Durability of Zirconia-based Ceramics and Composites for Total Hip Replacement

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**Abstract.** Ceramics have been increasingly used in orthopaedics during the last 30 years. Their biological inertness, high hardness and good mechanical strength make them excellent candidates for components such as femoral heads and acetabular cup in Total Hip Replacement prostheses. Currently used bio-inert ceramics – alumina and zirconia – give good clinical results, especially compared to metal – polymer couplings. However, they are subjected to severe biological, tribological and mechanical solicitations during more than fifteen years for the most successful prostheses. They answer these solicitations by presenting specific degradation mechanisms. We will thus examine the phenomena that can account for the long-term behaviour of zirconia components (heads and cups) in THR prostheses.

**Introduction**

Zirconia can exist under three different crystal structures: monoclinic (m), tetragonal (t) and cubic (c). The tetragonal to monoclinic (t-m) transformation occurring upon cooling around 1000°C in pure zirconia results in a large volume increase and shear strains. As a result, samples of pure zirconia fracture during cooling from the sintering temperature. The addition of yttrium oxides (resulting in Yttria Stabilised Zirconia – Y-TZP), lowering the t-m transformation temperature, can stabilize the t phase to a certain extent at room temperature, thus allowing zirconia to be used as a bulk, structural material. However, the t phase remains metastable. This results in the transformation toughening mechanism acting to resist crack propagation evidenced in 70’s [1]. The stress - induced phase transformation involves the transformation of metastable tetragonal crystallites to the monoclinic phase at the crack tip, which, due to the volumetric expansion, induces compressive stresses slowing down the crack propagation. Since the late 80’s, Y-TZP zirconia became very popular to manufacture femoral heads for hip prosthesis applications [2]. Y-TZP was preferred to other zirconia ceramics, because of its unique balance between toughness and strength. Today, more than 600 000 zirconia femoral heads have been implanted worldwide, mainly in the US and in Europe. Zirconia is also increasingly used in dental applications thanks to recent developments in CAD/CAM procedures.

However, a serious limitation of Y-TZP ceramics was discovered by Kobayashi [3]: Y-TZP ceramics undergo a slow, tetragonal - to - monoclinic (t-m) transformation at the sample surface in a humid atmosphere, followed by micro - cracking and a loss in strength (this phenomenon is called “Aging”). Until the beginning of the present decade, the problem of aging under in vivo situation was considered as irrelevant by the zirconia manufacturers. Indeed, the transformation rate is the highest around 250°C and was considered as negligible at 37°C. However in 2001, several hundreds failures of deficient hip prosthesis were reported in a very short period [4] and directly related to aging. Furthermore, it was shown that aging also affect zirconia processed in normal conditions [5]. This could lead to critical health and economical issues in a near future, considering the large number of zirconia femoral heads implanted during the last decade. There is thus a trend to develop