Robotic Total Hip Arthroplasty

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KEYWORDS

• Hip • Arthritis • Joint replacement • Arthroplasty • Robotic • Navigation

KEY POINTS

- Component position influences functional outcome, durability, and risk of complications after total hip arthroplasty.
- Optimal component position requires meticulous planning based on reliable information, followed by accurate and precise execution of the plan.
- Surgical robotics provides the detail-oriented surgeon with a robust tool to optimize the accuracy and precision of total hip arthroplasty.

INTRODUCTION

Total hip replacement (THR) was described as the "operation of the [twentieth] century."[1] Although highly cross-linked polyethylene has reduced wear at the bearing surface and cementless fixation has reduced mechanical failure at the fixation interface, several attempts to improve on John Charnley's innovation in the early twenty-first century have proved less rewarding.[2] A trend toward cementless tapered femoral implants, cementless hemispherical acetabular implants, and cobalt-chromium or ceramic on highly cross-linked polyethylene articulations is emerging.[3] When proven implants are used, high rates of patient satisfaction are experienced and durability longer than 20 years is anticipated.[4]

Is there room for improvement in modern THR? Patients and payers are no longer willing to tolerate early failure after THR,[5] but infection, dislocation, leg length discrepancy, and periprosthetic fracture continue to occur. Furthermore, edge loading, impingement, and other mechanical consequences of imprecise implant positioning continue to adversely affect implant durability for many patients.[6–9] Recent Medicare data show that 10% of patients age 65 to 74 years at the time of hip replacement undergo revision surgery within the first 10 years,[10] and recent European registry data show a 17% revision rate at 10 years for patients less than 50 years old at the time of surgery.[11]

As surgeons try to meet ever-higher expectations, they must endeavor to embrace improvements without subjecting patients to the safety concerns that come with unproven technologies.[2] The last 10 years have provided ample opportunity to reflect with humility on the consequences of supposedly improving THR. Nevertheless, avoidance of mechanical failure requires improvements in surgical implants and/or technique.

With surgeons, regulators, and patients now more skeptical of new THR implants, the greatest opportunities for improvement may be at the level of surgical technique. Imprecision of acetabular component position, a major source of variability in THR outcomes,[6,7,9,12–16] presents such an opportunity.

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Surgeons embarking on THR, whether simple or complex, must first establish targets for component position and then endeavor to reproduce the plan within accepted tolerances.[17] Several investigators have proposed ranges of acceptable component acetabular position.[12,13,18–20] Femoral offset and length must be informed by both femoral anatomy and the selected acetabular position so as to optimize limb length reconstruction, abductor function, joint stability, and impingement-free range of motion.[21] Ideal implant position for a given patient may also be affected by surgical approach, soft tissue constraints, functional requirements, and extra-articular deformities such as fixed pelvic obliquity or tilt.

Planning based on plain radiographs remains limited by inability to (1) consistently control or assess magnification and (2) obtain simultaneous perfect anteroposterior (AP) images of the pelvis and proximal femur in patients with joint contractures. The imprecision of manual component positioning is well documented, and rigorous assessment of radiographic outcomes reveals that a large percentage of acetabular prostheses are implanted outside accepted parameters for optimal position.[19]

Computer navigation was developed to improve on manual techniques and can be image guided or imageless. Although imageless navigation can improve intraoperative assessment of component position and limb length change, only image-based systems can improve surgical planning. Preoperative planning based on three-dimensional (3D) patient anatomy facilitates restoration of acetabular center of rotation and allows the ideal acetabular abduction and anteversion angle to be informed by relationships with bone anatomy. For example, patients with anteverted dysplastic acetabulae are at risk for psoas tendon impingement if the acetabular implant is not positioned within the anterior lip of the acetabular bone. Preoperative 3D planning allows the surgeon to select a position that avoids implant prominence but also avoids excessive anteversion or reaming through the medial wall of the acetabulum, technical errors that can easily occur in the service of a well-covered implant in a dysplastic acetabulum. However, navigation alone inadequately facilitates this precision because depth and location of acetabular reaming are not precisely controlled.

Surgical robotics allows the coupling of 3D planning with precision bone preparation and implant insertion. Robots have been investigated for use in joint replacement since the 1980s and used clinically since 1992. ROBODOC (Curexo Technology Corporation, Fremont, CA) was the first surgical robot developed and commercialized for THR.[22] Although initially developed domestically by IBM, the ROBODOC active robotic system has had limited popularity in the United States and much of the published experience is from Europe and Asia.[23–25] The system is approved by the US Food and Drug Administration (FDA) for THR, but has not yet been widely accepted by the domestic orthopedic community.

Widespread interest in robotic joint replacement surgery began with the commercialization of the RIO Robotic Arm Interactive Orthopedic System (Stryker Mako Surgical Corporation, Fort Lauderdale, FL) for partial knee replacement. The device has been shown to improve the precision of limb and implant alignment compared with manual techniques,[26–28] but does not remove the necessity of attention to details such as cement technique.[29] Short-term clinical outcomes have been favorable, but long-term results are not available. Software and hardware to facilitate THR were recently introduced.[30] The robot assists with reaming of the acetabular cavity and positioning the acetabular implant using haptics, and its software package allows navigation of the femoral neck cut, leg length, and offset. The remainder of this article describes techniques for leveraging surgical robotics to optimize implant positioning for hip reconstruction, with figures to clarify the technique and illustrate the capacity of the robot to simplify complex reconstructions. The details described are specific to the widely available Mako RIO robot, but the concepts are generally applicable to other robotic platforms using image-based navigation and haptic control.

SURGICAL TECHNIQUE

The design of a surgical robot could theoretically limit the surgeon's choice of surgical approaches. The Mako RIO robot has software packages to facilitate THR through posterior, lateral, anterolateral, and direct anterior approaches. The posterior approach is emphasized in this review, followed by changes in the workflow for the direct anterior approach.

Preoperative Planning

Segmentation

Surgical planning software accompanies the Mako RIO surgical robot. A computed tomography (CT) scan of the pelvis and both femora is performed according to a specific protocol. CT images are segmented and 3D reconstruction is performed. Bony landmarks such as the anterior superior iliac spines and the medial tips of the lesser trochanters are identified. This process is performed by engineers but can be verified by the surgeon.