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# Ceramic Femoral Component Fracture in Total Knee Arthroplasty: An Analysis Using Fractography, Fourier-Transform Infrared Microscopy, Contact Radiography and Histology

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ABSTRACT

Ceramic components in total knee arthroplasty (TKA) are evolving. We analyze the first case of BIOLOX delta ceramic femoral component fracture. A longitudinal midline fracture in the patellar groove was present, with an intact cement mantle and no bony defects. Fractographic analysis with laser scanning microscopy and white light interferometry showed no evidence of arrest lines, hackles, wake hackles, material flaws, fatigue or crack propagation. Analysis of periprosthetic tissues with Fourier-transform infrared (FT-IR) microscopy, contact radiography, histology, and subsequent digestion and high-speed centrifugation did not show ceramic debris. A macrophage-dominated response was present around polyethylene debris. We conclude that ceramic femoral component failure in this case was related to a traumatic event. Further research is needed to determine the suitability of ceramic components in TKA.



Total knee arthroplasty (TKA) is a current standard for treatment of advanced osteoarthritis of the knee. Common etiologies leading to failure are infection, malalignment, osteolysis and aseptic loosening. Metal hypsersensitivity is emerging as a significant problem in joint arthroplasty surgery affecting up to 16% of the population [1–3]. Ceramic articulating surfaces provide a potential solution in metal hypersensitivity [4]. Since metallic debris is not released into the periprosthetic tissue, ceramics are the materials of choice in metal hypersensitivity [4,5]. In the context of total hip arthroplasty, ceramic surfaces have been extensively used and modes of failure are well described [6–10].

The first alumina ceramic (Al2O3) total knee prosthesis was developed by the Kyocera Corp. (Kyoto, Japan) and implanted by Oonishi in the early 1980 s [11–14]. The use of ceramics in knee arthroplasty is evolving. Short-term clinical outcomes of TKA with ceramic femoral components have been reported [15] but long-term data to confirm the potential benefits of ceramic femoral components is lacking. It has been suggested by Bergschmidt et al [15] that the specific material properties of ceramic implants must be considered during implantation. Ceramic femoral components in TKA are exposed to stress due to pressure at the edges of the femoral resection and shear forces at the femoral condyles [4,16,17]. A harmonic force distribution to the ceramic component is thought to be achieved by cemented implantation techniques [15,17].

BIOLOX delta ceramic is a composite matrix material composed of aluminium oxide (Al2O3) and zirconium oxide (ZrO2), with improved strength and resistance [15]. In this study, we report the first case of a fractured BIOLOX delta ceramic femoral component fracture in TKA. We performed a fractographic analysis of the fractured femoral component using laser scanning microscopy and white light inferometry as well as Fourier-transform infrared (FT-IR) microscopy, contact radiography and histology of the periprosthetic tissues. Subsequently, tissue digestion and high-speed centrifugation were performed to characterize the wear debris.

## Materials and Methods

### *Case Report*

A 63 year-old female patient underwent primary TKA for osteoarthritis. A cemented ceramic femoral component (Multigen Plus Knee System, femoral size 2, LIMA Spa., Italy), 10 mm fixed bearing polyethylene insert and cemented tibial component (Multigen Plus Knee System, size 3, LIMA Spa., Italy) were used. Postoperative recovery was uneventful and 3 months after surgery, HSS

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Score was excellent (85/100), WOMAC Score showed 138 points and Short Form 36 Score (SF 36) revealed a score of 85 points.

Four years after the surgery the patient experienced a traumatic event (fall on her flexed right knee). She suffered from a minor contusion of the knee, with only limited pain, that regressed within one day. No further incident of mechanical failure (i.e. clicking, cracking, squeaking) was observed. The knee was stable and she was bearing full weight on her right knee.

During the following year the overall function of the right knee gradually deteriorated. The patient reported pain after exercise (walking, stretching). Mobility was limited to 30 min or 500 m walking distance. She sought medical attention one year after her trauma. At this time, antero-posterior plain radiographs of the right knee revealed a midline longitudinal crack of the ceramic femoral component.

Due to the possible abrasive potential of the ceramic debris another cemented femoral component was used for the revision TKA. Post-operative recovery was uneventful and the patient was discharged with full-weight bearing.

*Tissue Sampling and Histology*

Periprosthetic tissue samples were taken from the anterior, medial, lateral and posterior capsule during the revision surgery. Histologic examination of the tissue samples was performed according to routine protocols. Tissues were fixed in 5% formalin, fixed in paraffin, and 5–10 μm sections were cut. Sections were routinely stained with Haematoxylin/Eosin. Sections that were intended for FT-IR analysis as well as contact radiography were not stained.

*Fractography*

The explanted ceramic femoral component was thoroughly and carefully rinsed. The fracture surface was inspected via a combination of scanning laser microscopy and white light interferometry (Zygolot GmbH, Darmstadt, Germany). This technique provides a noncontact, 3-dimensional method of measuring surface roughness and analyzing the fracture surface with the objective of establishing the origin of the crack and therefore the cause for initiation as well as propagation of the crack. Characteristic features of the fracture surface and the overall pattern of crack initiation and propagation help to determine the cause of failure, particularly for brittle materials.

*Fourier-Transform Infrared Microscopy*

Formalin-fixed tissue specimens were analyzed by FT-IR microscopy (Bruker Optics, Karlsruhe, Germany). Infrared (IR) spectroscopy is a method of measuring the infrared intensity versus wavelength (wavenumber) of light. It detects the vibration characteristics of chemical functional groups in a sample. When an infrared light interacts with the material, chemical functional groups will adsorb infrared radiation in a specific and consistent wavenumber range [18]. FT-IR microscopy allows the tissue specimen to be 'mapped'. Infra-red spectra are obtained at defined positions along the tissue specimen and compared against a reference library of known spectra.

FT-IR microscopy was performed on 5 tissue samples (5 to 10 μm sections) mounted on glass slides backed by aluminium foil to facilitate the use of reflective modes and minimize scatter of the infrared beam. A background spectrum was obtained for each sample at the periphery and this background spectrum was calibrated and subtracted from the spectra obtained at the regions of interest. All spectra obtained were compared against a known reference library and the hit quality index determined. The hit quality index is a number that approximates how close the spectrum obtained from an unknown substance is to a known spectrum available from the reference library. A hit quality index of >300 was taken as significant.

*Contact Radiography*

Contact radiography was performed on 5 tissue samples mounted on glass slides using 24 keV soft electromagnetic radiation (Mammomat NovationDR, Siemens AG, Erlangen, Germany). The tissues were embedded in paraffin blocks and 5 to 10 μm sections were cut using a microtome and mounted on glass slides. Using this technique of contact radiography, polyethylene debris will not be visualised but ceramic debris will show up as radio-opaque foci. As a control, we performed contact radiography on periprosthetic tissue samples obtained from a patient with known failure of a second-generation ceramic total hip arthroplasty.

*Tissue Digestion and Characterization of Wear Debris*

Periprosthetic tissue samples were subjected to digestion protocols using serially increasing concentrations of sodium hydroxide (NaOH) in a boiling water bath. Using this method, organic matter except bone will dissolve, but inorganic wear debris will not. Thereafter, the suspension was placed in 1.5 ml Eppendorf tubes centrifuged at 10,000 rpm for 10 min to separate the wear debris according to density. Polyethylene, being less dense than water and hydrophobic in nature, will float on the surface whereas ceramic and metallic wear debris will be found at the bottom of the tube after centrifugation. As a control, the periprosthetic tissues retrieved from the patient with known second generation THA failure were also digested and wear debris examined. Energy dispersive x-ray spectroscopy (EDX) was performed for elemental analysis.

## Results

*Intraoperative Findings*

Intraoperatively clear synovial fluid was found. There was no marked effusion. The synovial tissue did not demonstrate signs of inflammation or marked thickening macroscopically. There was minimal scarring from the index operation (primary TKA).

The femoral component showed a complete longitudinal fracture in the midline, though firmly attached to the underlying cement mantle (Fig. 1). After removal of the ceramic component a complete, intact femoral cement mantle was found. There were no flaws in the cementation. The cement–bone interface showed adequate indentation of the polymethylmethacralate (PMMA) cement into the cancellous bone.

Microbial workup was uneventful. A set of 3 cultures taken during surgery was negative. Loss of bone stock during the explantation was minimal and the quality of the underlying cancellous bone was

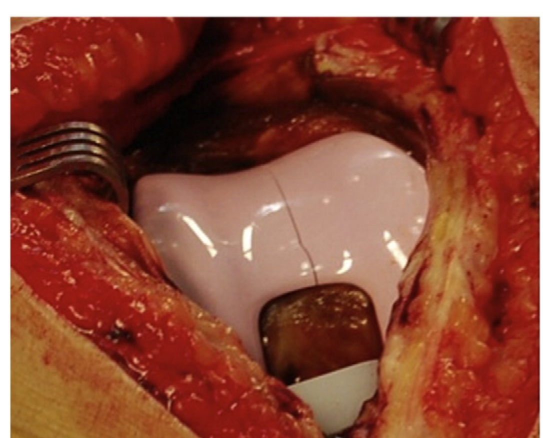

**Fig. 1.** Midline longitudinal fracture of the ceramic femoral component.