WEAR BEHAVIOR OF TWO ALTERNATIVE CERAMIC-ON-CERAMIC BEARING SYSTEMS
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Introduction
The wear of ultra high molecular weight polyethylene (UHMWPE) remains one of the major causes of the aseptic loosening of total joint prostheses [1]. Alternative bearing articulations like metal-on-metal or ceramic-on-ceramic were developed in Europe to minimize the incidence of aseptic loosening of total joints prostheses. Ceramic-on-ceramic bearings are an attractive solution due to their biostability, their high hardness and their low roughness. The current European ceramic-on-ceramic solution is a bearing manufactured in alumina-on-alumina. As this solution has an in-vivo fracture rate of about 1:2,000 [2], alternative ceramic-on-ceramic bearings are currently being evaluated to reduce this fracture rate. Two possible solutions are currently investigated to replace alumina.

• Zirconia toughened alumina (ZTA) has a higher toughness [3] and therefore should minimize the risk of in-vivo failures.
• Zirconia has also a higher toughness [4] and therefore should also minimize the risk of in-vivo failures.

These bearings have already been evaluated in-vitro with different protocols. Therefore the goal of this investigation was a direct comparison between these two new possible ceramics for ceramic-on-ceramic bearings.

Methods
Six 22.22 mm zirconia-on-zirconia (Prozyr™ - Saint-Gobain - France), six 28.00 mm zirconia-on-zirconia (Prozyr™ - Saint-Gobain - France) and three 28.00 mm ZTA-on-ZTA (Biolox Delta™ - CeramTec - Germany) were tested up to five million cycles on the AMTI hip simulator using the ISO kinematics described in the document ISO/DIS 14242-1 (flexion - extension: 25° - 18°; abduction - adduction: 7° - 4°, internal / external rotation: 10° - 2°, maximum load [double peak]: 3000 N) with following parameters: temperature: 37°C, Speed: 1.0 Hz. All the wear tests were lubricated with a stabilized mixture of Ringer's solution with 33 per cent calf serum, buffered at pH 7.6. The surface dimensions of the components were measured prior to each experiment (total of 577 measurements for each component).

The wear of the components was measured by a co-ordinate measuring machine with a measurement resolution lower than 1 µm. A measurement was made every 7.5 degrees on 12 concentric circles as well as on the pole of the component (total of 577 measurements for each component). The volume change according to the ISO 14242-2 standard (dimensional change method).

Half of the zirconia bearings were heat-treated for 24 hours at 140°C to stimulate the monoclinic transformation. The influence of the heat treatment on the tetragonal-monoclinic phase transformation was measured by standard RX diffraction techniques.

All results were analyzed statistically with a homoscedastic (equal variance) t-test (level of significance of 0.05).

Results
Following amounts of linear running-in wear were measured:

• Zirconia 22.22 mm not heat-treated: 9.5 ± 3.7 µm
• Zirconia 22.22 mm heat-treated: 8.0 ± 2.4 µm
• Zirconia 28.00 mm not heat-treated: 10.3 ± 2.6 µm
• Zirconia 28.00 mm heat-treated: 8.6 ± 2.5 µm
• ZTA 28.00 mm: 9.4 ± 0.8 µm

No statistically significant differences were seen between the five running-in wear values.

Following amounts of linear wear rate were measured:

• Zirconia 22.22 mm not heat-treated: 0.0 µm/10^6 cycles
• Zirconia 22.22 mm heat-treated: 0.0 µm/10^6 cycles
• Zirconia 28.00 mm not heat-treated: 0.6 ± 0.6 µm/10^6 cycles
• Zirconia 28.00 mm heat-treated: 0.3 ± 0.2 µm/10^6 cycles
• ZTA 28.00 mm: 0.8 ± 0.2 µm/10^6 cycles

No statistically significant differences were seen between the five linear wear rates.

As no differences were seen between the heat-treated and the heat-treated zirconia bearings, no differentiation between the two zirconia groups was made for the determination of the volumetric wear rate.

Following amounts of volumetric wear rate were measured:

• Zirconia 22.22 mm: 0.06 ± 0.02 mm^3/10^6 cycles
• Zirconia 28.00 mm: 0.21 ± 0.04 mm^3/10^6 cycles
• ZTA 28.00 mm: 0.28 ± 0.23 mm^3/10^6 cycles

The volumetric wear rate of the 22.22 mm zirconia-on-zirconia bearing was significantly lower than the volumetric wear rate of the two types of 28.00 mm bearing.

Discussion
This experiment shows that zirconia-on-zirconia bearing and ZTA-on-ZTA bearing systems have very stable wear behavior with a low linear wear rate and a low volumetric wear rate and they may both be an alternative solution for the currently used alumina-on-alumina bearings. The measured volumetric wear rates are extremely low compared to the usual values obtained with bearings containing polyethylene, where values in the range 30 - 50 mm^3/10^6 cycles are typically obtained [5]. As the toughness of these two types of ceramics is approximately two times higher than the one of alumina, these two possible solutions should minimize the risk of in-vivo failures.

The heat treatment (24 hours at 140°C) of the zirconia components gives 10 to 15% of phase transformation. This amount of monoclinic phase has no influence on the wear behavior of these bearings. The 22.22 mm zirconia-on-zirconia bearings have a statistically significant lower volumetric wear rate than the 28.00 mm zirconia-on-zirconia bearings. This influence of the heat diameter on the volumetric wear rate was also recently described by Smith [6] for metal-on-metal bearings and indicates that the lubrication of these zirconia-on-zirconia bearings is a boundary lubrication.

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References
2 Sedel; CORR, 379, 2000, p. 48
3 Masson et al., SICOT 2001, Paris, paper 41
4 Calès et al.; CORR, 379, 2000, p. 94