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CASE REPORT

Phase transformation of a new generation yttria-stabilized zirconia femoral head after total hip arthroplasty

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Abstract We examined a new-generation yttria-stabilized zirconia head manufactured by NGK 1 year after total hip arthroplasty. Monoclinic content of the retrieved head was twice that of the unused head at the pole and equator. A fourfold increase in monoclinic content was observed at 5 mm below the equator. Transformation from the tetragonal phase to the monoclinic phase occurred in the new generation zirconia with alumina doping within a relatively short period in vivo.

Keywords Ceramic head · Phase transformation · Polyethylene wear · Total hip arthroplasty · Zirconia

Introduction

Total hip arthroplasty (THA) is a reproducible treatment procedure to improve the quality of life for patients with rheumatic diseases of the hip, such as osteoarthritis, osteonecrosis, and rheumatoid arthritis [1]. The implant material, design, and surgical techniques are equally important for good functional results and longevity. Reduced wear of the bearing materials is one of the keys for longevity [2], and several ceramic materials including alumina ceramics and zirconia ceramics were introduced to reduce wear of the mating polyethylene sockets in THA. Yttria-stabilized zirconia ceramics have higher mechanical strength than alumina ceramics, but degradation of yttria-stabilized zirconia femoral heads in vivo has been a matter of concern, given the resultant increased roughening and even fracture of the femoral head [3]. Transformation from tetragonal to monoclinic phase in service in vivo has been reported in retrieved femoral heads manufactured by Kobelco [4], and accelerated polyethylene wear has been reported with the same zirconia femoral heads [5]. However, not all types of zirconia balls can be assumed to be identical in quality, regardless of existing manufacturing standards, as zirconia is a complex ceramic material, and zirconia-processing includes proprietary methods unique to each manufacturer [6]. Although three manufacturers are distributing zirconia ceramic femoral heads in Japan, information is still lacking on the characteristics of degradation in vivo for each zirconia ceramic head. One report has described higher radiological penetration of an old zirconia femoral head manufactured by NGK Spark Plug (Nagoya, Japan) compared to a stainless steel head in the English literature [7]; however, no retrieved study on the NGK zirconia heads was found. NGK released a new generation zirconia head in 1998, and we had the chance to analyze a retrieved new generation zirconia femoral head and report herein on the results.

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Case report

A 65-year-old woman with osteoarthritis of the right hip underwent THA in 2001. A size 4 Super Securefit cementless stem, a 44-mm Trident Metal Shell, and a 10°

Fig. 1 Anteroposterior radiography of the hip showing stable fixation of a cementless total hip implant after six dislocations

Crossfire elevated polyethylene liner (Stryker Howmedica Osteonics, Allendale, NJ) were used with a 26-mm zirconia ball. The zirconia ball was a yttria-stabilized zirconia manufactured by NGK.

Postoperatively, the patient experienced pain relief and could walk without a cane, but developed dislocation six times within 1 year and was referred to us. Anteroposterior radiography of the hip showed that both cup and stem were fixed to bone without radiolucent lines (Fig. 1). Cup orientation was 41° of abduction and 3° of anteversion in the radiographic definition [6]. On physical examination with fluoroscopic imaging, the femoral head subluxed with the hip in 90° of flexion and 20° of internal rotation. In 2002, we revised the implants to a metal-on-metal large-diameter femoral head bearing (Birmingham system; MMT, Birmingham, England) through a posterior approach (Fig. 2). The top of the elevated liner was found to have been directed laterally, and the prosthetic neck impingement on the elevated rim was observed at 90° of flexion and 20° of internal rotation. The Trident titanium alloy cup was well fixed to the acetabulum, and the cup was chiseled out. After 1 mm under reaming of the acetabulum, a Birmingham HA coated cobalt-chrome cup of 48 mm outer diameter was impacted in the acetabulum with a press-fit technique. The Super Securefit stem was removed, and a cobalt chrome stem was fixed with cement with a 42-mm Birmingham modular cobalt-chrome head. Then, no impingement of the prosthesis or instability was intraoperatively seen at 90° of flexion and 60° of internal rotation. As of 5 years after revision, no dislocations have occurred.

The articulating surface of the retrieved polyethylene liner showed no visible scratches or wear path. The elevated rim, however, was placed laterally and rim deformation

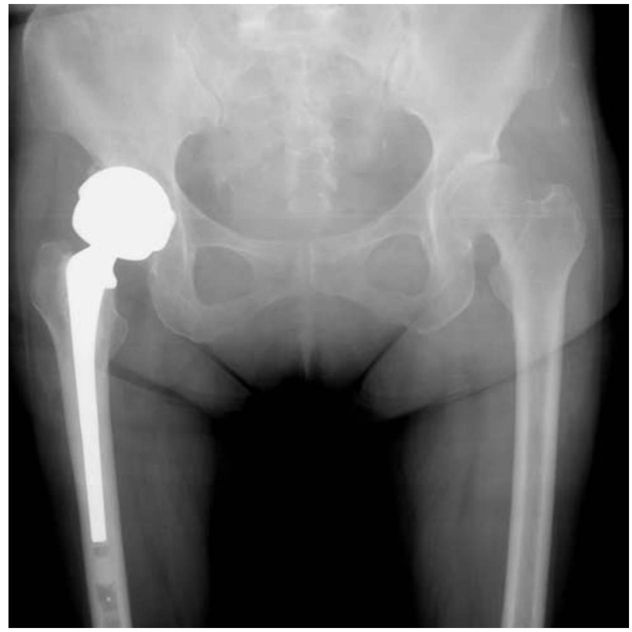

Fig. 2 Anteroposterior radiography of the hip after revision using a metal-on-metal large-diameter bearing

due to neck impingement was apparent. The articulating surface of the zirconia head also revealed no visible scratches or wear. On scanning electric microscope (SEM) photographs of the femoral head surface, some small surface defects were identified at the pole of the femoral head, at the equator, and 5 mm below the equator (Fig. 3). An unused zirconia femoral head with 26-mm diameter manufactured by the same company in 2000 was also examined as a control. SEM showed the same surface pores as the retrieved head. Average surface roughness (Ra) of both zirconia heads was measured using a surface roughness measurement tool (ST501; Mitutoyo, Kawasaki, Japan). Crystal contents were evaluated using an X-Ray diffractometer (RINT 1400 V, RIGAKU Co., Tokyo, Japan). These results are shown in Table 1. No difference in Ra was seen at any surface areas between the retrieved and unused zirconia heads. Monoclinic content of the retrieved head, however, was twice that of the unused head at the pole and equator. A fourfold increase in monoclinic content was observed at 5 mm below the equator. Mean crystal size of zirconia was 0.41 µm. Minor contents of the heads were 4.68% Y_2O_3 (yttria), 0.94% Al_2O_3 (alumina), and 0.01% SiO_2.

Discussion

Osteolysis due to polyethylene wear particles is one of the major factors in the failure of THA. To improve wear performance of polyethylene cups, ceramic femoral heads

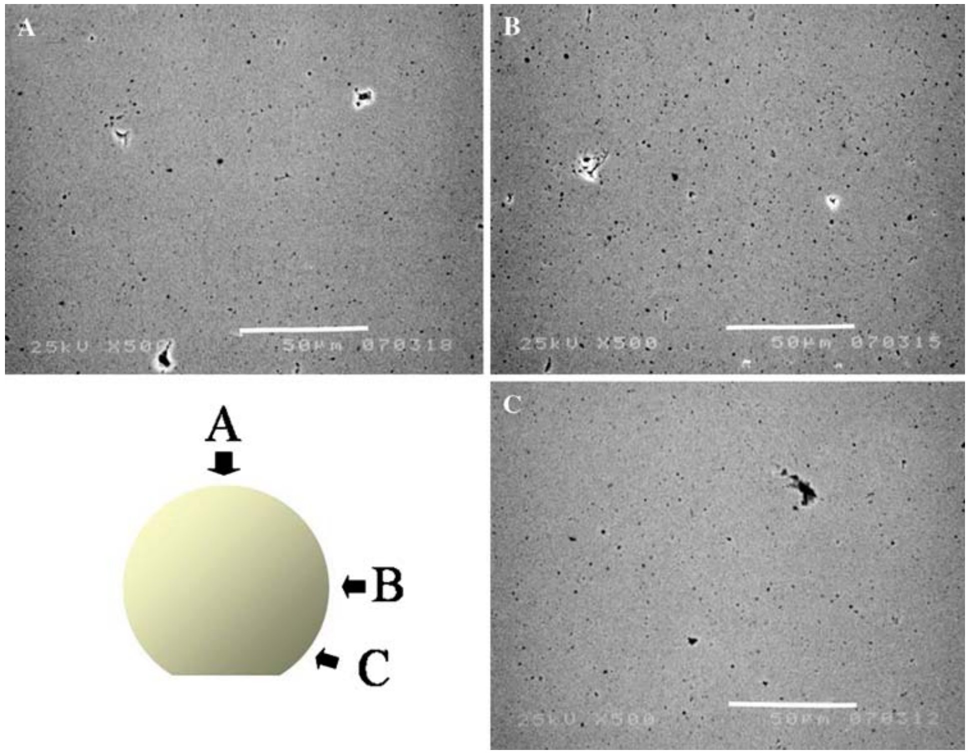

Fig. 3 SEM of the retrieved zirconia head. **a** Pole, **b** equator and **c** 5 mm below the equator

Table 1 Surface roughness in Ra and monoclinic content of the retrieved zirconia head and an unused zirconia head

Site of measurement	Retrieval		Unused	
	Ra (μm)	Monoclinic content (%)	Ra (μm)	Monoclinic content (%)
Pole	0.009	6.4	0.007	3.0
Equator	0.010	6.8	0.007	3.0
5 mm below the equator	0.010	13.0	0.007	3.0

made of alumina or zirconia have been introduced. Zirconia ceramic heads display better mechanical strength than alumina ceramic heads and can be used with smaller diameters than alumina heads. However, recently published results of THA using a zirconia head failed to show polyethylene wear reduction [5, 7, 9]. One cause is thought to be phase transformation in vivo [4]. Zirconia ceramics display three phases of crystal structure: monoclinic, tetragonal, and cubic. The tetragonal phase shows the greatest mechanical strength of these phases, but is unstable, and approximately 5% of yttria is used for surgical-grade zirconia ceramics for stabilization. Transformation from the tetragonal phase into the monoclinic phase brings a 3% increase in ceramic volume, and extensive transformation causes an increase in surface roughness. In the present case, transformation from the tetragonal phase to the monoclinic phase did occur within a relatively short period of 1 year in vivo, but did not affect surface roughness. Although repeated dislocation may have partly contributed to phase transformation in this case, most of phase transformation in vivo is supposed to be occur due to heat generation by articulating friction [10], and this implicates that even though the quality of the new generation zirconia head has been improved by cold isostatic pressing and 0.94% of alumina doping [11], it may show extensive transformation in longer-term service in vivo, leading to surface deterioration and to an accelerated polyethylene wear. Although information of the phase transformation observed in a short-term in vivo service, such as 1 year in this case, is limited, caution should be taken concerning the performance of new-generation zirconia ceramics as a bearing material in THA. Therefore, clinical studies are necessary to evaluate continuously the effect of this new generation zirconia head on polyethylene wear reduction.

Conflicts of interest statement There are no conflicts of interests associated with this article.

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