Case Report

Failure of a Metal-on-Metal Total Hip Arthroplasty From Progressive Osteolysis

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Abstract: Ultra-high–molecular weight polyethylene (UHMWPE) wear, debris-induced osteolysis is a frequent cause of failure of total hip arthroplasty. Metal-on-metal total hip arthroplasty eliminates the generation of UHMWPE particulate debris. Although the volumetric wear of a metal-on-metal articulation may be lower than a metal-UHMWPE articulation, the number of particles may be higher. Osteolysis can develop in response to metallic and UHMWPE debris. The following case of massive osteolysis associated with large amounts of cobalt-chrome wear debris shows adhesive and abrasive wear mechanisms, as well as wear caused by third-body cobalt-chrome debris and impingement of the femoral component against the rim of the acetabular cup, which led to failure of a metal-on-metal total hip arthroplasty.
Key words: wear, metal, hip, arthroplasty, cobalt-chrome.

Polyethylene wear and osteolysis can limit the longevity of total hip arthroplasty (THA). It has been suggested that metal-on-metal articulations may generate less wear and perform more favorably than metal-on-polyethylene articulations [1]. Some studies have reported volumetric wear rates for metal-on-metal articulations that are 10 to 100 times lower than those reported for metal-on-polyethylene couples [2]. It is unknown, however, how the biologic environment is affected by the presence of high levels of foreign ionic species. Cobalt, chromium, and titanium may bind to proteins and circulate in the blood [3]. Because of its stiffness and hardness, the real area of contact associated with a metal-on-metal bearing couple is small, and the contact stresses are high compared to a metal-on-metal polyethylene joint. The volumetric wear of a metal-on-metal hip may be lower than a metal-on-polyethylene articulation, but the number of particles generated may be higher. The metal-on-metal particles may be smaller and more numerous. Because of interest in alternatives to metal-on-polyethylene articulations, several trials of modern metal-on-metal bearings are currently underway [4]. The following case report of osteolysis associated with large amounts of cobalt-chrome debris illustrates a potential failure mechanism of metal-on-metal THA.

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Case Report

A 76-year-old man complained of left hip pain 14 years after THA with a Sivash metal-on-metal prosthesis (Joint Medical Products, Port Washington, NY) (Fig. 1) [5,6]. The patient weighed 75 kg.

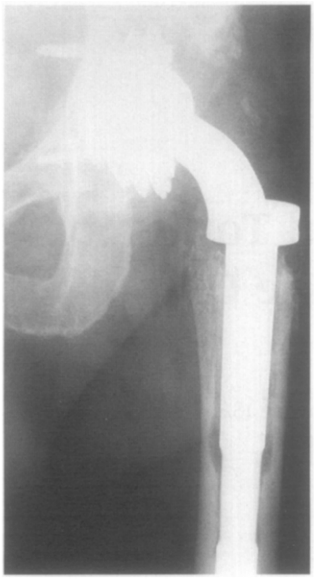

Fig. 1. Anteroposterior radiograph of Sivash implant after 14 years *in vivo.*

Osteolytic defects were present in the proximal femur and acetabulum. One year later, the patient's hip pain worsened, and the osteolytic areas increased in size (Fig. 2). The serum titanium level was 0, and the serum chromium level was 44.0 µg/L (normal level ≤1.4 µg/L). The patient was treated with revision THA. At surgery, dark-stained tissue was present throughout the hip joint capsule, periacetabular bone, and proximal femur. Black debris was found along the edges of the metal-on-metal articulation. Both the acetabular cup and the femoral stem were loose. There was no evidence of cement fracture or debris. The discolored tissue was debrided, and the hip was revised to an uncemented porous-coated arthroplasty with a cobalt-chrome 28-mm modular head and polyethylene liner. Bone defects were filled with morcellized allograft. Three months after surgery, the serum chromium level was 8.6 µg/L. Six months after surgery, the patient has no pain and is ambulating without support.

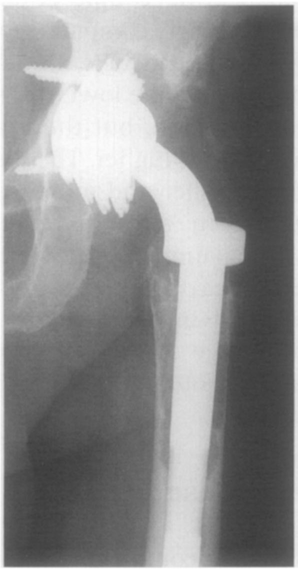

Fig. 2. Anteroposterior radiograph of Sivash implant after 15 years *in vivo* shows increased osteolysis.

The retrieved implant was examined with scanning electron microscopy, optical analysis, and profilometry measurements. Specimens of periarticular soft tissue were fixed in formalin, stained with hematoxylin and eosin, and examined with light microscopy (Fig. 3).

Optical Analysis

The cobalt-chrome liner consists of 2 halves that form a hemisphere when press-fit into the hemispherical titanium acetabular component. Approximately two thirds of the ball is constrained by the cup, and the 2 cannot be separated during the service life. This design feature has resulted in difficult disassembly of the 2 components during revision [5].

Portions of the prosthesis were heavily coated with black debris. Dried fluid was found on both of the articulating surfaces and in the groove between the 2 halves of the cobalt-chrome liner as well as between the liner and the outer titanium cup. A divot in the liner at its pole was filled with dark metal debris.

The proximal half of the cobalt-chrome liner was thinner than the distal half (1.53 mm proximally vs 2.18 mm distally). The distal half exhibited coarse scratching. The area near the pole of the cup was less severely scratched, which is consistent with the highly polished pole of the ball. The proximal half was highly polished and had burrs of plastically deformed metal around its rim. The ball was also marked by a highly grooved distal area and a polished proximal region. A map of the damage is provided in Fig. 4. A flattened area and an indentation from the edge of the liner divot are visible at the pole of the ball, indicating overloading from stress concentration at the edge of the divot. The ball is nonspherical, or *out-of-round,* in several places. The flattened areas on the ball are deeply grooved, indicating that wear debris became trapped in these areas of higher clearance and caused severe third-

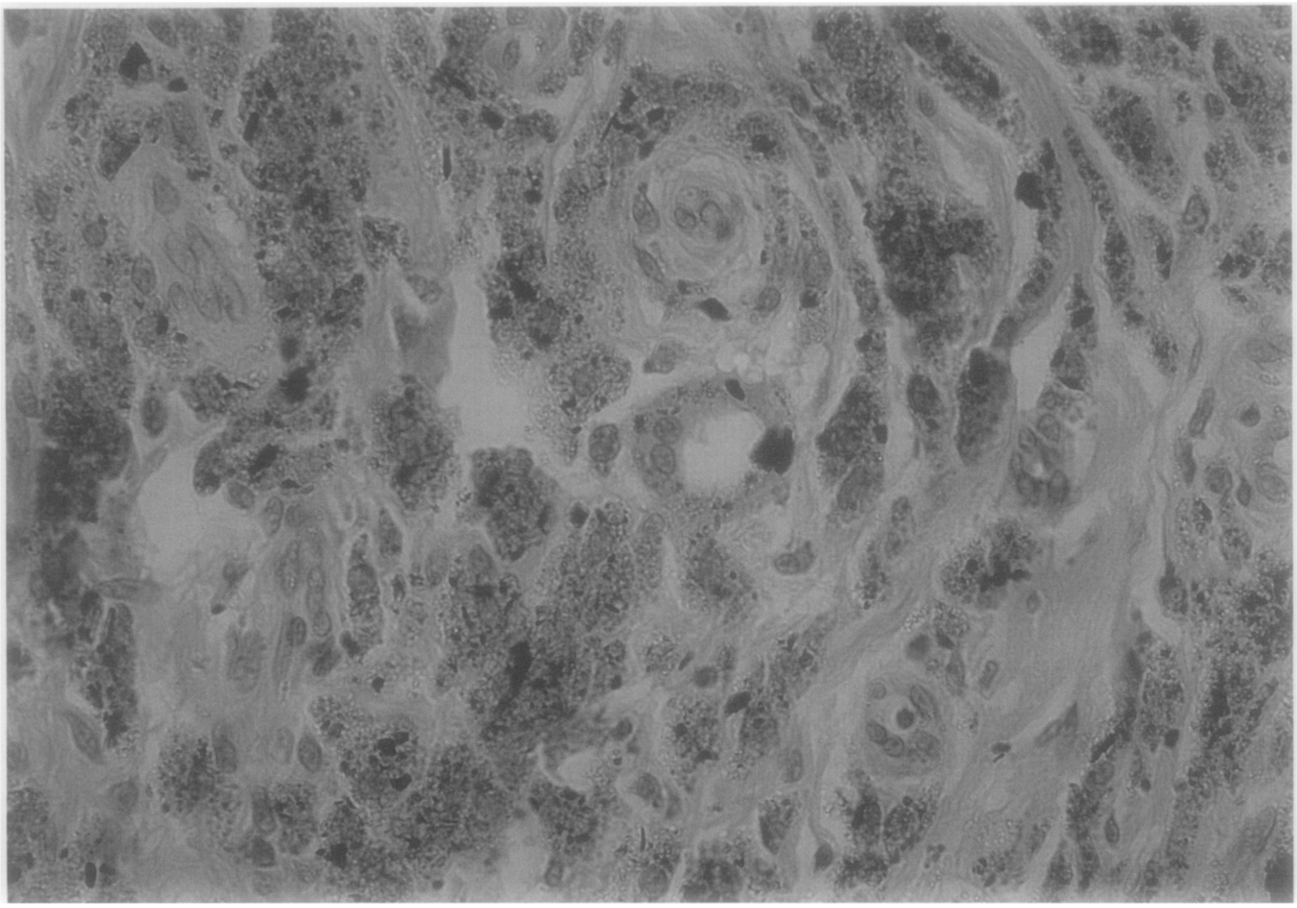

Fig. 3. Histology of periarticular tissue demonstrates macrophages with large amounts of intracellular metallic debris.

body abrasive wear at these locations. These flattened areas are marked on the map with dark lines. The solid continuous line represents the boundary between the highly polished proximal region and the deeply scored distal region. The dotted area on the lateral face represents an area of optically visible pitting.

Microscopic Analysis

A JOEL 35-CF scanning electron microscope (SEM) was used to image both the ball and the cup of the prosthesis. The cup was cut in half, and one half was sectioned radially into 4 parts. After sectioning, the cobalt-chrome liner separated easily from the titanium acetabular component. The cobalt-chrome ball was separated from the stem and collar using electronic discharge machining. The positions of each component in the body were noted before disassembly. Each of the separated cobalt-chrome liner segments and the ball were ultrasonically cleaned in detergent and degreased with acetone before SEM examination.

SEM of the acetabular cup revealed microscopic (approximately 1 μm diameter) pitting in roughly hexagonal patterns resembling grain boundaries. Coalescence of some of these pits had led to larger surface flaws (Fig. 5). The pitting appeared to be concentrated near the outer edge of the liner. Extreme macroscopic scoring observed optically was also seen with the SEM. The surface of the ball exhibited evidence of several wear mechanisms and scars from seizing events. Microscopic pitting, as noted on the cup liner, was also seen on the surface of the ball. Larger areas of plowing scars from third-body wear were also noted (Fig. 6). Several incidences of third-body particles embedded in the ball surface were observed (Fig. 7). Near the stem insertion point on the distal medial part of the ball, evidence of plastic flow as a result of cyclic loading is observed (Fig. 8).

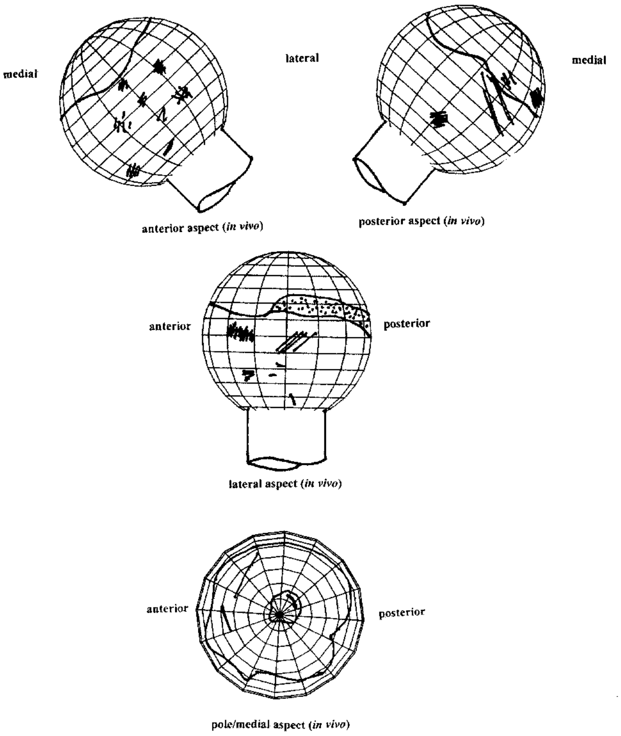

Fig. 4. Map of cobalt chromium ball wear.

Profilometry

A DekTak IID surface profilometer was used to measure the arithmetic mean roughness (R_a) of the cobalt-chrome liner. The standard initial R_a roughness for a metal hip component is 0.025 to 0.05 µm, and retrievals have reported R_a values as high as 0.1 to 1.0 µm [7]. The roughness of the highly grooved area of the cup was as high as 1.2 µm, indicating a gross loss of debris.

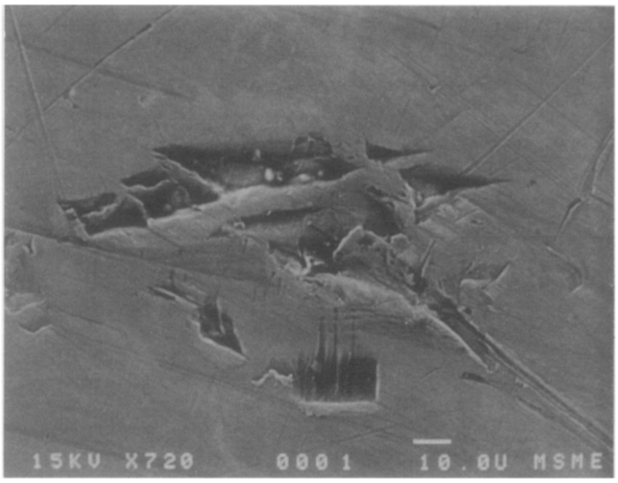

Fig. 6. Scanning electron microscope micrograph of surface of femoral head shows severe scratches from third-body abrasion.

Discussion

Other investigators have examined failed metal-on-metal prostheses or those removed postmortem. In many of these retrieved acetabular liners, it was observed that most of the wear is from the superior portion of the articulating surface, where the pole of the femoral head contacts the liner [8–10]. Wear causes this area to appear highly polished. Numerous, fine scratches in multiple directions can be seen in the superior, highly worn area, ranging in size

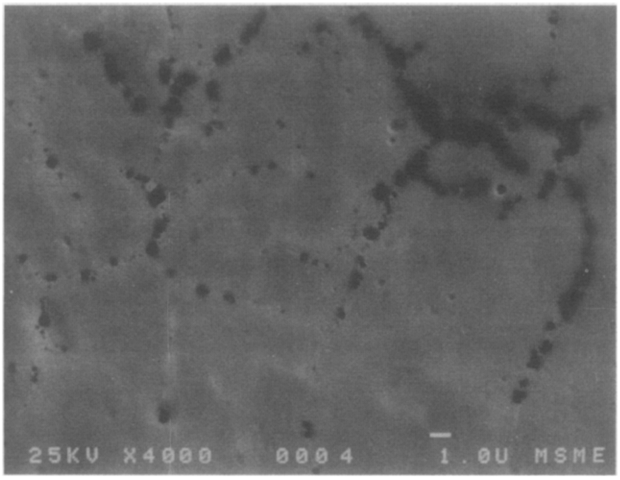

Fig. 5. Scanning electron microscope micrograph of acetabular cup surface shows evidence of micropitting and coalescence of micropits into larger defects.

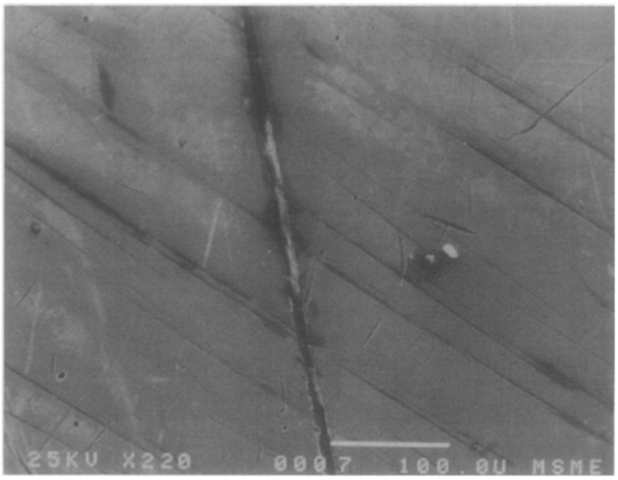

Fig. 7. Scanning electron microscope micrograph of surface of femoral head shows multidirectional scratches and abrasive particles embedded in the surface.

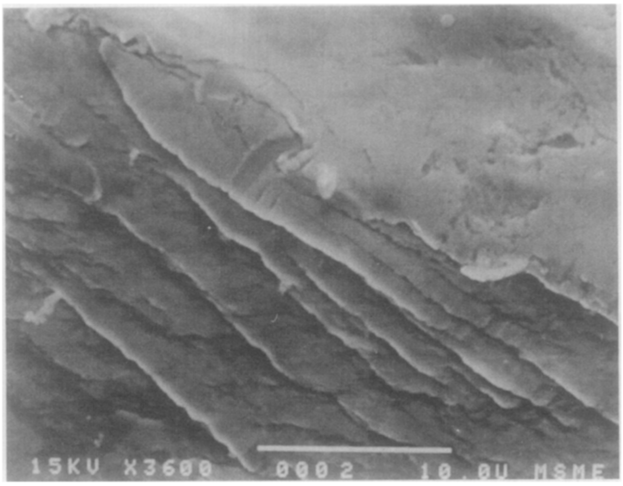

Fig. 8. Scanning electron microscope micrograph of surface of femoral head shows evidence of possible plastic flow under cyclic loading.

from less than 1 μ to 20 μ in length. Most, but not all, of these scratches are parallel to the direction of hip flexion/extension. Micropitting on balls and cups was observed by Campbell et al. [2], but the origin of the pitting was not discussed.

The Sivash metal-on-metal hip replacement is composed of 2 different alloys. The stem and the backing of the acetabular cup are made of Ti6A14V alloy. The ball and the acetabular liner are made of CoCrMo alloy. The alloy is a cast CoCrMo, ASTM F75-87. The markedly elevated serum chromium level and low serum titanium level dictate that the wear debris was caused by the cobalt-chrome bearing rather than abrasion of the titanium cup or stem against bone. We believe that the high surface roughness and low clearance between the ball and cup of this Sivash metal-on-metal total hip prosthesis probably did not allow adequate fluid-film lubrication of the joint, which led to asperity contact at the microscopic level. This contact, combined with the out-of-roundness, resulted in some adhesive wear and a cascade of abrasive wear mechanisms. It appears that the clearance between the ball and the cup was too small to allow flushing of the larger wear particles, and so these became trapped in the interface and caused gross third-body wear as shown by the SEM micrographs. The constrained design may also have contributed to the high wear rate in other ways: At rest, the ball was able to impinge on the rim of the cup, causing plastic deformation of the rim. Burrs present on the inner edge of the rim later abraded the distal area of the ball. The accumulation of wear debris from these mechanisms led to osteolysis and implant loosening. The findings in this case illustrate mechanisms of catastrophic metal-on-metal wear and suggest that metal-on-metal articulations should be designed to avoid these failure mechanisms.

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