Reduced Articular Surface of One-piece Cups

A Cause of Runaway Wear and Early Failure

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Abstract

Background Despite the clinical success of modern metal-on-metal articulations, concerns with wear-related release of metal ions persist. Evidence suggests metal ion release is related to the effective coverage of the head in the metal shell (the cup's functional articular arc). A recent study suggests a reduced functional articular arc is associated with increased ion release and the arc is a function of component design, size, and the abduction angle.

Questions/purposes The purposes of this study were to (1) measure the functional articular arc in different sizes of currently available one-piece metal shells from several different manufacturers; and (2) compare the functional articular arc of these one-piece metal shells with the 180° arc of conventional hip arthroplasty acetabular components.

Methods We calculated the available articular surface arc for 33 one-piece metal cups using measurements of cup depth and internal cup radius.

Results The arc of the articular surface varied among manufacturers and generally decreased with decreasing shell diameter. The mean functional articular arc was $160.5^\circ \pm 3.6^\circ$ (range, 151.8°–165.8°), which was less than the 180° arc of a conventional acetabular component.

Conclusions Our data show certain cup designs are at higher risk for failure as a result of the decreased articular surface arc. This, along with analysis of abduction angles, supports the recent findings of bearing failure with vertically placed implants. Care must be taken when implanting these shells to ensure they are placed in less abduction to avoid edge loading and the potential for early bearing failure.

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Introduction

Although some of the earliest THA designs incorporated metal-on-metal bearings, poor understanding of the manufacturing and tribologic needs of these bearings led to high implant failure rates and, as a result, metal-on-polyethylene became the dominant articular couple for several decades. Improved metal implant manufacturing techniques with better tolerance, roundness, and metallurgy, however, have led to recent increases in the use of metal-on-metal bearings. Metal-on-metal articulations are associated with a very low wear rate and as a result of the tribology of the materials, unlike metal-on-polyethylene articulations, the wear rate improves as the head size increases [6, 7, 9, 14]. This combination of low wear and large head sizes with metal-on-metal bearings has prompted the resurgence of hip resurfacing arthroplasty [3, 18].

Moreover, as a result of the additional stability afforded by large femoral heads against dislocation, use of one-piece metal shells with large-diameter heads are now being used routinely in THA.

Despite the benefits and clinical success of modern metal-on-metal articulations, concerns with wear-related release of metal ions persist. Elevated chromium and cobalt levels have been found in both the serum and remote organs of patients with metal-on-metal bearings [1, 2, 10]. Studies have also demonstrated excessive wear with one-piece metal shells in women with smaller diameter components as well as in hips in which the shell is oriented more vertically in the pelvis (a higher abduction angle) [5, 11, 13, 16, 19]. Occasionally, more dramatic local reactions to metal-on-metal articulations occur with a wide spectrum of presentations; excessive metal wear can lead to asymptomatic effusions, pseudotumors, and wide zones of soft tissue necrosis with loss of abductors and bone death [8, 17].

Evidence has emerged that such elevated metal ion release with resurfacing hip arthroplasty is related to the effective coverage of the head in the metal shell or the cup's functional articular arc. De Haan et al. [5] showed elevated metal ion release correlates with a reduced functional articular arc, in which the arc is a function of component design, component size, and the abduction angle of the cup. They suggested high wear is likely to occur in metal-on-metal resurfacing arthroplasties if the acetabular components are implanted steeply, likely as a result of a greater risk of edge loading, and this is particularly problematic in patients with a small acetabulum and in low-profile acetabular components. The authors stressed surgeons needed to be aware of functional arc of the acetabular component they implant.

Although De Haan et al. [5] have demonstrated the importance of functional articular arc in the performance of hip replacement components, it is still not a widely known concept nor are the data on functional articular arcs readily available from manufacturers. Moreover, as longer followup becomes available for one-piece metal cups, it is evident some patients develop metal sensitivity reactions attributable to increased metal wear associated with

variables such as tolerances, material, roundness, as well as mechanical factors related to cup design. Because of the correlation with elevated wear and potential higher risk of failure, knowledge of how these cup characteristics differ among manufacturers as well as how they differ from conventional 180° components is important for hip replacement surgeons.

The purposes of this study were therefore (1) to measure the functional articular arc in different sizes of currently available one-piece metal shells from several different manufacturers; and (2) to compare the functional articular arc of these one-piece metal shells with the 180° arc of conventional hip arthroplasty acetabular components.

Materials and Methods

New one-piece metal-on-metal acetabular components were obtained from four different manufacturers in multiple sizes (Table 1). Eleven cups with sizes ranging from 44 to 66 mm were obtained both from Smith and Nephew (Birmingham Hip Resurfacing; Smith and Nephew, Memphis, TN) and BIOMET (Magnum; BIOMET, Warsaw, IN). Six cups ranging in size from 42 to 62 mm were obtained from Wright Medical Technology Inc (Conserve Plus; Wright Medical Technology Inc, Arlington, TN), and three cups were obtained from Stryker Orthopaedics (Cormet; Stryker Orthopaedics, Mahwah, NJ). Two additional cups that are currently on the market (ASR; DePuy, Warsaw, IN, and Durom; Zimmer, Warsaw, IN) were retrieved during revision arthroplasty and included in the analysis. In all, we studied 31 new and two revision-retrieved one-piece metal-on-metal acetabular components.

For each component, we calculated the arc of the available articular surface (Fig. 1) with trigonometry using measurements of cup depth (measured with a Mitutoyo Series 129 depth micrometer; Mitutoyo America Corporation, Aurora, IL) and the manufacturer-supplied internal radius of the cup. Cup depth was defined as the distance from the functional rim to the internal dome, taking into account any cutaways or bevels at the rim. All depth measurements were repeated 10 times per cup and the

Table 1. Distribution of cups studied

Manufacturer	Cup	Number of cups	Sizes (mm)
Smith and Nephew	Birmingham Head Resurfacing (new)	11	44, 46, 48, 50, 52, 54, 56, 60, 62, 64, 66
BIOMET	Magnum (new)	11	44, 46, 48, 50, 52, 54, 56, 60, 62, 64, 66
Wright Medical Technology Inc.	Conserve Plus (new)	6	42, 46, 48, 52, 56, 62
Stryker Orthopaedics	Cormet (new)	3	52, 56, 62
DePuy	ASR (retrieved)	1	48
Zimmer	Durom (retrieved)	1	44

Fig. 1 The functional articular arc (a) is a function of radius (r) and depth of the cup (d). The articular arc angle is a measure that is design-specific. The amount of coverage laterally over the head is a function of the abduction angle of the cup and the functional articular surface. Reproduced (in amended form) with permission and copyright © of the British Editorial Society of Bone and Joint Surgery (De Haan R, Pattyn C, Gill HS, Murray DW, Campbell PA, De Smet K. Correlation between inclination of the acetabular component and metal ion levels in metal-on-metal hip resurfacing replacement. *J Bone Joint Surg Br.* 2008;90:1291–1297, Fig. 2).

average value recorded and used for articular surface calculations.

Head size versus measured articular surface arcs was graphed for each of the manufacturers. For parametric data, we used a one-sample t-test to compare the mean of a population to a known number. Because values for articular surface arc assessed in this study were normally distributed, we used a one-sample t-test to compare the mean value for the 33 articular surface arcs in this study to a fixed value of 180°, the theoretical arc for a conventional acetabular implant. Owing to the small sample size, we did not compare differences among manufacturers. Instead, we assessed whether, as a group, these one piece metal cups have an articular surface arc that was different from 180°. We performed the statistical analysis using SPSS software (SPSS Version 8.0; SPSS Inc, Chicago, IL).

Results

The arc of the articular surface varied among manufacturers and generally decreased with decreasing shell diameter (Fig. 2). The amount of articular surface coverage

Fig. 2 Head size (mm) versus functional articular arc (degrees) is graphed for different manufacturer shell designs assessed in this study.

ranged from a high of 165° in the largest sizes of two of the manufacturers designs to 151.8° encountered in the smaller retrieval specimen. In general, the Conserve cup had the largest functional arcs across cup sizes, whereas the BHR and the Cormet had the smallest functional arcs across the range of cup sizes.

The mean functional articular arc for the 33 cups assessed in this study was $160.5^\circ \pm 3.6^\circ$ (range, 151.8°–165.8°), which was less than ($p < 0.001$) the 180° arc of a conventional acetabular component.

Discussion

With the increase in the number of resurfacing and THAs performed with large, nonhemispheric one-piece metal cups, new complications associated with wear have been noted. These complications include runaway wear, pseudotumor formation, and acute lymphocytic vascular-associated lesions [8, 16, 17]. Several reports have recently been published regarding acetabular component position as it relates to serum metal ions [5, 11, 13] and cup loosening [4, 15]. Cups implanted with inclinations ranging from 45° to 60° showed signs of increased edge loading, loosening, and serum metal ion levels. Additionally, De Haan et al. have demonstrated the importance of functional articular arc as it relates to wear complications with large metal-on-metal articulation [5]. De Haan et al. showed elevated

metal ion release correlates with a reduced functional articular arc, in which the arc is a function of component design, component size, and the abduction angle of the cup. The purpose of the current study, therefore, was to build on the work of De Haan et al. [5] and (1) to measure the functional articular arc in different sizes of currently available one-piece metal shells from several different manufacturers; and (2) to compare the functional articular arc of these one-piece metal shells with the 180° arc of conventional hip arthroplasty acetabular components.

We acknowledge several limitations of the current study. The primary limitation is that articular surface wear is a multifactorial process and there are many variables that affect it which we do not address, including bearing diameter and cup anteversion. The focus of this study, however, is functional articular arc. All else being equal, functional articular arc matters [5] and surgeons should be more aware of it. Quantification of functional articular arcs for cups presently on the market may help surgeons improve their outcomes by enabling them to understand which shell designs are at increased risk for edge loading, specifically if they are positioned suboptimally. Second, we did not evaluate the full range of implants for each manufacturer. Although we would have preferred to evaluate many more cups, we were only able to study those cups donated by the different manufacturers. However, all cups donated were evaluated and included in the present analysis. Future analyses should include more cups from different manufacturers with a complete range of cup sizes.

We observed a wide variation of functional arcs among currently available manufacturers and cup sizes in which functional arc generally decreased as shell diameter decreased. In general, the Conserve cup (Wright Medical) had the largest functional arcs, whereas the BHR (Smith and Nephew) and the Cornet (Stryker) had the smallest functional arcs across the range of cup sizes. Of all the cups studied, the 44-mm ASR (DePuy) had the smallest functional articular arc. The reason for the variation among manufacturers is related to design. Design decisions that compromise hemisphericity are based on many factors, including retention of bone stock and reducing the risk of impingement in a resurfacing situation. Some cups are designed to be less than a hemisphere to prevent impingement of the native femoral neck against the shell edge. Some designs reduce hemisphericity by incorporating a thickened dome to stiffen the shell and lessen the deformation that can occur during press-fit implantation. Still other designs incorporate a tapered radius at their rim to eliminate sharp edges and maintain fluid ingress into the articulation. Overall, these design differences result in variability in functional articular arcs. This difference between designs is clearly demonstrated by a recent clinical report. In a single center study of 660 metal-on-metal

resurfacings, Langton et al. [12] reported 17 failures from adverse reactions to metal debris in patients implanted with ASR implants (3.5%) and no failures of this nature in patients implanted with BHR (Smith and Nephew) implants. Langton et al. suggest the increased failure of the ASR cup (DePuy) secondary to the increased generation of metal debris was the result of its reduced functional articular arc as compared with that of the BHR (DePuy) component [12].

The articular surface arcs of cups in the current study averaged 160.6°, which was substantially less than the 180° arcs associated with standard THA components. The smaller bearing surface arc demonstrated with these and other one-piece metal cups results in a smaller amount of coverage laterally over the head, which could lead to edge loading at much lower abduction angles, resulting in elimination of fluid film lubrication and increased metal wear. This is consistent with the reports of edge loading and component loosening as well as increased metal ions noted in subjects with inclination angles averaging 45° or more [5, 11, 13, 15]. As previously noted, the amount of arc available for coverage is a function of the abduction angle of the cup, the functional arc of the particular cup design, and the size of the implanted cup. Cups with a smaller functional articular surface are at higher risk of edge loading and high wear rates. As an example, if a cup with a functional articular surface of 151° is implanted at 55° abduction, it will behave like a 180° cup implanted at 69.5° of abduction and be at risk for edge loading. A traditionally acceptable 45° inclination angle leaves no room for error in these nonhemispheric cups, particularly in smaller sizes. This supports the findings of Olliviere et al. who studied the rate and mode of early failure in 463 Birmingham hip resurfacings [16]. They reported a 3.1% rate of metallosis-related revision at 5 years with risk factors for revision including female gender and a high abduction angle. When combined with excessive anteversion, these one-piece cups provide even less coverage of the weightbearing portion of the femoral head. Given this possibility, and the increasing number of reports of runaway wear and loosening as well as pseudotumor formation and devastating soft tissue necrosis and nerve palsies, it may be advisable to implant nonhemispheric resurfacing cups between 40° to 45° of abduction and 15° of anteversion and check for impingement intraoperatively. Because cup position error is not well tolerated with these designs, an intraoperative radiograph may be advisable to ensure accurate position.

Our data and analysis of abduction angles are consistent with recent findings of bearing failure with vertically placed implants. It is evident certain designs are at higher risk for failure as a result of the decreased articular surface arc. Care must be taken when implanting these shells to

ensure they are placed in less abduction to avoid edge loading and the potential for early bearing failure.

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References

1. Bhamra M, Case C. Biological effects of metal-on-metal hip replacements. *Proc Inst Mech Eng H*. 2006;220:379–384.
2. Brown C, Fisher J, Ingham E. Biological effects of clinically relevant wear particles from metal-on-metal hip prostheses. *Proc Inst Mech Eng H*. 2006;220:355–369.
3. Buergi ML, Walter WL. Hip resurfacing arthroplasty: the Australian experience. *J Arthroplasty*. 2007;22(Suppl 3):61–65.
4. De Haan R, Campbell PA, Su E, De Smet K. Revision of metal-on-metal resurfacing arthroplasty of the hip. *J Bone Joint Surg Br*. 2008;90:1158–1163.
5. De Haan R, Pattyn C, Gill HS, Murray DW, Campbell PA, De Smet K. Correlation between inclination of the acetabular component and metal ion levels in metal-on-metal hip resurfacing replacement. *J Bone Joint Surg Br*. 2008;90:1291–1297.
6. Dowson D. Tribological principles in metal-on-metal hip joint design. *Proc Inst Mech Eng H*. 2006;220:161–171.
7. Dowson D, Jin Z-M. Metal-on-metal hip joint tribology. *Proc Inst Mech Eng H*. 2006;220:107–118.
8. Grammatopoulous G, Pandit H, Kwon YM, Gundle R, McLardy-Smith P, Beard DJ, Murray DW, Gill HS. Hip resurfacings revised for inflammatory pseudotumour have a poor outcome. *J Bone Joint Surg Br*. 2009;91:1019–1024.
9. Isaac G, Thompson J, Williams S, Fisher J. Metal-on-metal bearing surfaces: materials, manufacture, design, optimization, and alternatives. *Proc Inst Mech Eng H*. 2006;220:119–133.
10. Jacobs JJ, Skipor AK, Doorn PF, Campbell P, Schmalzried TP, Black J, Amstutz HC. Cobalt and chromium concentrations in patients with metal on metal total hip replacements. *Clin Orthop Relat Res*. 1996;329(Suppl):S256–S263.
11. Khan M, Kuiper J-H, Richardson J. The exercise related rise in plasma cobalt levels after metal-on-metal hip resurfacing arthroplasty. *J Bone Joint Surg Br*. 2008;90:1152–1157.
12. Langton DJ, Jameson SS, Joyce TJ, Hallab NJ, Natsu S, Nargol AV. Early failure of metal-on-metal bearings in hip resurfacing and large-diameter total hip replacement: a consequence of excess wear. *J Bone Joint Surg Br*. 2010;92:38–46.
13. Langton DJ, Jameson SS, Joyce TJ, Webb J, Nargol AV. The effect of component size and orientation on the concentrations of metal ions after resurfacing arthroplasty of the hip. *J Bone Joint Surg Br*. 2008;90:1143–1151.
14. Lee R, Essner A, Wang A. Tribological considerations in primary and revision metal-on-metal arthroplasty. *J Bone Joint Surg Am*. 2008;90(Suppl 3):118–124.
15. Morlock M, Bishop N, Zustin J, Hahn M, Ruther W, Amling M. Modes of implant failure after hip resurfacing: morphological and wear analysis of 267 retrieval specimens. *J Bone Joint Surg Am*. 2008;90(Suppl 3):89–95.
16. Ollivier B, Darrah C, Barker T, Nolan J, Porteous MJ. Early clinical failure of the Birmingham metal-on-metal hip resurfacing is associated with metallosis and soft-tissue necrosis. *J Bone Joint Surg Br*. 2009;91:1025–1030.
17. Pandit H, Glyn-Jones S, McLardy-Smith P, Gundle R, Whitwell D, Gibbons C, Ostlere S, Athanasou N, Gill H, Murray D. Pseudotumors associated with metal-on-metal hip resurfacings. *J Bone Joint Surg Br*. 2008;90:847–851.
18. Schmalzried TP. Why total hip resurfacing. *J Arthroplasty*. 2007;22(Suppl 3):57–60.
19. Williams S, Leslie I, Isaac G, Jin Z, Ingham E, Fisher J. Tribology and wear of metal-on-metal hip prostheses: influence of cup angle and head position. *J Bone Joint Surg Am*. 2008;90(Suppl 3):111–117.