The Journal of Arthroplasty Vol. 00 No. 0 2008

Surface Oxidized Zirconium Total Hip Arthroplasty Head Damage Due to Closed Reduction

Effects on Polyethylene Wear

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Abstract: Recent case studies of surface oxidized zirconium THA heads removed after attempted, closed reduction have shown significant surface damage that has been suggested as potentially deleterious to polyethylene wear. We obtained 4 clinically retrieved specimens, produced well-characterized surface damage on additional heads, and tested them on a hip simulator. After 1 million cycles, the amount of polyethylene wear was related to the extent of surface damage, the most damaged clinical specimen showing more than 50 times more wear than a new head. Although all heads after failed attempted closed reduction(s) should be replaced, surface oxidized zirconium heads are of particular concern; those patients with a successful, simple closed reduction should be monitored for excessive wear.
Key words: Oxinium, wear, polyethylene, closed reduction.

Closed reduction is the initial treatment for most dislocations in THA. Retrieval studies have shown various types of THA head damage attributed to dislocation and attempted reduction due to head impingement on the metal acetabular shell [1-8]. This damage is sometimes visually evident after failed closed reduction and includes head scratching and metallic transfer. It has been suggested to potentially cause accelerated polyethylene (PE) cup wear. Several recent clinical case studies [1,2] of dislocated surface oxidized zirconium (SOZ) heads have shown disruption of the outer, zirconia ceramic coating. Bourne et al [3] studied various types of retrieved, damaged heads. They created heads with controlled surface damage using a laboratory dislocation model and tested these heads in a hip simulator. These wear tests showed increased PE wear with the damaged heads compared to new heads; however, their attempts to simulate clinical damage in the laboratory were only partially successful.

We obtained 4 clinically retrieved SOZ heads from failed, attempted closed reductions and characterized the extent of damage. We also used an in vitro methodology similar to Bourne's study to create additional heads with controlled damage. These heads were tested in a hip wear simulator to evaluate the hypothesis that this type of damage can result in significantly increased PE wear.

Materials and Methods

A total of 2 severely damaged (28 and 32 mm) and 2 minimally damaged (36 mm) SOZ retrievals were evaluated in this study. The patients were from

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Submitted December 13, 2007; accepted July 10, 2008.
Presented, in part, as a Scientific Exhibit 2007 AAOS.
Benefits or funds were received in partial or total support of the research material described in this article. These benefits or support were received from the following sources: Stryker Orthopedics. Stryker orthopedics provided implants and payment for the supplies used in this study. Wear testing equipment and technical personnel were also provided by Stryker.
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0883-5403/08/2300-0000$34.00/0
doi:10.1016/j.arth.2008.07.009

1 to 3 weeks after their original surgery and underwent at least 1 attempted closed reduction before surgery for head/cup arthroplasty. Severe damage was defined as extensive visual damage covering more than 20% of the head (Fig. 1) and minimally damaged as less than 10%.

In addition, 3 new SOZ (Oxinium, Smith&Nephew Orthopedics, Memphis, TN) and 3 solid alumina-zirconia (Delta Ceramic, Stryker Orthopedics, Mahwah, NJ) 28-mm heads were artificially damaged using a test fixture that simulated the head moving against the metal shell after dislocation and attempted closed reduction (Fig. 2). Titanium acetabular shells (54 mm Reflection shell [Cat. # 74-3054], Smith&Nephew Orthopedics or a 54-mm Trident shell [Cat. #500-01-54E], Stryker Orthopedics) were mounted in an adjustable holder with acrylic bone cement so that their rims projected 6 mm above the cement.

The new 28-mm SOZ and Delta Ceramic heads were run against the cup rims in Alpha calf fraction serum with a contact load of 455 N at a rate of 1.0 cm/s. These heads were damaged in a single region approximately 0.5 × 2 mm.

To determine the profiles of the damaged regions on the retrievals and the artificially damaged heads, a White Light Interferometer (Zygo, Middlefield, CT) was used. Measurements were taken from at least 3 damaged positions on each head (3 runs on the single scar for the in vitro heads) before and after wear testing. The heads were also examined by scanning electron microscopy, and x-ray elemental analysis of the damaged regions was performed to identify any metallic transfer.

Fig. 1. A 28-mm severely damaged Oxinium head retrieval.

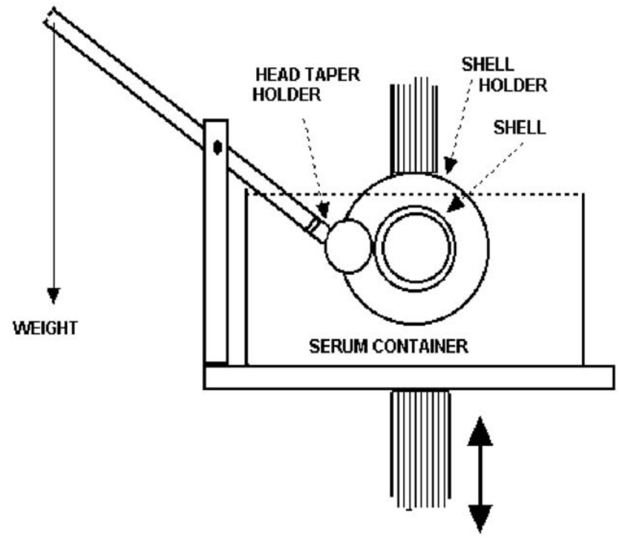

Fig. 2. Schematic of method for creating damaged heads in the laboratory.

For wear measurements, a multistation hip joint simulator (MTS, Eden Prairie, MN) was used to evaluate the effects of head damage on PE wear. Concurrent tests were run with 3 new SOZ and Delta Ceramic heads, the 6 in vitro damaged heads, and the 4 retrieved SOZ heads (the SOZ heads against Smith&Nephew Reflection XLPE acetabular liners and the Delta Ceramic against Trident X3 acetabular liners). Testing was performed at 1 Hz with cyclic, Paul curve, physiologic loading applied axially to a maximum load of 2450 N. Component assemblies were lubricated using Alpha Calf Fraction serum (Hyclone Labs, Logan, UT) diluted to 50% with deionized water. Control cups were run with no motion to determine weight changes due to fluid absorption. Testing ran for 1.0 million cycles with cups weighed (volume of PE lost calculated), and serum changed every 0.25 million cycles.

To determine dimensional changes, the PE acetabular liners were then analyzed using a Coordinate Measuring Machine (Mitutoyo, Aurora, IL). One hundred twenty cross-sectional scans were performed for each acetabular liner, ensuring a scan every 1.5°. The output data were processed to find the average radius and resulting radial indentation (deviation from average).

Results

A typical interferometry scan of an artificially damaged SOZ head is shown in Fig. 3 and is similar to the damaged clinical retrievals. The SOZ heads had cracks in the zirconia layer along the edge of the

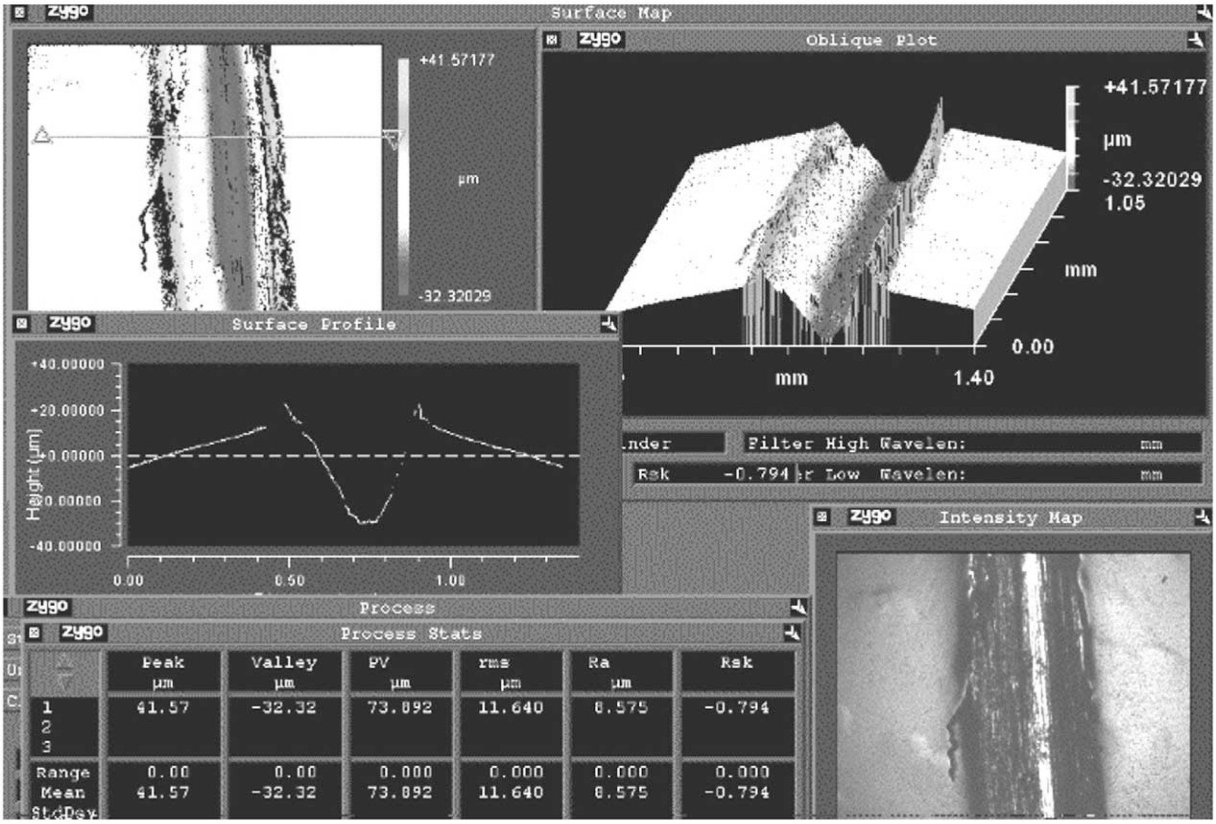

Fig. 3. White light interferometry scan for an Oxinium in vitro head before testing.

gouges and had a build up of substrate material on either side of the gouge (EDAX showed as also containing Ti from the shells). These scans showed that the average peak heights ranged from 14.5 to 66 μm high and the gouges from 14 to 55 μm deep, the severely damaged retrievals showing the greatest values (Table 1). The Delta heads only showed an average 15.7 μm peak height with no gouge. The peak also consisted of titanium from the acetabular shell.

The wear test results show that all damaged heads, both retrieved and simulated, demonstrated increased PE wear (Fig. 4). The 2 severely damaged retrieved SOZ heads showed an average PE volume loss from the cups of 28 mm^3, which represents over a 50-fold increase in simulator wear compared to a new SOZ head. The mean wear rates for the minimal, clinically damaged SOZ heads were at least 4 times that of the artificially damaged SOZ heads. The wear rate appeared to be linear to 1 million cycles.

Table 1. Peak and Valley Heights for the Damaged Heads

Specimen	Average Peak Height (μm)	Average Valley Depth (μm)
32 mm SOZ severe damage	19 (27-4)	14 (24-4)
28 mm SOZ severe damage	66 (113-16)	55 (130-10)
36 mm SOZ minimal damage (n = 2)	14.5 (21-6)	28 (37-19)
28 mm SOZ in vitro damage (n = 3)	16.2 (23-13)	18 (29-4)
28 mm Delta in vitro damage (n = 3)	15.7 (21-13)	No valley

Values in parentheses are ranges.

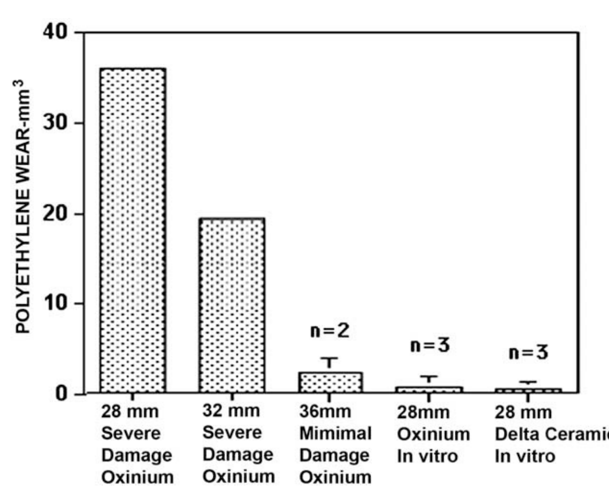

Fig. 4. Wear rates at 1.0 million cycles for all damaged heads tested. Rates for new Oxinium and Delta ceramic heads are 0.2 and 0.1 mm^3, respectively.

Table 2. Maximum Radial Deviations of PE Cups After Wear Testing

Specimen	Radial Deviation (μm)
32 mm SOZ severe damage	62
28 mm SOZ severe damage	215
36 mm SOZ minimal damage (n = 2)	43
28 mm SOZ in vitro damage (n = 3)	51
28 mm Delta in vitro damage (n = 3)	35

Direct measurement of changes in cup radius only showed a major difference for only the 28 mm severely damaged SOZ head in that its maximum radial deviation was 215 μm and the others averaged about 50 μm (Table 2).

Discussion

All of the SOZ heads tested demonstrated a layer of metallic transfer from the acetabular shell (verified by EDAX) that was an average 15 to 66 μm high and associated gouging resulting in valleys adjacent to the deposited peaks. The in vitro damaged SOZ heads had the same type and morphology of damage seen in clinically removed heads after attempted closed reduction; however, the clinically removed heads had a much greater extent of damage indicating that movement occurred in other planes and directions. This head damage demonstrated a 2 to more than 50-fold increase in PE wear compared to undamaged heads. Although SOZ has been shown in laboratory studies on hip implants [9] to have excellent wear resistance, it and other ceramics can be damaged by impingement or localized impaction stresses when there is ceramic-to-ceramic or ceramic-to-metal contact. In this case, the SOZ heads impinged against the metal acetabular shell during dislocation and attempted reduction(s). The brittle, thin coating on a more elastic substrate was unable to resist the high contact stresses and cracked and spalled off exposing the substrate that was also damaged and deformed into a ridge consisting of zirconium and material transferred from the acetabular shell.

It is well known that damage to the femoral head will contribute to increased PE wear. Kim et al [5,10] have shown that metal transferred to ceramic heads due to their impingement with the shell during dislocation and reduction results in clinically increased PE wear. Recently, Bourne et al [3] scratched SOZ heads and using a laboratory wear simulator, showed that their PE wear rate was higher than new SOZ heads. Other investigators [6-8,11] have found similar types of damage on metal and ceramic heads and have shown or suggested increased PE wear or increased metallic ion release. Because ceramic materials are harder than the metallic acetabular shell, metal is transferred and is usually visible on the colored ceramic surface. Metal heads can be softer or harder than the shell resulting in scratching that is usually apparent or transfer which can be difficult to detect due to similar color.

This study has the limitation of small sample size. As a result, the effect of head size on wear [11] cannot be separated from the effect of head damage extent on wear. The wear testing was run to 1 million cycles so a possible nonlinear increase in wear could not be assessed. There is some disagreement as to the heights of damaged areas in the literature, but this can be due to measurement techniques [12]. It is important to note that the damage shown can only occur from impingement of the head against a metal acetabular shell. Whether and to what extent this happens depends on the shell being sufficiently exposed, design of the shell edge, and extent of shell coverage by the PE liner and the nature and duration of the dislocation.

Conclusion

This study demonstrates that SOZ heads are at risk of significant damage occurring from dislocation and closed reduction, and this damage can lead to increased PE wear. This damage differs from that seen with other types of ceramic heads in that not only is there metallic transfer to the head surface, there can also be disruption of the surface itself. One should consider replacement of all heads in a failed closed reduction, and those patients successfully reduced should at least be monitored for excessive wear.

Acknowledgment

The authors thank Dr James Kudrna for providing several retrieved heads.

References

1. Evangelista G, et al. Surface damage to an Oxinium femoral head prosthesis after dislocation. J Bone Joint Surg [Am] 2007;89-B:535.
2. Kop A, et al. Damage of Oxinium femoral heads subsequent to hip arthroplasty dislocation. J of Arthroplasty 2007;22:775.
3. Bourne RB, et al. Arthroplasty options for the young patient: Oxinium on cross-linked polyethylene. Clin Orthop 2005;441:159.

4. Yamamoto T, et al. Wear analysis of retrieved ceramic-on-ceramic articulations in total hip arthroplasty: femoral head makes contact with the rim of the socket outside of the bearing surface. J Biomed Mater Res B Appl Biomater 2005;73:301.
5. Kim YH, et al. Surface roughness of ceramic femoral heads after in vivo transfer of metal: correlation to polyethylene wear. J Bone Joint Surg [Am] 2005;87:577.
6. Della Valle AG, et al. Wear of a highly cross-linked polyethylene liner associated with metallic deposition on a ceramic femoral head. J Arthroplasty 2004;19:532.
7. Muller FA, et al. Transfer of metallic debris after dislocation of ceramic femoral heads in hip prostheses. Arch Orthop Trauma Surg 2006;126:174.
8. Schuh A, et al. Severe damage of the femoral head after dislocation and difficult reduction maneuvers after total hip arthroplasty. Arch Orthop Trauma Surg 2006;126:134.
9. Good V, Ries M, Barrack RL, et al. Reduced wear with oxidized zirconium femoral heads. J Bone Joint Surg [Am] 2003;85:105.
10. Kim YH. Comparison of polyethylene wear associated with cobalt-chromium and zirconia heads after total hip replacement. A prospective, randomized study. J Bone Joint Surg [Am] 2005;87:1769.
11. Sychterz CJ, Engh Jr CA, Swope SW, et al. Analysis of prosthetic femoral heads retrieved at autopsy. Clin Orthop Relat Res 1999:223.
12. Hermida JC, Bergula A, Chen P, et al. Comparison of the wear rates of twenty-eight and thirty-two-millimeter femoral heads on cross-linked polyethylene acetabular cups in a wear simulator. J Bone Joint Surg [Am] 2003;85-A:2325.