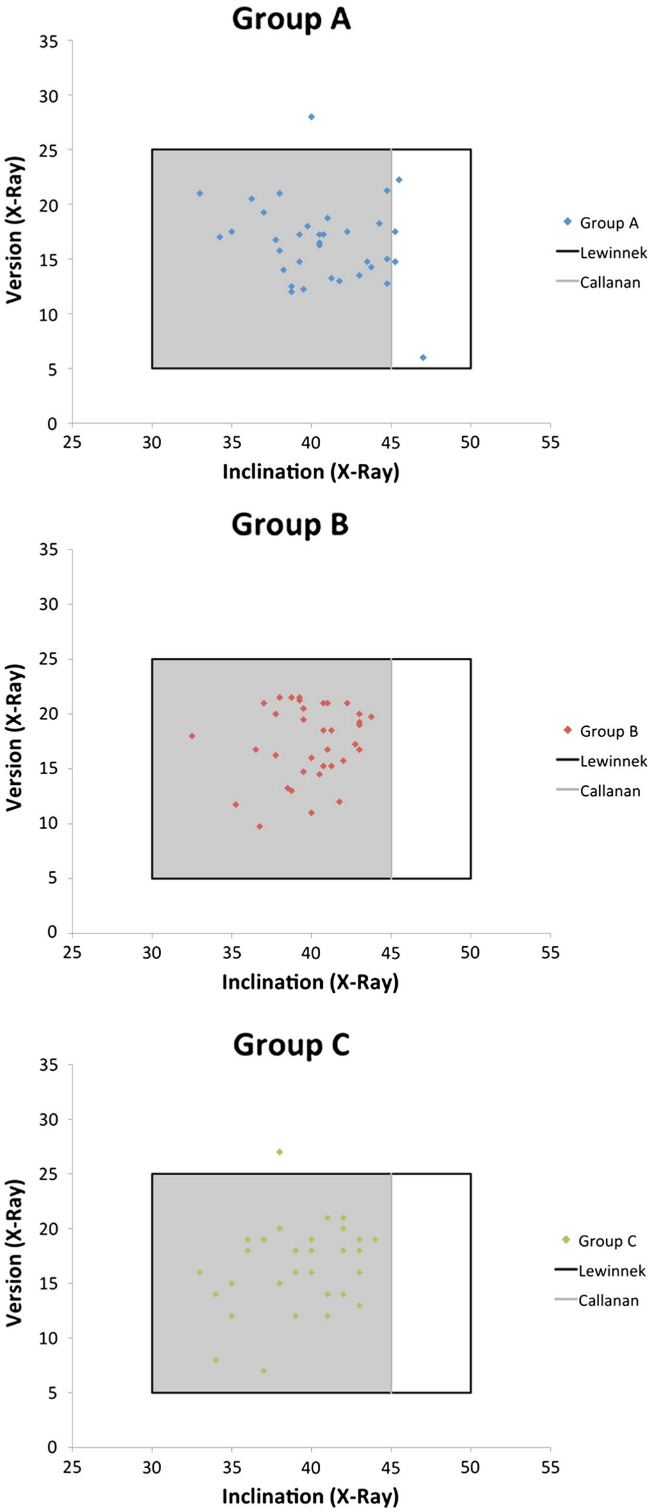

Fig. 1. Scatterplot of the robotic-assisted THA acetabular components in the safe zones defined by Lewinnek et al. and Callanan et al. for Group A (cases 1–35), Group B (cases 36–70), and Group C (cases 71–105).

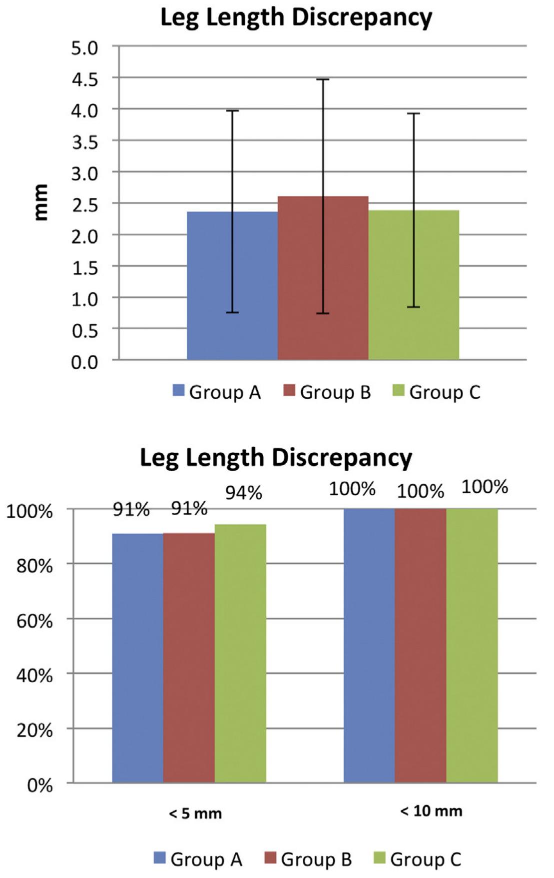

Fig. 2. Leg length discrepancy in millimeters; percent < 5 mm and percent < 10 mm for Group A (cases 1–35), Group B (cases 36–70), and Group C (cases 71–105).

software upgrade which allowed determination of femoral version, and a slightly increased BMI in Group C.

During the adoption of robotic assisted THA there were few intra-operative technical problems or complications. One technical problem that occurred in 5/105 (5%) cases was related to fixation of the femoral array. The screw used for the femoral array was inserted in the posterior border of the trochanter. In patients with compromised bone quality the screw can loosen during the operation. When this occurred it did not affect positioning of the acetabular component, but did affect intra-operative feedback on leg length and offset. Of note, none of the five patients with a loose femoral array had an LLD greater than 5 mm. During the 27th case in this series the navigated acetabular component position was felt to be inaccurate, and the acetabular component was repositioned based on anatomical landmarks. This acetabular component fell into both Lewinnek's and Callanan's safe zones with inclination of 38° and anteversion of 22°. No etiology for this incident was discovered. During the 31st case the pelvic array was lost during component impaction, and the acetabular component was placed using anatomical landmarks. Postoperatively this acetabular component was 40° of abduction and 28° of anteversion, which fell outside both safe zones for anteversion. Overall the risk of intraoperative technical problems or complications was quite small; that said, the surgeon should pay close attention to anatomical landmarks to ensure the robotic system is providing accurate information.

Table 4
Leg Length Discrepancy for Group A (Cases 1–35), Group B (Cases 36–70), and Group C (Cases 71–105).

Leg Length Discrepancy			
	Group A	Group B	Group C
Count	33	34	35
Average	2.4	2.6	2.4
Low	0.3	0.3	0.0
High	5.0	8.0	6.0
STD	1.6	1.9	1.5
P-value	0.78		

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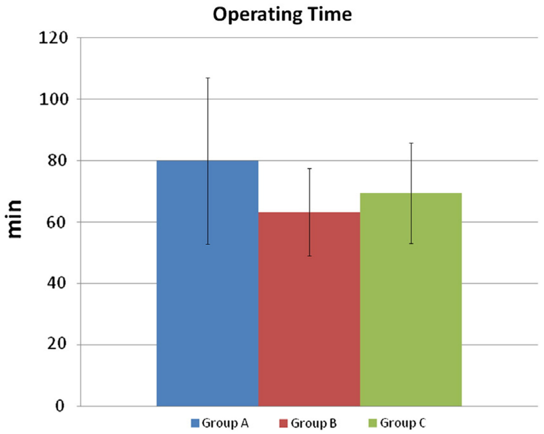

Fig. 3. Operating time for Group A (cases 1–35), Group B (cases 36–70), and Group C (cases 71–105).

The current study has several strengths. This is the first study to evaluate the learning curve of robotic assisted THA in the literature. It also contains the largest series in the literature on robotic assisted THA. The senior author had no experience with robotic assisted THA prior to the onset of this series. The series documents the chronologic learning curve by a single surgeon. Lastly, all radiographs were read by a blinded independent observer.

This study has several limitations. First, the determination of component position was based on post-operative AP radiographs. While post-operative CT scans may improve the reliability of measurements, post-operative measurements based on AP radiographs have shown excellent correlation to CT scan [26]. However, it should be noted that AP pelvic radiographs typically underestimate true version by 4–5° due to the oblique nature of the x-ray beam [27]. Second, the paper lacks clinical follow up. While component positioning based on radiographic data appears promising, no effect on dislocation rates or bearing wear is available at this time. Third, the senior surgeon in this study has a high volume, tertiary hip surgery practice. The learning curve evaluated in this study may not be directly applicable in different practice settings. Fourth, the criterion used to determine an acetabular outlier was Callanan's safe zone. This is arguably the most restrictive definition in the literature; nonetheless, acetabular outliers according to these criteria appeared to improve with experience. Lastly, studying the learning curve of a single surgeon may not accurately reflect the learning curve of other surgeons. Ideally the study would be performed utilizing multiple surgeons.

Conclusion

A learning curve was observed, as a decreased incidence of acetabular component outliers and decreased operative time were noted with increased experience. We did not observe a learning curve in relation to technical problems or complications. Satisfactory acetabular component positioning and leg length matching were found throughout the learning curve of robotic assisted total hip arthroplasty, with very few outliers in either category. Based on these findings, we conclude that there is a learning curve for robotic assisted total hip arthroplasty with decreasing operative time and acetabular component outliers after 35 cases.

Table 5
Technical Problems and Complications for Group A (Cases 1–35), Group B (Cases 36–70), and Group C (Cases 71–105).

Complications		
Group A	Group B	Group C
Lost femoral array Lost pelvic array Suspected navigation error	Femoral calcar fracture Lost femoral array Camera issues caused delay	Lost femoral array Lost femoral array Lost femoral array
P-value	1.00	

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