The Journal of Arthroplasty 29 (2014) 219–224

Contents lists available at ScienceDirect

The Journal of Arthroplasty

journal homepage: www.arthroplastyjournal.org

One-Component Revision of Failed Hip Resurfacing from Adverse Reaction to Metal Wear Debris

James W. Pritchett, MD, FACS *

Seattle, Washington

ARTICLE INFO

Article history:
Received 2 November 2012
Accepted 12 April 2013

Keywords:
total hip arthroplasty
revision
hip resurfacing
wear debris

ABSTRACT

This study assessed the results of 90 one-component revisions for failed hip resurfacing due to adverse reaction to metal wear debris (76 acetabular, 14 femoral). Patients with a femoral head size 40–45 mm (n = 33) received a two-piece titanium meshed shell with a cross-linked polyethylene liner and patients with femoral head size 46–54 mm (n = 43) received metal-on-metal components. Patients with femoral head size >45 mm who wished a metal-polyethylene bearing received a dual mobility femoral prosthesis. The mean follow-up was 61 months and the procedure was successful in 97% of the patients. Three failures required re-revision; there was one deep infection. There were no dislocations. One-component revision is a reasonable alternative to revision to total hip arthroplasty.

An adverse reaction to metal wear debris (metallosis) occasionally occurs after metal-on-metal hip resurfacing [1–4]. The treatment options have been revision to another hip resurfacing prosthesis or conversion to total hip arthroplasty (THA). Previous reports describe a high rate of complications such as infection, dislocation, component loosening, diminished function, and periprosthetic fracture with revision to THA [1–3,5]. Some patients also have recurrent metallosis. Previous reports have noted a high failure rate with metal acetabular-only revision [1–3].

There have been more failures of metal-on-metal resurfacing prostheses with smaller femoral head sizes compared to larger sizes [6–10]. The author postulated that revising smaller-sized resurfacing acetabular prostheses from metal-on-metal to metal-on-polyethylene might salvage the hip resurfacing procedure. For larger-sized components, revision of the acetabular prosthesis maintaining a metal component might be effective. The author also postulated that using the dual-mobility prosthesis to maintain a natural femoral head size when revising the femoral component might improve outcomes. The dual mobility prosthesis also allows conversion from a metal-on-metal to polyethylene-on-metal joint by way of a one-component revision. One surgical goal of the revision procedure was to provide a stable hip by maintaining the pre-revision femoral size. The other goals of one-component revision surgery were to limit complications, improve functional outcomes, and reduce surgical effort for the patient and surgeon.

For some patients with a failed resurfaced hip, the advantages of hip resurfacing may remain important and they may elect to undergo a revision of the acetabular component of their resurfacing procedure rather than THA. The advantages of hip resurfacing include less resection of femoral bone, reduced risk of dislocation, better function, and a less-complicated revision to THA, if necessary [6,11,12]. If one-component revision can be performed more efficiently and with favorable outcomes, it can be an alternative to complete revision to THA.

There is very limited literature on acetabular-only revision following hip resurfacing. Seven acetabular-only revisions with favorable outcomes in each patient were reported in 2008 [5] but the senior author reported an additional three acetabular revisions in 2011 and noted there were three failures of the 10 revision procedures [1]. A 2010 report from the Australian joint replacement registry showed a 20% failure rate with acetabular-only revisions of failed hip resurfacing [2]. These reports, however, used only one-piece metal components. Previously, this author reported 25 hip resurfacing revisions with favorable outcomes using either metal or polyethylene acetabular prostheses [13].

This prospective study was conducted to determine the results and complications of one-component only revision surgery.

Patients and Methods

The institutional review board approved this study. This is a prospective study of 89 selected patients (90 hips) who presented for treatment of an adverse reaction to wear debris following metal-on-metal hip resurfacing. Inclusion criteria were the author's indications for revision surgery: (1) pain, (2) an effusion that was evident clinically or by imaging, (3) a progressive increase in clicking or clunking

The Conflict of Interest statement associated with this article can be found at http://dx.doi.org/10.1016/j.arth.2013.04.011.

Reprint requests: James W. Pritchett, MD, FACS, 901 Boren Ave. #800, Seattle, WA 98104.

0883-5403/2901-0044$36.00/0 – see front matter © 2014 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.arth.2013.04.011

sensations from the hip, and (4) a feeling of vibration and/or instability [13] (Table 1). The decision to perform revision surgery was based on these clinical grounds rather than on elevated cobalt levels or radiographic evidence of component malposition in the absence of pain and mechanical symptoms. Component malposition is compatible with a satisfactory outcome in some instances. In this study, elevated blood cobalt levels (i.e., >7 μg/L) were considered as supportive evidence of an adverse reaction to wear debris. The indications for an acetabular-only revision were: (1) excellent initial functional outcome following primary hip resurfacing, (2) a healthy femur on imaging, (3) ideal femoral component position, (4) a well-fixed femoral component, and (5) an active patient. The indication for using a metal rather than a polyethylene acetabular bearing was based on the size the bearing surface. Patients with a femoral head component size ≤45 mm received a polyethylene acetabular revision prosthesis. Patients with a femoral head size of ≥46 mm received a metal acetabular revision prosthesis from the same manufacturer as the primary prosthesis. The indications for using the dual mobility prosthesis were: (1) a well-fixed and well-oriented acetabular component, (2) any concern about the health or security of the femur or position of femoral prosthesis, (3) patient desiring a metal-on-polyethylene bearing with a femoral head size > 44 mm. The dual mobility prosthesis is a bipolar prosthesis in which a large diameter mobile polyethylene head is snapped onto a small diameter fixed femoral head. The dual-mobility bearing articulates with any metal acetabular bearing and is fixed on the trunnion of any desired femoral stem.

The exclusion criterion for one-component resurfacing was concern about both the femoral and acetabular components. These patients were treated by revision to THA.

All patients had pre-revision radiographs. The position of the femoral component was determined by comparison to the femoral neck axis. Components that were in >5° of varus or valgus were considered to be in poor position. The method of Amstutz was used to determine the stability of the femoral component [6]. The acetabular cup position was assessed by measuring the lateral edge of the acetabular component relative to a horizontal reference line in the frontal plane. This abduction angle indicates the amount of lateral opening, typically between 30° and 60°. In the lateral plane, anteversion of the socket is measured by the angle created from a vertical line perpendicular to the horizontal plane and the edge of the acetabular component using a Johnson shoot-through lateral radiograph [14]. Typical values for anteversion are between 0° and 30°. Loose acetabular components were defined as components that had changed position or had radiolucent lines around more than 30% of the component. Spot welds and bone trabeculae through the metal indicated osseointegration. Blood cobalt levels were obtained preoperatively and repeated at final follow-up using the same laboratory (ARUP Lab, Salt Lake City, UT).

In all cases, the approach for revision surgery utilized the same approach as for the primary procedure. The posterolateral approach was used for 70 procedures, 3 patients had a direct anterior approach, and 17 had an anterolateral approach. The acetabular components were removed using hand chisels only, with care taken to preserve bone. Any retained component must be examined carefully for visual signs of damage.

Postoperatively, all patients underwent routine rehabilitation with full weight bearing allowed. No anti-dislocation braces were used and there were no additional precautions beyond those used after primary hip resurfacing surgery. Postoperatively, patients were followed radiographically at 2 weeks, 6 weeks, 6 months, and annually. The Harris Hip Scores were recorded prior to revision and at final follow-up [15].

Results

The author performed 90 (76 acetabular-only revisions and 14 dual-mobility, femoral-only) revisions in 89 patients with adverse reactions to wear debris following metal-on-metal hip resurfacing procedures. The patient demographics are shown in Table 2. The most common original diagnoses were osteoarthritis and dysplasia.

The one-component revision procedure was successful in 87 of the 90 (97%) revision procedures. For acetabular-only revision patients, the follow-up period averaged 65 months (range, 48–118 months) and for dual-mobility revision patients, the follow-up period averaged 41 months (range, 36–53 months). As a result of the acetabular-only revision, both the femoral and acetabular resurfacing components were retained in 73 of 75 patients (97%). There were no revisions or complications of any type with the dual-mobility prosthesis or with acetabular-only revision procedures using polyethylene.

All patients improved their Harris Hip Score by at least 12%, from a pre-revision average of 72.2 (±13) to an average of 93.2 (±9) at a mean follow-up of 61 months. The 21-point average improvement is clinically and statistically significant ($P < .0001$, paired t-test). Radiographic examination at regular intervals postoperatively showed that all components except one remained well fixed.

Table 1
Indications Leading to Revision.[a]

Pre-Revision Signs and Symptoms	Hips (n)
Pain, noise	30
Pain, noise, instability	18
Pain, noise, effusion	11
Pain, noise, cobalt	9
Pain, instability	4
Pain	3
Effusion, noise	3
Pain, cobalt, instability	3
Pain, noise, effusion, instability	3
Pain, effusion	2
Cobalt, noise, effusion	2
Cobalt, noise, effusion, pain	2
Pre-revision signs and symptoms	**Patients n (%)**
Pain	86 (96)
Noise	81 (90)
Effusion	36 (40)
Instability	34 (38)

[a] In this study, elevated blood cobalt levels (i.e., >7 μg/L) were considered as supportive evidence of an adverse reaction to wear debris.

Table 2
Patient Demographics.

Variable	Result
Revisions/re-revisions (n)	90/3
Male/female (n)	46/43
Mean age at revision surgery (years)	49.8 (32–71)
Primary diagnosis (n)	
Osteoarthritis	45
Dysplasia	36
Avascular necrosis	5
Fracture/trauma	2
Rheumatoid arthritis	1
Primary resurfacing components (n)	
Birmingham hip resurfacing system[a]	35
CONSERVE plus total resurfacing hip system[b]	32
Cormet hip resurfacing system[c]	7
ASR hip resurfacing system[d]	8
ReCap total hip resurfacing system[e]	4
Durom hip resurfacing system[f]	4
Mean time between index resurfacing and revision (months)	33.3 (16–59)

[a] Smith & Nephew, Inc., Memphis, TN, USA.
[b] Wright Medical Technology, Inc., Arlington, TN, USA.
[c] Stryker Orthopaedics, Mahwah, NJ, USA.
[d] DePuy Orthopaedics, Inc., Warsaw, IN, USA.
[e] Biomet, Warsaw, IN, USA.
[f] Zimmer, Inc., Warsaw, IN, USA.

There were no bone grafts and no blood transfusions. Of these revisions, 46 primary procedures had been performed elsewhere and 44 primary procedures were performed by the author. The incidence of an adverse reaction to metal wear debris following hip resurfacing could not be determined, as patients were referred from several centers.

The types of revision procedure and components used are shown in Table 3. The mean size of the revised acetabular components is 3 mm greater than the primary prosthesis (range, 0–6 mm increase). The composite thickness of the two-piece, polyethylene acetabular prosthesis is 10 mm (Figs. 1A and B). The shell is meshed titanium and the highly cross-linked polyethylene liner is 3.8 mm thick. The majority of polyethylene revision procedures matched a 44 mm polyethylene liner with a 44 mm metal femoral component. We did not mismatch component sizes for any revision procedures. We confirmed the correct size by referring to implant sticker, reading the markings etched on the explants, and measuring the explants. For metal-on-metal revision surgery, a 6 mm acetabular prosthesis was used whenever possible. An 8 mm or 10 mm prosthesis was used if fixation of the 6 mm prosthesis was not secure (Figs. 2A and B). We used the same manufacturer for the revision acetabular component as the retained femoral component. We were concerned about differences in metallurgy between manufacturers. The Birmingham prosthesis has three acetabular components that match each femoral component. The Conserve Plus has two acetabular components for each femoral size. Metal components remained available for the Biomet, Durom, and Cormet during this study. The Depuy ASR was recalled and metal revision components were not available. Two-piece titanium mesh, cobalt-chromium lined metal-on-metal components were used if there was adequate acetabular bone and if dome screw fixation was needed (Figs. 3A and B). The two-piece metal-on-metal components are 12 mm in composite thickness. The dual-mobility prosthesis is available in each femoral head size to match the retained resurfacing metal acetabular bearing (Figs. 4A and B).

All the polyethylene was GUR 1020 (Ticona, Oberhausen, Germany) consolidated by compression molding. Cross-linking was by three sequential exposures at 3 MRad (X3, Stryker Orthopaedics, Mahwah, NJ) followed by annealing and sterilized using gas plasma or a single 7.5 MRad exposure to gamma irradiation (Meditech, Fort Wayne, IN, and Orthoplastics Ltd., Lancashire, England) followed by sterilization using ethylene oxide after machining.

Cloudy or dark synovial fluid was found in the pre-revision joint aspirations of all patients, indicating an adverse reaction to metal debris. Intraoperative cultures were negative for all patients. The operative findings showed large quantities of pale-grey sterile fluid, thin purulent material, and inflammatory dark staining of the tissues. Histological examination of the periprosthetic tissues confirmed an adverse tissue reaction to metal debris in all cases. The typical histological changes were perivascular lymphocyte infiltration, acute and chronic inflammation, and the accumulation of macrophages loaded with metal debris [3,16,17]. There was extensive fibrinous necrosis in most cases. Post-revision joint aspirations found discolored or cloudy fluid in two symptomatic patients: one had a deep infection and the other continued to show symptoms and signs of an adverse reaction to metal wear debris, namely pain, clunking, and an elevated blood cobalt level.

Table 3
Type of Revision Component Used.

Component	n
6 mm	16
8 mm	9
10 mm	8
Dual mobility	14
Two-piece metal-on-metal	10
Two-piece polyethylene	33

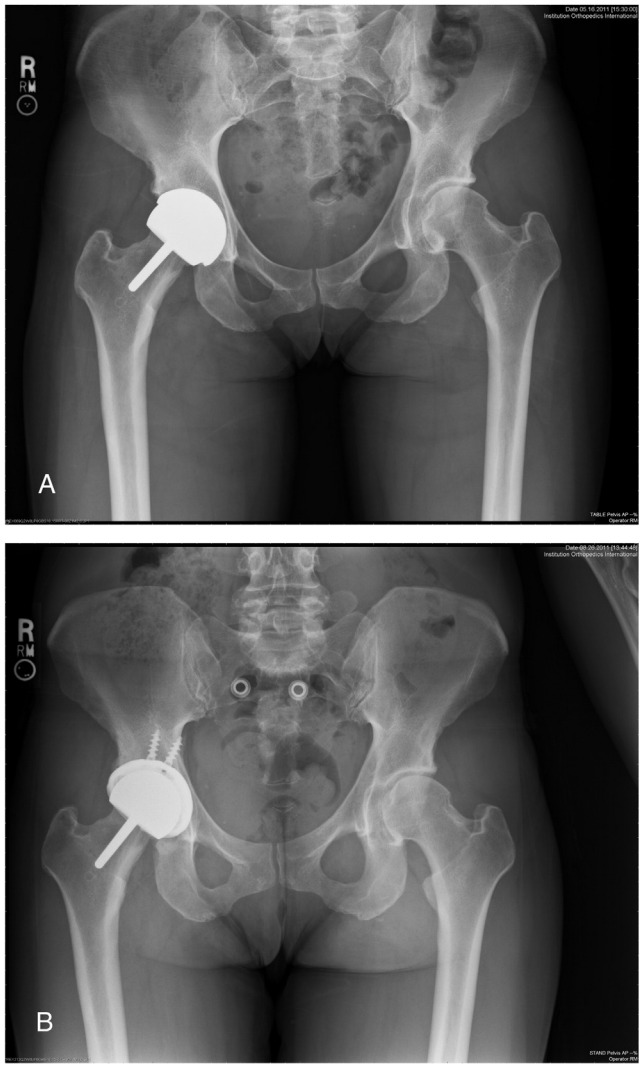

Fig. 1. (A) Anteroposterior radiograph of the pelvis showing a right CONSERVE Plus prosthesis in a 40-year-old woman. The abduction angle is 50°. This patient developed an adverse reaction to metal debris after 29 months. (B) The postoperative radiograph shows revision to a two-piece polyethylene acetabular prosthesis with retention of the femoral prosthesis.

Pre-revision cobalt levels averaged 54.7 μg/L. Post-revision cobalt levels at the final follow-up averaged 2.7 μg/L (reference range 0.5–3.9 μg/L) ($P < .001$). Pre-revision/post-revision component inclination angles averaged 48.3°/40° ($P < .001$) and pre-revision/post-revision anteversion angles averaged 19.0°/11.4° ($P < .01$). Additional results are shown in Table 4.

There were three failures (7%) among patients who continued with metal-on-metal prostheses that required another revision; one, one-piece metal acetabular component failed due to loosening and was revised to a two-piece metal component. One procedure failed due to continued adverse reaction to metal wear debris and was revised to a femoral dual-mobility prosthesis retaining the metal acetabular component. There was one deep infection treated by component removal and successful secondary reimplantation of ceramic-on-polyethylene THA. There were no dislocations and no patients were lost to follow-up.

Discussion

Salvage surgery for adverse reactions to wear debris following metal-on-metal hip resurfacing has been a challenge. This study was performed to determine the results and complications of one-

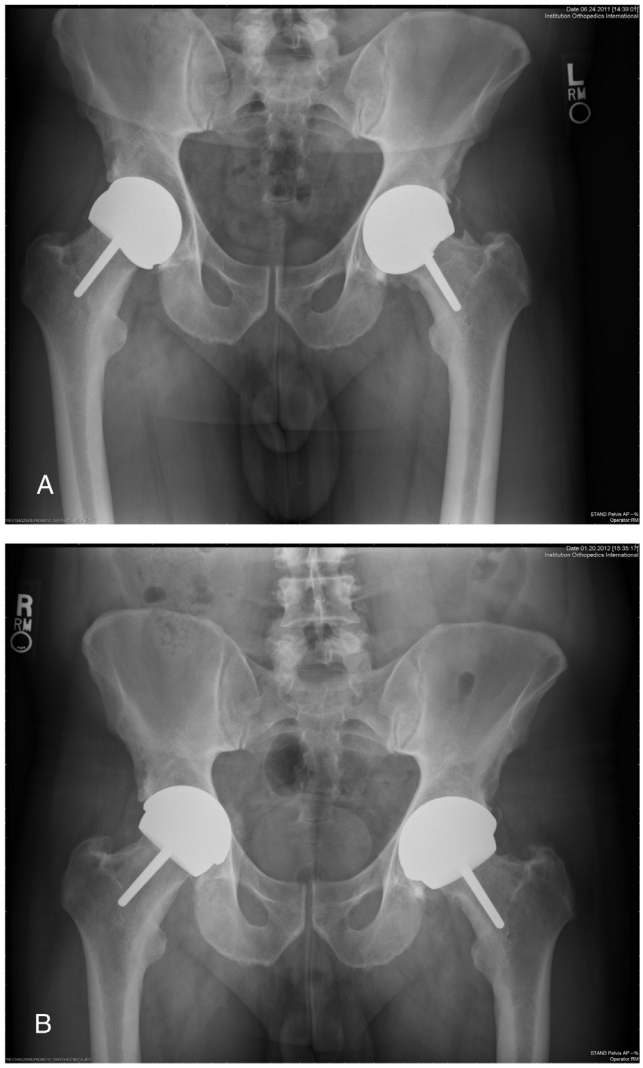

Fig. 2. (A) Anteroposterior radiograph of the pelvis showing bilateral CONSERVE® Plus prostheses in a 47-year-old man. The abduction angle on the right is 55°. On the left, the patient had loosening of the acetabular prosthesis with increased anteversion. The patient developed an adverse reaction to metal wear debris in each hip after 33 months. (B) The postoperative radiograph shows bilateral acetabular revisions using 10 mm metal prostheses.

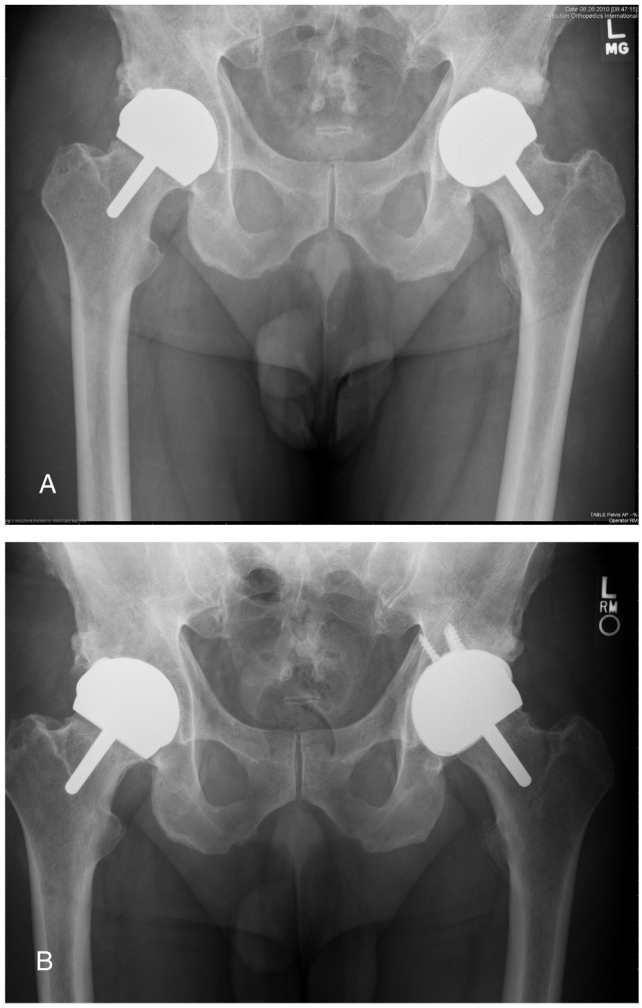

Fig. 3. (A) Anteroposterior radiograph of the pelvis showing bilateral Birmingham prostheses in a 41-year-old man. On the left the abduction angle is 60°. (B) The postoperative radiograph shows revision of the left prosthesis to a two-piece, metal-on-metal prosthesis using dome screws. The abduction angle is now 40°.

component only revision surgery. At final follow-up, 97% of our patients had no signs or symptoms of an ongoing reaction to wear debris, no surgical complications, improvement in their Harris Hip Score, and radiographic evidence of secure components in good position and without bone loss. These results suggest that one-component only revision is an effective treatment alternative to complete revision to THA for an adverse reaction to metal wear debris following metal-on-metal hip resurfacing.

There were few complications in this series. One patient continued to show signs of metallosis and underwent successful re-revision. There was one deep infection, treated successfully by revision consisting of a two-stage reimplantation with conversion to THA. One patient sustained an intraoperative acetabular fracture that healed after 3 months without additional care. One patient experienced failure of ingrowth of the acetabular prosthesis with loosening and underwent re-revision of the acetabular component only with a good outcome.

The relatively short follow-up period is a limitation of this study. However, a 61-month mean follow-up period is adequate to determine functional outcomes, complications, component security, and presence of a continuing adverse reaction to metal wear debris. A follow-up of at least 36 months is needed to detect an adverse reaction to wear debris. The long-term implant survivorship, however, cannot be determined from this work. In addition, the reason for the revision surgery in all patients was an adverse reaction to metal wear debris. Revision for other indications was the not the subject of this report.

Failures of both primary and revision resurfacing surgery are patient related, implant related, and surgeon related [6,8–10]. A patient with a small femoral head size is not as good a candidate for a metal-on-metal resurfacing prosthesis as a patient with a larger femoral head size [9–11]. Therefore, polyethylene was used for patients with femoral head sizes of 45 mm or less. Surgeons undertaking revision surgery must pay close attention to surgical technique, as the supporting soft tissues are often damaged. The results of the present study suggest the more limited procedure of one-component revision results in less blood loss and infection compared to revision to THA [2,3]. Although revision surgery for an adverse reaction to metal wear debris carries an increased risk of infection [2,3,18], there was only one infection (1%) and no patient required a blood transfusion. The fact that there were no dislocations can be attributed to great care in tissue handling, bone preservation, and using a femoral prosthesis that matched the natural femoral head size of the patient.

Since THA has generally been the option offered to a patient with a failure of either component of a hip resurfacing procedure,

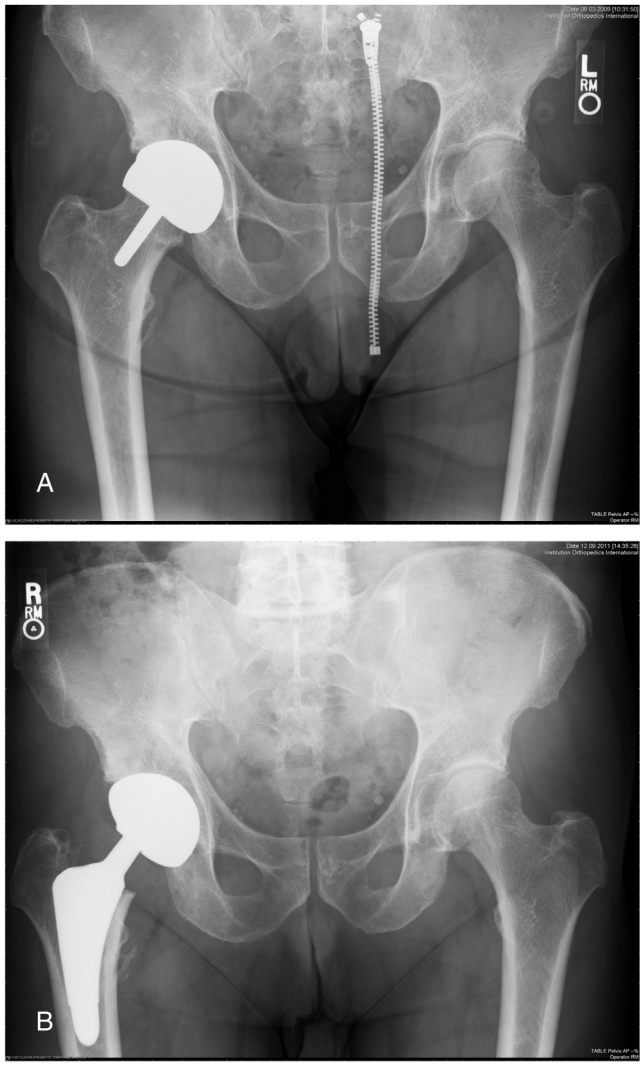

Fig. 4. (A) Anteroposterior radiograph of the pelvis showing a right Birmingham prosthesis in a 60-year-old man. The abduction angle is 50°. (B) The postoperative radiograph shows a revision to a dual-mobility prosthesis retaining the metal acetabular prosthesis. A 50 mm dual-mobility femoral prosthesis was used for the revision surgery. The 28 mm inner ceramic bearing is visible radiographically.

comparison of these results to THA is appropriate. Matching a stemmed total hip femoral component with a metal head to the existing metal acetabular component has been has been successful only when the reason for the resurfacing failure has been femoral loosening or femoral neck fracture [16,19,20]. The reported complication rate, however, with revision to THA for an adverse reaction to metal wear debris has been 10–50%, the re-revision rate has been 5–38 %, and the rate of dislocation has been 4.4–19% [1–3]. The higher dislocation rate may be because the femoral head diameter is decreased when revising to THA [3,4,17,19]. In addition, adverse reactions to metal wear debris damage the capsular tissues, predisposing to dislocation.

This study presents three revision techniques that produced results superior to other studies: (1) The use of two-piece cross-linked polyethylene acetabular components for smaller femoral head geometries has not been described previously as a treatment option for a failure of a metal-on-metal resurfacing prosthesis. (2) Also, use of the dual-mobility prosthesis has not been described with failure of a hip resurfacing procedure as the indication. The dual-mobility prosthesis proved useful in patients in whom there are concerns or potential concerns about the femoral prosthesis. Since it is available in all bearing surface sizes, it can be used to convert any metal

Table 4
Revision Results.

Factor	Result
Mean follow-up period (months)	61 (36–118)
Mean Harris Hip Score (pre/post revision)	72.2 (46–86)/93.2 (80–98)
Mean component inclination angle (pre/post)	48.3° (25°–70°)/40° (30°–55°)
Mean component anteversion angle (pre/post)	19° (10°–30°)/11.4° (0°–20°)
Mean cobalt levels (pre/post)	54.5 μg (17–136)/2.7 μg (0–30)
Complications (n)	
Acetabular fracture	1
Continuing metallosis	1
Infection	1
Loose acetabulum	1

resurfacing procedure with a secure acetabulum to a polyethylene-metal bearing [21]. There were no failures using polyethylene on either the femoral or acetabular side in this series. (3) The use of a two-piece metal-on-metal revision prosthesis has not been described for revision of a failed resurfacing procedure. Each of these three options proved useful for the patients in this study.

The success of cross-linked polyethylene in THA suggests that it may be an attractive option for hip resurfacing, as well [22]. Adverse reactions to wear debris may be less common with polyethylene – at least in the first several years following surgery – than when metal-on-metal is used. It is a challenge to make polyethylene thin enough for use in resurfacing. Thin cross-linked polyethylene requires a supportive metal backing and the composite thickness becomes 10 mm. Cross-linked polyethylene liners of up to 49 mm are available. Acetabular revision surgery is demanding and can be assisted by intraoperative radiography or CT scanning (O-arm). The present study used polyethylene for patients with smaller femoral head sizes and used metal-on-metal prostheses for larger sizes and where the literature is more supportive. The results of most polyethylene hip resurfacing prostheses from the 1970s and 1980s were poor and the procedure was largely abandoned. The thin, poorly designed, and poor-quality polyethylene cups were cemented in place. Femoral components without stems, poor technique and instrumentation led to the high failure rates [23,24]. With better quality polyethylene, two-piece acetabular components, stemmed femoral components, and good technique, component survivorship of 10 or more years has been reported using polyethylene for resurfacing [25,26]. However, polyethylene remains a concern not only for wear but for mechanical and oxidation failures. This is particularly true for thin cross-linked polyethylene liners. Also, young active patients elevate the concern for impingement exposing the polyethylene at the rim to increased contact stresses. Patients must be cautioned about these concerns and continued monitoring is necessary.

One-component revision is an effective procedure for hip resurfacing procedures that have failed as the result of an adverse reaction to metal wear debris. Most patients elect this limited option if it is presented.

Acknowledgment

The author thanks Janet L. Tremaine, ELS, Tremaine Medical Communications, Inc., Dublin, Ohio, for editorial assistance.

References

1. De Smet KA, Van Der Straeten C, Van Orsouw M, et al. Revision of metal-on-metal hip resurfacing: lessons learned and improved outcome. Orthop Clin North Am 2011;42:259.
2. de Steiger RN, Miller LN, Prosser GH, et al. Poor outcome of revised resurfacing hip arthroplasty. Acta Orthop 2010;81:72.
3. Grammatopolous G, Pandit H, Kwon Y-M, et al. Hip resurfacing revisions for inflammatory pseudotumor have a poor outcome. J Bone Joint Surg Br 2009:1019.
4. Langton DJ, Joyce TJ, Jameson SS, et al. Adverse reaction to metal debris following hip resurfacing. J Bone Joint Surg Br 2011;93:164.

5. de Haan R, Campbell PA, Su EP, et al. Revision of metal-on-metal resurfacing arthroplasty of the hip: the influence of malpositioning of the components. J Bone Joint Surg Br 2008;90:1158.
6. Amstutz HC, Le Duff MJ, Campbell PA, et al. Clinical and radiographic results of metal-on-metal hip resurfacing with a minimum ten-year follow-up. J Bone Joint Surg Am 2010;92:2663.
7. Jameson SS, Baker PN, Mason J, et al. Independent predictors of revision following metal-on-metal hip resurfacing. J Bone Joint Surg Br 2012;94:746.
8. McBryde CW, Shears E, O'Hara JN, et al. Metal-on-metal hip resurfacing in developmental dysplasia: a case–control study. J Bone Joint Surg Br 2008;90:708.
9. McBryde CW, Theivendrank J, Thomas AM, et al. The influence of head size and sex on the outcome of Birmingham hip resurfacing. J Bone Joint Surg Am 2010;92:105.
10. Shimmin A, Beaulé PE, Campbell P. Metal-on-metal hip resurfacing arthroplasty. J Bone Joint Surg Am 2008;90:637.
11. Coulter G, Youn DA, Dalziel RE, et al. Birmingham hip resurfacing at a mean of ten years. J Bone Joint Surg Br 2012;94:315.
12. Lavigne M, Masse V, Girard J, et al. Return to sport after hip resurfacing or total hip arthroplasty: a randomized study. Rev Chir Orthop Reparatice Appar Mot 2008;94:361.
13. Pritchett JW. Curved-stem hip resurfacing: minimum 20-year followup. Clin Orthop Relat Res 2008;466:1177.
14. Johnson CR. A new method for roentgenographic examination of the upper end of the femur. J Bone Surg Am 1932;14:859.
15. Harris WH. Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. J Bone Joint Surg Am 1969;51:737.
16. Bosker BH, Ettema HB, Boosma MF, et al. High Incidence of pseudotumour formation after large-diameter metal-on-metal total hip replacement. J Bone Joint Surg Br 2012;94:755.
17. Haddad FS, Thakrar RR, Hart AJ, et al. Metal-on-metal bearings: the evidence so far. J Bone Joint Surg Br 2011;93:672.
18. Merritt K, Brown SA. Effect of proteins and pH on fretting corrosion and metal ion release. J Biomed Mater Res 1988;22:111.
19. Bolland BJ, Culliford DJ, Langton DJ, et al. High failure rates with large-diameter hybrid metal-on-metal total hip replacement. J Bone Joint Surg Br 2011;93:608.
20. Ball ST, Le Duff MJ, Amstutz HC. Early results of conversion of a failed femoral component in hip resurfacing arthroplasty. J Bone Joint Surg Am 2007;89:735.
21. Guyen O, Pibarot V, Vaz G, et al. Use of a dual mobility socket to manage total hip arthroplasty instability. Clin Orthop Relat Res 2009;467:465.
22. Kelly NH, Rakadhyaksha AD, Wright TM, et al. High stress conditions do not increase wear of thin highly crosslinked UHMWPE. Clin Orthop Relat Res 2010;468:418.
23. Grigoris P, Roberts P, Panousis K, et al. The evolution of hip resurfacing arthroplasty. Orthop Clin North Am 2005;36:125.
24. Yue EJ, Cabanela ME, Duffy GP, et al. Hip resurfacing arthroplasty: risk factors for failure over 25 years. Clin Orthop Relat Res 2009;467:992.
25. Buechel FF, Pappas MJ. A metal/ultrahigh-molecular-weight polyethylene cementless surface replacement. Semin Arthroplasty 2011;22:66.
26. Malviya A, Lobaz S, Holland J. Mechanism of failure eleven years following a Buechel Pappas hip resurfacing. Acta Orthop Belg 2007;73:791.