Hip Resurfacing in the Setting of Retained Proximal Femoral Instrumentation or Complex Deformity

Ajay Premkumar, MD[1] Renee Ren, BS[1] Jonathan Spaan, MS[1] Edwin P. Su, MD[1]

[1] Department of Adult Reconstruction and Joint Replacement Service, Hospital for Special Surgery, New York, New York

Address for correspondence Jonathan Spaan, MS, Department of Adult Reconstruction and Joint Replacement Service, Hospital for Special Surgery, New York, NY 10021 (e-mail: jspaan22@gmail.com).

J Hip Surg

Abstract

Total hip arthroplasty (THA) in the setting of significant retained femoral instrumentation or complex proximal femoral deformity may be challenging and published reports of THA in this setting reveal sobering results. Hip resurfacing arthroplasty (HRA) is an alternative to THA and may avoid complex hardware removal or deformity correction at the time of hip arthroplasty. Twenty-three patients who underwent elective HRA in the setting of significant proximal femoral deformity and/or retained femoral instrumentation were identified from a prospectively maintained registry. Pre- and postoperative Lower Extremity Assessment Scores (LEAS), modified Harris Hip Scores (mHHS), Hip Disability and Osteoarthritis Outcome Scores for Joint Replacement (HOOS, JR) scores, Visual Analog Scale (VAS) pain levels, and metal ion levels were obtained. Median (interquartile range [IQR]) follow-up was 5.03 (2.07 – 7.91) years, and no patients had undergone revision surgery at their latest follow-up. The mean (standard deviation [SD]) surgical duration was 94.40 (12.00) minutes, and postoperative length of stay was 1.74 (1.80) days. There were no intraoperative complications, and all patients were discharged home. Median (IQR) postoperative LEAS, VAS pain scale, mHHS, and HOOS, JR scores were 13.00 (9.25 – 13.00), 2.50 (0.75 – 10.00), 92.60 (92.40 – 100.00), and 92.34 (85.26 – 100.00), respectively. Fourteen patients completed postoperative serum metal ion level testing at a mean (SD) of 4.24 (2.85) years, where cobalt and chromium levels were 1.22 (0.36) and 2.01 (0.80) parts per billion, respectively. HRA is a viable option for patients with significant proximal femoral deformity or retained instrumentation, and excellent results at mid-term follow-up can be achieved utilizing this strategy in this complex patient population.

Keywords

- hip resurfacing arthroplasty
- degenerative joint disease
- hip arthroplasty
- proximal femoral deformity
- retained hardware

Total hip arthroplasty (THA) remains one of the most efficacious surgical interventions in medicine and is most commonly performed for osteoarthritis, inflammatory arthritis, avascular necrosis, or femoral neck fracture.[1,2] Other indications for THA, such as hip degeneration in the setting of retained femoral instrumentation, may require removal of prior instrumentation, use of revision components, and/or management of residual proximal femoral deformity.

Several studies have noted inferior outcomes and higher complication rates in patients undergoing conversion THA necessitating removal of prior instrumentation, when compared with primary THA. Specifically, conversion THA often has longer operative times, increased blood loss, longer hospital length of stay, and higher rates of intraoperative and postoperative fracture, instability, infection, and all-cause revision.[3–5] Recent series have reported complication rates

received
March 19, 2023
accepted after revision
January 17, 2024

Thieme Medical Publishers, Inc.,
333 Seventh Avenue, 18th Floor,
New York, NY 10001, USA

DOI https://doi.org/10.1055/s-0044-1781435.
ISSN 2472-8446.

of up to 36% in conversion THA within 1 year of surgery.[6–15] These cases of conversion THA are often secondary to prior proximal femoral trauma and subsequent internal fixation, or from prior surgery for pediatric disease of the hip, namely developmental hip dysplasia, Legg–Calvé–Perthes (LCP) disease, and slipped capital femoral epiphysis (SCFE).

Hip resurfacing arthroplasty (HRA) is an alternative to conventional THA for end-stage osteoarthritis of the hip and is typically reserved for active, younger male patients with adequate femoral head bone stock and quality.[16,17] Both HRA and THA involve placement of an acetabular cup. However, unlike in THA, where the femoral head and neck are removed and an endoprosthesis is inserted into the femoral canal, in HRA, a thin surface layer of femoral head is removed and "capped" with a prosthesis of a similar size to the native femoral head, which then articulates directly with the acetabular component. In this manner, HRA allows for the utilization of larger femoral head sizes as well as the preservation of more proximal femoral bone. In the setting of prior femoral instrumentation, HRA may avoid removal of previously retained hardware. In the setting of complex proximal femoral deformities, HRA may allow for arthroplasty without requiring deformity correction, which would otherwise complicate use of traditional primary THA implants.

Modern approved implants for HRA involve large metal-on-metal bearings and have demonstrated excellent long-term survivorship in appropriately selected patients.[18] Reports on the utility of HRA in the setting of prior femoral instrumentation or complex deformity, however, are limited. A 2008 study involved 15 patients with extra-articular femoral deformities undergoing HRA, 5 of whom had retained instrumentation, and a more recent review of 61 HRA patients, of whom 5 had retained hardware, both demonstrated promising results.[19,20] To our knowledge, this study investigates the largest case series in the literature for metal-on-metal HRA in patients with retained femoral instrumentation or complex proximal femoral deformities. We will in turn examine intraoperative and postoperative complications, metal ion levels, as well as technical considerations for HRA in this clinical setting.

Methods

All patients who underwent elective HRA in the setting of significant proximal femoral deformity and/or retained femoral instrumentation due to prior hip procedures were identified from a prospectively maintained registry (Institutional Review Board approval STUDY 2020-0654). All procedures were performed by a single surgeon between January 2006 and December 2019 at an urban academic orthopedic specialty hospital. A total of 32 hips were identified. Two cases were excluded from analysis due to unclear patient and/or documented history of preoperative deformity. Seven cases were determined intraoperatively that THA would be the indicated procedure, rather than HRA. Of those seven hips, six were female. One case was determined intraoperatively to have extensive femoral deformity, and six cases involved removal of preoperative hardware that would not have allowed adequate bone stock for a successful HRA.

Of the remaining 23 identified cases, 22 (95.65%) were male, mean age was 47.44 years (standard deviation [SD]: 15.55) years at the time of surgery, mean body mass index was 29.08 kg/m^2 (3.80 kg/m^2), and median (interquartile range [IQR]) head and cup sizes were 52 (49–52) and 56 mm (5–58 mm), respectively (►**Table 1**). All cases underwent HRA through a posterolateral approach. The Birmingham Hip Resurfacing (BHR; Smith & Nephew, Warwick, UK) was used in 20 hips (86.96%) and the Biomet ReCap (Biomet, Inc., Warsaw, IN) was used in 3 hips (13.04%).

Immediately postoperation, patients were allowed to bear weight as tolerated, with the use of crutches as needed. Patients were allowed to return to activity on the stationary bike immediately. At 4 weeks' postsurgery, patients were transitioned to using a cane as needed and encouraged to improve range of motion and hip flexibility, including stretching exercises of the anterior capsule, iliotibial band, and hip flexors. Patients were allowed to restart lower impact activities such as racquet sports at 3 months and higher impact activities at 6 months postoperatively. Before a full return to high impact activity at 6 months, patients were evaluated to ensure they had achieved a full range of motion, muscle strength, and no pain or apprehension during activities.

Patients were followed postoperatively at 6 weeks, 3 months, 1 year, and annually after 1 year. Demographics, metal ion levels, radiographic evaluation, and patient-reported outcome measures (PROMs) were collected. Specific PROMs included were the Lower Extremity Activity Scale (LEAS), modified Harris Hip Scores (mHHS), Visual Analog Scale (VAS) Hip Pain, and Hip Disability and Osteoarthritis Outcome Scores for Joint Replacement (HOOS, JR). Anteroposterior pelvis and cross-table lateral radiographs were obtained at postoperative and annual visits. Baseline chromium and cobalt metal ion labs were obtained at the first annual postoperative visit and subsequently every 2 to 5 years. In patients with elevated levels of >7 parts per billion (ppb) per hip implant, metal ion measurements were obtained every 6 to 12 months.

Statistical analysis was performed using R statistical software (version 1.1.463). Descriptive statistics was used to assess cohort characteristics and outcomes. All statistical tests were two sided with a significance level of 0.05.

Results

Prior Operations

Twenty of the 23 patients (86.96%) had prior surgery (►**Table 1**). Of the 23 patients included in this study, a total of 17 patients had femoral instrumentation at the time of their HRA, and 2 patients underwent staged preoperative hardware removal at an outside center prior to presentation. Of the 20 patients with prior surgery, 8 were previous femoral head pinning procedures (34.78%), 6 were prior proximal femoral osteotomies (26.09%), and 6 underwent prior open reduction internal fixation (26.09%). ►**Figs. 1** and **2** demonstrate two cases of HRA in the setting of retained

Table 1 General Patient Characteristics

	Patient ($n = 23$)
Sex, male (%)	22 (95.65%)
Age, y (SD)	47.44 (15.55)
Laterality, left (%)	14 (61.00%)
Mean body mass index, kg/m^2 (SD)	29.08 (3.80)
Mean postoperative metal ion levels ($n = 14$)	
Cobalt, ppb (SD)	1.23 (0.36)
Chromium, ppb (SD)	1.94 (0.82)
Mean follow-up, y (SD)	5.10 (3.36)
Revisions (%)	0 (0.00%)
Mean surgical duration, min (SD)	94.40 (12.00)
Mean length of stay, d (SD)	1.74 (1.80)
Median head size, mm (IQR)	52 (49-52)
Median cup size, mm (IQR)	56 (54-58)
Implant type	
Birmingham hip resurfacing	20 (86.96%)
ReCap	3 (13.04%)
Presence of preoperative hardware (%)	17 (73.91%)
Removal of hardware in those with preoperative hardware (%)	2 (11.76%)
Surgical history (%)	
Pinning/hardware	8 (34.78%)
Osteotomy	6 (26.09%)
Open reduction and internal fixation	6 (26.09%)
No previous surgery	3 (13.04%)
Femoral deformity (%)	
Trauma	8 (34.78%)
Slipped capital femoral epiphysis	6 (26.09%)
Polyostotic fibrous dysplasia	3 (13.04%)
Legg–Calvé–Perthes disease	3 (13.04%)
Childhood (unknown cause)	2 (8.70%)
Developmental dysplasia of the hip and congenital clubfoot	1 (4.35%)

Abbreviations: BMI, body mass index; IQR, interquartile range; ppb, parts per billion; SD, standard deviation.

femoral instrumentation that would require complex partial or complete hardware removal for THA.

Femoral Deformity

Causes of femoral deformities varied from prior trauma (30.43%), SCFE (26.09%), polyostotic fibrous dysplasia (13.04%), LCP disease (13.04%), cerebral palsy (4.35%), developmental dysplasia (4.35%), and two cases had unknown congenital etiologies for their femoral deformities (8.70%, ►**Table 1**). ►**Figs. 3** and **4** demonstrate HRA in the setting of femoral deformity, which would complicate insertion of standard THA components.

Postoperative Outcomes

Median (IQR) follow-up was 5.03 (2.07 – 7.91) years, and no patients required revision surgery at their latest follow-up. The mean (SD) surgical duration was 94.40 (12.00) minutes, and the mean (SD) postoperative length of stay was 1.74 (1.80) days. All patients were discharged home weight-bearing as tolerated and received physical therapy instructions for mobilization as noted previously. Review of operative documentation indicated none of the 23 patients experienced intraoperative complications. One patient experienced two subluxation events without frank dislocation, at 14 months after the index procedure, although radiographic analysis revealed implants in good position and no further surgery was required. One patient required a prolonged postoperative hospital stay secondary to medical comorbidities, but the discharge and postoperative recovery course was not noted to be complicated. No other patients noted complications at the most recent follow-up visit.

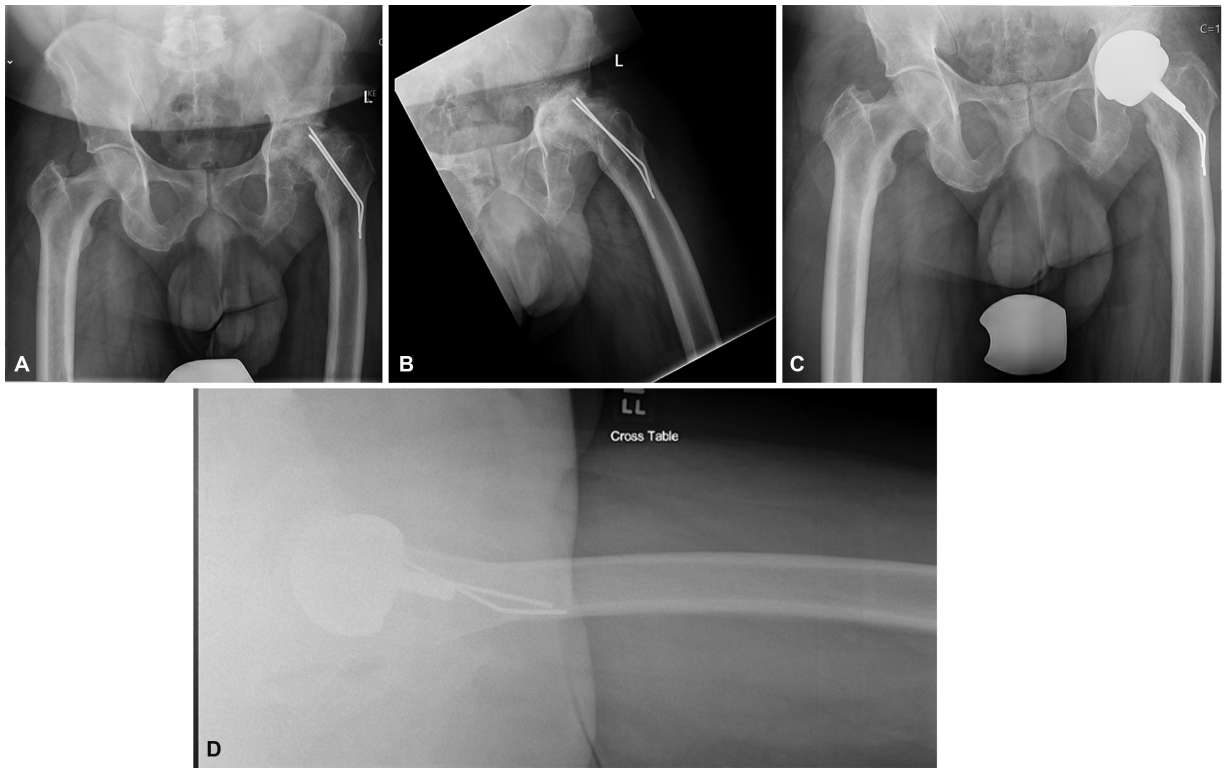

Fig. 1 (A) Preoperative anteroposterior (AP) pelvis radiograph can visualize the degenerative hip joint and the migrated femoral pins. (B) Preoperative lateral hip radiograph assesses the articular surface of the femoral head. (C) Postoperative 3-month AP pelvis radiograph demonstrates a Birmingham Hip Resurfacing implant in appropriate positioning. (D) Postoperative cross table lateral radiograph visualizes implant positioning and acetabular anteversion. HRA, hip resurfacing arthroplasty.

Fourteen patients completed postoperative metal ion level testing at a mean (SD) of 4.24 (2.85) years, in units of ppb. Mean (SD) cobalt and chromium levels were 1.22 (0.36) and 2.01 (0.80) ppb, respectively (►**Table 1**). Median (IQR) postoperative LEAS, VAS pain scale, mHHS, and HOOS, JR scores were 13.00 (9.25 – 13.00), 2.50 (0.75 – 10.00), 92.60 (92.40 – 100.00), and 92.34 (85.26 – 100.00). Median (IQR) preoperative to postoperative improvements in LEAS, mHHS, VAS pain scale, and HOOS, JR scores were 2.00 (0.00 – 3.00), 48.40 (37.40 – 54.90), −50.00 (−40.00 to −59.00), and 32.95 (28.44 – 37.56), respectively (►**Table 2**). All improvements in the patient-reported outcomes scores reached statistical significance ($p < 0.001$).

Discussion

Hip arthroplasty in the setting of degenerative joint disease and retained instrumentation or proximal femoral deformity can be complex. While THA remains the most common treatment strategy, several studies have noted the difficulty of conventional THA in this setting, and available outcomes data confirm sobering results.[6–15] Mortazavi et al discussed results from 11 studies of patients with prior hip instrumentation who converted to THA and found dislocation rates of up to 20% and reoperation rates ranging from 4 to 18%.[10] To our knowledge, this study evaluates the largest series in the literature of metal-on-metal HRA for patients with retained femoral instrumentation or proximal femoral deformity that would have complicated standard THA. This series includes 23 HRA patients with mid-term follow-up (median: 5.03 years); none of the patients in this series had intraoperative complications, all patients demonstrated significant improvements in postoperative outcomes measures, and metal ion levels were all within previously established expected limits of 7 ppb.[21] At final follow-up, no patients had undergone revision of their index HRA.

These findings are in line with prior studies on HRA in the setting of deformity or retained implants in the proximal femur. Mont et al described 15 HRA patients with a mean follow-up time of 3 years who had retained implants or proximal femoral deformity and received the Conserve Plus prosthesis.[20] They similarly demonstrated excellent postoperative outcomes and only one patient required reoperations, secondary to falls over a year postoperatively and subsequent periprosthetic fractures requiring additional surgery. Pritchett reported no dislocations, periprosthetic fractures, dislocations, and infections in 61 patients receiving HRA with a metal-on-polyethylene bearing, with retained implants that would complicate THA.[19] A case series of three patients similarly found that HRA provided excellent pain relief without complications, precluding the need for hardware removal after operative reduction and internal fixation procedures due to proximal femoral fractures.[22] Another study investigating patients who underwent HRA for hip arthritis and deformity due to LCP and SCFE found excellent implant survival and clinical functional outcomes, aligning with our findings that patients with retained implants for childhood hip disease can also achieve favorable outcomes.[23]

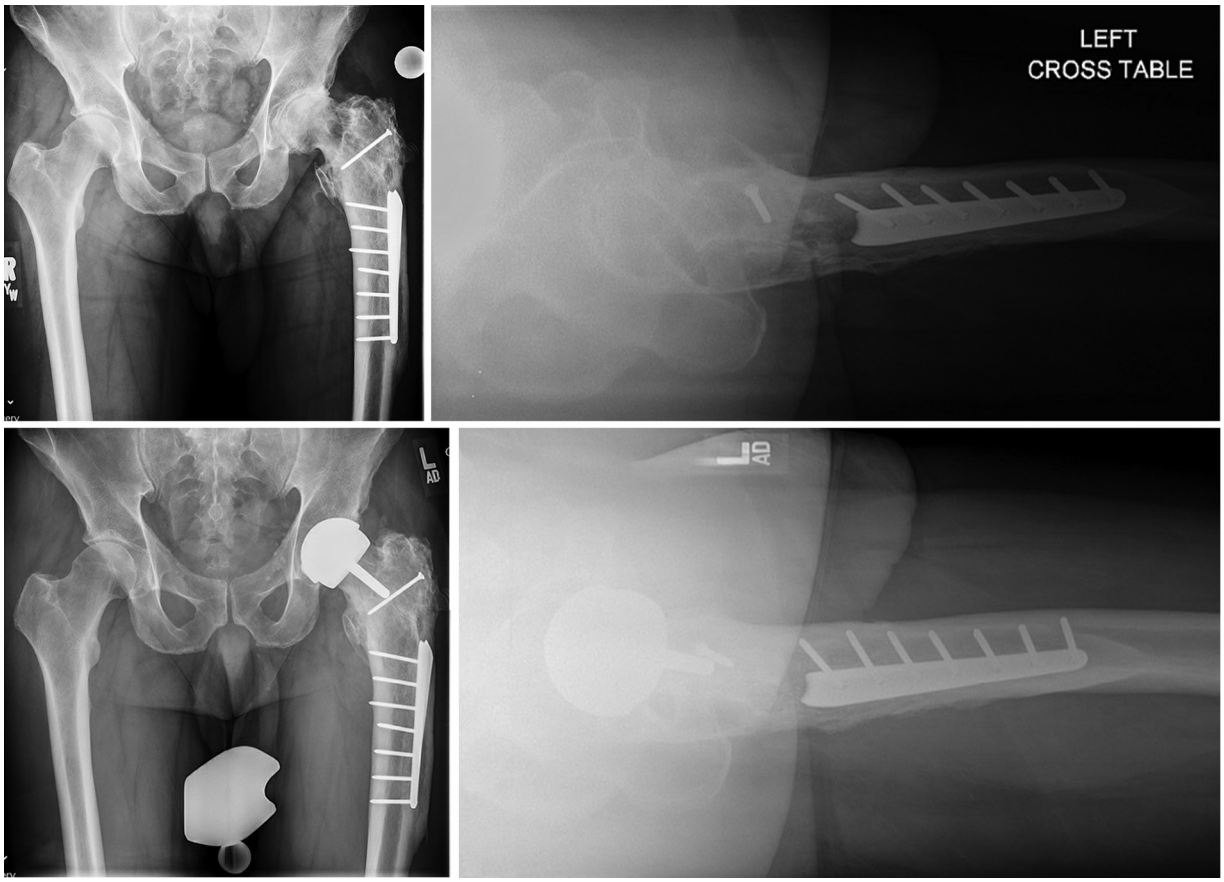

Fig. 2 Preoperative images demonstrated partial hardware removal of a McLoughlin nail and plate implant, which had been implanted 30 years previously after a skiing injury for a peritrochanteric fracture. Notably, hardware removal, which was performed at an outside center many years prior to HRA, consisted of cutting the plate and retaining a portion of the implant. THA in this setting would require not only at least partial removal of hardware, including of an intraosseous lateral plate, but also appropriate implant selection and implantation to address residual femoral deformity. The patient underwent uncomplicated HRA without removal of hardware, with a Harris Hip Score of 100 at most recent follow-up at 9.4 years. HRA, hip resurfacing arthroplasty; THA, total hip arthroplasty.

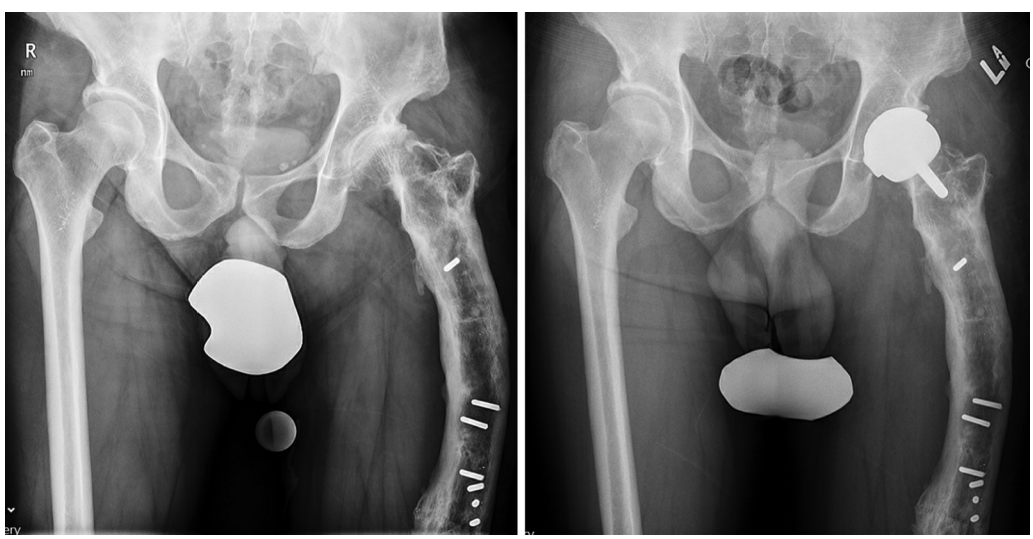

Fig. 3 Preoperative images demonstrated extensive femoral deformity and several retained broken intramedullary screws in the setting of a childhood femoral deformity and over 20 prior operations. The patient underwent HRA without deformity correction or hardware removal, with a Harris Hip Score of 90 at most recent 8-year follow-up. HRA, hip resurfacing arthroplasty.

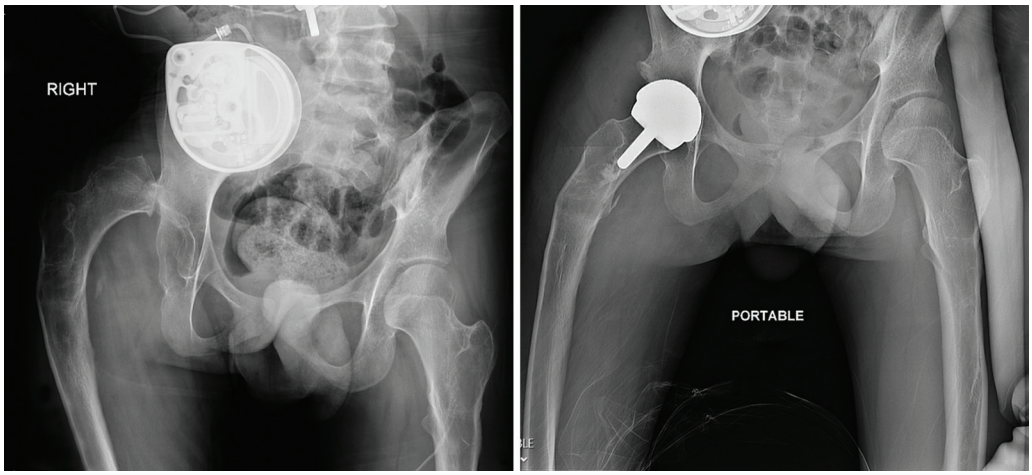

Fig. 4 Preoperative images demonstrated hip dislocation in the setting of cerebral palsy and multiple prior surgeries including varus derotational femoral osteotomies 10 years prior. The patient underwent HRA with substantial functional improvements and a Harris Hip score of 86.9 at most recent 7-year follow-up. HRA, hip resurfacing arthroplasty.

Table 2 Median (IQR) of Preoperative and Postoperative patient reported outcomes

	Preoperative score	Postoperative score	Change	*p*-Value
LEAS	9.50 (8.25–11.00)	13.00 (9.25–13.00)	2.00 (0.00–3.00)	< 0.001
Modified HHS	47.30 (42.35–54.45)	92.60 (92.40–100.00)	48.40 (37.40–54.90)	< 0.001
VAS Pain Scale	60.00 (50.00–82.75)	2.50 (0.75–10.00)	−50.00 (−40.00 to −59.00)	< 0.001
HOOS, JR	52.96 (43.34–64.66)	92.34 (85.26–100.00)	32.95 (28.44–37.56)	< 0.001

Abbreviations: HHS, Harris Hip Score; HOOS, JR, Hip Disability and Osteoarthritis Outcome Score for Joint Replacement; LEAS, Lower Extremity Activity Scale; VAS, Visual Analog Scale.

Regarding technical considerations of HRA in this setting, all patients in this series underwent surgery with an experienced surgeon who performs HRA regularly through a posterior approach. In some cases, partial hardware removal may be possible to facilitate HRA expeditiously, and in addition to implant-specific removal tools, a midas rex burr can be helpful in this setting. If there is a concern for avascular necrosis, cancellous reamings can be used to bone graft small defects or cysts in the femoral head prior to femoral component implantation. Of note, the absolute lowest head size in our cohort were 46 mm BHR femoral heads, used in two patients. A 2014 International Consensus meeting determined that femoral head sizes <46 mm were contraindications for HRA regardless of gender and age.[24] Otherwise, the coverage angle of the implant may not be large enough to avoid edge wear.

Furthermore, given the severity of case complexity encountered in this series, some patients required a deviation from routine cup exposure or central guide pin placement. Specifically, for patient who had remote childhood femoral head pinning, had one pin in a position that would preclude optimal central pin placement, and this pin was visible and a cannulated drill was used to over-drill this pin like a trephine, to facilitate partial hardware removal. Another patient had cerebral palsy with severe preoperative contractures with the native hip held in a flexed and adducted position, which required extensive releases off the ilium for acetabular exposure and was later positioned supine for flexor and adductor releases, to improve hip range of motion. It should be noted that while this patient's postoperative course was uncomplicated and they did not develop instability or metallosis, there is limited literature to guide the results of HRA in the cerebral palsy population and it is possible that in this patient population, inadequate dynamic stabilizers or underlying spasticity could potentially increase incidence of these complications.

The majority of cases in this series utilized a BHR implant, with the ReCap implant system used for a minority of cases. Implant choice was at the discretion of the operating surgeon, and typically a ReCap implant system was used if there was a potential concern about the sizing available for the BHR implant. These two implant systems have slight differences in the dimensions and lengths of their femoral stems, and familiarity with these subtleties can help guide femoral component placement to avoid conflict between the femoral stem and retained instrumentation in the femoral neck (►**Table 3**). While off-label, the senior author has also shortened the femoral stem by a few millimeters in a custom fashion intraoperatively to facilitate implantation in certain cases. It should be noted that in the setting of severe deformities, corrective osteotomies may be required to optimize hip biomechanics and a preoperative infectious work-up should be obtained whenever clinical concern for infection is present. In the case that a surgeon encounters potential concerns regarding version abnormalities, CT imaging or Budin views can be obtained preoperatively for

Table 3 Comparison of Birmingham hip resurfacing and Biomet ReCap implants

	Birmingham hip resurfacing (BHR; Smith & Nephew, Warwick, UK)	Biomet ReCap (Biomet, Inc., Warsaw, IN)
Radial clearance (μm)[26]	105.10	120.93
Wall thickness at rim (mm)	3.6	3.4
Surface roughness (μm)	0.029	0.031
Mean deviation of roundness (μm): head	0.9	3.2
Mean deviation of roundness (μm): cup	0.9	1.9
Femoral component	Cemented as cast cobalt–chromium	Uncemented as cast cobalt–chromium
Acetabular component	Uncemented as cast cobalt–chromium	Uncemented as cast cobalt–chromium
Acetabular component design	Chamfer design	Spherical geometry
Image		

planning purposes. If a corrective osteotomy is required, it is likely that a THA would be pursued. In general, HRA should be avoided in femoral neck nonunions, and the possibility of intraoperative conversion at the time of surgery to THA should be planned for and discussed with the patient preoperatively.

This study had several limitations. The overall number of patients was relatively small, and there was no comparison group. Given the unique nature of these cases, it should be noted that not all retained hardware or femoral deformities are equal. For example, three screws that can be removed in standard fashion represent a very different proposition than a well-fixed intramedullary device with significant residual extra-articular femoral deformity. In this series, we aimed to include only patients in whom standard THA would be considered significantly complex or impossible without challenging hardware removal, osteotomies, or custom implants. Another limitation is that postoperative metal testing was only completed for 14 patients. This is mostly due to loss to follow-up, especially if patients either transferred care to another practice, moved to another geographic area, and/or labs from other facilities were not manually uploaded into the electronic medical record. However, with the available data, postoperative chromium and cobalt levels fall within previously reported metal ion levels in patients with well-functioning long-term metal-on-metal HRA.[18,21,25] Due to the retrospective nature of this study, we cannot guarantee if the implants were still fully functioning or required revision since the patient's last follow-up visit, thereby introducing risks of selection bias. Nevertheless, we provide a unique cohort of cases that can inform surgeons about the utility of HRA in the setting of complex deformity.

Conclusions

Compared with revision THA procedures, HRA is a viable option for patients with significant proximal femoral deformity and retained instrumentation. All subjects who completed patient-reported outcome surveys at follow-up demonstrated improvements from baseline scores, and all metal ion test results fell within acceptable limits. Thus, this case series demonstrates excellent results at mid-term follow-up can be achieved utilizing this strategy in this complex patient population.

Conflict of Interest
None declared.

References

1 (AAOS) AAoOS. American Joint Replacement Registry (AJRR): 2021 Annual Report. 2021Rosemont, IL
2 Crawford RW, Murray DW. Total hip replacement: indications for surgery and risk factors for failure. Ann Rheum Dis 1997;56(08): 455–457
3 Woodcock J, Larson AN, Mabry TM, Stans AA. Do retained pediatric implants impact later total hip arthroplasty? J Pediatr Orthop 2013;33(03):339–344
4 Yun A, Qutami M, Pasko KBD. Salvage of failed femoral neck fracture fixation with conversion total hip arthroplasty using the direct anterior approach. Hip Pelvis 2020;32(04):199–206
5 Dietz MJ, Chase S, Burke DW, Kwon YM. Novel technique for removal of a broken intracortical screw during THA. Orthopedics 2013;36(11):846–849
6 Lu M, Phillips D. Total hip arthroplasty for posttraumatic conditions. J Am Acad Orthop Surg 2019;27(08):275–285
7 Haidukewych GJ, Berry DJ. Hip arthroplasty for salvage of failed treatment of intertrochanteric hip fractures. J Bone Joint Surg Am 2003;85(05):899–904
8 McKinley JC, Robinson CM. Treatment of displaced intracapsular hip fractures with total hip arthroplasty: comparison of primary arthroplasty with early salvage arthroplasty after failed internal fixation. J Bone Joint Surg Am 2002;84(11):2010–2015
9 Mabry TM, Prpa B, Haidukewych GJ, Harmsen WS, Berry DJ. Long-term results of total hip arthroplasty for femoral neck fracture nonunion. J Bone Joint Surg Am 2004;86(10):2263–2267
10 Mortazavi SM, R Greenky M, Bican O, Kane P, Parvizi J, Hozack WJ. Total hip arthroplasty after prior surgical treatment of hip fracture is it always challenging? J Arthroplasty 2012;27(01):31–36
11 Archibeck MJ, Carothers JT, Tripuraneni KR, White RE Jr. Total hip arthroplasty after failed internal fixation of proximal femoral fractures. J Arthroplasty 2013;28(01):168–171

12 DeHaan AM, Groat T, Priddy M, et al. Salvage hip arthroplasty after failed fixation of proximal femur fractures. J Arthroplasty 2013; 28(05):855–859
13 Pui CM, Bostrom MP, Westrich GH, et al. Increased complication rate following conversion total hip arthroplasty after cephalomedullary fixation for intertrochanteric hip fractures: a multi-center study. J Arthroplasty 2013;28(8, Suppl):45–47
14 Hernandez NM, Chalmers BP, Perry KI, Berry DJ, Yuan BJ, Abdel MP. Total hip arthroplasty after in situ fixation of minimally displaced femoral neck fractures in elderly patients. J Arthroplasty 2018;33(01):144–148
15 Jacofsky DJ, Haidukewych GJ, Zhang H, Sim FH. Complications and results of arthroplasty for salvage of failed treatment of malignant pathologic fractures of the hip. Clin Orthop Relat Res 2004;(427):52–56
16 Clough EJ, Clough TM. Metal on metal hip resurfacing arthroplasty: where are we now? J Orthop 2020;23:123–127
17 Quesada MJ, Marker DR, Mont MA. Metal-on-metal hip resurfacing: advantages and disadvantages. J Arthroplasty 2008;23; (7, Suppl):69–73
18 Su EP, Ho H, Bhal V, et al. Results of the first U.S. FDA-approved hip resurfacing device at 10-year follow-up. J Bone Joint Surg Am 2021;103(14):1303–1311
19 Pritchett JW. Hip resurfacing in patients with severe osteoarthritis and blocked medullary canal. Hip Int 2018. Doi: 10.1177/1120700018778537
20 Mont MA, McGrath MS, Ulrich SD, Seyler TM, Marker DR, Delanois RE. Metal-on-metal total hip resurfacing arthroplasty in the presence of extra-articular deformities or implants. J Bone Joint Surg Am 2008;90(Suppl 3):45–51
21 Hart AJ, Sabah SA, Bandi AS, et al. Sensitivity and specificity of blood cobalt and chromium metal ions for predicting failure of metal-on-metal hip replacement. J Bone Joint Surg Br 2011;93 (10):1308–1313
22 Maguire CM, Seyler TM, Jinnah RH, Ward WG. Hip resurfacing with retention of existing hardware - case report. Bull NYU Hosp Jt Dis 2011;69(Suppl 1):S98–S102
23 Su EP, Morgenstern R, Khan I, Gaillard MD, Gross TP. Hip resurfacing arthroplasty for end-stage arthritis caused by childhood hip disease. Hip Int 2020;30(05):572–580
24 Van Der Straeten C, De Smet KA. Current expert views on metal-on-metal hip resurfacing arthroplasty. Consensus of the 6th advanced Hip resurfacing course, Ghent, Belgium, May 2014. Hip Int 2016;26(01):1–7
25 Van Der Straeten C, Van Quickenborne D, De Roest B, Calistri A, Victor J, De Smet K. Metal ion levels from well-functioning Birmingham hip resurfacings decline significantly at ten years. Bone Joint J 2013;95-B(10):1332–1338
26 Heisel C, Kleinhans JA, Menge M, Kretzer JP. Ten different hip resurfacing systems: biomechanical analysis of design and material properties. Int Orthop 2009;33(04):939–943

