Research Article

Robotics and Navigation as Learning Tools for Fellows Training in Hip Arthroplasty

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Abstract

Introduction: The association between implant malpositioning and complications has been repeatedly demonstrated. Recently, technological advancements have allowed for more consistent implant placement. Beyond this obvious application, these technologies may also serve as a learning tool. Thus, the aim of this study was to evaluate the accuracy of fellows' estimation of implant positioning using a robotic system.

Methods: Data were prospectively collected for all patients undergoing total hip arthroplasty between September 2019 and December 2019. The fellow was blinded to the robotic system. Before reaming and broaching by the senior surgeon, the fellow was asked to place the reamer at 40° of cup inclination and 20° of version. The resulting values were recorded before the true measurements were revealed. A similar process was followed for femoral broaching.

Results: The mean difference between the estimated and actual cup inclination and version was 7.24° (P = 0.060) and 4.81° (P = 0.031), respectively. The mean difference in broach version was 7.00° (P = 0.159). Without the robotic system, 43.47% and 69.57% of patients would have had the cup placed outside of the safe zones described by Lewinnek and Callanan, respectively.

Conclusion: The estimated anteversion of the acetabular implant was found to be markedly different from its actual anteversion. A considerable portion of the cups would have been positioned outside of the Lewinnek and Callanan "safe zones" provided that the implants would have been manually positioned. The use of robotic or navigation systems may provide useful learning tools for fellows in training to understand their own inaccuracies in estimated implant position and hence refine their abilities.

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This study was performed in accordance with the ethical standards in the 1964 Declaration of Helsinki. This study was carried out in accordance with relevant regulations of the US Health Insurance Portability and Accountability Act (HIPAA). Details that might disclose the identity of the subjects under study have been omitted. This study was approved by the IRB. (IRB ID: 5276). This study was performed at the American Hip Institute Research Foundation.

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The body of the literature has shown that accuracy in cup positioning during hip arthroplasty remains susceptible to human error.[1,2] Factors that are correlated with cup mispositioning include surgical approach, body mass index (BMI), and soft-tissue tensioning.[1,3] In addition, surgeon-related factors such as experience, volume, and even hand dominance relative to the side of the operated hip have been shown to influence the accuracy and reproducibility of acetabular implant placement.[1,4-7] To reduce the variability in implant positioning, C-arm fluoroscopy has been widely implemented.[8,9] However, fluoroscopy carries its own drawbacks. It may be associated with increased risk of infection, increased radiation exposure to the medical staff, and misleading spatial orientation because of the two-dimensional representation of a three-dimensional (3-D) structure.[10-14] Therefore, fluoroscopic guidance may impair, rather than improve, the accuracy of cup positioning, more notably affecting low-volume surgeons.[9,12]

In recent years, new technologies have emerged, providing better consistency in implant placement, regardless of the surgeon's experience.[15,16] In addition to the immediate improvement in accuracy, these technologies may also serve as novel learning tools. Intraoperative navigation systems deliver a 3-D representation of the patient's anatomy along with real time feedback on the geometrical orientation of the implants relative to that anatomy. Consequently, these navigation systems may have the potential to improve a surgeon's spatial orientation while also providing them with a better understanding of the technical challenges they personally encounter when performing hip arthroplasty. Therefore, these technologies may help surgeons become more independent and self-aware. Because a navigation system may not be available at all times, improving a surgeon's perception of appropriate implant placement is quite valuable and can bridge the gap between accuracy and experience.

Thus, the aim of this study was to evaluate the accuracy of implant positioning skills using the real time feedback provided by a CT-based 3D software for orthopaedic surgery fellows in training.

The authors' hypothesis was that a notable difference in degrees of version and cup inclination would be seen between the estimated and actual positioning of implants.

Methods

Patient Selection

Data were prospectively collected for all patients undergoing total hip arthroplasty (THA) between September 2019 and December 2019. Patients undergoing robotic arm-assisted direct anterior approach THA by surgical fellows under the supervision of the senior surgeon (B.G.D.) were included in the study. Conversely, patients were excluded if the cases were completed in express, initial registration failed, or if fellows did not participate in the procedure. During the study period, our standard surgery planning procedures were maintained. Patients were recommended for a direct anterior approach THA unless MRI revealed a notable gluteus medius tear. In these scenarios, patients were recommended for a posterior approach THA.

Surgical Technique

The MAKO robotic hip system (MAKOplasty total hip application; MAKO Surgical Corporation) is a robotic arm-assisted computer navigation system that guides bone preparation, acetabular reaming, and implant placement using RIO (Robotic Arm Interactive Orthopedic System). Two forms of preoperative planning were used. First, a two-dimensional plan was created using the patient's AP pelvis x-ray and the TraumaCad software (TraumaCad; Brainlab). In addition, CT scans of the affected hip and knee were obtained preoperatively for all patients. From these images, the robotic system created a 3-D, patient-specific model of the pelvis and proximal femur that were used to guide the execution of the THA.

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All THAs included in this study were performed through the direct anterior approach with the patient in the supine position. Using spatial information from patient-specific landmarks, a robotic system guided the acetabular reaming, cup placement, femoral broaching, and stem placement. During the procedure, the system also provided the surgeon with feedback regarding implant placement, leg length, and global offset. The robotic software was able to account for pelvic tilt and rotation throughout the procedure while also making measurements in the coronal (functional) plane, as described by Murray.[17] The target values for cup inclination and anteversion were 40° and 20°, respectively.

Study Protocol

Before reaming and broaching, the fellow was blinded to the robot's measurements. The fellow was asked to place the reamer at 40° of cup inclination and 20° of version. The resulting values were recorded before revealing the true measurements to the fellow. The position was then corrected before reaming. Similarly, the fellow stated their estimated broach version. The actual broach version was then noted, and the difference was recorded.

Statistical Analysis

Data were analyzed using Microsoft Excel (Microsoft Corporation) in addition to the Real Statistics Add-In. Assuming a mean difference of 7.24° for acetabular inclination, 4.81° for acetabular version, and 7.00° for femoral broach version, an a priori power analysis revealed that eight patients were required to achieve at least 80% power.[18] The mean and SD were calculated for each measurement and the difference between estimated and actual values. Normality and equal variance were assessed using the Shapiro-Wilk test and *F* test, respectively. Differences between the estimated values and actual measurements were analyzed using 2-tailed paired *t* tests. *P* values < 0.05 were considered statistically significant. Furthermore, a correlation coefficient was calculated to determine how closely the fellow's perceived femoral broach version matched the measured broach version. A correlation coefficient between 0.5 and 0.7 was considered moderately positive, whereas a value greater than 0.7 was considered strongly positive. Owing to the nature of the study and the targeted 40° of cup inclination and 20° of cup version, these measurements had a SD of zero, and therefore, a correlation coefficient could not be calculated. However, theoretical cup position could be compared with previously described safe zones. Using the perceived and final measurements, the number of hips that were in the safe zones described by Lewinnek et al (inclination of 30° to 50°, anteversion of 5° to 25°) and Callanan et al (inclination of 30° to 45°, anteversion of 5° to 25°) were calculated for inclination, anteversion, and the combination of the two.

Table 1

Demographics

Demographics	**n (%) or Mean ± SD (Range)**
Hips included in study	
Left	7 (30.4)
Right	16 (69.6)
Sex	
Female	15 (65.2)
Male	8 (34.8)
Age at surgery (yr, mean, SD, range)	53.95 ± 10.62 (22.79-73.07)
BMI (kg/m2, mean, SD, range)	28.19 ± 6.65 (20.6-48.61)

BMI = body mass index

Results

Patient Demographics

Between the months of September 2019 and December 2019, 23 robot-assisted total hip arthroplasties were performed by fellows under the supervision of the senior surgeon (B.G.D.). This patient cohort consisted of 8 (34.8%) men and 15 (65.2%) women, with 7 (30.4%) left hips and 16 (69.6%) right hips. The mean age was 53.95 years, and the mean BMI was 28.19 kg/m^2 (Table 1).

Component Placement

In all cases, the goal was to achieve 40° of acetabular inclination and 20° of acetabular version. With these values in mind, the reamer was placed at an average 43.33° of inclination and 22.52° of version. However, when comparing the difference between the estimated values and actual measurements, the average difference was 7.24° and 4.81° for inclination and version, respectively (Table 2). These differences produced a *P*-value of 0.060 for inclination and 0.031 for acetabular version.

The final femoral stem version was determined by spatial registration of the trial implant. The mean difference between the estimated and actual femoral broach version measurements was 7.00°, resulting in a *P*-value of 0.159 (Table 3). When assessing the relationship between the perceived and measured femoral broach version, a moderately positive correlation coefficient of 0.556 was returned.

Table 2

Perceived Acetabular Implant Placement Compared with Previously Established Target Measurements

Factors	Mean ± SD (Range)	*P*
Inclination		0.060
Measured (degrees, mean, SD, range)	43.33 ± 7.98 (31-59)	
Delta (degrees, mean, SD, range)	7.24 ± 4.52 (0-19)	
Anteversion		0.031
Measured (degrees, mean, SD, range)	22.52 ± 5.17 (13-31)	
Delta (degrees, mean, SD, range)	4.81 ± 3.03 (0-11)	

Delta values indicate difference from the 40° inclination target and 20° version target.

Table 3

Comparison of Femoral Implant Positioning Based on Human Perception Versus CT-based Robotic Guidance

Femoral Component Placement	Mean ± SD (Range)	*P*
Broach version		0.159
Perceived (degrees, mean, SD, range)	4.84 ± 5.98 (−5 to −15)	
Measured (degrees, mean, SD, range)	7.53 ± 9.56 (−6 to −25)	
Delta (degrees, mean, SD, range)	7.00 ± 4.42 (2-20)	

To determine the potential outcome of these THAs if they had been performed manually, the Lewinnek and Callanan safe zones were referenced. Four theoretically-placed cups (19.05%) would have fallen outside of Lewinnek's 30° to 50° abduction safe zone and 11 (52.38%) would have fallen outside of Callanan's 30° to 45° abduction safe zone. In addition, seven (33.33%) of the fellows' perceived measurements were outside of the 5° to 25° range for version. One patient (4.76%) would have had the cup placed outside of both Lewinnek safe zones and two patients (9.52%) would not have had acetabular implants within the Callanan safe zones. Therefore, without guidance of a robotic system, 43.47% of patients would have had the acetabular implant placed outside of the Lewinnek safe zone and 69.57% of patients would have an acetabular implant that is outside the Callanan safe zone (Figure 1).

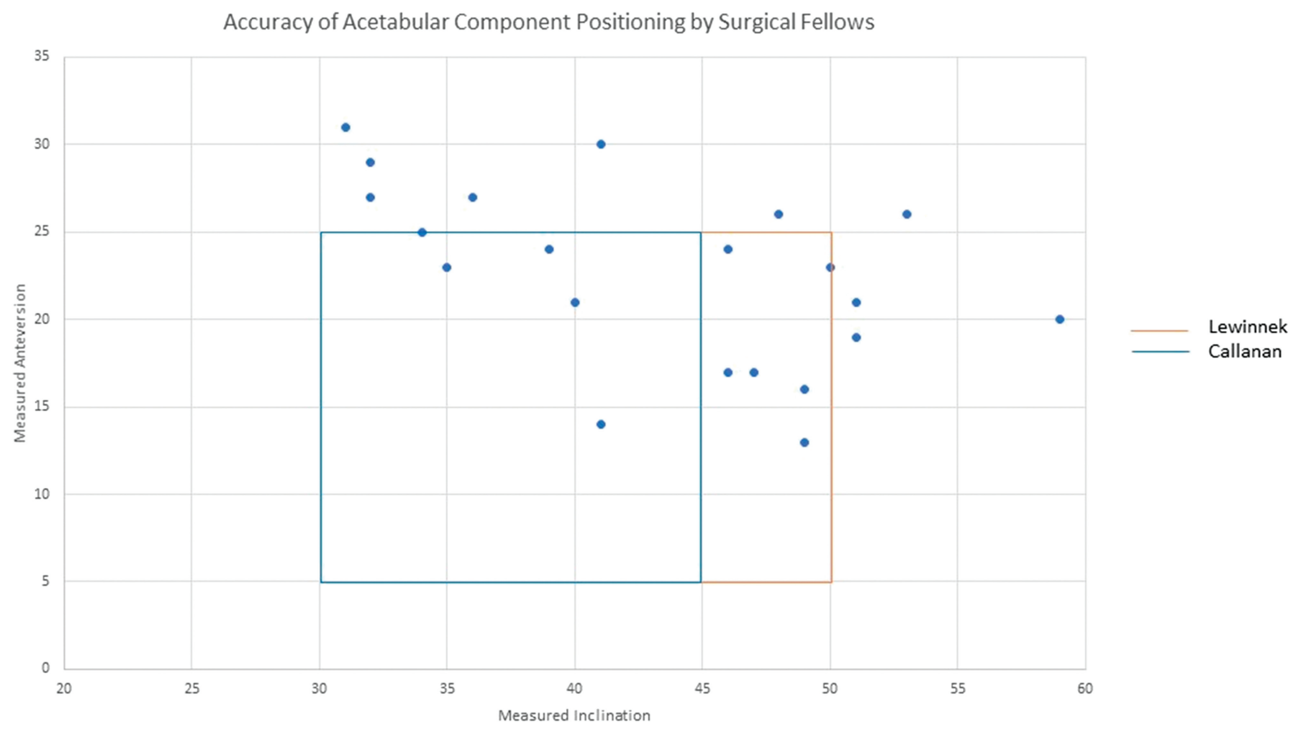
Discussion

This study aimed to investigate the potential use of a robotic system as a learning tool. Orthopaedic surgery fellows in training estimated the position of the reamer during THA before reviewing the real time feedback provided by a CT-based 3D robotic software. After an a priori power analysis, 23 consecutive robotic arm-assisted total hip arthroplasties were prospectively enrolled in this study. Three orthopaedic surgery fellows in training estimated the manual position of the acetabular reamer and the femoral broach before receiving real time feedback, indicated by the CT-based 3D robotic software. The estimated anteversion of the acetabular reamer was markedly different from the actual anteversion, whereas the differences in the estimated acetabular inclination and femoral version were not notable. In addition, a correlation coefficient of 0.556 indicated a moderately positive correlation between the estimated position of the femoral broach and the actual femoral anteversion.

The accuracy of manual implant placement in THA was assessed by comparing the perceived position of the instrument to its actual orientation. Callanan et al[1] aimed to determine the percent of optimally positioned acetabular components and the factors that may have affected the implant's position. Of 1823 hips, 1,144 (63%) acetabular cups were within the abduction range, 1,441 (79%) were within the version range, and 917 (50%) were within both ranges. Surgical approach, surgeon volume, and obesity (BMI > 30) independently predicted the malposition of the cups. In relation to Callanan et al, this study demonstrated that 10 (43.47%) and 16 (69.57%) cups would have been positioned outside the Lewinnek and Callanan "safe-zones", respectively, provided that the components would have been manually placed.

Interestingly, the difference between the perceived and the actual orientation of the instruments was only significant for cup inclination. This unexpected result could have been influenced by the surgical approach. Kobayashi et al[19] evaluated implant positioning when a surgeon is novice to the anterior approach. Overall, 80 patients were operated on by two senior surgeons using the anterior approach. When the final position of implants placed through the anterior approach was compared to those placed during previous posterior approach THAs, the authors noted a higher degree of cup anteversion. They speculated that the excessive anteversion was due to interference of the straight impactor with the femoral neck, resulting in inadequate hand-down. Corroborating Kobayashi et al, the significant difference between the perceived and actual anteversion may be the result of the

Figure 1



Graph showing the acetabular implant positioning by surgical fellows compared with previously described safe zones.

straight configuration of the instrumentation, which does not seem to effect cup inclination.[4]

Kamara et al[8] investigated the immediate improvement in implant positioning following the implementation of robotic guidance. This study aimed to assess the betterment of cup positioning after switching from manual technique to robotic or fluoroscopic guidance. In order to do this, the first 100 fluoroscopically guided direct anterior approach THAs were compared to the first 100 robotic-assisted posterior THAs and the last 100 manual, posterior THAs done by each surgeon before adopting the novel techniques. Seventy-six percent of the manual posterior THAs were within the surgeons' target zones, while 84% of the fluoroscopic-guided anterior approach and 97% of the robotic-guided anterior approach THAs were within the target zones. Although a learning curve still exists with fluoroscopic-guided THA, the authors concluded that robotic techniques may lead to significant and immediate improvement in the precision of cup positioning during the learning curve. Similar to the surgeons switching to the anterior approach, fellows-in-training are also somewhere along a learning curve. While performing THA with robotic guidance has been demonstrated to better the surgical technique, perhaps its greater benefit is in providing surgeons with a 3-D representation of the patients anatomy and a real-time feedback of their geometrical alignment. This may allow surgeons to refine their technique by noting their own margin for error. This way, the clinician's learning curve can be enhanced rather than diminished and to become a more independent surgeon.

The strengths of this study include the use of a power analysis and prospective design to increase the validity of the conclusions. Additionally, by contemporarily comparing the positioning of the components on the same patient by the same surgeon, the potential for selection bias is minimized considerably. Further, using a CT-based 3D robotic software, which accounted for the position of the pelvis, allowed measurements to be retrieved with high accuracy. Lastly, in contrast to previous studies that exclusively investigated the position of the acetabular component, this study also includes the version of the femoral component.

This study also has some limitations. First, despite showing higher accuracy for robotic arm-guided total hip arthroplasty, this study does not investigate the correlation between accurate implant placement and clinical outcomes. Second, there may have been potential differences between the perceived position of the instruments and the final implementation if the latter would occur without robotic guidance. Third, determining the ideal acetabular cup position prior to reaming the acetabulum did not allow the surgeon to use the anatomical landmarks that are available after the completion of reaming and osteophyte removal. However, pre-reaming assessment was chosen for this study since the surgeons could have been biased by the position of the instruments during reaming, which is performed under robotic guidance.

Conclusion

The estimated anteversion of the acetabular implant was found to be markedly different from its actual anteversion. A considerable portion of the cups would have been positioned outside of the Lewinnek and Callanan "safe zones," provided that the implants would have been manually positioned. The use of robotic or navigation systems may provide useful learning tools for fellows in training to understand their own inaccuracies in estimated implant position and hence refine their abilities. Future studies should investigate the effect of self-assessment on accuracy in implant positioning over time.

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References printed in **bold type** are those published within the past 5 years.

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