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Hip Resurfacing Using Highly Cross-linked Polyethylene: Prospective Study Results at 8.5 Years

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ABSTRACT

Background: Hip resurfacing is an option to consider when treating younger, more active patients. Advantages over total hip arthroplasty include a more normal gait and a lower incidence of thigh pain.
Methods: In this prospective study, 190 hip resurfacing procedures (164 participants) were performed using a cobalt-chromium femoral component and a cementless acetabular cup with a 3.8-mm highly cross-linked polyethylene acetabular liner.
Results: The mean follow-up was 8.5 (range, 7-10) years. Two participants were lost to follow-up and 2 died. One participant underwent successful revision surgery for acetabular loosening. Four participants underwent successful revision to a total hip arthroplasty because of femoral neck fracture (2), femoral loosening, or infection. The Kaplan-Meier survivorship was 97%. Acetabular bone conservation was assessed using computed tomography by measuring the medial acetabular wall. The mean thickness was 9 mm. Femoral bone was well preserved with a mean head:neck ratio of 1.37. There were 4 (2%) osteolytic defects up to 0.9 cm^3 on computed tomography and no instances of impending polyethylene wear-through. Seven polyethylene retrievals had a measured wear rate of 0.05 mm/y.
Conclusion: Hip resurfacing using a highly cross-linked polyethylene acetabular component is a reliable procedure. Both femoral and acetabular bones are reasonably preserved compared with prior resurfacing methods. The low incidence of osteolysis and the low rate of wear found on retrievals suggest that many years of use in highly active patients is possible.

The procedural advantages of hip resurfacing usually have benefitted the femoral side, namely preservation of the femoral bone, the ability to maintain a natural femoral head, better revision options, and limiting stress shielding. The functional advantages of hip resurfacing compared with total hip arthroplasty (THA) have been a more normal gait and a better chance of returning to sports [1,2]. There is no uniform agreement that resurfacing offers all these theoretical advantages compared with THA [3,4]. Concerns about resurfacing include the ability to restore the biomechanics of the hip, femoral neck fracture, osteonecrosis, femoral loosening, and the difficulty of acetabular revision [4-6]. The spatial limitations of the native joint place constraints on the aggregate component thickness.

Attempts to use metal on polyethylene in the past were unsuccessful because of the poor performance of thin, non–wear-resistant polyethylene, and cementless metal backed or cemented fixation that was intrusive to the pelvis resulted in failures that were difficult to reconstruct [7-9]. Prior teaching with conventional polyethylene suggested that minimum acceptable polyethylene thickness was 6 mm, producing composite component thicknesses that were 14-16 mm greater than the retained femoral head, which is typically 40-50 mm [10]. This presented a challenge to bone conservation.

Several iterations of metal-on-metal (MoM) resurfacing devices have produced implants that are quite thin (3-mm-thick monoblock acetabular component and 3-mm-thick femoral component). These implants minimized bone loss and eliminated polyethylene wear debris. For femoral head sizes ≥50 mm, the performance of MoM has been satisfactory, and for the last 15 years, most hip resurfacing procedures have been performed using this technology [3,7,11-13]. Cup fixation remains problematic especially in dysplastic patients.

No author associated with this paper has disclosed any potential or pertinent conflicts which may be perceived to have impending conflict with this work. For full disclosure statements refer to http://dx.doi.org/10.1016/j.arth.2016.03.013.

The author certifies that he has institutional approval for this study and the investigation was conducted in conformity with ethical principles of research and that informed consent was obtained.

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Some disastrous results from adverse reactions to metal wear debris, particularly in the smaller sizes, have reduced the interest in MoM resurfacing [13-15]. MoM hip resurfacing using component sizes ≤46 mm does not meet the National Institutes of Health and Care Excellence guidelines for use [16,17].

With highly cross-linked polyethylene, much thinner acetabular liners can be used [7,18-20]. Ten years ago, a 3.8-mm cross-linked polyethylene liner using a sequential annealing and irradiation process became available. With the metal backing, the composite component thickness is 10 mm. Femoral heads of 40 and 44 mm have been used with this material for THA with a clinical survivorship similar to THA using standard thickness liners [18,19,21-24]. This finding led the author to propose the use of these thin highly cross-linked polyethylene liners for resurfacing using a proven design femoral component in combination with a thin cementless shell.

This study evaluated a highly cross-linked polyethylene acetabular component for hip resurfacing in terms of (1) function and complications, (2) implant survivorship, (3) bone conservation and biomechanics of the resurfaced joint, and (4) osteolysis and polyethylene wear.

Participants and Methods

Our Institutional Review Board approved this single-center prospective study. The option of THA was discussed with all participants, but those included in this study chose hip resurfacing. There were 164 participants (190 hip procedures) who underwent resurfacing using a cemented cobalt-chromium femoral prosthesis and a cementless acetabular shell with a highly cross-linked polyethylene liner (Fig. 1). Inclusion criteria were (1) pain and functional compromise that made a participant a candidate for THA, (2) femoral head diameter 40-46 mm, (3) University of California, Los Angeles (UCLA) score goal of ≥6, (4) age ≤65 years, and (5) satisfactory bone quality and geometry (ie, the bone structure could accommodate the resurfacing components without notching the femoral cortex or overreaming the acetabulum and medial wall thickness >5 mm; Fig. 2A). At the time participants were enrolled in this study, patients presenting for hip resurfacing with femoral head diameters ≥48 mm were treated with MoM hip resurfacing, as only size 40 and 44 acetabular components were available. Currently, highly cross-linked acetabular components up to 52 mm are used in appropriate patients. Patients with less femoral or acetabular bone than necessary underwent THA using cross-linked polyethylene and a cementless titanium femoral stem. Approximately one-third of patients presenting to the author were candidates for polyethylene hip resurfacing with the implants available. Exclusion criteria were (1) poor femoral bone quality as indicated by femoral head cysts >1 cm or osteonecrosis, (2) below normal bone density determined by the radiograph, (3) leg-length discrepancy >3 cm or femoral neck shaft angle <120°, (4) geometry that would not allow stable placement of the prosthesis with at least 5 mm of medial acetabular wall preservation (approximately 5% of presenting patients) and a head:neck ratio of at least 1.29 without notching, and (5) revision of prior implant procedures. Bone quality was assessed qualitatively as within normal range or below normal [25,26]. Enrollment was not affected by the presence of abnormalities in the hip center of rotation, femoral offset, or the shape of the femoral head or neck. We did not use dual-energy X-ray absorptiometry or magnetic resonance imaging scans to determine candidacy for hip resurfacing.

All femoral prostheses were a cast cobalt-chromium stemmed design (CONSERVE Plus Total Hip Resurfacing System; Microport Orthopedics, Memphis, TN), and all were cemented. The 2-piece acetabular components consisted of a porous-coated titanium shell 50 or 54 mm with a 40- or 44-mm highly cross-linked polyethylene liner (Fig. 1). The polyethylene liners were fabricated from GUR 1020 resin (Ticona, Kelsterbach, Germany) highly cross-linked by 3 sequential exposures to gamma irradiation at 3 MRads followed by annealing below the melting temperature and sterilization with gas plasma. The polyethylene thickness was 3.8 mm. The liners were seated into a hydroxyapatite-coated cluster-hole acetabular shell (Trident PSL HA; Stryker Orthopedics, Mahwah, NJ). Both the femoral and acetabular components are Food and Drug Administration cleared, but they have not been cleared for use together. The cross-linked components used were the only devices compatible with a resurfacing procedure.

The 44-mm femoral component was seated on a femoral head prepared to 46 or 44 mm depending on the native size of the femoral head and chosen thickness of the cement mantle. The 40-mm component was seated on a femoral head prepared to 42 or 40 mm [25]. Therefore, only patients with femoral heads of 40-46 mm were enrolled in this study. The author, with many years of experience with polyethylene hip resurfacing from predicate devices, performed all the procedures using a posterior approach.

The goal for acetabular inclination was 40° compared with the native acetabular inclination of between 55° and 65°. The acetabular anteversion was reduced as necessary to achieve a combined femoral and acetabular anteversion of 45°. After impaction, the acetabular component was tested manually, and 1 or 2 screws were placed, if needed, to provide complete stability.

Participants were permitted to bear weight immediately postoperatively and had no limitations after their initial recovery. Using the UCLA Activity Score, we asked participants preoperatively about their goals after hip resurfacing. Follow-up examinations were performed at 8 weeks, 6 months, and annually, and outcomes were assessed using the Modified Harris Hip Score, Western

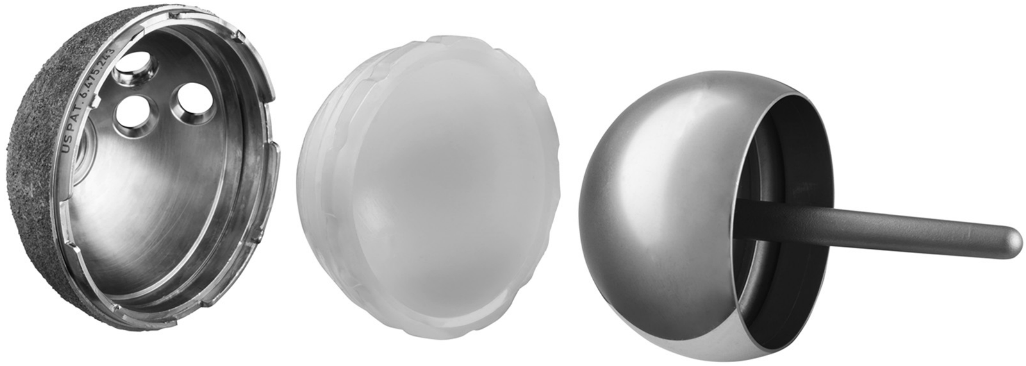

Fig. 1. This photograph shows the resurfacing implants used. They consist of a 2-piece acetabular component with a porous titanium shell and a highly cross-linked polyethylene liner. The femoral component is cobalt-chromium.

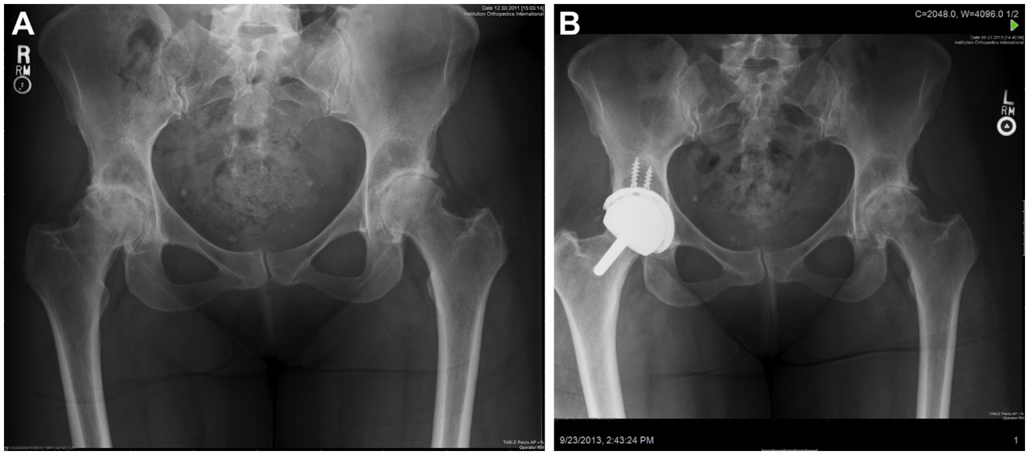

Fig. 2. (A) This anteroposterior pelvis radiograph shows a 49-year-old woman with severe right hip osteoarthritis. (B) The postoperative radiograph shows the resurfaced hip, using a 2-piece acetabular component with a highly cross-linked polyethylene component and a cemented cobalt-chromium femoral component.

Ontario and McMaster Universities Arthritis Index instrument, 12-Item Short Form Survey, and UCLA Hip Score [3,27-29].

At each follow-up visit, we obtained a digital anteroposterior view radiograph of the pelvis centered over the symphysis (Fig. 2B), an anteroposterior view of the hip centered over the femoral head, and a Johnson shoot-through lateral radiograph [30]. Two independent observers not involved in this study analyzed all images.

The cup inclination and anteversion angles were measured on the pelvic and lateral radiographs and computed tomographic (CT) scans. The inclination of the femoral component was also measured with respect to the preoperative femoral neck shaft angle. The radiographs were evaluated for radiolucent lines and osteolysis in the acetabular zones described by DeLee and Charnley [31]. Fixation of the femoral component was evaluated radiographically as described by Amstutz et al [3]. Sclerotic lines indicating a bony reaction to the femoral component were considered stable unless there was a sign of implant migration [3]. The acetabular components were inspected radiographically for signs of osseointegration. The presence of spot welds and bone trabeculae through the metal indicated ingrowth; radiolucencies or migration indicated the failure of ingrowth.

All images were examined for osteolysis, which was defined as an area of lucency seen within bone with a defined sclerotic border. Lucent areas were not considered to be osteolytic if they were associated with cystic changes present on the preoperative or immediate postoperative radiographs [32].

High-resolution CT scans with metal artifact reduction software were performed in 51 participants. These participants received their CT scan when they presented after 8-10 years, and additional participants are offered CT scans as part of their future follow-up evaluations. Qualitative polyethylene wear and related osteolysis were assessed by CT scanning. Precise radiographic and CT scan polyethylene wear measurements are beyond the scope of this work and are being addressed in another study.

Computed tomographic scans were used in addition to digital radiographs to measure biomechanical and bone conservation parameters. Femoral bone conservation was measured using the head:neck ratio (Fig. 3A). Acetabular bone retention was determined by measuring the medial acetabular wall thickness as the shortest distance from the cup to the pelvic brim (Fig. 3B). We also measured the distance to Kohler's line. The horizontal center of rotation was a measure of hip biomechanics and acetabular bone retention. We measured limb length as the perpendicular distance from the horizontal teardrop to the base of the lesser trochanter and also measured the vertical center of rotation and horizontal femoral head offset (Fig. 3B) [12,33].

Twenty-four of the 51 participants with a CT scan had a normal contralateral hip, 8 had a contralateral hip resurfacing, 5 had a

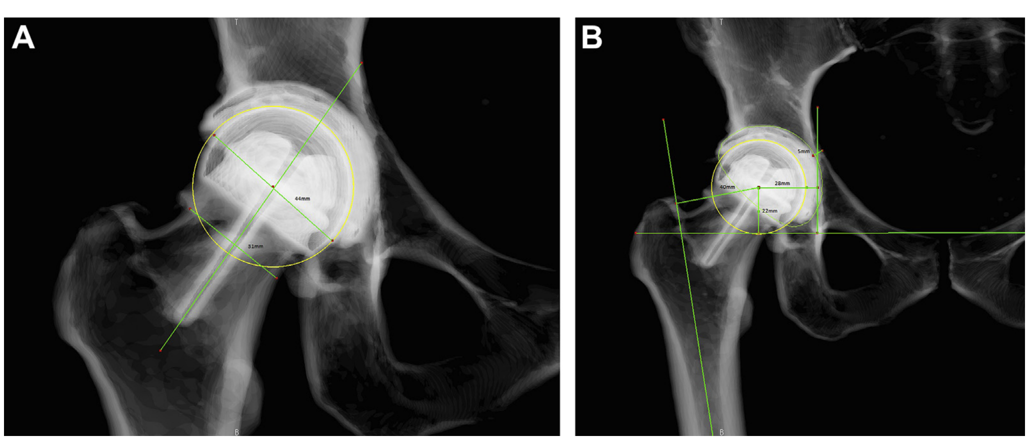

Fig. 3. (A) This anteroposterior hip computed tomographic (CT) scan of a 46-year-old woman was obtained 9 years after her right hip resurfacing. It demonstrates that her femoral head:neck ratio is 1.42. (B) This CT image demonstrates a medial wall thickness of 5 mm, a horizontal center of rotation of 28 mm, and a vertical center of rotation of 22 mm. The femoral offset is 40 mm.

contralateral THA, and 14 had a dysplastic or arthritic contralateral hip. In calculating the biomechanics of the resurfaced hip, comparison was to the normal contralateral hip (when present) and to the preoperative hip.

Explanted liners were inspected using optical microscopy for evidence of rim damage, cracking, and fatigue. The rim was inspected with particular attention to evidence of abrasion, burnishing, scratching, embedded debris, and plastic deformation [19,21,22].

Polyethylene wear was calculated using the retrieved liners rather than CT or digital radiography. As an indication of polyethylene wear, linear femoral head penetration was measured with a digital coordinate measuring machine (Mitutoyo America Corporation, Aurora, IL). The thickness in 300 points was measured in loaded and unloaded areas. The mean femoral head penetration rate was calculated by dividing the measured head penetration by time (mm/y).

Statistical Analysis

Two-tailed, paired, Student *t* tests were used to compare the postoperative and most recent follow-up clinical scores. A *P* value <.05 was deemed significant. The Kaplan-Meier survivorship method with revision for any reason was used as the end point.

Results

Of the 190 procedures, 105 were performed for osteoarthritis (Fig. 2A), 11 hips had previous trauma-related surgery, and 74 procedures were performed to treat degeneration due to hip dysplasia. There were 115 women with a mean age of 49 years, and a mean body mass index of 24 (range, 19-38) kg/m^2. There were 49 men with a mean age of 47 years and a mean body mass index of 29 (range, 25-40) kg/m^2. The follow-up ranged from 7-10 (mean, 8.5) years. Two participants were lost to follow-up and 2 participants died from unrelated causes.

Using the UCLA Activity Score, participants' mean preoperative goal for activity was 8 (range, 6-10), defined as very active [34]. The postoperative Harris Hip Scores, Western Ontario and McMaster Universities Arthritis Index, 12-Item Short Form Survey, and UCLA Activity all improved (Table 1), as did the range of motion (Table 2). The average radiographic acetabular component inclination angle was 41° (range, 30°-53°), and the average anteversion angle was 16° (range, 0°-25°). The average femoral anteversion was 14° (range, 0°-20°). The average combined femoral acetabular anteversion was 32° (range, 25°-45°). All femoral components were neutral or placed in a valgus orientation with respect to the native femur. There were no instances of femoral neck notching. One femoral and one acetabular implant were loose. No other hips showed femoral or acetabular radiolucencies or migration.

There were complications that did not interfere with the outcome (3 wound infections and 2 cases of Brooker 2 heterotopic ossification) [35]. There were no dislocations. Three participants continued to report pain (2 mild, 1 moderate). There were 4 instances of osteolysis identified by the CT scan but not by the radiograph. The largest was 0.9 cm^2. Radiolucent lesions were seen in 9 hips, but comparison to preoperative radiographs showed that these were cystic lesions of the acetabulum.

Table 1
Results of Scoring Assessments.

Instrument	Preoperative Mean (Range)	Postoperative Mean (Range)	*P* Value
Harris Hip	53.3 (21-81)	96 (52-100)	<.0001
WOMAC	52.7 (30-68)	5.7 (0-16)	<.0001
SF-12			
Mental	47 (22-61)	54 (24-64)	<.005
Physical	38 (22-48)	52 (26-64)	<.0001
UCLA	4.1 (2-7)	8.1 (6-10)	<.0001

WOMAC, Western Ontario and McMaster Universities Arthritis Index; SF-12, 12-Item Short Form Survey; UCLA, University of California, Los Angeles.

Table 2
Range of Motion Results.

Motion	Preoperative Mean (Range), Degree	Postoperative Mean (Range), Degree	*P* Value
Flexion	98 (70-130)	120 (110-140)	<.0001
Internal rotation	4 (−10 to 20)	30 (15-60)	<.0001
External rotation	20 (0-35)	40 (25-50)	<.001

Four participants (2%) underwent revision to THA at 3-10 years after resurfacing because of femoral neck fracture (2), femoral loosening (1), and infection (1). One participant underwent successful revision using an acetabular shell 2 mm larger for loosening with retention of the femoral resurfacing prosthesis. In all 4 revisions to THA, the metal-backed acetabular component was preserved and the acetabular liner was exchanged to allow use of new polyethylene. Using revision for any reason as the end point, the Kaplan-Meier survival estimate of mean survivorship was 97% (95% CI: 95%-99.9%) at 10 years (Fig. 4). There were no bearing surface failures or pending failures.

Seven polyethylene retrieval specimens were obtained at revision or postmortem at periods of 3, 5, 7, 8, 9, 9, and 10 years after resurfacing. These specimens showed a mean wear rate of 0.05 mm/y (range, 0.03-0.10 mm/y). There was no internal or rim cracking, scratching, burnishing, or delamination, and the original machining marks were visible for 6 of the seven liners. Two liners showed signs of polyethylene creep into the screw holes.

The mean postoperative head:neck ratio was 1.37 compared with the preoperative ratio of 1.43 ($P = .02$). The mean medial wall thickness was 9 mm compared with 14 mm preoperatively ($P = .05$; Table 3). The mean distance from the acetabular component to Kohler's line was 3.9 (range, 1.0-4.7) mm. Two patients required more femoral reaming than planned to achieve a stable prosthesis. One acetabular screw was used in 17 participants (9%), and 2 acetabular screws were used in 6 participants (3%; Fig. 1).

Compared with the normal contralateral hip, the center of rotation of the resurfaced hip was displaced 4 mm more medially (range, 8 mm medialized-5 mm lateralized). The horizontal femoral head offset was medialized 1 mm (range; 6 mm medialized-7 mm lateralized). For the 5 patients with contralateral THA, the same-size acetabular component was used for the resurfacing. The acetabular component was placed at or below the teardrop for 4

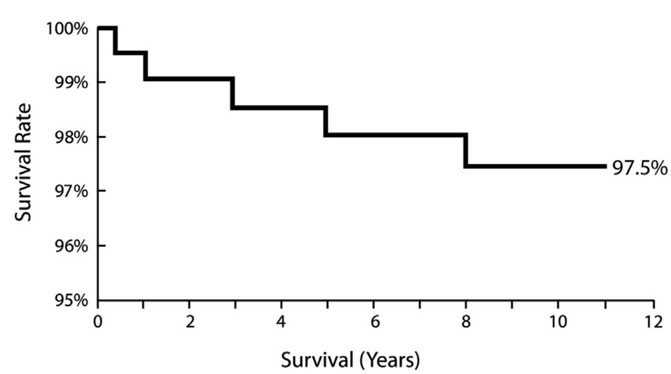

Fig. 4. This is the Kaplan-Meier survivorship curve for highly cross-linked polyethylene hip resurfacing.

Table 3
Bone Conservation and Center of Rotation Measurements.

Measurement	Preoperative	Postoperative	Difference
Medial acetabular wall thickness mean (range), mm	14 (4-19)	9 (1.5-17.5)	5
Head:neck ratio mean (range)	1.43 (1.29-1.50)	1.37 (1.26-1.52)	0.6
Center of rotation			
Horizontal	39.4 (23-49)	32.5 (18-41)	−6.9
Vertical	16.5 (19.3-25.4)	16.0 (7-24)	−0.5

participants. Two participants with contralateral total hip arthroplasty had acetabular components placed at or below the teardrop. The center of rotation was also 0.5 mm lower (range, 6.4 lower-7.2 mm higher) compared with the preoperative measurement and 2.1 mm lower (range, 1.2 mm lower-8.9 mm higher) compared with the normal contralateral hip. The leg-length measurement showed an increase of 4.5 mm from preoperative (range, 5.0 mm decrease-11 mm increase) and 4.6 mm increase compared with the normal contralateral hip (range, 2.9 mm decrease-8.2 mm increase; Fig. 3B).

Discussion

Highly cross-linked polyethylene as a bearing surface for hip resurfacing produced satisfactory functional results, bone conservation, maintenance of biomechanics, and implant survivorship. There was limited polyethylene-related osteolysis and no polyethylene liners failed.

This study has limitations. The follow-up period is midterm yet is comparable to the follow-up periods of most other hip resurfacing reports [3,7,11,13]. The author was not able to determine the relative effectiveness of the procedure regarding patient gender, but this was not a goal of the study. The size of the femoral components was limited to just 2 of the smaller range of possible choices available (40 and 44 mm). Similarly, there were just 2 acetabular shells (50 and 54 mm) used. The author and now others perform hip resurfacing using highly cross-linked polyethylene in sizes up to 52 mm [5]. Another limitation of this study may be that a single surgeon with extensive experience in hip resurfacing performed all procedures; thus, these results may not be reproducible in other centers. Also, careful templating was done to assure the correct component selection and bone preparation. The author found that 5% of patients are not candidates for polyethylene hip resurfacing because they do not have sufficient acetabular bone to retain both the anterior and posterior walls and at least 5 mm of the medial wall. Component positioning is important in hip implant surgery. Because many of the participants had dysplasia, the combined anteversion and acetabular inclination may be important variables. It is possible the results would be less favorable with less precisely placed components. The components in this study were well placed.

This study found that the functional results of hip resurfacing using highly cross-linked polyethylene were equal to the results of MoM resurfacing without the risk of an adverse reaction to metal wear debris [3,7,11,13,36]. Participants made significant functional gains in all measured parameters and achieved their preoperative goals, which were very high. There were 5 revisions (2%) in this series.

In addition, this study found the survivorship of hip resurfacing with highly cross-linked polyethylene to be superior to MoM resurfacing performed for component sizes ≤46 mm [7,13,36]. MoM resurfacing using component sizes ≤46 mm has failure rates up to 15% in both the Australian and England, Wales, and Northern Ireland registries at 10 years [16,37]. The results in this study using highly cross-linked polyethylene meet the National Institutes of Health and Care Excellence guidelines [17]. The survivorship and functional outcomes are equivalent to or better than those of THA [1,2,11,13]. The survivorship of highly cross-linked polyethylene for hip resurfacing is far superior to hip resurfacing with conventional polyethylene. The poor survivorship of earlier conventional polyethylene resurfacing procedures used with femoral components without stems was due to femoral component loosening, femoral neck fracture, acetabular wear, osteolysis, and acetabular loosening [8,9,38].

The low incidence of osteolysis and no polyethylene wear-through at a mean of 8.5 years indicate that cross-linked polyethylene is superior to conventional polyethylene and also more bone sparing. The mean polyethylene wear of 0.05 mm/y is consistent with other studies, and only 1 patient had wear greater than the osteolysis threshold of 0.1 mm/y [39]. The low incidence of osteolysis is also consistent with previous THA studies using cross-linked polyethylene [20,32,40]. The femoral head penetration of second- and third-generation, highly cross-linked polyethylene is 50%-87% less than conventional polyethylene [18-22].

The bone conservation and biomechanics afforded by polyethylene hip resurfacing can be compared with both THA and MoM hip resurfacing. Studies have compared acetabular bone retention of MoM resurfacing with THA [41,42]. Typically, there is 2 mm of acetabular component medialization with MoM resurfacing compared with THA [12,26]. Comparing the bone retention in the present study with MoM resurfacing, there was 1.5 mm less medial wall preserved using polyethylene and a 2.5-mm reduction in femoral head size [12]. Many of the participants in this study had lateralization of their hip center from preoperative dysplasia. Participants did not complain of pain in the lateral hip structures. With careful technique and patient selection, it is possible to place a polyethylene acetabular component and retain adequate acetabular and femoral bone. There are, however, patients with insufficient acetabular bone to host this cross-linked polyethylene acetabular component.

There are technical considerations that potentially limit the use of even thinner highly cross-linked polyethylene for hip resurfacing. Because highly cross-linked polyethylene can fracture, its thickness and the thickness of the metal backing are subject to engineering limitations. The minimum polyethylene thickness in this study was 3.8 mm [18,19]. Because of the metal backing, the composite component thickness was 10 mm compared with 6 mm for MoM. If thinner polyethylene shells are used, cup deformation with the potential for loss of fixation and acetabular cup clamping on the femoral head can occur [43]. Also, an effective locking mechanism has not been available for thinner acetabular components. Thinner components would need to be one piece. One-piece components will have the attendant difficulties of providing an effective insertion tool and method for later bearing surface exchange if necessary, as well as limiting the possibility for adjunctive screw fixation [5,20].

There is substantial favorable clinical experience using cross-linked polyethylene in 36- and 40-mm sizes for THA [18,19,21-23], as well as clinical experience in THA for 44-mm polyethylene [22,23]. Wear simulator data are favorable for polyethylene diameters of 44 and 46 mm, but long-term clinical data are not yet available [18,19].

There are a few prior reports with a limited number of participants using highly cross-linked polyethylene for resurfacing applications [5,34,44], and this study will continue to acquire additional and longer term data. There were no bearing surface failures at 10 years, but much thicker (mean, 14 mm) acetabular components were used in a prior study and there was less bone conservation measured by lower head:neck ratios [34]. The wear properties of highly cross-linked polyethylene make metal on polyethylene a reasonable alternative to MoM when the acetabulum has sufficient capacity for the acetabular component. The favorable results in this study can be attributed to careful patient selection, careful bone conserving surgery, avoidance of increased inclination and anteversion angles, and the use of high-quality cross-linked polyethylene. The participants in this study were a carefully selected group that were all treated by a highly experienced resurfacing surgeon.

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