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Surgical technique

Conversion of Hip Arthrodesis Using Robotic Arm Technology

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ABSTRACT

Recent advancements in computer-assisted surgery have led to a renewed interest in robotic-assisted hip arthroplasty. This technology assists with component position which is especially useful in prior trauma or dysplasia cases. We present a case of a surgical hip fusion conversion to total hip arthroplasty with the use of robotic-assisted technology. Enhanced preoperative planning with the ability to manipulate implant position before execution can be invaluable during complex procedures. Further research is warranted before revision cases using computerized navigation systems becomes more prevalent.

Introduction

Computers have been assisting surgeons in the operating theater for the past 3 decades. Recently this technology has become a renewed interest for arthroplasty surgeons. Recent studies have shown computer assistance improves the accuracy of implant position for both hip and knee replacements [1-3]. In addition, computers yield more predictable alignment in cases of severe deformity or prior trauma [4]. During hip arthroplasty, the computer helps identify the precise location of the femoral neck osteotomy and assists in placement of the acetabular component to accurately restore leg length and femoral offset. In addition, several studies have demonstrated computer-assisted hip surgery may decrease the risk of dislocation by ensuring the acetabular component is within Lewinnek's safe zone [4,5].

Hip arthrodesis has been shown to provide durability, stability, and long-term pain relief for patients with labor-intense occupations [6]. However, arthrodesis usually results in altered gait mechanics, slower walking speeds, and compensatory stress of adjacent joints including the lumbar spine, ipsilateral knee, and contralateral hip [7-10]. With today's advances in implant design and bearing surfaces, hip arthrodesis is becoming an uncommon option for young patients with severe hip pathology [11].

We present a unique case using a MAKO robotic arm system to assist conversion of a surgical hip arthrodesis to total hip arthroplasty (THA). This conversion surgery represents a technically demanding procedure that historically has been accompanied with significant complications including fracture, infection, and dislocation [7,9]. Our described technique represents an off-label use of this robotic system. Patient informed consent was obtained before this case study.

Case history

A 45-year-old Caucasian male sustained a closed displaced and comminuted left femoral neck fracture after a motor vehicle accident at the age of 15. After 2 unsuccessful hip surgeries, a surgical hip arthrodesis was performed (Fig. 1). The patient functioned well for the next 30 years until low back pain, ipsilateral knee pain, and contralateral hip pain became symptomatic and unresponsive to conservative measures.

Preoperative planning

After obtaining a thin-cut computed tomography (CT) scan of the pelvis and hip, further image analysis was performed with 3DSlicer software (Boston, MA). With the help of our University

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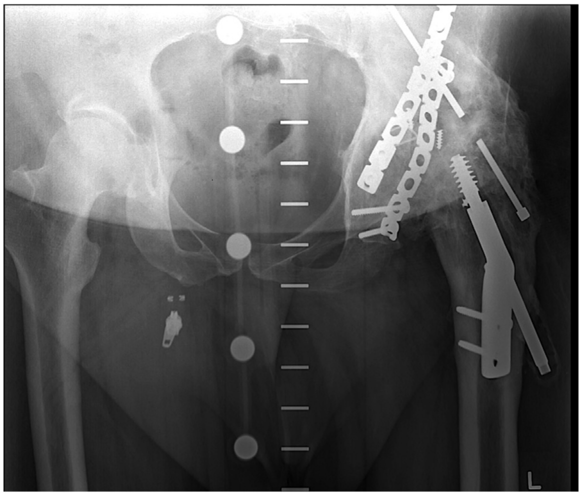

Figure 1. AP pelvis view showing left hip fusion mass with hardware in place.

graphic design department, a 1:2 scale printed model of the hemipelvis, fusion mass, and proximal femur was manufactured on a Formlabs Form 2 three-dimensional (3D) printer (Somerville, MA) (Figs. 2-4). In addition, CT images were sent to our MAKO product specialist to create a virtual 3D model of the pelvis and operative hip (Figs. 5 and 6). The existing hardware was delineated on both the CT scan and 3D printed model. The medial extent of the native acetabular fossa was identified on axial CT scans situated between the anterior and posterior columnar reconstruction plates distal to the tip of the compression screw within the femoral neck.

To separate the proximal femur from the hip fusion mass, essential landmarks including the remnants of the greater and lesser trochanters were used to determine the precise location of the osteotomy on both the virtual and 3D-printed models. The templated position of the acetabular component was based on requirements to optimize leg length and offset to address a 5-cm preoperative leg length discrepancy. A primary hip stem was chosen to satisfy the virtual model parameters during the planning stage, but a revision hip stem would be used intraoperatively (Figs. 7 and 8). Currently the MAKO robotic-arm system does not have the ability to template with revision components.

Figure 2. Anterior view of the 3D printed model of the hip fusion mass, left hemipelvis, and proximal femur.

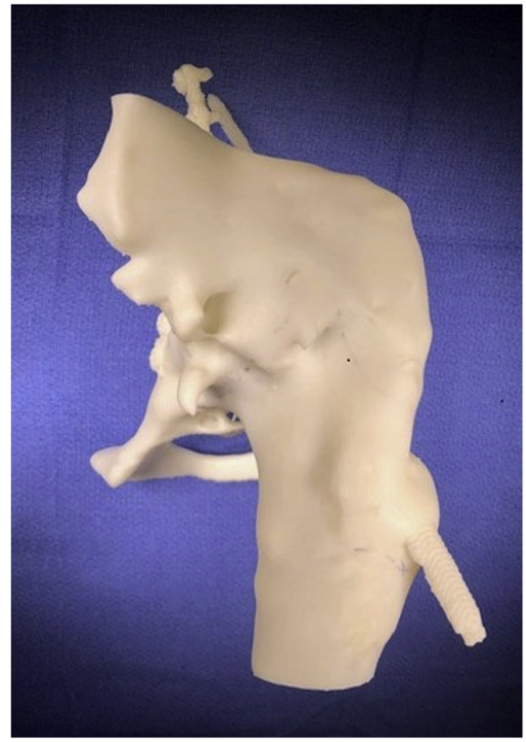

Figure 3. Oblique view of the 3D printed model of the hip fusion mass, left hemipelvis, and proximal femur.

Figure 4. Lateral view of the 3D printed model of the hip fusion mass, left hemi-pelvis, and proximal femur.

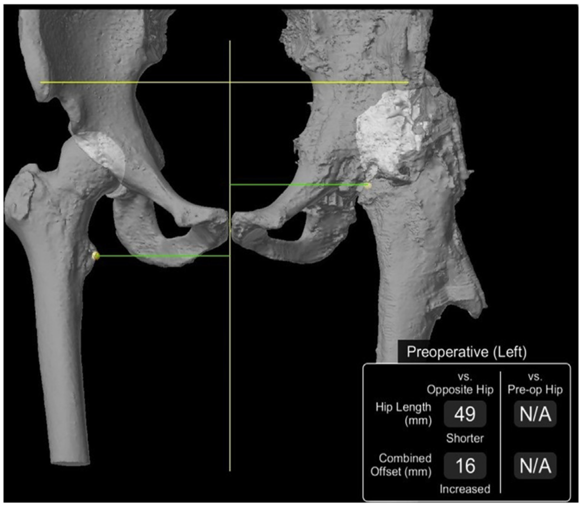

Figure 5. AP view of virtual representation of the fusion mass created using MAKO software from CT images. There is a leg length discrepancy of 49 mm and a decreased offset of 16 mm in the operative extremity.

Conversion surgery

After securing a vizadisc real-time optical tracking array to the ipsilateral iliac crest through a separate stab incision, the prior posterior hip incision was used to gain access to the hip fusion mass and proximal femur. The hip fusion mass was circumferentially defined by removing excess scar tissue while protecting the remaining insertion of the abductor musculature. A 3.5-mm hex impaction checkpoint was placed on the superior ilium away from the hip fusion mass while an identical second checkpoint was placed at the most lateral portion of the proximal femur. Then, preliminary measurements of leg length discrepancy (49 mm) and decreased offset (16 mm) were recorded after comparing to the contralateral hip.

Then, a micro burr was used to remove ectopic bone surrounding the side plate and hip compression screw which were then removed with the aid of an osteotome and a screwdriver,

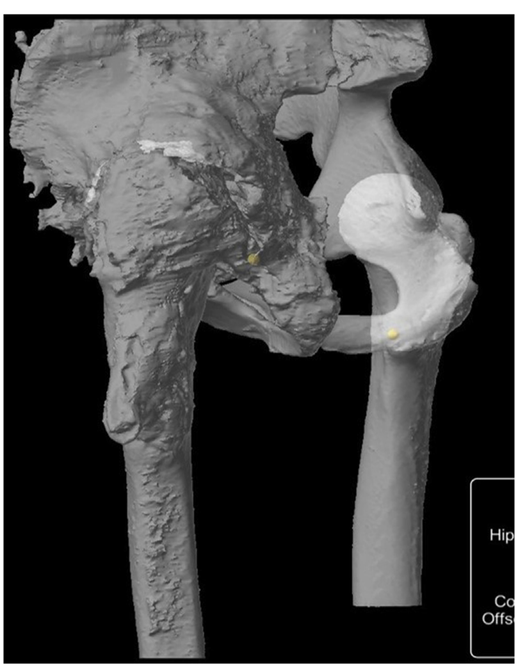

Figure 6. Lateral view of virtual representation of the fusion mass created using MAKO software from CT images. There is a leg length discrepancy of 49 mm and a decreased offset of 16 mm in the operative extremity.

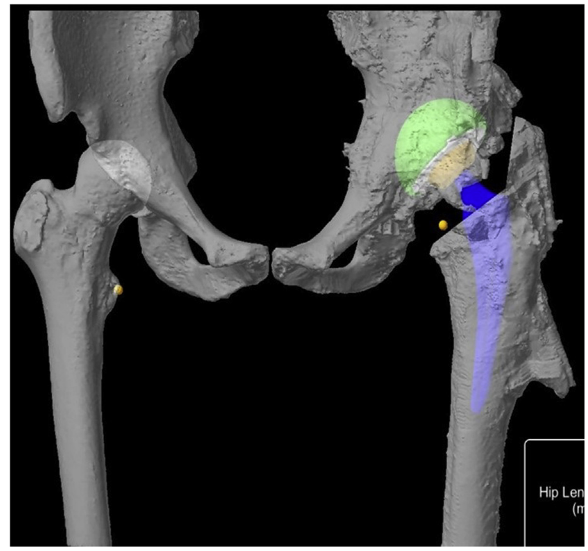

Figure 7. AP view of the pelvis displaying preoperative Templating of the fusion mass osteotomy and implant positioning using the virtual model generated by MAKO software from CT images. Yellow circles represent lesser trochanters.

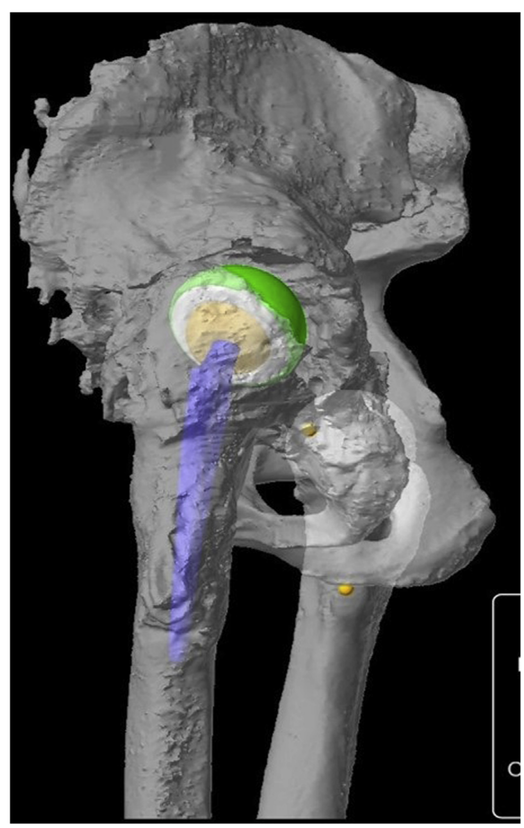

Figure 8. Lateral view of the pelvis displaying preoperative Templating of the fusion mass osteotomy and implant positioning using the virtual model generated by MAKO software from CT images. Yellow circles represent lesser trochanters.

respectively. At this point, registration of the hip fusion mass was accomplished using a specific probe outfitted with vizadisc arrays. Data points included the anterior, posterior, and superior aspects of the bony mass as well as the native ilium, ischium, and pubis and most lateral portion of the proximal femur. Registration of the deeper portions of the acetabulum were acquired later in the case. Verification spheres confirmed data points were within 0.5 mm of the virtual CT model.

After confirming the location of the osteotomy with the probe, a precision saw was used to separate the proximal femur from the fusion mass. Then, to enable further mobilization of the femur and to protect the remaining abductor musculature, a 12-cm proximal femoral/extended trochanteric osteotomy was performed.

At this point, attention was focused on locating the native acetabulum. The remaining corridor from the hip compression screw was used to direct further medial dissection. Bone was removed in piece-meal fashion with a combination of osteotomes and rongeurs. At frequent intervals, the probe was used to correlate the remaining bone with the location of the probe on the computerized virtual model. After reaching the appropriate depth, the bony channel was carefully enlarged with a rongeur to ensure an acetabular reamer would pass with minimal obstruction. At this stage, data points from the medial portion of the acetabulum were obtained, thus satisfying the data registration portion of the procedure.

Then, the proposed virtual position and orientation of the acetabular component was reviewed. To ensure adequate contact with bone and to avoid the existing hardware, the implant was positioned at 35° of acetabular abduction and 20° of anteversion. While using the robotic arm, line-to-line reaming proceeded within the aforementioned parameters until final depth was attained. Then, the robotic arm was used to position a 56-mm Stryker Tritanium revision acetabular component (Mahwah, NJ) within the aforementioned orientation. The component was fully seated and secured with screws. Any excess bone protruding around the periphery of the acetabulum was removed with a rongeur to prevent bony impingement during range-of-motion. Then, a dual mobility liner was secured to the acetabular component.

The trochanteric osteotomy was anatomically reduced and stabilized with cerclage cables. The femur was then prepared for the revision stem by reaming in sequential fashion until adequate cortical chatter was encountered. At this point, a trial body and dual mobility head were applied, and the hip was reduced. The hip was gently taken through available range-of-motion, and the construct was found to be stable. Then, the checkpoints were registered again denoting an increase in offset by 10 mm with an anticipated leg length discrepancy of 3 cm.

The trial components were removed, and a monolithic Smith & Nephew Redapt stem (17 mm × 240 mm; Memphis, TN) was impacted down the femur noting appropriate anteversion. Then, a 28-mm (+8) Smith & Nephew Oxinium head was appropriately inserted into the 42-mm Stryker dual mobility polyethylene component. Given the unreliable nature of the abductor musculature, a constrained component was available in the event that the dual mobility construct was unstable. At this point, the head was impacted onto the trunnion, and the hip was reduced and the wound was irrigated and closed in regular fashion (Fig. 9).

Follow-up

The patient participated in outpatient physical therapy for the next 5 months focusing on range-of-motion, strength, balance, and endurance. Weight-bearing progressed from toe-touch to 50% at 8 weeks then to full weight-bearing as tolerated by 12 weeks while following posterior hip precautions during the recovery process.

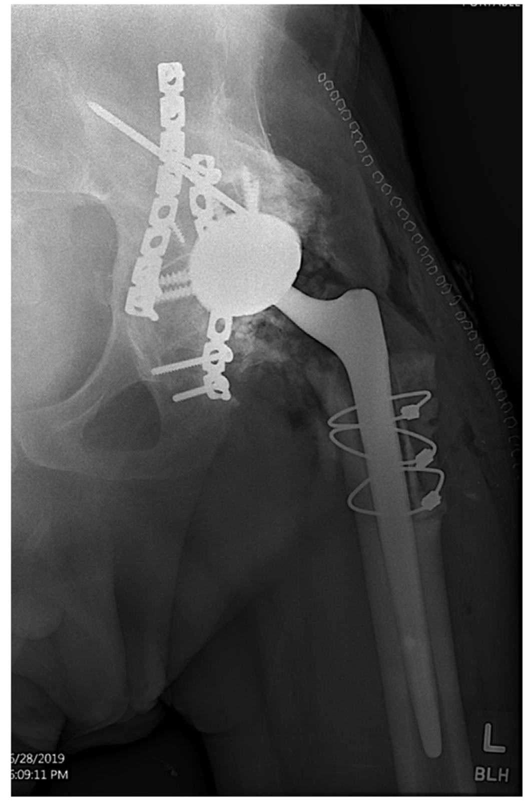

Figure 9. AP of left hip showing immediate postoperative total hip arthroplasty and takedown of fusion mass.

The patient continues to display a Trendelenburg gait pattern despite attempts to maintain abductor attachments. Currently, the patient ambulates without an assistive device for short distances but relies on a single-point cane most of the time.

The patient reported a fall about 3 months from surgery which did not result in serious injuries. The patient reports complete resolution of contralateral hip and ipsilateral knee pain, but he continues to have low back pain for which he sees a pain medicine specialist. The patient is happy with his progress and is actively seeking employment 1 year after the conversion procedure. To date, there have been no issues with infection or instability.

Discussion

To our knowledge, this is the first report of computerized robotic arm technology used during conversion of a surgical hip arthrodesis to THA. Currently, the MAKO system has only been approved for primary hip and knee replacement, thereby making our case an off-label indication. Ingenuity served as the blueprint for this procedure. Meticulous preoperative planning, knowledge of hip anatomy and biomechanics, and a firm understanding of the technology workflow were all necessary for a successful outcome.

Arthrodesis conversion to THA represents one of the most challenging procedures for arthroplasty surgeons. Preoperative planning via CT scans, a computerized 3D model, and a physical 1:2 scale model all enabled a thorough understanding of the spatial representation of the operative hip anatomy before entering the operating room. Various pieces of hardware were buried deep within the fusion mass, and removal of these components would risk sacrificing supporting bone stock for the acetabular component. Alternating between data collection mode and real-time navigation permitted the acquisition of all necessary data points to satisfy computer requirements. Armed with this information, we were able to position the acetabular component close to the native acetabulum while avoiding the deep hardware. The accuracy between the computerized model and patient landmarks was less than 0.5 mm, thus ensuring the acetabular component was exactly positioned within the planned parameters.

Chai et al. described their technique of robotic-assisted conversion of ankylosing spondylitis patients with hip arthrodesis to THA [12]. Their data point registration included various points around the periphery of the symptomatic hip joint, but unlike our case, the authors did not have to account for existing hardware around the hip fusion. Instead of collecting data points from the inside of the acetabulum, they relied on the accuracy of the preoperative CT scan. The authors concluded that robotic-assisted THA improved the frequency of achieving cup position for their patients [12].

Several studies have examined outcomes of THA after hip arthrodesis with the majority reporting improved function [9,10,13,14]. In addition, studies have shown decreased back pain, ipsilateral knee pain, and contralateral hip pain after conversion [9,14]. Conversion THA has been shown to significantly improve function after arthrodesis [7-9]. One study compared patients undergoing conversion from arthrodesis to THA with patients undergoing a primary THA and found no difference in Oxford Hip Score, Rosser Index Matrix Quality of Life, or Harris Hip Score between the 2 groups [15].

Arthrodesis conversion surgery to THA is not without risks and complications. One systematic review of 1104 hips found a 5.3% rate for infection and a 12% revision rate for dislocation and aseptic loosening [16]. Multiple studies cited limb length inequality, dislocation, and peroneal nerve palsy as complications of conversion surgery [10,13,14,16]. Fracture of the greater trochanter or proximal femur is another potential complication during conversion surgery [10]. Inconsistent bone quality within the fusion mass in conjunction with an excess of nonpliable scar tissue can place undue stress on the bone with aggressive attempts at mobilization after osteotomy. Therefore, an extended trochanteric osteotomy was performed after the initial osteotomy to enhance visualization and decrease risk of further fracture.

It was necessary to deviate from the computerized plan during evaluation of leg length and hip offset. Although the preoperative plan used a primary femoral stem to satisfy planning parameters, the surgeons used a monolithic revision stem during surgery to bypass cortical stress-risers remaining after removing the proximal femur compression plate and screws. Judging intraoperative stability is a difficult task after conversion surgery because of the extensively scarred soft tissue envelope. Excessive leg length or offset may have risked fracture when testing intraoperative range of motion. Thus, the team relied on the preoperative plans, computerized acetabular positioning, and the dual mobility construct to achieve stability. Likewise, we were unable to fully address the entire preoperative leg length inequality for the aforementioned reasons. Postoperatively our patient has a 3-cm leg length inequality that is being currently managed with a heel lift. Preoperative education ensured realistic goals were attained with this surgery.

In the past, Lewinnek proposed a “safe zone” of acetabular orientation to prevent dislocation [4]. Today this concept has been largely replaced with a “functional” model of acetabular positioning which can change depending on sitting or standing postures [4]. Newer studies have elucidated the influence of spinal mechanics on hip function as it relates to dislocation [17]. Researchers are working to incorporate various biomechanical parameters such as lumbar disc disease into next generation software to produce a custom hip replacement experience [3,4,18].

Multiple studies have demonstrated computer-assisted surgery improves implant position and overall accuracy, but resultant outcomes have not demonstrated superiority over conventional instrumentation for primary arthroplasty [5,19]. Computer assistance during revision procedures continues to remain an area of current investigation. Prognostic algorithms continue to be developed to enable computers to extrapolate anatomy when particular defects and voids are present such as with pelvic discontinuity [20]. Further application of machine learning and artificial intelligence may hold the key to afford arthroplasty surgeons another valuable tool during revision procedures [18,20]. One potential downside of this area research is the cost to develop the technology to benefit a small subset of revision arthroplasty patients [21].

As technology continues to evolve, the authors believe robotic navigation systems will become a universal option for complicated primary and revision arthroplasty cases. Enhanced preoperative planning with the ability to manipulate implant position to reestablish hip center of rotation to maximize stability can become invaluable during complex procedures. The ability to incorporate immediate feedback from the computer system enables the surgeon to quickly identify and adjust technical aspects of the surgery on a consistent basis. Virtual models can quickly identify component and/or bony impingement situations which can sometimes be difficult to appreciate during revision scenarios. Having the ability to seamlessly modify the surgical plan with the click of a mouse can save valuable time in the operative suite which benefits the patient and surgeon.

Summary

Today surgical hip arthrodesis is a rare procedure thanks to expanding indications for hip arthroplasty. We have presented our off-label technique of converting a hip arthrodesis to THA while using a MAKO robotic arm system. Communication among the various team members and referencing several hip models lead to a successful outcome. We believe future surgeons will gain more experience with computerized systems during arthroplasty cases. It is imperative to have a firm understanding of technology and data workflow to anticipate shortfalls as well as being able to complete the case if technology should fail. It is the role of the surgeon to optimize the patient for surgery and use all the tools available to decrease risks associated with infection, fracture, and dislocation.

Conflicts of interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: M.B. serves on the Arthroplasty Today Editorial Board. He was not involved in the peer review process.

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