CASE REPORT

Suboptimal Component Position Leading to Severe Wear of an Alumina-Alumina Total Hip Coupling: Biomechanical Analysis and Documentation of Limited Tissue Response

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Introduction

Alumina-on-alumina articulations were first introduced into total hip arthroplasty in 1970 by Boutin et al. in France [3], and were approved by the Food and Drug Administration for their use in the USA in 1982. The ceramic-on-ceramic coupling was intended to reduce wear and particulate debris generated by metal-on-plastic articulations being used at that time. Modern alumina-on-alumina articular couplings have extremely low wear rates [1, 6, 10, 12, 15, 18] on the order of 0.004 mm³ per million cycles [2, 11, 17].

Early concerns for ceramic fractures have been addressed by improvements in the alumina material [11, 15, 19] and, in some cases, the introduction of a metal backing to the

alumina acetabular insert [4, 8]. Modern fracture rates are estimated at 0.04% for ceramic femoral heads and 0.015% for ceramic acetabular liners [7, 8, 14]. Three cases of metal-backed acetabular liner fracture requiring reoperation were reported over the past 5 years, all occurring more than 2 years after the original surgery [4, 5].

We report a case of acetabular rim fracture and extreme wear due to the vertical positioning of the acetabular component of an alumina-on-alumina total hip coupling with a metal-backed acetabular insert and its associated benign particle-induced soft tissue reaction.

Case Report

In May of 2007, a 46-year-old male with a body mass index (BMI) of 33.5 underwent a primary right hip resurfacing arthroplasty for osteoarthritis. At 2 months, radiographs revealed loosening of the components, requiring revision arthroplasty to a ceramic-on-ceramic bearing (Fig. 1). Using the previous posterolateral approach, and after line-to-line reaming, a 58-mm Trident® acetabular shell (Stryker Orthopaedics, Mahwah, NJ) was press-fit into the acetabulum and secured with two screws. A 32-mm titanium-encased ceramic liner was inserted into the titanium acetabular shell. A cementless Accolade® (Stryker Orthopaedics, Mahwah, NJ) size 4 femoral stem was press-fit, and a 32-mm (+0) alumina ceramic head (Stryker Orthopaedics, Mahwah, NJ) was placed. Cerclage wires around the proximal femur were used to treat a calcar fracture identified intraoperatively. After recovering from this procedure, the patient underwent a staged, ceramic-on-ceramic left total hip arthroplasty with an uneventful recovery. The patient did well until February of 2008, when he developed pain in the right groin, a sensation of hip instability, and a Trendelenburg lurch. These symptoms partially resolved with conservative management, but in April 2012, and 2 weeks after a fall, the patient presented with excruciating pain and a sensation of subluxation and relocation of the hip. Radiographic evaluation showed the femoral

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Fig. 1. Radiograph showing mechanical failure of a hip resurfacing arthroplasty due to acetabular cup loosening and migration.

head to be eccentrically located in a well-fixed acetabular component suggesting to the senior author a fracture of the ceramic-ceramic bearing (Fig. 2). The radiographic acetabular abduction angle was 55°.

The patient underwent a second hip revision in May of 2012. Intraoperative findings included a fracture of the ceramic liner rim and an oval-shaped femoral head with evident metal transfer and a clearly visible wear patch on the articular surface (Figs. 3, 4, 5, and 6). The amount of metal transfer was not recognized as remarkable considering this specific scenario. No macroscopic ceramic fragments were visualized in the surgical field. The femoral stem and acetabular shell were solidly fixed. There was no deformity of the femoral neck or metal rim of the acetabular insert suggestive of impingement. There was also no gross metallosis. The surgical field was copiously irrigated. To avoid the recurrence of this event and given the lack of macroscopic alumina debris, the decision was made to insert a cross-linked polyethylene liner and a cobalt chrome femoral head.

Fig. 2. Radiograph at the 4-year follow up evaluation showing the eccentric location of the femoral head into the acetabulum in the right hip.

Fig. 3. Retrieved bearing couple depicting severe wear in vivo. The superimposed dashed circle illustrates the original diameter of the femoral head.

Histopathological Analysis

Overall, the synovium had a flat appearance, and the surface synoviocytes were not present and were replaced by a layer of organizing fibrin and small areas of focal necrosis. Localized to the fibrin and subsynovial compartment were large nodular deposits of refractile ceramic particles. The particles were located in the cytoplasm of collections of histiocytes or formed extracellular aggregates. Present in smaller amounts within the fibrin and subsynovial compartment were black round to elongate particles of variable size that had irregular edges characteristic of metal debris. The synovium contained a variable inflammatory infiltrate with much of the tissue containing only few inflammatory cells. In the more hypercellular areas, small collections of perivascular lymphocytes and plasma cells or single lymphocytes were present beneath the fibrinous surface exudate. Occasional intraluminal and diapedising neutrophils were also present in the tissue beneath the fibrinous exudate. They were limited in number, and were interpreted as likely being secondary to the surgical procedure. These findings are illustrated in Fig. 7.

Based on a previously described classification system developed by Esposito et al. [9] assessing synovial changes due to alumina wear debris, the architectural and inflammatory features in the synovial tissues in this case were graded as 6 (architecture of the synovium = 2, lymphoplasmacytic cellular infiltrate = 2, and macrophage infiltrate = 2), representing moderate synovitis. This was true despite the very large volume of wear debris.

Retrieval Analysis

Microscopic analysis of the retrieved components was conducted to further assess the severity of the wear and damage to the ceramic liner and head. Evaluation of the acetabular liner revealed an acetabular rim fracture and severe wear of the articular surface. There was no deformation of the metal

Fig. 4. Retrieved femoral head. Superior view (a) showing the crisp edge of the wear patch on the articular surface (arrows) and lateral view (b) showing the oval shape of the femoral head due to ceramic wear and scratches in the articular surface.

backing of the liner suggestive of damage during insert impaction or evidence of impingement along the metal rim.

Assessment of the femoral head revealed a wear patch covering ~70% of the articular surface with a clear demarcation between the patch and the remaining unworn region (Fig. 5). Further investigation of this transition region using scanning electron microscopy between the worn and unworn areas revealed a surprising finding of the worn region. While the unworn area still contained evidence from manufacturing polishing processing, the worn area showed evidence of the severe wear with pits on the surface the size of multiple grains (Fig. 8). In addition, there were several white regions on the wear patch of the femoral head that under high power displayed evidence of chunks or bundles of grains being ripped from the surface as pieces of ceramic were being ground and dragged across the surface. This is most compatible with an abrasive type of wear caused by the sharp edge at the liner fracture site (Fig. 9).

The amount of material lost from the femoral head was estimated based on surface deformation by scanning the retrieved femoral head with a 3D laser scanner (NextEngine, Santa Monica, CA) with a resolution of ± 0.005 in. A pristine femoral head was scanned and used as reference geometry. The two components were aligned using a best-fit algorithm in Geomagic® and obtained a material loss of 0.6 cm^3 . This method to indirectly assess material does not take into consideration other potential causes of head deformation such as material bedding in.

Fig. 5. The magnified image of the femoral head shows the clear demarcation between the worn patch and the remaining unworn region in the articular surface.

Discussion

Because of their lower wear rates and improved implant longevity, alternative bearings are popular in total hip arthroplasty for younger, more active patients. Alumina-alumina bearings are highly wear resistant with in vitro wear rates of only $0.004 \text{ mm}^3/\text{million cycles}$, compared with $35 \text{ mm}^3/\text{million cycles}$ for metal-on-cross-linked polyethylene bearings [2, 4, 16]. Clinical concerns using ceramic-on-ceramic couples include squeaking and catastrophic fracture. Modifications to implant design and material manufacturing processes have been implemented to address these obstacles. Hot isostatic pressing produces a highly pure, dense ceramic with small grain size which makes this material more fracture and wear resistant. Proof testing is done to validate these mechanical properties during the manufacturing process. Laser etching rather than mechanical engraving is used to prevent stress risers. Liner metal backing avoids direct contact of the ceramic with the prosthetic neck in case of impingement. Nonetheless, we report an interesting combination of a liner rim fracture and excessive alumina wear that led to failure of an alumina-alumina hip arthroplasty.

Component malposition has been well-correlated with increased wear rates in total hip arthroplasty [13]. In our case, the radiographic and intraoperative assessment of acetabular component positioning during the second revision surgery revealed that the acetabular shell was placed at approximately 55° inclination, which may have contributed to an increase in edge loading in the antero-superior aspect of the liner. This extreme edge loading of the femoral head at the edge of the acetabular shell along with joint laxity would increase contact stress near the rim, increasing the mechanical burden on the ceramic in this region, leading eventually to crack initiation and fracture.

There were no signs of impingement in the prosthetic femoral neck or the acetabular elevated metal rim. Moreover, the design of the Trident® bearing system (Stryker Orthopaedics, Mahwah, NJ) used in this case incorporates a metal-backed recessed ceramic liner, thus, minimizing the risk of liner fracture due to impingement [4]. Rim damage at the time of liner insertion was also considered as a possible cause of fracture, but there were no signs of deformation of the metal backing of the ceramic liner.

Extreme asymmetric wear of the ceramic bearings was evidenced in our case. Our explanation for this is that once

Fig. 6. Rim fracture and severe wear (*arrows*) of the acetabular articular surface. No evidence of deformation or signs of impingement were identified along the metal rim.

fracture occurred, the extremely sharp inner edge of the fracture surface would be highly abrasive against the ceramic femoral head. The presence of joint laxity perceived clinically and third body alumina particles seen histologically would have additionally aggravated the severity of wear. The patient's Trendelenburg lurch, his sensation of hip

instability, and metal transfer onto the femoral head support the theory of femoral head positioning directly over the ceramic liner at the fracture site.

Although macroscopic ceramic fracture fragments were not identified in the joint during surgery, there were large chunks of ceramic as well as pools of grain-size ceramic

Fig. 7. Synovial like tissue with surface fibrin and marked fibrosis nodular aggregates of brown pigmented staining material (*arrow*) representing histiocytes filled with ceramic debris (**a**), intracellular ceramic deposits (*arrow*) in the cytoplasm of histiocytes (**b**), fibrinous debris containing chunks of ceramic (*arrow*) and metal particles (**c**), and large clear spaces representing areas occupied by sheets of grain-size alumina crystals (**d**).

Fig. 8. Macroscopic and electronic microscopy evaluation of the transition zone between the crisp edge of wear patch (*arrow*) and unworn region of the ceramic femoral head. The unworn area still contained evidence of the manufacturing polishing processing and the worn area shows severe wear with pits the size of multiple grains.

particles seen histologically. This supports the importance of third body wear as an explanation for the severe wear seen in this case.

The periprosthetic soft tissues response to the substantial amount of ceramic debris was graded as moderate with a minor lymphoplasmacytic response and small areas of focal necrosis. This differs from the severe inflammation and architectural changes seen in the periprosthetic tissues of

failed metal-on-metal arthroplasties, where a significant burden of metallic debris provokes considerable synovial derangement, soft tissue necrosis, and a massive lymphoplasmacytic reaction. In addition, the number of macrophages seen in this case was also significantly less than what is seen in the histopathological analysis of periprosthetic tissues after a failed cemented metal-on-polyethylene prosthesis.

Fig. 9. Macroscopic and electronic microscopy evaluation of white regions on the wear patch of the femoral head. The high-power EM image demonstrates evidence of fractures as multi-grain size chunks of alumina have been ripped from the head as pieces of ceramic are being ground and dragged across the surface.

Lusty et al. [13] evaluated the in vivo wear rates from 33 retrieved ceramic-on-ceramic bearings that had remained in situ for more than 6 months. The median overall volumetric wear rate was 0.1 mm³/year for the femoral heads and 0.04 mm³/year for the acetabular liners. Femoral head wear rates appeared to increase exponentially when the acetabular shell anteversion was less than 15°. No correlation was found between the rate of ceramic wear and inclination of the acetabular component. The estimated volumetric wear of the femoral head from our case was 600 mm³, 6000 times higher than that found in these implants, though none had suffered a rim fracture. We attributed this to the longstanding contact of the femoral head with the hard edge of the fracture surface during the hip range of motion.

Based on the macro- and microscopic analysis performed in these retrieved components, we believe the rim fracture in the ceramic liner in this case was likely due to extreme edge loading related to the vertical position of the cup, and not impingement of the liner with the femoral component. Severe wear of modern alumina-alumina bearings can occur specially in cups placed in a suboptimal position. In this case, the combination of abrasive wear through the fracture site and joint laxity contributed to the excessive wear. There was a relatively benign tissue reaction despite the considerable volume of ceramic debris, and this was remarkably benign compared to that seen with polyethylene and metal debris. Due to their high modulus of elasticity, the clinician should be aware that hard-on-hard bearings such as ceramics are less forgiving to non-uniform loading, and thus, component positioning is crucial to prevent component failure.

Disclosures

Conflict of Interest: Jaime A. Carvajal Alba, MD, Marcella E. Elpers, BS, Andrew E. Rosenberg, MD, and Raymond P. Robinson, MD, FACS have declared that they have no conflict of interest.

Human/Animal Rights: All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5).

Informed Consent: Informed consent was obtained from all patients for being included in the study.

Required Author Forms Disclosure forms provided by the authors are available with the online version of this article.

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