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Influence of cyclic fatigue in water on the load-bearing capacity of dental bridges made of zirconia

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Abstract

The humid atmosphere and permanent occurrence of chewing forces in the oral environment lead to degradation of ceramics used for prosthetic restorations. The aim of this in vitro study was to evaluate the influence of artificial aging on the load-bearing capacity of four-unit bridges, with both undamaged and predamaged zirconia frameworks. Additionally, different parameters for chewing simulation have been investigated and a finite element analysis was made to predict the location of highest tensile stresses within the bridges. A total of 60 frameworks were milled from presintered zirconia and divided into six homogeneous groups. Prior to veneering, frameworks of two groups were "damaged" by a defined saw cut similar to an accidental flaw generated during shape cutting. After veneering, FPDs were subjected to thermal and mechanical cycling – with the exception of control groups. The load-bearing capacity of tested FPDs was significantly reduced by artificial aging. In comparison to unaged specimens, fracture resistance decreased by about 40%, whereas preliminary damage did not have a significant effect. Increasing number of cycles and increasing upper load limit failed to show any additional effect on fracture force. To predict the progression of degradation under the terms of in vitro simulation for even longer periods, further aging experiments are required.

Keywords: Dental bridges; Zirconia; Load-bearing capacity; Cyclic loading; FEA

1. Introduction

All-ceramic dental restorations have become more and more important, in particular, due to their favorable esthetics and their outstanding biological compatibility. The recent incorporation of high-strength zirconia into dentistry has increased the spectrum of indications for ceramic materials, allowing fabrication of implants, all-ceramic crowns and fixed partial dentures (FPDs) for the highly loaded posterior region [1]. This type of zirconia owes its high-strength to so-called transformation reinforcement, a complex mechanism involving transformation from tetragonal-to-monoclinic structure and associated with a local 4% increase in volume [2,3]. For this process to be effective, the tetragonal structure must be stabilized at room temperature, for which reason almost all zirconium dioxide ceramics used for dental restorations contain yttrium oxide (Y_2O_3).

Under functional loading in the oral environment, zirconia-based materials, despite their remarkably high-strength, undergo fatigue and subcritical crack growth that can significantly reduce their strength over time [4]. Subcritical crack growth occurs due to the stress-assisted reaction of water molecules with the ionic–covalent bonds at the crack tip [5]. Furthermore, water molecules can be incorporated into the zirconia lattice by filling oxygen vacancies [6]. This reduces the energy barrier for the tetragonal-to-monoclinic transformation and thus increases the rate of transformation which, due to the associated volume increase, results in microcrack formation within the lattice. Although this mechanism is usually very slow at oral temperatures, it may lead to a significant decrease in the strength of dental restorations over periods of wear of several decades [7].

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Mechanical loading and a moist environment are the conditions encountered in the mouth during mastication. Thus, determining the influence of degradation effects to load-bearing capacity under cyclic stresses in water is prerequisite to predict the sustainable success of zirconia-based restorations in dentistry. There are only a few investigations that have dealt with the strength-degrading effect of cyclic loading in water on zirconia ceramics [8–10].

Besides cyclic loading in a moist environment, flaws within the ceramic structure could lead to subcritical crack growth and, eventually, catastrophic failure [11]. These defects may be conditional on the manufacturing of the zirconia blanks used or could be created by the technician on the material's surface during production or finishing. In particular, the gingival embrasure of FPDs is the most sensitive site for any kind of flaw. By means of finite element analysis (FEA) and fractography, Kelly et al. determined that the highest tensile stress within the connectors of an all-ceramic three-unit FPD is at this site [12]. They evaluated the failure mode of FPDs made of glass-infiltrated alumina, taking into account the resilient embedding of abutment teeth.

The aim of the present study was to test the hypothesis that the in vitro load-bearing capacity of a posterior dental bridge made of zirconia is reduced by aging in an artificial oral environment. Additionally, the hypotheses were tested that an increasing number of mechanical cycles or an increasing upper load limit and a defined mechanical damage to the framework at a sensitive location causes a decrease in load-bearing capacity. Furthermore, the site of the highest tensile stresses within the zirconia FPD was determined by means of FEA.

2. Materials and methods

2.1. Preparation

In an upper jaw plastic model (Frasaco OK 119, A-3 T, Franz Sachs & Co., Tettnang, Germany), teeth 24 and 27 were prepared to accommodate a four-unit all-ceramic FPD. Stone casts (Fuji Rock, GC, Leuven, Belgium) were produced by means of individual impressions of the prepared teeth, and were used as a basis for manufacturing zirconium dioxide bridge frames. During aging and static testing, the FPDs were cemented to and supported by duplicates of the prepared original abutment teeth. These duplicates were made of reinforced polyurethane (PUR) resin (Alpha-Die-Top, Schütz Dental, Rosbach, Germany). Natural periodontal resilience was simulated by coating the roots of these stumps with an elastic latex material (Erkoskin, Erkodent, Pfalzgrafenweiler, Germany). The latex-coated roots were imbedded in a PUR base that reached as far as 3 mm below the preparation margin.

2.2. Manufacture of FPDs

A total of 60 frameworks were fabricated in partially sintered zirconia (Cercon base, DeguDent, Hanau, Germany). The frames were made by repeated copying of a master frame in a computer-aided machinery (CAM) unit (Cercon brain, DeguDent, Hanau, Germany) with subsequent firing in the system oven (Cercon heat, DeguDent, Hanau, Germany). The dimensions of all frames were practically the same, connector width and height differing by less than 0.2 mm. Connector cross-sections were elliptically shaped, their areas being (from mesial to distal) 12.5, 15.6 and 11.6 mm^2, respectively. Before veneering, 20 frames were selected at random and a U-shaped cut of width 180 μm and depth 60 μm was made at the gingival surface of the connector between teeth 25 and 26 (the presumed location of highest tensile stress during loading) (Fig. 1). This was done to simulate possible damage to the core during the manufacturing process and to test the influence on load-bearing capacity. Such cutting (subsequently referred to as "predamaging") was performed with an annular diamond saw (Microslice 2, Metals Research Ltd., Royston, UK). After veneering, the undamaged specimens were also randomized and divided into homogeneous groups of 10 each, resulting in a total of six groups.

2.3. Aging

The bridges were fixed onto the PUR abutments by means of glass-ionomer cement (Ketac-Cem, 3M ESPE, Seefeld, Germany). With the exception of two groups (undamaged/predamaged), the bridges were subjected to thermal and mechanical cycling (TMC) during 200 days storage in distilled water at 36 °C. During this period, 1×10^4 thermal cycles between 5 and 55 °C (30 s dwell time at each temperature) and a mechanical loading (load frequency 2.5 Hz) with varying number of cycles (1×10^6/2×10^6) and varying upper load limits (100 N/200 N) were applied successively (Table 1 and Fig. 2).

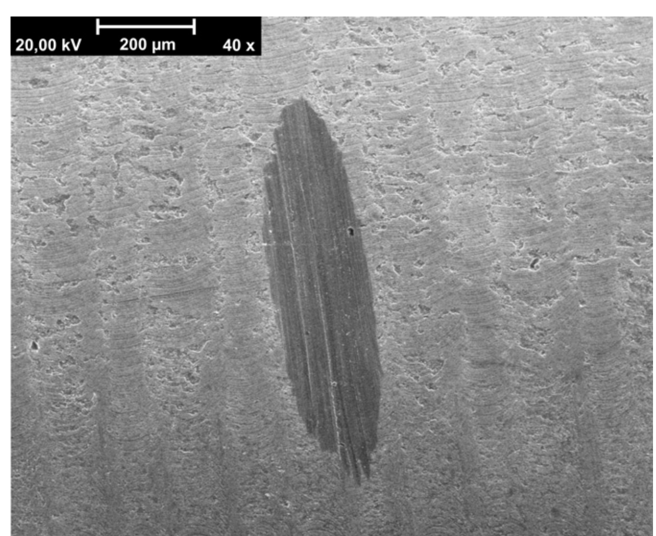

Fig. 1. SEM image of preliminary damage generated on the gingival embrasure of a zirconia framework.