Y-TZP Zirconia Run against Highly crosslinked UHMWPE in Knee Simulator Study

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Introduction
Zirconia (Y-TZP) was introduced as high-strength and high toughness ceramic as an alternative to alumina ceramic [1, 2]. Zirconia (ZrO2) ceramics combined with highly crosslinked polyethylene appears to be a promising approach to minimize wear in artificial knee joints. Since the introduction of zirconia in 1985, the clinical outcomes and successes for hip joint have been controversial [3]. The main concern regarding the medical use of zirconia has been its crystallographic metastability at body temperature, manifested by a reversible transformation between two of its main polymorphs, tetragonal and monoclinic phases (t→m transformation). In our study, we have investigated 1) better quantify such wear performance and 2) detect any tetragonal to monoclinic phase transformation in zirconia femoral condyles.

Method
ZrO2 and CoCr femoral condyles were compared in the Bisurface knee configuration (Japan Medical Materials Inc, Japan). The tibial inserts (XLPE) were gamma-irradiation sterilization to 3.5-Mrad and 7-Mrad. Additional tibial inserts were used for soak control and stored unloaded in deionised water for 60 days prior to testing. Knee simulation was conducted on a 6 station simulator (Shore Western Manufacturing, Monrovia, CA). Motion included 20 degrees of flexion/extension, ±5 degrees of internal/external rotation, and 5mm of anterior/posterior translation. All knee components were subjected to 10 million cycles (Mc) of normal walking (2-9 kN max, freq 1.8 Hz). Lubricant was 50% Alfa calf sera (20mg/ml protein) with additive EDTA. Serum was changed every 0.5million cycles until 5 Mc and every 1 million cycles until 10 Mc. Wear was measured gravimetrically. Microscopic characterization was carried out on the femoral condyles using confocal Raman microprobe spectroscopy (RS) (irradiation with a blue laser, wavelength 488 nm) [4]. Also surface profilometer (Ra; average roughness, Rp; maximum scratch, measure the scratch damage area) was carried out on the femoral condyle and PE tibial inserts.

Results
The control CoCr / XLPE of wear rate averaged 4.5 mm3/Mc and the set showed fair control of experimental variance (<10%) (Fig 1). The Zr / XLPE 7-Mrad combination also showed excellent linear trending (r > 0.96) and good control of experimental variance (<5%). However, with net weight gain evident, throughout the study, wear was unmeasurably small with this latter combination (Fig 2). Surface profilometer studies confirmed that minimum scratch of the zirconia surface occurred. RS in two main wear zones of the zirconia femoral condyles (Fig 4 A, B) confirmed that a tetragonal to monoclinic transformation was not present after 10 Mc duration of wear test. As can be seen from a typical spectrum collected in the main wear zone (Fig 5), only the tetragonal bands (letter ‘t’) could be observed. There was no trace of the monoclinic doublet that would have been located at bands 180 and 190 cm−1 if monoclinic surface transformation had occurred.

Discussion
The remarkable finding was zero wear at 10-Mc duration. Thus the combination zirconia/7-Mrad XLPE appeared superior. This is also the first study of zirconia knees/XLPE by Raman Spectroscopy and surface profilometer. This appears to be the first examination of surface roughness evident in ceramic and CoCr femoral condyles following a simulator study. The difference in roughness values was dramatic. The zirconia roughness was unchanged at 10 Mc duration (Ra < 8 nm) whereas the CoCr wear zone had increased from generally an average Ra ≤ 50 nm to Ra = 250 nm by end of study. At 10 Mc duration, microscopic examination by a highly spatially-resolved, confocal Raman probe did not detect any transformation on the surface of the zirconia condyles. Clinical use of Bi-Surface™ knee joints has appeared satisfactory with up to 9 years follow up. Thus the present results can be considered extremely encouraging for the use of advanced zirconia materials in TKR and also may prove excellent for active patients who may otherwise risk high wear rates over many years of use.

References

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Fig 1; Excellent linear trending (weight-loss) evident for CoCr/XLPE-3Mrad combination (N=3).

Fig 2; Excellent linear trending (weight-gain) evident for Zr/XLPE-7Mrad combination (N=3).

Fig 3; Comparison of the worn surfaces of CoCr and Zirconia femoral condyles analyzed after 10 Mc by laser interferometry

Fig 4; Raman spectroscopy (RS) sites (A, B) studied on zirconia femoral condyles
Fig 5; Typical Raman spectrum showing only tetragonal phase after 10 Mc duration.

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