Accuracy Characterization of Robotically-Assisted Revision Total Hip Arthroplasty

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INTRODUCTION: In revision total hip arthroplasty (THA), acetabular component location is still a key factor in stability, impingement, wear, and biomechanics. However, because of distorted anatomy and previous implants, the surgeon may find it difficult to achieve precise positioning. Although there is little evidence to support its usage in a revision scenario, robotic assistance may increase the fidelity of the plan and execution [1]. We measured the precision and accuracy of robotically-assisted revision THA (Revision RA-THA; acetabular component only) using a computed-tomography (CT)-based technique that is the same as that used by Smith et al [2] and compared absolute errors with a published manual primary THA (M-THA) benchmark. We predicted that, especially for cup inclination, Revision RA-THA would lower absolute orientation error and variability.

METHODS: There were six fresh-frozen, torso-to-toe cadavers (seven hips) that had previously undergone primary total hip arthroplasty (THA) utilized for this study. The cadaver demographics for this study included four men and two women who had a mean age of 75 years (range, 61 to 99 years) and a mean body mass index of 23 (range, 18 to 30). The specimens underwent revision using robotically-assisted total hip arthroplasty (Revision RA-THA) with CT scans obtained pre- and postoperatively. The revision operations were each completed by a different surgeon using the manufacturer's workflow, which only utilized the robotic assistance for the acetabular component. Surgeons had varying RA-THA primary case volumes, with more than 150 cases per year considered high volume, 25 to 150 cases per year considered medium volume, and less than 25 cases per year considered low volume. There were two different shell types (some utilizing an augment) and three different surgical approaches employed. The surgical parameters for each specimen are highlighted in Table 1.

To characterize the accuracy of the implant placement, this study followed the methods outlined by Smith et al. [2] Pre- and postoperative CT scans were used to virtually reconstruct the hip and implant components (Figure 1). Acetabular implant placement for the planned and executed positions was defined using the shell center of rotation (COR) position along the three anatomical axes, the shell inclination angle, and the shell version angle. Measurements are reported in terms of the absolute error, or the absolute difference between the planned and executed values for each parameter. The absolute error from this study was compared with values from manual primary total hip arthroplasties (M-THA) reported by Smith et al. [2]. Normality was established with the Anderson-Darling test. To assess differences in the standard deviation of each measurement, two-variance testing was performed using alpha = 0.05. Mean differences between cadaver-based revision RA-THA and published M-THA values were compared with Welch's t-test for superiority using alpha = 0.05 and effect sizes were reported as mean differences with 95% upper bounds.

RESULTS: The mean absolute errors and standard deviations for each parameter are shown in Figure 2 alongside values from M-THAs reported by Smith et al. [2]. The surgeons performing Revision RA-THA demonstrated significantly greater accuracy for inclination (2.5 ± 1.9° versus 7.2 ± 3.2°, $P < 0.05$) and version (2.2 ± 1.6° versus 7.8 ± 4.6, $P < 0.05$) using Welch's t-test, as well as significantly greater precision for version ($P < 0.05$), and directionally lower error for all measured parameters compared with M-THA. There were no statistically significant differences seen in the COR measurements. The Revision RA-THA cases demonstrated greater accuracy than the M-THA cases for each parameter, with mean differences in absolute error of -5.7° for the shell version angle and -4.7° for the shell inclination angle with 95% upper bounds of -1.9 for both version and inclination. The surgeon performing a low RA-THA case volume had the highest absolute error for shell inclination angle and shell version angle (5.5° and 5.0°).

DISCUSSION: When using robotic guidance for the acetabular section of the case, Revision RA-THA demonstrated improved plan adherence, as seen by its significantly reduced absolute errors for both cup inclination and version, and tighter dispersion for cup version when compared to the M-THA benchmark (2.5 ± 1.9° versus 7.2 ± 3.2°, $P < 0.05$ and 2.2 ± 1.6° versus 7.8 ± 4.6, $P < 0.05$) in this cadaver series. With mean differences of -4.7° (inclination) and -5.7° (version) compared to M-THA, errors were directionally reduced for Revision RA-THA across all parameters, even though center-of-rotation (COR) differences did not reach statistical significance. Interestingly, the surgeon with the lowest RA-THA volume had the largest inclination and version errors (5.5° and 5.0°), while this was still more accurate than M-THA, it may indicate that even in a streamlined, acetabulum-only workflow, there may be a learning curve and experience impact.

This work has potential limitations. It is a small cadaver study that varies in terms of surgical technique, augment use, and shell type. The comparator is a cross-study, although the identical CT measurements may mitigate method bias [2]. For subgroup effects (e.g., surgeon volume, approach, and augment usage), the study lacked sufficient power. Confirmation of functional outcomes, complication profiles, and durability will need a prospective clinical series.

SIGNIFICANCE/CLINICAL RELEVANCE: When compared to a manual benchmark, robotic assistance for the acetabular component in a revision THA model decreased absolute error in cup inclination and version, and variability in cup version, reducing the potential risks associated with malposition (e.g., instability, impingement, wear) [3]. While larger clinical studies are needed to assess impact on complications and re-revisions, these data suggest the inclusion of RA-THA in revisions.

Specimen	Approach	Acetabular Shell	Augment	Surgeon Primary RA-THA Case Volume
S241073 Right	PL	Restoration Anatomical Hemispherical Shell (Stryker, Mahwah, NJ)	No	High
S241138 Right	PL	Trident II Tritanium (Stryker, NJ, Mahwah)	No	High
S241174 Left	PL	Trident II Tritanium (Stryker, NJ, Mahwah)	No	Medium
S241191 Left	DA	Restoration Anatomical Hemispherical Shell (Stryker, Mahwah, NJ)	No	Medium
S241073 Left	AL	Trident II Tritanium (Stryker, NJ, Mahwah)	Yes	Medium
S241173 Right	PL	Trident II Tritanium (Stryker, NJ, Mahwah)	Yes	High
S232178 Right	PL	Trident II Tritanium (Stryker, NJ, Mahwah)	No	Low

Table 1: Specimen information with surgical approach, acetabular shell, augment information, and surgeon's primary RA-THA case volume. The approaches have been abbreviated: postero-lateral (PL), direct anterior (DA), and antero-lateral (AL).

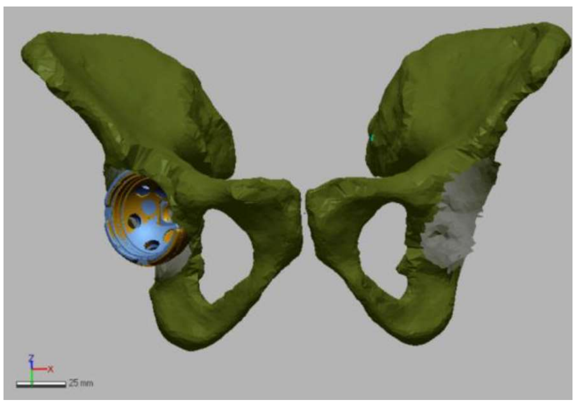

Figure 1: Coronal view of Specimen S241138R showing the pelvis (green), the implant in the planned position (blue), and the implant in the executed position (gold).

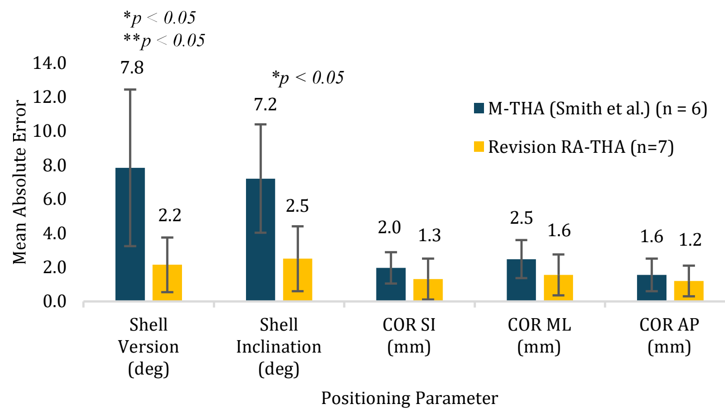

*Figure 2: Mean absolute error of each angle and position measurement for the Revision RA-THAs completed in this study compared with M-THAs reported in Smith et al. [2]. * indicates statistical significance on the Welch's T-test and ** significance in two-variance test.*

References

[1] X.-D. Wu, Y. Zhou, H. Shao, D. Yang, S.-J. Guo and W. Huang, "Robotic-assisted revision total joint arthroplasty: a state-of-the-art scoping review," *EFORT Open Reviews,* vol. 8, no. 1.

[2] R. Smith, I. Borukhov, E. Hampp, M. Thompson, Z. O. Byrd, N. Sodhi, M. A. Mont and L. Sholl, "Comparison of Precision for Manual versus Robotic-Assisted Total Hip Arthroplasty Performed by Fellows," *J Hip Surg,* pp. 117-123, 2020.

[3] J. Parvizi, K.-I. Kim, G. Goldberg, G. Mallo and W. J. Hozack, "Recurrent Instability after Total Hip Arthroplasty," *Clinical Orthopaedics and Related Research,* vol. 447, pp. 60-65.