Surface Roughness of Femoral Head Prostheses After Dislocation

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Abstract

The effects of damaged femoral heads on long-term wear in total hip arthroplasties are not well known. In the study reported here, we compared the surface roughness of dislocated femoral heads, retrieved at time of revision, with that of heads revised for reasons other than dislocation. The dislocated heads, including 6 cobalt-chrome (Co-Cr), 2 oxidized zirconium, and 2 alumina (ceramic) heads, were compared with nondislocated Co-Cr and ceramic heads. Scratch marks on the dislocated Co-Cr and alumina heads were considerably smaller and shallow than those on the dislocated oxidized zirconium heads. Mean surface roughness of the dislocated heads was 368 nm (Co-Cr), 376 nm (alumina), and 2137 nm (oxidized zirconium). On the contrary, the mean surface roughness for nondislocated Co-Cr and alumina heads was 307.44 nm (outlier excluded) and 138.8 nm, respectively. Our data suggest that increased surface damage and roughness can occur after dislocation.

Metal-on-polyethylene articulation, the standard bearing couple for total hip arthroplasty (THA), has had good clinical results.[1,2] Despite improvements in surgical technique and implants, dislocation and polyethylene-wear–related osteolysis continue to limit the durability of the procedure.[1,3-5] New bearing surfaces—oxidized zirconium and monolithic ceramics (with their high wear and damage resistance) and highly cross-linked polyethylene—have been introduced to reduce osteolysis and aseptic loosening.[6,7] In vitro testing and short-term clinical follow-up of these bearing couples are promising, but long-term performance is unknown.[6-9] The surface roughness and finish of femoral heads also have an effect on polyethylene wear. However, less is known about the head surface damage caused by dislocation and about the potential negative effect of this damage on the long-term wear of polyethylene. Metallic heads, retrieved post mortem or at revision for reasons other than dislocation, have been found to have generally minor surface scratches.[10] As described in a recent case report, oxidized zirconium heads retrieved at time of revision for dislocation had visually significant surface damage, especially in the region that contacts the acetabular rim at time of dislocation.[11] Although some authors have tried to study heads damaged in laboratory simulations of dislocation,[8,9,12-15] a comprehensive analysis of the types of damage incurred on various bearing surfaces that have sustained recurrent dislocations is lacking. In addition, the surface roughness of heads retrieved from prosthetic hips subjected to recurrent in vivo dislocation is unknown. Although findings from in vitro testing of artificially damaged heads suggest the likelihood of increased polyethylene wear,[8,9,12-14] the relevance of such "simulated damage" is questionable, and additional data are needed from retrieval analysis.

In the present study, we examined the surface damage patterns and surface roughness of dislocated metal (cobalt-chrome [Co-Cr]), oxidized zirconium, and alumina (ceramic) femoral heads retrieved at time of revision. We sought to determine whether surface damage and surface roughness were higher in hips revised for dislocation than in hips revised for other reasons.

Materials and Methods

Implant retrieval collection at the orthopedic research laboratory at our institution was reviewed with the goal of obtaining femoral heads from hips revised for recurrent dislocation over the preceding 2 years. We wanted heads made from various materials that are in contemporary use. In the study, we included only those specimens for which specific information was available—manufacturer name, primary surgery date, revision date, complete clinical record before revision, and verifiable number and direction of dislocations. Excluded were specimens from patients who had undergone their primary surgery at another institution, specimens damaged during revision, and specimens obtained by outside surgeons. Six Co-Cr, 2 oxidized zirconium, and 2 alumina heads retrieved at revision for instability met our criteria for analysis. In

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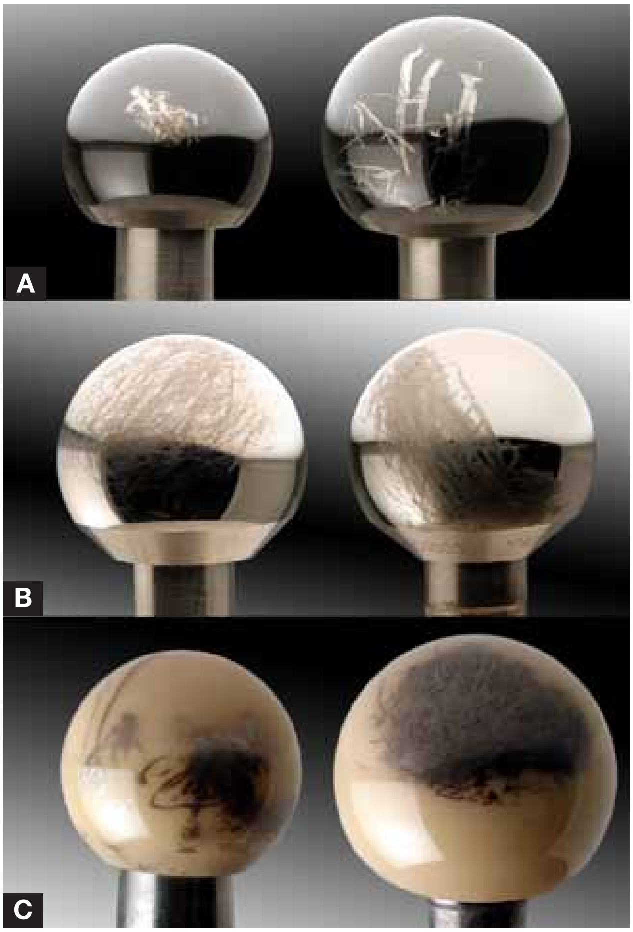

Figure 1. Dislocated oxidized zirconium **(A)**, cobalt-chrome **(B)**, and alumina **(C)** femoral heads.

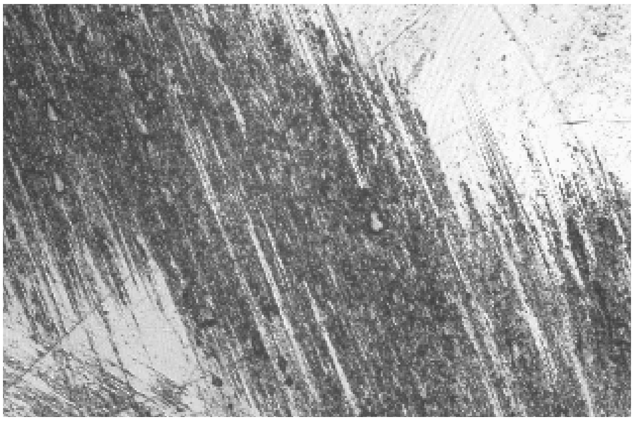

Figure 2. Scratch marks of nondislocated cobalt-chrome femoral head.

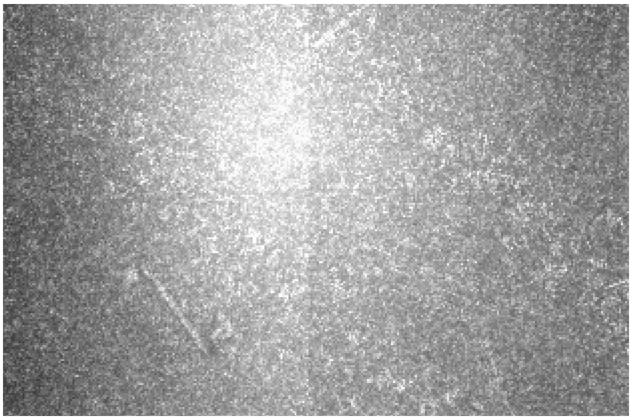

Figure 3. Surface of nondislocated alumina femoral head.

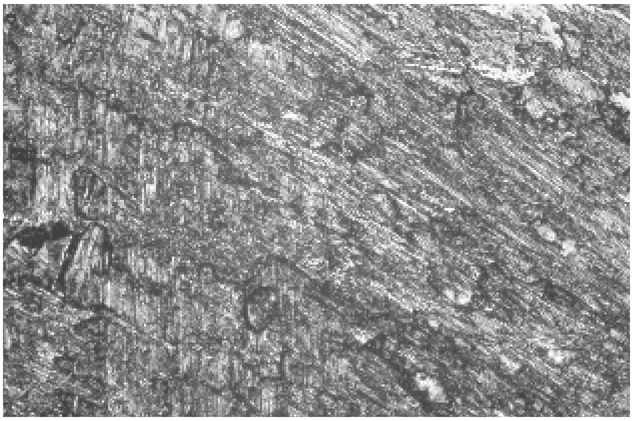

Figure 4. Scratch marks of dislocated cobalt-chrome femoral head.

addition, 5 Co-Cr heads and 1 alumina head retrieved at revision for polyethylene wear were included for comparison; none of these "control" heads had any evidence of third-body wear or extrinsic damage, and none came from a hip with a fragmented cement mantle.

At our institution, closed reductions were routinely performed with the patient under heavy intravenous sedation or in the operating room under general anesthesia. Before reduction, dislocation direction was confirmed with cross-table lateral radiographs. Fluoroscopy was used for guidance, and extreme care was taken to minimize contact between femoral head and acetabular rim during relocation maneuvers to prevent additional damage to the head.

All femoral heads were modular and of contemporary designs. The oldest THA was performed in 1992. At time of revision, each head was carefully retrieved to prevent further damage. Of the 6 nondislocated control heads (specimens 1 to 6), 3 were from hybrid THAs, and 3 were from uncemented THAs (Table I). Of the 10 dislocated heads (specimens 7 to 16), 2 were from hybrid THAs, and 8 were from uncemented THAs; 6 of the 10 dislocated heads were from primary THAs, and 4 were from revisions. Some dislocated hips were revised before the traditional 3 dislocations because of painful subluxation or malpositioned components. Almost all femoral head dislocations occurred in the posterior direction; in specimen 13 (oxinium head), anterior dislocation was followed 4 months later by posterior dislocation, and in specimen 14, anterior dislocation followed recurrent episodes of subluxation. Almost all specimens were articulating with polyethylene liners in vivo; specimens 15 and 16 had ceramic-on-ceramic bearing couples. Mean time in

Table I. Retrieved Femoral Heads

Specimen	Material	Head Size (mm)	Time In Vivo (mo)	Fixation Method	Dislocation: No. of Episodes (Direction)	Reason for Revision	Manufacturer
1	Co-Cr	28	120	Hybrid	No	Aseptic loosening	Stryker
2	Co-Cr	28	144	Hybrid	No	Polyethylene wear	Zimmer
3	Co-Cr	28	140	Uncemented	No	Aseptic loosening	Stryker
4	Co-Cr	28	159	Uncemented	No	Polyethylene wear	Stryker
5	Co-Cr	32	180	Uncemented	No	Polyethylene wear	Stryker
6	Ceramic	28	55	Hybrid	No	Polyethylene wear	Stryker
7	Co-Cr	28	62	Uncemented	1 (posterior)	Recurrent subluxation	Stryker
8	Co-Cr	28	52	Hybrid	2 (posterior)	Instability	Stryker
9	Co-Cr	28	41	Uncemented	3 (posterior)	Instability	Stryker
10	Co-Cr	28	83	Hybrid	3 (posterior)	Instability	Stryker
11	Co-Cr	32	0.25	Uncemented	1 (posterior)	Dissociated liner	Stryker
12	Co-Cr	32	2	Uncemented	4 (posterior)	Instability	Stryker
13	Oxinium	32	5	Uncemented	2 (anterior & posterior)	Instability	Stryker
14	Oxinium	28	2	Uncemented	1 (anterior)	Recurrent subluxation/pain	Smith & Nephew
15	Ceramic	36	1	Uncemented	2 (posterior)	Instability	Stryker
16	Ceramic	28	42	Uncemented	1 (posterior)	Pain/clicking	Stryker

Abbreviation: Co-Cr, cobalt-chrome.

vivo was much longer for the nondislocated group (133 months) than the dislocated group (29 months).

All extracted femoral heads were washed and sterilized and then subjected to macroscopic inspection (Figure 1), microscopic examination, and surface roughness measurement. Surface roughness was measured by an outside institution using a validated optical profilometer (Zygo NewView 6000; Zygo, Middlefield, Connecticut). Surface roughness within the area having the most visible damage was measured 3 times, and then mean surface roughness (R_a) was calculated. For control purposes, surface roughness also was measured at a spot within the area having the least damage. Surface morphology of the damaged region was examined at ×10 magnification. For each femoral head, R_a and surface morphology of the damaged area were compared with those of the surrounding area.

Results

All dislocated heads had visible signs of surface damage. R_a values for the damaged and surrounding areas of each head are listed in Table II. For the nondislocated group, R_a ranged from 49.14 to 788.65 nm. The 1 outlier, specimen 5, had a much higher R_a (1801.62 nm); we found nothing in the patient's history, radiographic file, or operative observations to account for this finding. With the outlier excluded, mean R_a was 307 nm for the nondislocated Co-Cr group and 368 nm for the dislocated Co-Cr group. For the dislocated oxinium and ceramic-on-ceramic groups, mean R_a was 2137 and 376 nm, respectively.

There was considerable R_a variability in the dislocated Co-Cr heads. For 3 specimens, damage was minimal; R_a was roughly 50 to 60 nm, or only marginally higher than the R_a of new heads (~25 nm). In contrast, 2 other specimens had R_a values of 808 nm and 1017 nm. Mean R_a for all 6 dislocated Co-Cr heads was 368 nm. In contrast, the 2 dislocated alumina heads had R_a values of 245 and 508 nm, for a mean of 376 nm. Of the entire cohort of analyzed heads, the 2 dislocated oxidized zirconium heads had the roughest damaged areas (R_a values, 2026 and 2246 nm; mean, 2137 nm). We did not find a correlation between time in vivo and R_a in this

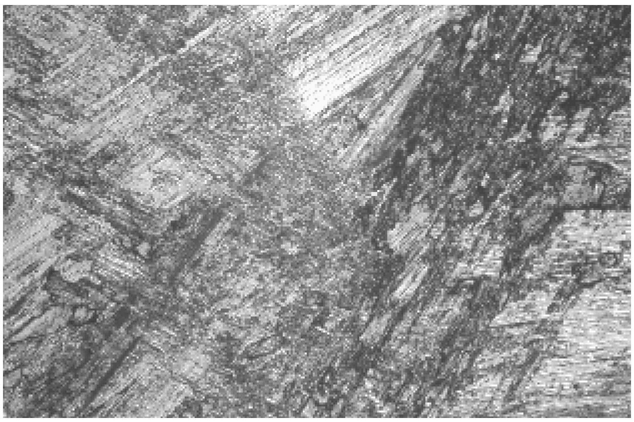

Figure 5. Surface of dislocated alumina femoral head.

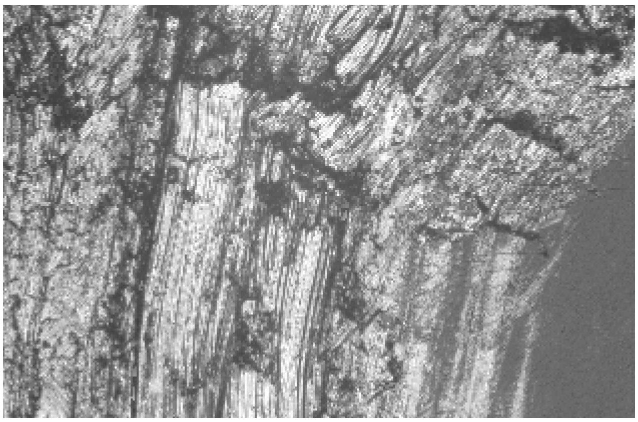

Figure 6. Surface of dislocated oxidized zirconium femoral head.

Table II. Surface Roughness (R_a) of All Retrieved Femoral Heads

Specimen	Material	Dislocation	Mean R_a (nm), Damaged Area	R_a (nm), Surrounding Area	Mean Peak Damaged Area (µm)	Mean Valley Damaged Area (µm)
1	Co-Cr	No	163.87	69.86	1.9	4.01
2	Co-Cr	No	228.09	3.29	3.34	2.22
3	Co-Cr	No	788.65	28.83	7.31	4.25
4	Co-Cr	No	49.15	3.16	3.42	2.74
5	Co-Cr	No	1801.62	8.4	9.95	7.34
6	Ceramic	No	138.8	13.5	3.92	4.21
		Mean	**307.44**	**Specimens 5 + 6**	**Excluded**	
7	Co-Cr	1 (posterior)	63.28	3.17	2.21	1.96
8	Co-Cr	2 (posterior)	1017.7	6.22	8.54	4.42
9	Co-Cr	3 (posterior)	808.07	6.3	6.22	4.74
10	Co-Cr	3 (posterior)	64.45	1.86	2.81	1.87
11	Co-Cr	1 (posterior)	202.55	8.67	3.33	2.17
12	Co-Cr	4 (posterior)	51.13	6.83	4.83	3.81
		Mean	**367.86**			
	New Co-Cr		25			
13	Oxinium	2 (anterior & posterior)	2026.65	15.5	7.55	10.74
14	Oxinium	1 (anterior)	2246.56	18.98	8.24	12.5
		Mean	**2136.61**			
	New		20-30			
15	Ceramic	2 (posterior)	507.62	3.21	7.5	3.2
16	Ceramic	1 (posterior)	244.88	3.39	3.74	2.66
		Mean	**376.25**			
	New		20			

Abbreviation: Co-Cr, cobalt-chrome.

series. Similarly, our data did not show a correlation between number of dislocations and R_a values.

At ×10 magnification, the surface of the nondislocated metal heads showed multidirectional scratches with small amounts of material built up ("snowplowed") along the sides of each scratch (Figure 2). In contrast, the surface of the nondislocated ceramic heads had small, smooth scratches (Figure 3) without any significant buildup of material along the sides. We did not have a nondislocated control oxidized zirconium head for analysis. In contrast to the relatively benign scratches on the nondislocated heads, there were larger scratches with more material buildup on the dislocated Co-Cr and alumina heads (Figures 4, 5). The damaged surface of the dislocated oxidized zirconium heads had the largest scratches with the most material buildup (Figure 6). In addition, the dislocated oxidized zirconium heads had the most surface roughness, the highest peaks, and the deepest valleys for each scratch (Table II).

Discussion

Co-Cr femoral heads, articulated with polyethylene sockets, have been the standard femoral bearings used in THA, in part because of their high wear resistance and hardness.[3,10] Newer materials may be more wear resistant than Co-Cr when articulated against polyethylene. There is a lack of data directly comparing the damage susceptibility of these materials when subjected to recurrent dislocation and subsequent reduction. Our analysis showed that Co-Cr, alumina, and oxidized zirconium femoral heads were all damaged after dislocation, but there was no correlation of increased surface roughness with increased number of dislocations. In addition, of the 3 materials evaluated, oxidized zirconium sustained the most damage. Because surface roughness is known to correlate with wear, we believe that, given our data set, all dislocated hips should be considered potentially "at risk" for accelerated polyethylene wear.

Jasty and colleagues[10] found that femoral heads retrieved from uncomplicated THAs had multidirectional scratches caused by entrapped metal, bone, or cement debris. Our Co-Cr heads retrieved at time of revision for reasons other than dislocation had similar multidirectional scratches (Figure 2), but the severity of these scratches varied from one specimen to the next, and the reason for the variance is not clear. Time in vivo did not correlate with surface roughness in our nondislocated control group. Overall, these scratches had a small amount of material built up along their sides—consistent with the literature.[10,16,17] Scratches on the surface of our dislocated ceramic heads also appeared to be multidirectional and to have small material buildup (Figure 6). One reason could be the high scratch-resistance of ceramic heads. Another could be the polishing that may occur when the roughened surface of a ceramic head articulates against another hard surface, such as the ceramic liner against which this head is paired. This mechanism also may partly explain the low surface roughness of the dislocated ceramic heads in our study.

An unusual finding in our study is that of a nondislocated Co-Cr head (specimen 5, Table II) with high R_a plus surface morphology similar to that of dislocated Co-Cr heads. Although third-body wear and recurrent subluxation in vivo can contribute to increased surface damage, we cannot explain why this specimen had so much surface roughness. We did not find any potential causes, such as metallosis, metal-to-metal impingement, or damage at time of retrieval. Perhaps the specimen had been improperly stored and handled before analysis.

Oxidized zirconium heads have been shown to be more resistant to third-body abrasion and to have improved wear properties when compared with Co-Cr heads in well-functioning THAs.[7] These wrought zirconium metal heads have a surface of hard zirconium oxide ceramic. Although this surface is extremely hard, the zirconium alloy substrate is softer than Co-Cr. Kop and colleagues[11] showed that visibly severe damage to oxidized zirconium heads can occur during dislocation and closed relocation. They also found that, in laboratory simulations of dislocation, oxidized zirconium heads sustained more surface damage than Co-Cr heads did. Our findings regarding oxidized zirconium heads retrieved at revision for recurrent dislocation are consistent with those reported by Kop and colleagues. The pattern and extent of damage were very similar between our 2 specimens, and these specimens were very similar to the 3 reported by Kop and colleagues. The material snowplowed along the sides of the scratches formed tall, sharp edges that can gouge or scratch the polyethylene liner and potentially increase wear.

In our study, we characterized the types of damage that occur with in vivo hip dislocation. An obvious limitation of this study is the small sample size available for analysis—a problem inherent to many retrieval studies. In particular, the limited number of dislocated ceramic and oxidized zirconium heads is such that sweeping conclusions should not be inferred from our data. Undoubtedly, each in vivo dislocation and reduction is different, and such individual differences cannot be controlled for in comparisons of retrieved specimens. In addition, the ceramic heads we obtained were from ceramic-on-ceramic couplings, whereas the Co-Cr and oxidized zirconium heads were from couplings with polyethylene. As we could not control for the potential wear-polishing effect of hard-on-hard articulations, we cannot comment on how the Co-Cr and oxidized zirconium heads would have fared in such articulations. We also did not have any dislocated ceramic heads from ceramic-on-polyethylene bearings, which would have allowed for a more uniform comparison. Last, profilometers are limited in that they provide surface images only at ×10 magnification. Despite these limitations, a major advantage of retrieval analyses is that the potential errors inherent to laboratory simulations of prosthetic behavior are eliminated.

"Our analysis showed that Co-Cr, alumina, and oxidized zirconium femoral heads were all damaged after dislocation, but there was no correlation of increased surface roughness with increased number of dislocations."

Our findings suggest that, when femoral heads dislocate after THA, surface damage can be increased, but the amount varies. Surface damage may be unavoidable during reduction, regardless of bearing material. Further, of the heads retrieved in this study, the oxidized zirconium heads that were complicated by dislocation had the most surface damage and roughness. Given the limited number of specimens and the variable results after dislocation, we cannot demonstrate a significant difference in surface damage between dislocated and nondislocated femoral heads.

Although the amount of head damage found after dislocation in this study is worrisome, the data are insufficient for making specific prognostic statements or generalized treatment recommendations regarding dislocated hips. In addition, we found that head damage was not uncommon after dislocation, but we do not have enough data to address whether revision THA should be considered in certain groups of patients. Clearly, surgeons making such decisions would need to weigh the benefits of a new bearing surface against the considerable morbidity and unclear outcomes associated with revision THA. We believe that further analysis of large numbers of dislocated femoral head prostheses, followed by appropriate wear simulation, will be useful in reaching a better understanding of the potential relationships among dislocation, surface damage, and subsequent wear.

Authors' Disclosure Statement

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