Tribological and Material Analyses of Retrieved Alumina and Zirconia Ceramic Ball Heads Correlated with Polyethylene Wear After Total Hip Replacement

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Introduction: Zirconia ceramic heads were introduced to reduce the fracture of the alumina ceramic head. However, the phase transformation of zirconia head could lead to increase wear from increasing surface roughness. The purpose of this study was to examine the surface characteristics of explanted alumina and zirconia ceramic heads and to analyze phases of explanted zirconia heads. Also, we studied the wear performance of alumina and zirconia ceramic femoral heads articulating against a contemporary conventional UHMWPE liner.

Materials and Methods: We examined 30 alumina ceramic and 24 zirconia ceramic femoral heads retrieved at revision (Fig 1a and 1b) from 54 patients with a mean age at the time of operation of 47.8 years (range, 29-71 years), a mean weight of 67.1 kg (range, 51-91 kg), and a mean duration of implantation was 10.6 years (range, 8.1 to 16.2 years). All heads articulated with conventional UHMWPE liners. The surface characteristics of the 54 explanted ceramic femoral heads were evaluated with use of two different methods: interferometry, and environmental scanning electron microscopy (ESEM). Phase analysis was performed by X-ray diffraction for 24 zirconia ceramic heads. The interometry measurements were undertaken using a Wyko RST500 interferometer (Wyko, USA) at two different magnification with use of 20 x and 40 x lenses. The areas of analysis were 125 by 125 um and 64 and 64 um, respectively. At each magnification, 6 measurements were made of the pole areas (weight-bearing areas). The results are presented in terms of Ra and Rpm. Further analysis was completed using an ESEM (Leeds University, Leads, UK), secondary and back scattered images at various magnifications to assess the pits and scratches on the head surfaces.

Tetragonal and monoclinic phase composition of the 24 zirconia ceramic heads was examined using x-ray diffraction study. A stereoscopic zoom microscope (Nikon, Melville, New York) was used to examine embedded particle debris in UHMWPE. We measured the linear wear of UHMWPE liner radiographically of the cup using software program. We compared the radiographic measurements with the direct measurements of all 54 cups to validate this wear-measurement technique. The linear wear was measured directly from the retrieved UHMWPE liners with use of a 3-dimensional coordinated measuring device (BHN 305; Mitutoyo, Tokyo, Japan).

Results: The mean Ra and Rpm values of the 30 implanted alumina ceramic heads were 40.12 nm and 578.34 nm, respectively. The mean Ra and Rpm values of the 24 implanted zirconia heads were 36.21 nm and 607.34 nm, respectively (p=0.102). The mean surface roughness values for the weight-bearing surfaces in 18 alumina heads without 3rd-body debris embedded in the corresponding UHMWPE liner (Ra=38.26 nm; Rpm=567.18 nm) were lower than those for 12 alumina ceramic heads with embedded debris (Ra=168.27 nm; Rpm=1132.77 nm) (p=0.03 for both). Phase analysis of zirconia heads consistently gives lower values for the amount of monoclinic zirconia. (Fig. 2) The mean value of monoclinic phase was 6.8% (range, 1 to 26%) and that of tetragonal phase was 93.2% (range, 74 to 99%). The mean surface roughness values in 15 zirconia ceramic heads without 3rd-body debris embedded in corresponding UHMWPE liner (Ra=42.67 nm; Rpm=619.29 nm) were lower than those for 9 zirconia heads with embedded debris (Ra=181.33 nm; Rpm=1627.44 nm) (p=0.02 for both).

ESEM evaluation of alumina and zirconia ceramic heads revealed small pits and scratches on the surfaces of all heads. (Fig. 3a and 3b)

The mean linear wear rate of UHMWPE was 0.11 mm/yr (range, 0.09 to 0.19 mm/yr) in the hips with alumina heads and 0.12 mm/yr (range, 0.10 to 0.2 mm/yr) in the hips with zirconia heads (p=0.195).

The mean UHMWPE linear wear rate in the alumina and zirconia head groups and 0.234 mm/yr, respectively for the cups with 3rd-body embedded debris and 0.07 and 0.08 mm/yr, respectively for the cups without 3rd-body embedded debris (p=0.003).

Discussion: The zirconia ceramic heads which had a minimal phase transformation had similar surface roughness and similar wear rate of UHMWPE as in the alumina ceramic heads. Additional retrieval and tribologic studies are needed to confirm or refute these observations.