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Original Article

Adoption of Robotic vs Fluoroscopic Guidance in Total Hip Arthroplasty: Is Acetabular Positioning Improved in the Learning Curve?

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ABSTRACT

Background: Acetabulum positioning affects dislocation rates, component impingement, bearing surface wear rates, and need for revision surgery. Novel techniques purport to improve the accuracy and precision of acetabular component position, but may have a significant learning curve. Our aim was to assess whether adopting robotic or fluoroscopic techniques improve acetabulum positioning compared to manual total hip arthroplasty (THA) during the learning curve.
Methods: Three types of THAs were compared in this retrospective cohort: (1) the first 100 fluoroscopically guided direct anterior THAs (fluoroscopic anterior [FA]) done by a surgeon learning the anterior approach, (2) the first 100 robotic-assisted posterior THAs done by a surgeon learning robotic-assisted surgery (robotic posterior [RP]), and (3) the last 100 manual posterior (MP) THAs done by each surgeon (200 THAs) before adoption of novel techniques. Component position was measured on plain radiographs. Radiographic measurements were taken by 2 blinded observers. The percentage of hips within the surgeons' "target zone" (inclination, 30°-50°; anteversion, 10°-30°) was calculated, along with the percentage within the "safe zone" of Lewinnek (inclination, 30°-50°; anteversion, 5°-25°) and Callanan (inclination, 30°-45°; anteversion, 5°-25°). Relative risk (RR) and absolute risk reduction (ARR) were calculated. Variances (square of the standard deviations) were used to describe the variability of cup position.
Results: Seventy-six percentage of MP THAs were within the surgeons' target zone compared with 84% of FA THAs and 97% of RP THAs. This difference was statistically significant, associated with a RR reduction of 87% (RR, 0.13 [0.04-0.40]; $P < .01$; ARR, 21%; number needed to treat, 5) for RP compared to MP THAs. Compared to FA THAs, RP THAs were associated with a RR reduction of 81% (RR, 0.19 [0.06-0.62]; $P < .01$; ARR, 13%; number needed to treat, 8). Variances were lower for acetabulum inclination and anteversion in RP THAs (14.0 and 19.5) as compared to the MP (37.5 and 56.3) and FA (24.5 and 54.6) groups. These differences were statistically significant ($P < .01$).
Conclusion: Adoption of robotic techniques delivers significant and immediate improvement in the precision of acetabular component positioning during the learning curve. While fluoroscopy has been shown to be beneficial with experience, a learning curve exists before precision improves significantly.

Total hip arthroplasty (THA) is considered to be one of the most successful orthopedic interventions [1]. Despite an abundance of literature describing 95-100% durability with modern implants at 10 years, recent Medicare and registry data show a 10% rate of revision within 10 years after surgery with higher failure rates in younger patients [2-5]. While some surgeons have achieved durability as high as 93% at 20 years [6], others have observed greater rates of failure [7,8]. Variations in implant choice and patient characteristics undoubtedly account for some portion of the

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observed variability in prosthetic durability, but surgical technique has proven to be contributory [3,4].

Acetabular component positioning affects dislocation rates, component impingement, bearing surface wear rates, and need for revision surgery [9]. A commonly referenced "safe zone" for acetabular component positioning was described by Lewinnek et al [10] as 5° to 25° of anteversion and 30° to 50° of inclination. Callanan et al [11] later modified the safe range of inclination to 30° to 45°, primarily out of concern for the risk of edge loading with less than hemispherical acetabular implants used for hip resurfacing and large head diameter metal-on-metal hip replacement. The validity of these safe zones has been questioned by those who propose alternative safe zones [12], or argue that dislocations have similar prevalence among arthroplasties within and outside the safe zone [13,14], but they remain widely accepted targets for acetabular component position. The authors of this study, based on experience with posterior approach THA, have historically aimed for a "target zone" of 10° to 30° of acetabular anteversion and 30° to 50° of inclination, depending on patient anatomy and femoral version.

Various techniques have been introduced to improve the accuracy and precision of acetabular cup positioning in THA. These include using preoperative templating, manual guides, intraoperative landmarks, intraoperative X-ray or fluoroscopy, computer navigation, and robotics [15]. The direct anterior approach (DAA) for THA has become increasingly popular over the past several years, with claims of faster recovery and improved component positioning related to the use of intraoperative fluoroscopy. These claims have been substantiated in several well-done studies [16-18], but a significant learning curve has been observed with the adoption of this surgical exposure [19,20].

The Mako RIO (Robotic-arm Interactive Orthopaedic System, StrykerMako, Fort Lauderdale, FL) introduced a new haptic robotic technique for acetabular bone preparation and cup insertion, which has improved the accuracy and precision of acetabular cup position in cadaveric research and clinical practice [21-23]. This technology does not expose the surgical team to radiation and does not require the surgeon to learn new soft-tissue exposure. It has been proposed that haptic robotic guidance delivers immediate improvements in surgical quality without exposing the patient or the surgeon to a clinically important learning curve [23].

This study has 2 goals. The primary objective is to independently verify reports that adoption of haptic robotic guidance through the posterior approach results in immediate improvements in acetabular cup positioning as compared to manual posterior (MP) techniques without navigation or fluoroscopy. The secondary objective is to ascertain whether a posterior approach surgeon switching from manual techniques to robotic guidance will achieve improvements in acetabular component position greater than those achieved by a posterior approach surgeon converting to fluoroscopic guidance through the DAA.

Materials and Methods

This is a retrospective study comparing 3 cohorts of patients undergoing THA at a single institution between 2008 and 2014. Institutional review board approval was obtained before initiation of the study. The first 100 robotic-assisted posterior approach THAs (robotic posterior [RP]) performed by the principal investigator (M.S.H.) formed the study group and were compared to 2 control groups—the first 100 fluoroscopy-guided DAA THAs (fluoroscopic anterior [FA]) performed by the senior investigator (J.A.R.) and 100 consecutive cases from each investigator's immediate prior experience with MP THA, for a total of 400 THA procedures. We currently aim for slightly less anteversion when performing THA through a DAA, but during the study period, both surgeons used inclination 30°-50° and anteversion 10°-30° as a target zone for acetabular component position regardless of surgical approach [20,24].

Subjects

Within our institution, 1 highly experienced adult reconstructive surgeon (J.A.R.) transitioned from MP to FA THA beginning in 2008. Another fellowship-trained adult reconstructive surgeon (M.S.H.) transitioned from MP to RP THA in 2013. The first 100 consecutive primary elective THAs from each cohort were selected for inclusion and are considered the learning curve groups, as both the surgeons were transitioning to new techniques. No THAs for femoral neck fracture were included, as the robot was not used for fracture patients. Conversions from prior open hip surgery such as osteotomy and fracture repair were included, whereas revision arthroplasty procedures were not included. For a control group, the first 100 elective MP THAs performed by M.S.H. after fellowship between 2010 and 2013 were included in the study, along with the last 100 MP THAs performed by the senior investigator during 2008 and 2009, before transitioning completely to direct anterior hip surgery.

During the transition to FA THA, the senior investigator (J.A.R.) initially restricted this approach to lighter weight patients with anatomy deemed favorable for the approach. This transition occurred over an 11-month period during which 100 FA and 45 MP THAs were performed. Conversely, the principle investigator (M.S.H.) preferentially used robotic assistance for obese patients and those with more challenging anatomy during the learning curve and began using it routinely for standard cases once comfort and efficiency with the technology were achieved. This transition occurred over a 12-month period during which 63 RP and 27 MP THAs were performed. The cohorts were therefore compared with respect to age, sex, body mass index (BMI), diagnosis, and the presence of preoperative gross bone deformity or joint subluxation. The sole exclusion criterion was inadequate postoperative radiographs.

Surgical Techniques

For MP and FA THAs, preoperative planning using plain radiographs was used to anticipate component sizing and position, level of neck cut, and the amount of leg lengthening needed. For DAA THA, the patient was supine and exposure was achieved through a modified Heuter approach. Acetabular cup positioning was assessed with preoperative plain radiographic templating, anatomic landmarks (transverse acetabular ligament, anterior and posterior walls of the acetabulum), and intraoperative fluoroscopy. For posterior approach surgery, manual or robotic, the patient was positioned in the lateral decubitus position and the pelvis was secured to minimize motion. Exposure was performed using a posterior approach as previously described [24]. For MP surgery, the surgeon used preoperative plain radiographic templating, anatomic landmarks (transverse acetabular ligament, anterior and posterior walls of the acetabulum), and Ranawat's coplanar test to assess acetabular cup positioning [25].

For RP THAs, preoperative computed tomography (CT) scans of the involved hip were obtained and 3-dimensional templating using the Mako software was used to plan acetabular component position. Anteversion and abduction angles are reported by the Mako system in a supine functional plane determined by the pelvic position in the CT scanner, accounting for variable pelvic tilt, rather than according to the anterior pelvic plane. The relative merits of functional versus anatomic definitions of anteversion have been discussed at length [14,26,27]. The default cup position was 40° of