



Low-temperature degradation of different zirconia ceramics for dental applications

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ABSTRACT

The aim of this investigation was to determine the influence of simulated ageing on the tetragonal to-monoclinic phase transformation and on the flexural strength of a 3Y-TZP ceramic, compared to alumina toughened zirconia (ATZ) and ceria-stabilized zirconia (12Ce-TZP). Standardized disc specimens of each material were hydrothermally aged in steam at 134 °C and 3 bar for 0, 16, 32, 64 or 128 h. The phase transformation was determined by X-ray diffraction (XRD) and atomic force microscopy. Scanning electron microscopy was performed to estimate the depth of the transformation zone. The flexural strength was investigated in a biaxial flexural test. XRD revealed a significant increase in the monoclinic phase content for 3Y-TZP and ATZ due to ageing, although this increase was less pronounced for ATZ. In contrast, the monoclinic phase content of 12Ce-TZP was not influenced. For 3Y-TZP and ATZ, a transformation zone was found of which the depth linearly correlated with ageing time, while for 12Ce-TZP no transformation zone could be observed. Changes in flexural strength after ageing were heterogeneous: while 3Y-TZP showed a significant decrease in strength – from 1740 to 1169 MPa – with ATZ there was a considerable increase – from 1093 to 1378 MPa. The flexural strength of 12Ce-TZP remained unaffected at the low level of about 500 MPa. These results indicate that both alumina and ceria, as stabilizing oxides, reduce the susceptibility of zirconia to hydrothermal degradation; the alternative use of these oxides may enhance the clinical long-term stability of dental zirconia restorations.

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1. Introduction

In recent years, dental implantology has gained increasing importance. According to current estimations, there are approximately 25 million dental implants inserted worldwide every year, with an upward trend. Due to their excellent biocompatibility, low thermal conductivity and high flexural strength, combined with an excellent “white aesthetic”, zirconia ceramics are becoming increasingly favoured for use as implant abutment material [1–3]. Moreover, zirconia ceramics are also widely used for the fabrication of tooth-supported restorations like single crowns, fixed dental prostheses or telescopic crowns [4,5]. However, all these dental zirconia restorations are exposed in the oral cavity to various factors which promote degradation. Exposure to aqueous saliva, temperature changes, acidification during food intake and cyclic loading during chewing all tend to lead to a decrease in mechanical stability [6,7]. Zirconia can assume three different crystal structures, depending on the temperature. At room temperature it is monoclinic, but transforms at ~1170 °C into a tetragonal structure and at 2370 °C becomes cubic. The tetragonal structure of zirconia can be retained

in a metastable phase at room temperature, by adding oxides like CaO, MgO, Y₂O₃ or CeO₂. For dental applications, tetragonal zirconia polycrystals are commonly stabilized with 3 mol% yttria (3Y-TZP) [8]. The high strength and toughness of these zirconia materials result from a toughening phenomenon, due to transformation from the tetragonal to the monoclinic structure (*t* → *m* transformation). This transformation is associated with a volume increase of about 4%, which induces localized compressive stresses and, eventually, microcracks around the transformed zirconia particles [9,10]. This transformation tends to take place in regions of concentrated stress, in particular at flaws at the surface or within the lattice, and effectively opposes the opening of cracks, thus increasing the resistance to further crack propagation. However, aside from this favourable effect at crack tips, the *t* → *m* transformation may also be unintentionally induced by hydrothermal ageing in the humid environment of the oral cavity [11,12]. This process is commonly referred to as low-temperature degradation (LTD). With LTD, the energy barrier for *t* → *m* transformation is reduced, due to incorporation of water constituents into the zirconia lattice by a mechanism which has not yet been fully clarified [13–15]. Consequently, the *t* → *m* transformation spreads gradually along the surface and penetrates into the depth of the material in a so-called “nucleation-and-growth” process [16]. At oral temperatures, the transformation proceeds very

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