The Problem with Large Diameter Metal-on-Metal Acetabular Cup Inclination

Jonathan R.T. Jeffers, Ph.D., Anne Roques, Ph.D., Andy Taylor Ph.D., and Mike A. Tuke, HNC Mech Eng

Abstract

Large diameter metal-on-metal hip bearings have proven to be clinically successful in active patients, but, in a small number, they are associated with elevated wear and high metal ion levels when cup inclination angles are too steep and the version is too extreme, or either alone. Based on the geometry of six different commercially available large diameter metal-on-metal acetabular components, this study demonstrated that the critical bearing surface operates at an angle up to 16º greater than the cup face inclination. Due to geometry alone, measured cup inclination is not the angle that most surgeons perceive it to be. We strongly recommend when employing large diameter metal-on-metal bearings that lower inclination and version angles are targeted to prevent excessive wear.

Long-term retrievals of first-generation large diameter metal-on-metal (MoM) bearings demonstrate very low wear. Current studies related to MoM hip replacement and resurfacing have identified a relationship between a steep acetabular cup angle and elevated levels of wear.[1-3] This data has been reported in terms of elevated metal ion levels in the blood[1,3] and run-away edge wear in retrieval analysis.[2] Elevated levels of wear have been associated with aseptic lymphocytic vasculitis associated lesions (ALVAL), hypersensitivity, and pseudotumours.[4,5] Further problems, including cytotoxicity and chromosomal aberrations, have been identified for large diameter MoM bearings at midterm and may also be caused by malpositioned cups. Excess metal debris production is likely to cause problems, which may be quite varied in outcome and symptoms, due to ion or particle size, transport mechanisms, patient sensitivity, rate of generation, and duration of exposure. The ideal physical position of cups and the mechanism of debris production are not well understood, but notably not a problem of any significance in the first decade of these implants. The influence of cup design on all these factors has not been well understood and potential issues and concerns have not been widely disseminated.

An abduction angle of 45° and an anteversion of 15° to 20° are usually considered optimum for the acetabular cup in hip replacement. This orientation has been arrived at after several decades of success with low friction metal-on-polyethylene devices. It is important to note that the orientation of an acetabular cup is generally defined by the cup face, but the wear properties of the cup are the result of the position of the bearing surface, and in particular its edge relative to the load axis. Although the external shape of the contemporary large diameter MoM cup is equivalent to the polyethylene cup mentioned above (i.e., hemispherical), the bearing surface is not. Low-friction polyethylene cups have a hemispherical bearing surface, but large diameter MoM cups have a bearing surface that is less than a hemisphere. Because of this difference, the bearing surface of a contemporary MoM acetabular cup operates at a significantly steeper angle than that defined by the cup face, and hence perceived by the surgeon. This is both manufacturer design and size dependent and has important consequences in terms of bearing wear.

Materials and Methods

Six different commercially available large diameter MoM acetabular cup designs were included in the current study (Fig. 1). All cups had a 50 mm diameter bearing surface and were production implants, apart from design D, which was

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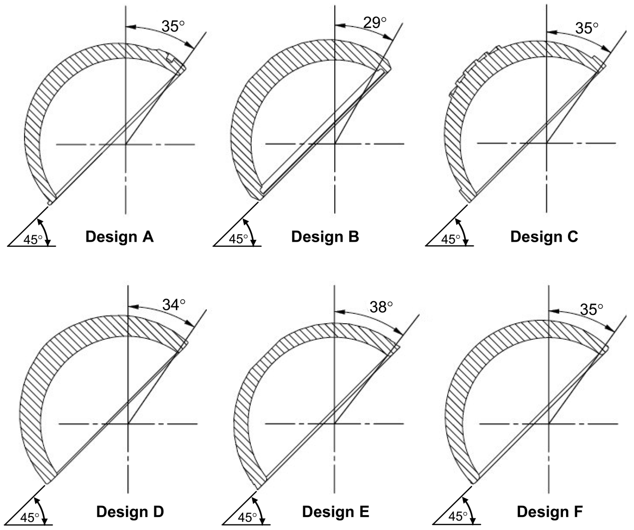

Figure 1 Cross-sections of six different commercially available large diameter MoM acetabular components placed at 45° abduction identifying the center-edge angle.

marked "Sample." The cup geometry was obtained by scanning the internal cup bore and rim, using a coordinate measuring machine (CMM) (Mitutoyo Crysta-Plus, Mitutoyo, Andover, United Kingdom). This machine had a specified accuracy of plus or minus 5 µm and a resolution of plus or minus 1 µm. Two traces were obtained at 90° to each other to ensure repeatability of the measurements.

The data from the CMM were imported into computer-assisted design (CAD) software (Solidworks 2007, Dassault Systèmes, Paris, France) and used to generate CAD models of the six different designs. Each cup was positioned at abduction and anteversion angles of 45° and 20°, respectively (assuming the radiographic definition of abduction and anteversion[6]). A cross-section was taken through the center of the cup in the frontal plane, and a line was drawn from the center of the bearing surface in the vertical direction. A second line was drawn from the center of the bearing surface to the superolateral edge of the bearing surface. The angle between these lines was defined as the "center-edge angle" of the bearing and measured for all six designs.

Results

The bearing surface of each design was less than a hemisphere, which meant that the center of the bearing was outside the face of the cup in all cases (Fig. 1). The bearing surface did not extend to the face of the cup in any of the designs due to design features at the rim. This comprised a small fillet radius for designs A, C, D, E, and F and, for design B, additionally included a recess around the internal rim to allow attachment of an introducer (Fig. 1B). These design features acted to reduce the center-edge angle of the acetabular cups. With a cup face abduction angle of 45°, the center-edge angles were between 38° and 29°. Design B had the notably smallest center-edge angle (29°), due to the recess around the internal rim of the cup. To simplify the interpretation of the data, the current study considered a section of the cups in the frontal plane, which effectively neglected the contribution of anteversion to the inclination of the cup (Fig. 2, black arrow). If 20° of radiographic anteversion was considered, the truly most superior point of the bearing surface, rotated out of the frontal plane, is indicated by the white arrow in Figure 2. If the center-edge angles are measured at this location, they are reduced by 3° in all cases, compared with Figure 1. The edge of the bearing surface, therefore, is 3° closer to the wear patch area than shown in Figure 1, due to 20° anteversion. The contribution of cup anteversion to the position of the bearing surface relative to the load, consequently, is considered secondary to cup abduction.

Discussion

The center-edge angle of the acetabular cup was defined here as the angle created by lines drawn on an anteroposterior view from the articulation center to vertical as the patient stands, and from the articulation center to the edge of the articulation. It is the same as that measured for dysplastic hips that are not replaced and has an analogous aspect with respect to joint function. It measures the amount of superior coverage the cup has over the femoral head. Reducing the center-edge angle, therefore, reduces the superior coverage of the bearing and brings the edge of the bearing surface closer to the load vector. This is critical for large diameter MoM hip bearings, as any partial fluid film lubrication occurs at the area around the load vector,[7] as illustrated in Figure 2, but cannot occur at the edge the bearing surface.[8] Studies of retrieved bearings, tunnel wear, and Charnley's original work with Teflon® bearings have demonstrated the load vector in practice is close to the vertical axis in most hips.

The optimum acetabular cup abduction angle is usually considered to be 45° and related to the cup face, but this position has been largely arrived at for low friction metal-on-polyethylene articulations (e.g., Charnley and similar devices), where the acetabular bearing surface is hemispherical. The center-edge angle of a hemispherical bearing surface is 45° when the cup face is positioned at 45° abduction. For a hemispherical-bearing polyethylene cup to have an equivalent center-edge angle to those mea-

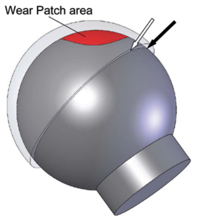

Figure 2 Illustration of the typical wear area of a MoM bearing. The black arrow identifies the closest point of the bearing surface to the lubrication area as considered in the current study. The white arrow indicates the true location of this position due to anteversion. (Adapted from Tuke MA, Scott G, Roques A, et al. J Bone Joint Surg Am. 2008;90(Suppl 3):134-41.[7] © The Journal of Bone and Joint Surgery, Inc. With permission.)

sured in this study, it would require an abduction angle of between 52° and 61°. These abduction angles would be considered excessively steep, yet represent the inclination of large diameter MoM bearing surfaces when positioned at an abduction angle of 45°, as shown in Figure 1. Therefore, as the bearing surface operates at a steeper angle than the cup inclination, the inclination of large diameter MoM cups must be reduced to achieve a center-edge angle equivalent to that of a Charnley type cup. For most of these cups, the center-edge angle thereby achieved does not induce early impingement, with the possible exception being cup B. Hence, contrary to what is perceived, closing the abduction angle, as is recommended here, will *not* increase the risk of impingement; indeed, it only brings the impinging edge to the position originally perceived that it should be for a typical Charnley type cup. In any case, the perceived risk of impingement can be mitigated by improved trial reduction, with dedicated cup trial instrumentation allowing for the trial cup position to be optimized for range of motion and edge wear, and for the cup implant to be placed in that exact position.

The wear mechanism starts with the bedding-in wear process for MoM heads and cups and is a self limiting process that allows a slower rate of wear once the developed bedded patches are of sufficient size to support partial fluid film lubrication on the newly developed matching patches. That there is ongoing slow wear thereafter (i.e., steady-state wear), as shown by studies that confirm continuing metal ion release that is halted only by removing the components.[9] The second stage steady-state wear, however, slowly expands the initial wear patch on each component; thus, increasing the area of the bearing that has been lapped together from the first postoperative movement. When this expanding patch comes under the influence of the cup edge, the wear rate will accelerate due to destruction of the steady-state wear mechanism, if that has started, as lubrication cannot occur at the edge of the bearing surface.[8] The hard edge of the cup will enhance the wear rate together with the now unbalanced load platform presented by the cup to the head. As a result of these physical phenomena, the effect of a steep cup edge will become apparent with time at some point in the implant's life. A steeper inclined cup will bring this wear problem to the forefront sooner than a more shallow inclined cup that has a greater area of head cover. Cups that are performing satisfactorily with low metal ions at say 5 years, with a cup face at 55°, will not necessarily remain satisfactory a few years later. This phenomenon is time-dependent.

The size of articulation is a further factor that exacerbates this phenomenon. The study presented here only shows one size of component results in detail. The Australian National Joint Registry has found a five-times greater revision rate for head diameters less than 44 mm, compared to those greater than 55 mm, and it must be emphasized that this is not gender dependent (i.e., small males are at the same risk as many females).[10] This is almost certainly due to the design aspects described above, and factors relating to smaller components. There are at least five reasons why design geometry increases the risk of problems for smaller articulation diameters in particular.

1. The distance from the load vector to the edge of the bearing surface is smaller for smaller diameter components. This occurs even if the center-edge angle remains constant due to the articulation surface segment simply being a smaller diameter "cheese." This will place smaller components at greater risk of edge-wear problems at any given cup inclination.
2. Some designs of cups have a common center-edge angle across the size range, but others have a common offset of the articulation center outside the cup edge. The latter results in a more shallow center-edge angle for smaller cups than larger cups (Fig. 3) and can lead to as much as an 8° difference across the cup size range.
3. Sizing of resurfacing components generally provides for a head that is smaller than the patient's original head for MoM resurfacing. Components that historically have had only 4 mm head increments have resulted in undersizing of the natural head by an average of 6 mm, as reported by McMinn.[11] It is likely that with constant increments and market-leading brand penetration, this undersizing has been of greater proportional impact on smaller sizes than larger sizes.
4. Patients with smaller diameter components do not generally weigh less nor are they any less active than those with larger components; hence, the early interplay of a steep cup might be further "working against" smaller patients. This is likely due to the wear mechanism itself, which is progressing in all of these joints over time.[7]
5. Low clearance, favored by at least one manufacturer, achieves a lower initial bedding-in wear; however, this is at the expense of time to failure, due to the continuing steady state wear that progresses at essentially the same rate irrespective of starting clearance.[7] The starting clearance is being consumed at the same rate irrespective of that clearance; hence, any of the factors that bring the cup edge into play as accelerating wear will do so sooner on components that have a smaller starting clearance.

Geometry of these cups is a further compounding factor when the cups are placed relatively steeply, since their bone surface and articulating surface centers are usually eccentric by a few millimeters. As such a cup is rotated more steeply, the lateral edge is moved medially to shorten the articulating surface, as described above, but the head center, at the same time, is moved laterally by the eccentricity of the geometry so that the load axis and lateral edge are moving closer to each other with every degree of cup opening.

A steeper cup, a smaller cup, and one with lower starting clearance will bring this wear problem to the forefront sooner than a large cup with a shallow angle placement and higher start clearance. Clinical data appears to corroborate this,[1] and reducing the inclination of MoM cups in the smaller

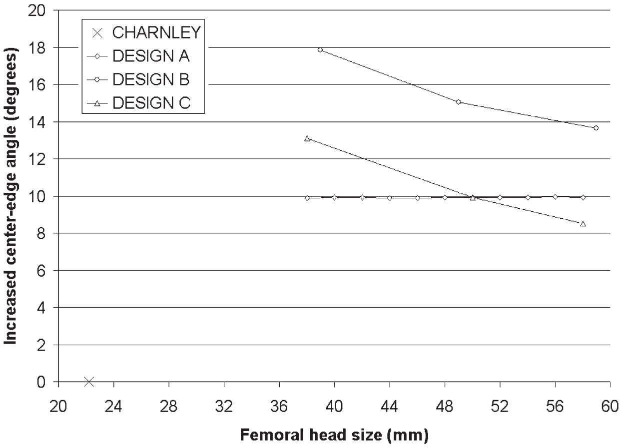

Figure 3 Three different cup designs showing the difference of the center-edge angle with head diameter, compared to a typical Charnley type polyethylene cup.

end of a typical size range is particularly important.

The Ring hip was studied for the parameters used in modern MoM implants by the current investigators. We have not seen a Ring hip retrieval with edge wear. Figure 4 demonstrates a hip that was implanted using a superomedial long screw into the ischium. There are retrievals that do show some neck impingement, but this does not appear to have caused adverse problems for the patients. Such cups show abduction angles of about 25° and have lasted up to 3 decades of active life with extremely low wear.

Conclusions

There are many factors that influence the functional life of MoM hip bearings, including clearance, bearing diameter, and cup placement. The data presented in the current study indicates that surgeons need to target a reduced cup abduction and version angle to achieve an equivalent center-edge angle to a hemispherical polyethylene bearing and keep the edge of the bearing surface away from the wear patch area. The center-edge angle varies between designs, and indeed varies between different sizes of a particular range, indicating a responsibility for manufacturers to inform surgeons what angles to target for their particular MoM products. Although a reduced abduction angle is beneficial for long implant life, it should be achieved without compromising range of motion, if possible, and requires a more reliable method of achieving any targeted angle. Surgeons have demonstrated wide variation in cup position, even when targeting a nominal 45/20 placement.[12] Improved instrumentation for acetabular cup placement would be beneficial in this regard, since there is no currently reliable system that provides predictable placement.

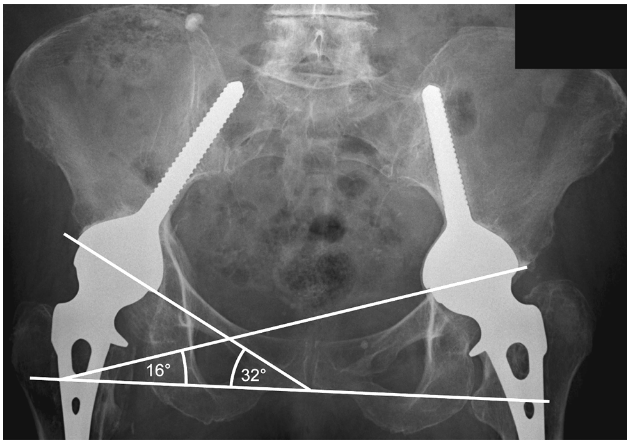

Figure 4 Ring hip with average cup abduction angles of 25°.

Disclosure Statement

The authors have a financial or proprietary interest in the subject matter or materials discussed, including, but not limited to, employment, stock ownership.

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