Original Article

Journal of Orthopaedic Case Reports 2026 September:16(9):Page 477-482

Use of a Robotic Platform Compared with Manual Preparation for Revision Total Hip Arthroplasty: A Cadaver-Based Feasibility Study

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Learning Point of the Article:

Robotic assistance in revision total hip arthroplasty has the potential to enhance pre-operative plan accuracy, optimize screw fixation, avoid pelvic perforation, and streamline augment preparation.

Abstract

Introduction: Aim and Background: Revision total hip arthroplasty (THA) is technically demanding, particularly when acetabular bone loss, distorted anatomy, and uncertain screw fixation complicate reconstruction. Robotic-assisted platforms may improve pre-operative planning and intraoperative execution, but its role in revision THA has not yet been fully established. This cadaver-based feasibility study evaluated the effectiveness of robotic-assisted technology in revision THA acetabular reconstruction.

Materials and Methods: In one fresh-frozen specimen with prior bilateral manually performed total hip arthroplasties, full acetabular revision with standardized acetabular defects was performed. Computed tomography-based robotic-assisted revision THA was performed on one side and conventional manual revision THA on the contralateral side. Pre-operative planning, acetabular preparation, component positioning, screw number and length, quadrant distribution of screw fixation, pelvic perforation, and augment preparation were assessed.

Results: Robotic-assisted revision THA achieved fixation in all four acetabular quadrants using screws ranging from 20 mm to 40 mm, without pelvic perforation. The final construct closely matched the pre-operative plan, with 1.2 absolute inclination error, and augment preparation and implantation required <5 min. Manual revision THA achieved fixation across three acetabular quadrants using six screws ranging from 15 to 40 mm; however, all demonstrated pelvic perforation. Manual preparation showed greater intraoperative variability, and augment preparation and implantation required approximately 15 min.

Conclusion: Robotic-assisted revision THA demonstrated greater concordance with pre-operative planning, broader acetabular screw fixation, avoidance of pelvic perforation, and faster augment preparation compared with manual techniques. These findings suggest robotic-assisted technology may enhance precision and reproducibility in complex revision THA and warrant further clinical investigation.

Keywords: Acetabulum, bone loss, pre-operative planning, robotic-assisted, revision total hip arthroplasty.

Introduction

The number of total hip arthroplasty (THA) procedures performed annually in the United States (US) continues to rise, and as a result, the burden of revision THA (rTHA) is expected to increase substantially over the coming decades. Current projections estimate that rTHA procedures in the US will increase by approximately 70–100% by 2030, driven by expanding primary arthroplasty volume, younger patient age at implantation, and longer life expectancy [1,2]. Recent epidemiologic data confirm that rTHA volumes have continued

Access this article online

Website: www.jocr.co.in

DOI: https://doi.org/10.13107/jocr.2026.v16.i09.8128

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Submitted: 21/06/2026; Review: 05/07/2026; Accepted: August 2026; Published: September 2026

DOI: https://doi.org/10.13107/jocr.2026.v16.i09.8128

to climb, with aseptic loosening and instability remaining the leading indications for revision [3]. rTHA is associated with increased operative complexity, higher complication rates, greater costs, and worse patient outcomes compared with primary procedures, with patients reporting significantly less improvement and higher rates of worsening in patient-reported outcomes compared with primary THA [4,5]. These challenges underscore the importance of technologies that may improve surgical planning and execution. In parallel, robotic-assisted arthroplasty has seen rapid growth in surgeon adoption and utilization across both the US and Europe, reflecting increasing confidence in these platforms as tools to enhance precision and reproducibility [6,7,8]. Patient-related comorbidities have been independently associated with increased risk of periprosthetic joint infection and post-operative mortality following THA, further emphasizing the need for optimized surgical execution [9].

Robotic-assisted THA platforms have demonstrated improved accuracy of acetabular component positioning compared with manual techniques in both primary and revision settings [10,11,12]. Systematic reviews and meta-analyses have shown that robotic-assisted THA provides greater implant placement accuracy and lower complication rates compared with conventional approaches [11], and prospective randomized data have confirmed superior acetabular cup positioning with computed tomography (CT)-based robotic planning [12]. These benefits appear to extend even into the learning curve, with early adopters achieving improved acetabular positioning relative to fluoroscopic or manual guidance [13]. In the revision setting specifically, early clinical data suggest that robotic-assisted acetabular reconstruction can achieve reliable component positioning with favorable outcomes [14], and cadaver-based work has demonstrated improved accuracy of acetabular component positioning with robotic assistance during rTHA [15].

An extremely technically demanding aspect of rTHA is acetabular reconstruction. Surgeons must often contend with bone loss, distorted anatomy, prior hardware, and unpredictable bone quality [16]. Contemporary analyses of rTHA failure have identified instability and aseptic loosening as the predominant modes of failure, with instability alone accounting for approximately 52% of re-revisions [17]. These failure modes, along with infection and periprosthetic fracture, collectively represent the majority of revision failures [5,17]. While templating using plain radiographs remains common practice, accurate prediction of cup position, screw trajectory, and available bone stock is frequently limited until intraoperative exposure is achieved. Ideally, acetabular fixation in rTHA should maximize initial mechanical stability through optimal component positioning, broad host bone contact, and strategic screw fixation. In the most severe cases, such as pelvic discontinuity, even advanced reconstruction strategies such as cup-cage constructs carry failure rates of up to 15%, highlighting the difficulty of achieving durable fixation in compromised acetabular bone stock [18].

A commonly accepted principle in revision acetabular fixation is the distribution of screws across all four acetabular quadrants; anterior-superior, anterior-inferior, posterior-superior, and posterior-inferior, to enhance construct stability, reduce toggle, and minimize the risk of loosening or migration [19]. In practice, however, screws are often placed in only two or three quadrants due to uncertainty regarding bone availability, screw length, and proximity to neurovascular structures. Furthermore, longer screws with optimal trajectory provide superior purchase and resistance to pullout, yet are frequently avoided because of limited pre-operative visualization and intraoperative guesswork.

To address these challenges, a next-generation robotic application for rTHA (Mako Total Hip 5.0, Stryker, Weston, Florida, US) has recently been developed. This system allows CT-based pre-operative planning of acetabular and femoral component positioning, identification of remaining host bone, planning of screw number, length, and trajectory across all four quadrants, and virtual planning of augments. Such capabilities may offer meaningful advantages over traditional manual techniques, particularly in complex revision scenarios.

This is a cadaver-based, proof-of-concept evidence study evaluating the effectiveness of robotic planning on acetabular reconstruction for rTHA. We compared robotic-assisted rTHA techniques with conventional manual rTHA preparation in a standardized acetabular defect model. We specifically assessed concordance between pre-operative planning and final construct, screw number and quadrant distribution, screw length, and ease of augment preparation and implantation. Beyond feasibility, this study sought to evaluate whether robotic-assisted rTHA could meaningfully impact construct quality metrics that are known to influence mechanical stability and early failure.

Materials and Methods

There was one fresh-frozen human cadaver specimen used for this study. The cadaver had prior bilateral THAs done manually through a posterior approach. These were revised, and a supero-lateral acetabular defect was created to simulate bone loss that would require an augment during a full acetabular revision.

The specimen underwent standardized pre-operative imaging, including anteroposterior and lateral radiographs of the pelvis and a CT scan. Pre-operative planning, acetabular preparation, component positioning, screw number, screw length, quadrant distribution of fixation, and augment preparation were assessed.

The robotic-assisted case utilized CT-based planning with the Mako Total Hip 5.0 application to optimize implant positioning and screw trajectory (Fig. 1.). The femoral component size and version were planned, and the acetabular component was positioned to restore the hip center of rotation while maximizing host bone contact. The plan was for a 52 mm acetabular cup to be placed at 45° of inclination. Screw number, length, and trajectory were preoperatively planned with the goal of achieving fixation in all four acetabular quadrants using the longest safe screws possible. Augment size (52 mm) and location were also planned preoperatively. There were four screws planned for: One in each acetabular quadrant (112, 22, 18, and 14 mm). Bone mapping was performed using both the probe and the reamer basket.

The manual case relied on templating from anteroposterior and lateral radiographs for planning of the estimated acetabular component size, cup position, screw placement, and management of the acetabular defect. A 50–58 mm cup with an inclination of 40° was planned. Screw positions and lengths were not exactly planned, as the surgeon felt they would choose these intraoperatively, as they had done in their practice.

The procedures were performed through a direct anterior approach by two surgeons who had extensive experience in revision arthroplasty.

Results

Both the robotic-assisted and manual rTHA procedures were completed successfully using a standard anterior approach. A comparison of the constructs is summarized in Table 1.

Robotic-assisted rTHA

A 52 mm acetabular component was implanted according to the pre-operative plan (Fig. 2). On post-operative CT scan evaluation (Fig. 3), the final component inclination was 43.8°, compared with a planned inclination of 45°, resulting in an absolute deviation of 1.2°.

There were four acetabular screws placed, with lengths ranging from 20 to 40 mm (20, 25, 25, and 40 mm). Fixation was achieved in all four acetabular quadrants. There was no pelvic perforation observed with any screw.

Augment preparation was done in one stage with a diameter of 52 mL, and two screws were used (35 and 45 mm) with no perforation. The augment preparation and implantation were completed in <5 min.

Manual rTHA

A 50 mm acetabular component was implanted (Fig. 3). The final component inclination was 58.6°, compared with a planned inclination of 40°, resulting in an absolute deviation of 18.6°. A total of six acetabular screws were placed, ranging from 15 to 40 mm (15 × 4, 30, and 40 mm). Fixation was achieved in three of the four acetabular quadrants, missing the anterior-inferior quadrant. All six screws demonstrated pelvic perforation, including two screws exceeding 15 mm beyond the pelvic cortex. Preparation and implantation of the superolateral augment used two screws (25 and 35 mm) and required approximately 15 min.

Discussion

This cadaver-based feasibility study demonstrates several potential advantages of robotic-assisted technology in rTHA. Although limited to a single bilateral case, the findings highlight important differences regarding planning accuracy, screw fixation strategy, and efficiency of augment preparation.

Beyond feasibility, the present study examined construct quality metrics that have been associated with mechanical stability in rTHA. Accurate restoration of acetabular orientation, avoidance of pelvic perforation, and broad screw distribution across all four quadrants collectively represent factors associated with improved initial fixation and reduced micromotion, particularly in the setting of compromised bone stock. This is critical given that instability and aseptic loosening account for approximately 65% of rTHA failures [20].

A notable observation was the strong concordance between the pre-operative plan and the final construct in the robotic-assisted case. In rTHA, accurate restoration of the hip center of rotation and maximization of host bone contact are critical to long-term implant survival [19]. The ability to visualize remaining bone stock and plan component positioning three-dimensionally may reduce intraoperative uncertainty and variability, particularly in cases that have distorted anatomy or prior hardware.

The robotic platform enabled planned screw fixation across all four acetabular quadrants with screw lengths optimized to available bone corridors. Prior biomechanical and clinical work suggests that broader screw distribution and longer screws can improve initial construct stability by reducing micromotion, toggle, and pullout risk [21,22]. In manual rTHA, surgeons may limit screw length or trajectory because of uncertainty regarding bone corridors and proximity to intrapelvic structures. The use of CT-based robotic planning and execution may mitigate these constraints by allowing more deliberate use of available host bone while maintaining safe trajectories. In the present study, this approach achieved four-quadrant fixation without pelvic perforation, supporting a potential role for robotic assistance in standardizing higher-quality acetabular fixation strategies.

A particularly notable finding in this study was the absence of pelvic perforation among all screws placed during robotic-assisted acetabular fixation, whereas all screws perforated during manual acetabular fixation. Although cadaver-based and not associated with clinical sequelae in this setting, pelvic perforation in rTHA carries potential risk to intrapelvic neurovascular and visceral structures. The ability to preoperatively plan screw length and trajectory based on three-dimensional CT data and to execute that plan accurately represents a meaningful safety advantage of robotic-assisted revision surgery.

Another important finding was the reduction in time and apparent ease of augment preparation in the robotic-assisted versus manual case. Augment positioning and preparation during rTHA can be technically demanding and time-consuming, even for experienced surgeons. Pre-operative planning and guided execution may streamline this step, potentially reducing operative time, blood loss, and fatigue, factors known to influence complication rates in complex revision procedures [4,23]. Complex acetabular reconstruction techniques, including cup-cage constructs for pelvic discontinuity, remain technically demanding with non-trivial failure rates even at experienced centers [18], further supporting the potential value of robotic-assisted planning and execution for augment and component placement.

Both procedures in this study were performed by surgeons who had extensive revision experience, each having performed thousands of hip revisions. It is reasonable to speculate that the relative benefit of robotic-assisted revision technology may be even greater for surgeons who have lower revision volumes or are earlier in their learning curve. In this context, robotic platforms may serve not only as a technical aid, but also as an educational tool that standardizes planning principles and execution strategies.

As rTHA volumes continue to rise in the US and globally, the technical demands placed on surgeons will continue to rise. Technologies that enhance reproducibility, precision, and safety, particularly in complex acetabular reconstruction, may play an increasingly important role in maintaining outcomes as case volume and complexity increase. While this study does not address clinical outcomes, it provides early evidence that robotic-assisted platforms may serve as enabling technology in this evolving field. Larger clinical studies will be necessary to determine whether these advantages translate into improved implant survivorship, reduced complications, and better patient-reported outcomes.

This study has several potential limitations. As a single cadaver-based feasibility study of two rTHAs, the sample size did not allow for statistical analyses, and the findings may not be generalizable to all clinical settings or patient populations. The use of a cadaver-based model, while valuable for demonstrating technical feasibility and workflow, introduces inherent limitations such as the absence of physiologic conditions and differences in biomechanical tissue properties that may not fully replicate the in vivo intraoperative environment. In addition, cadaver-based models preclude assessment of functional outcomes, complication rates, and patient-reported measures. The cases presented reflect the experience of two surgeons, and results may differ across levels of robotic or revision arthroplasty experience. The Mako 5.0 platform was used for the robotic-assisted rTHA in a cadaver that had a bone defect, and the findings may not apply to revisions with differing defect classifications, implant configurations, or patient-specific anatomic considerations. Despite these factors, the planning environment, visualization, and feedback provided by the robotic platform may assist residents and surgeons who have limited rTHA experience. Future in vivo studies with larger sample sizes and control groups are needed to determine whether the strong adherence to planned alignment and optimization of screw number and length for fixation in four acetabular quadrants observed in the robotic-assisted case translates into reduced complication rates and improved patient-reported outcomes in rTHA.

Conclusion

In this cadaver-based feasibility study, robotic-assisted rTHA demonstrated strong alignment between pre-operative planning and final construct, optimized screw number and length with fixation across all four acetabular quadrants without pelvic perforation, and efficient augment preparation compared with conventional manual techniques. These findings suggest that robotic-assisted technology may offer meaningful advantages in rTHA and warrant further clinical investigation as revision volumes continue to expand.

Clinical Message

Robotic-assisted revision THA may provide clinically meaningful advantages in complex acetabular reconstruction by improving translation of the pre-operative plan, enabling safer and broader screw fixation, avoiding pelvic perforation, and simplifying augment preparation. However, larger clinical studies are needed to determine whether these technical benefits translate into improved patient outcomes.

Declaration of patient consent: The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given the consent for his/ her images and other clinical information to be reported in the journal. The patient understands that his/ her names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Conflict of interest: Nil **Source of support:** None

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Authors' Contributions: M.C. and M.T. contributed to the conceptualization and critical revision of the manuscript. C.W.S. contributed to the conceptualization, original drafting, and critical revision of the manuscript. R.C.M. and M.A.M. contributed to the conceptualization, laboratory work, original drafting, and critical revision of the manuscript. All authors read and approved the final manuscript.

Conflict of Interest: Nil
Source of Support: Nil

Consent: The authors confirm that informed consent was obtained from the patient for publication of this article

How to Cite this Article

Caba M, Thompson M, Smitterberg CW, Marchand RC, Mont MA. Use of a Robotic Platform Compared with Manual Preparation for Revision Total Hip Arthroplasty: A Cadaver-Based Feasibility Study Journal of Orthopaedic Case Reports 2026 September;16(09): 477-482.