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Impact of oral fluids on dental ceramics: What is the clinical relevance?☆

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ABSTRACT

Objectives. In this brief and selective overview, basic factors contributing to aqueous induced dissolution, phase changes of zirconia and mechanical strength degradation of dental ceramics are considered.

Methods. Dissolution is important for porcelain and glass-ceramic materials as they predominantly contain a silica glass structure with various other cations incorporated which disrupt the silica network. In glass-ceramic materials and porcelains containing crystalline components the situation is more complex as the difference in the dissolution rate may increase the surface roughness and contribute to abrasion of the opposing definition.

Results. Factors contributing to the aqueous dissolution of silicate based dental ceramics and induced destabilization of Y-TZP zirconia or low temperature degradation (LTD) are considered. It is also noted that there have been a number of reports of spontaneous fracture of 3Y-TZP specimens because of LTD in the absence of external stress. A simple analysis of this situation is presented which indicates a strong specimen-size effect and also implicates the role of the remnant “pseudo-grain” structure resulting from the pressing of spray-dried powder agglomerates.

Significance. The final section of this review addresses the consequences of various environments on crack growth and strength degradation. In some situations it is suggested that the aqueous environment may enhance the strength of restorative materials. In all instances discussed above the clinical consequences are pointed out.

1. Introduction

The oral cavity is a potentially very hostile environment despite the critical role of the salivary glands in buffering this situation. The saliva not only buffers but also contains Ca^{2+} and $PO_4{}^{3-}$ ions that mediate dissolution and facilitate deposition of apatite on enamel. The pH range experienced in the oral cavity ranges from 1 to 10 [1] with the highly acidic conditions associated with reflux of gastric fluid [2]. More typically the pH of ingested beverages ranges from 3 to 8 with carbonated acidic beverages including sport drinks and energy drinks that have stimulants such as guaronic acid with low pH values.

The bacteria naturally present in the oral cavity are also highly effective in developing low pH conditions. A typical measurement of the pH changes with time of inoculated

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bacteria from a patient, that developed into a plaque biofilm on enamel, fed with pulses of sucrose in an artificial mouth model varies from 3 to 6 [3]. In the above case the essentially static situation coupled with limited amount of sucrose, plus the buffering by enamel dissolution leads to a gradually rising pH following each sucrose addition. The low pH (3.5) that develops can result in substantial dissolution of enamel and onset of caries.

The major difference between external ingested beverages and caries beneath biofilms is that the latter are static adjacent to the adherent biofilm whereas the former are more general and react with the entire exposed teeth surfaces. The recent widespread use of energy and sports drinks is contributing to the world-wide incidence of tooth erosion (corrosion), especially of young people. Apart from acidic ingested fluids, Ccahuana et al. [4] have also shown that clinically applied acid fluoride varnishes have low pH (3.6–3.9) and contain HF. To date the emphasis has been on the role of low pH but a number of common foods (Lima and soy beans, spinach) have pH values of 8 and higher [1].

Apart from the range of pH, the oral cavity experiences a substantial temperature range (0–67 °C [5]). The higher temperatures would accelerate the kinetics of any reactions between the liquids and the ceramic surfaces present. This has tended to influence the current ISO Standard 6872 test for evaluation of the solubility of dental ceramics, which measures the weight loss after various time periods at 80 °C. There have been a range of studies that have also investigated the influence of the pH on the release of ions from various dental ceramics [6,7]. The most recent study by Esquivel-Upshaw et al. [1] suggests that high pH conditions are most deleterious to the mass loss from glass based systems because the high pH is more effective in breaking up the silica glass framework.

The other major factor contributing to aqueous degradation of dental ceramic is the presence of stress on these structures placed in the oral cavity. There are three major sources of stress on or within materials in the mouth: (i) associated with mastication loads developed by the jaw muscles that may generate substantial contact and flexural stresses, (ii) associated with residual stresses that are present upon cooling after fabrication because of thermal expansion mismatch or temperature gradients, and (iii) localized stresses in materials because of their microstructure and presence of multiple components [8]. For example, in the glass matrix of veneering porcelains containing leucite crystals because of the thermal expansion mismatch, at grain boundaries in single-phase non-cubic structured materials such as alumina (hexagonal) and zirconia (tetragonal) because of thermal expansion anisotropy (TEA) of these structures [9]. These various sources of stress, especially in the presence of a corrosive medium, may initiate enhanced dissolution and/or local cracking. The extent of any such crack extension will be highly dependent on the size of the feature or body responsible for the stress and its magnitude. For instance in the case of TEA induced stresses these will be of short range typically less than the grain size but which can assist with the initiation of cracking and phase changes. These stresses combine with the known propensity for brittle ceramics to undergo stress corrosion cracking potentially resulting in time and fatigue dependent strength degradation [10].

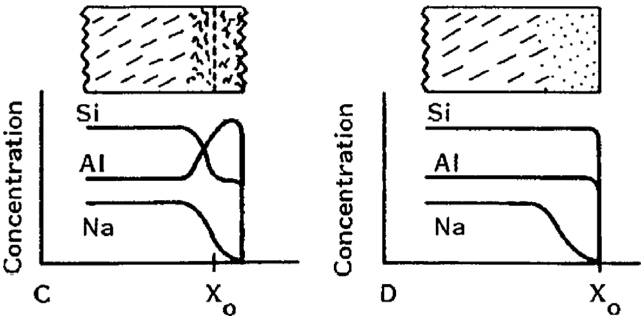

Fig. 1 – A schematic diagram from White [12], illustrating two responses of sodium aluminosilicate glass in an aqueous environment. In these figures X_o is the initial surface position. C shows the dissolution and reprecipitation on the surface under a more static environment whereas D shows the formation of a partially hydrated porous layer at the surface caused by the dissolution of Na ions to the environment.

The dental ceramic material systems considered in this article are: (i) feldspathic glass based porcelains, (ii) glass-ceramic systems, and (iii) sintered crystalline ceramics with a focus on zirconia. While in some situations the surface roughness developed upon exposure to a hostile environment is seen as detrimental to the wear of the opposing antagonist, it is also considered as beneficial to assist with the adhesive bonding of such etched and pitted materials. In this article some of the basic issues that determine the dissolution of ceramic materials in liquid environments will be considered. In the following section the role of liquids and temperature on the phase changes of zirconia are considered. The final section will consider the additional role of stresses on the mechanical response.

2. Dissolution of glass and ceramic materials

The focus of this section will be on the dissolution of dental ceramic materials in aqueous environments.

The dissolution of glass is an active area of research not only for dental applications but diverse fields ranging from nuclear waste containment, preservation of stained glass in the polluted urban environment to domestic kitchen ware. The dissolution of glass depends strongly on the composition of the glass and the leaching environment. The environment may also change with time depending upon whether it is static or flowing. For instance in a static environment the leaching out of alkali elements will increase the pH of the solution, which may then lead to a greater rate of dissolution of the silica matrix. Hench and Clark [11], based upon the chemistry of a glass and associated (effective) pH, identified 5 types of dissolution of glass: Type 1, pure silica in neutral pH resulting in a very thin (<5 nm) hydrated layer. Type 11 and 111 are durable glasses (low alkali content with pH <9) that develop a hydrated layer (<200 nm) denuded of alkali elements [12] (see Fig. 1). Type IV glasses have a high alkali content where the hydration layer does not limit continued dissolution. Type V corresponds

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