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Tutorial

Characterization of wear debris released from alumina-on-alumina hip prostheses: Analysis of retrieved femoral heads and peri-prosthetic tissues

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ABSTRACT

We analyzed by SEM three alumina-on-alumina femoral heads obtained from three patients who underwent revision for an aseptic loosening of the acetabular component. In parallel, the peri-prosthetic tissues were analyzed histologically in search of wear debris coming from the ceramic. Stripe wears, abrasive streaks, craters, and areas with extensive biomaterial removal were evidenced on the three femoral heads by SEM. In the altered area, the structure of the ceramic composed of minute polyhedric grains packed together was evidenced. In the peri-prosthetic tissues, the alumina particles were present in different forms: larges particles appeared transparent and birefringent, small particles engulfed by the macrophages had a light brown tint and were not birefringent. Large particles corresponded to the grains observed by SEM. EDS microanalysis confirmed the presence of aluminum oxide in these particles. Alumina debris are difficult to identify microscopically due to their pleomorphism.

1. Introduction

The placement of a total hip arthroplasty (THA) in patients with end-stage osteoarthritis intends to provide a pain-free and long-lasting functional hip joint in patients with an altered function. Other indications are represented by osteonecrosis of the femoral head and other destructive joint diseases. The total joint implants used to repair the articular surface include a metal component articulating against a polymeric component fabricated from ultra-high molecular weight polyethylene (the classical metal-on-polyethylene couple). This generates high amounts of wear debris in the joint cavity of patients responsible for aseptic loosening as the debris are capable to increase the osteoclastic activity (Massin et al., 2004a,b; Willert, 1977). In addition, these debris can migrate around the prosthesis stem and in the porosity of cortical and trabecular bone (Libouban et al., 2009). They can also accumulate in the lymph nodes at a considerable distance from the prosthesis (Baslé et al., 1996). Several alternatives have been proposed to combine materials with a low friction, good biocompatibility and low wear debris production to ensure a good ten year outcome. Among the different solutions proposed by several surgical groups, total hip prostheses using metal-on-metal (cobalt-chromium CoCr) have been proposed (Garbuz et al., 2010). However, the possibility to develop pseudo-tumors due to metal wear debris has been reported (Pandit et al., 2008). Total hip arthroplasty using alumina ceramic heads and cross-linked polyethylene cups has been proposed (Sugano et al., 1995; Zichner and Willert, 1992). The results in long term studies have reported the possibility for the ceramic head to penetrate in the polyethylene liner and metalback with massive foreign body granulomas (Simon et al., 1998). Zirconia femoral heads were proposed but this ceramic is largely instable and phase changes resulted in a considerable decrease of biomechanical properties with fracture of the material (Hummer et al., 1995). The couple alumina-on-alumina couple have been used for several decades because of the high mechanical resistance and excellent biocompatibility of this ceramic (Hamadouche et al., 2002). The tribological properties of the alumina-on-alumina produce a friction torque generating 4000 times less wear particles than the metal-polyethylene couple and therefore a low peri-prosthetic osteolysis rate is reported (Bizot et al., 2001; Prudhommeaux et al., 2000). Analysis of alumina explants have shown that *in vivo* wear is very low, less than 1 μm/year under normal conditions (Dorlot et al., 1989).

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The link between the wear of alumina heads and their presence in peri-prosthetic tissues has been seldom studied and only a few studies have concerned the histopathological analysis of peri-prosthetic tissues retrieved at the time of revision of an alumina-on-alumina prosthesis (Lerouge et al., 1996). The aim of our study was to report three patients with a histological analysis of peri-prosthetic tissues taken during revisions of total hip prosthesis with alumina-on-alumina couple and a scanning electron microscope analysis of the removed ceramic beads.

2. Patients and methods

2.1. Patients

2.1.1. Patient #1

This 48 y.o. female patient who presented an aseptic post-traumatic osteonecrosis of the femoral head underwent THA with a prosthesis composed of a hydroxyapatite-coated titanium acetabular component Cerafit HAC™ T-titanium alloy (Ceraver, Roissy CDG, France) an alumina insert, and a short femoral neck (−3.5 mm) receiving an alumina head (28 mm in diameter). The patient presented mechanical hip pain in the postoperative period that were due to a defect in the anteversion of the femoral stem (Fig. 1A). The femoral stem was changed 22 months later; the alumina femoral head was sent for analysis with the peri-prosthetic tissues.

2.1.2. Patient #2

This 61 y.o. female patient underwent THA for an end-stage hip osteoarthritis. The prosthesis was composed of a hydroxyapatite-coated titanium acetabular component Cerafit HAC™ T-titanium alloy (Ceraver), a long neck (+3.5 mm) with an aluminum head (28 mm in diameter). She reported progressive mechanical hip pain which started three years after the THA. X-rays, CTscan and ^{99}Tc-MBP scintigraphy showed an aseptic loosening of the acetabular component (Fig. 1B–C). The revision was done with unipolar change of the acetabular and head components five years after the primary THA.

2.1.3. Patient #3

This 62 y.o. female patient underwent THA for an end-stage hip osteoarthritis. The prosthesis was composed of a hydroxyapatite-coated titanium acetabular component Cerafit HAC™ T-titanium alloy (Ceraver), a short neck (−3.5 mm) with an aluminum head (32 mm in diameter). She reported progressive mechanical hip pain which started five years after the THA. X-rays, CTscan and ^{99}TcMBP scintigraphy showed an aseptic loosening of the acetabular component (Fig. 1D–E). The revision was done with unipolar change of the acetabular and head components eight years after the primary THA.

After examining the transmitted documents and the Rapporteurs' reports, the members of the Ethical Subcommittee of our university hospital approved the use of patient material as the work is retrospective from sampling of bone samples (complementary histological study). Consent was given oral, which is possible in non-interventional study cases. The members of the committee do not raise any objection to the implementation of this study which does not raise ethical questions.

2.2. Histological analysis

The prosthetic materials were carefully harvested at the time of revision, with special precautions being taken to avoid any mechanical damage of the ceramic femoral head during retrieving. The alumina heads were transferred to the laboratory without fixative. Digestion of the remaining organic phase present at the surface of the femoral head was done in a bath of sodium hypochlorite (50% in distilled water) during 24 h. The femoral heads were then extensively rinsed in successive baths of distilled water. They were allowed to dry at room temperature and were glued on brass stubs for scanning electron microscopy (SEM) with a Conductive Carbon Glue (Pelco, Agar Scientifc, Stansted, United Kingdom). They were coated with a 20 nm layer of platinum by sputtering with a high vacuum coater (Leica EM ECA600, Leica, France). Examination was done on an EVO LS10 (Zeiss) field emission microscope equipped with an energy dispersive X-ray microanalysis machine (EDS-INCA- Oxford). Images were captured in the secondary electron mode with an acceleration tension of 3 kV with a 30° tilt and 33 mm working distance. Energy Dispersive X-Ray Spectroscopy (EDS or EDX) is a microanalysis technique that detects X-rays emitted from a sample during bombardment by the electron beam

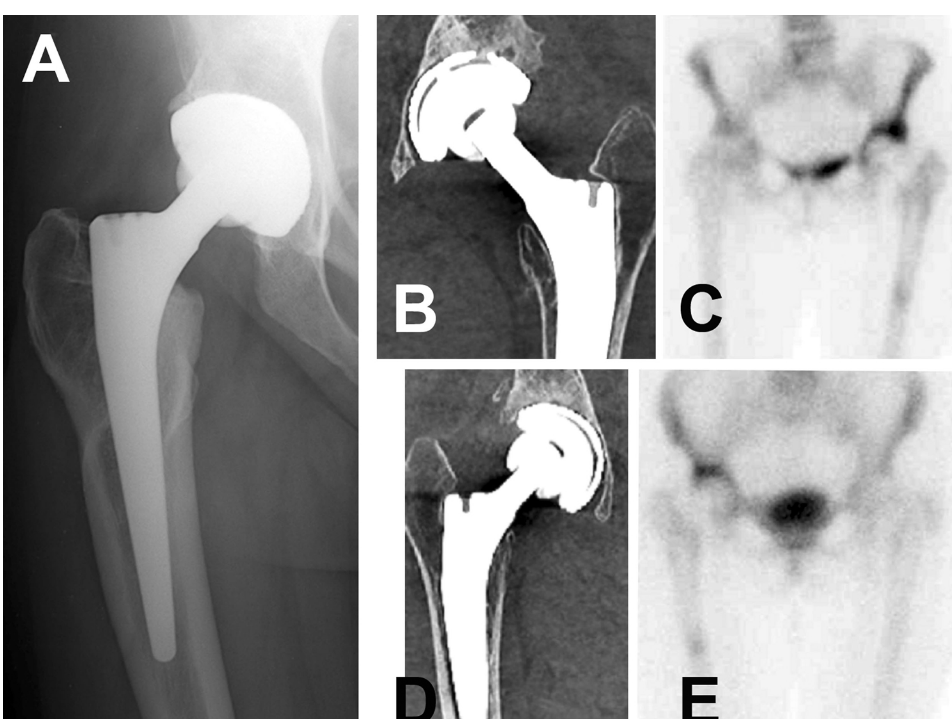

Fig. 1. X-ray analysis of the three patients with aseptic loosening of an alumina-on alumina prosthesis. A) Patient #1 with anteversion of the femoral stem. B-C) Patient #2 CTscan showing an aseptic loosening and ^{99}Tc-MBP scintigraphy showing increased fixation in the iliac bone. D-E) P < ùatient #3 with similar signs on the CTscan and scintigraphy.