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Comparison of fatigue resistance and failure modes between metal-ceramic and all-ceramic crowns by cyclic loading in water

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ABSTRACT

Objectives: To compare fatigue resistance and fracture mode of metal-ceramic crowns with all-ceramic crowns containing yttria tetragonal zirconia polycrystal (Y-TZP) frameworks under compressive cycling loading in water.

Methods: Twenty specimens of ivory were randomized and individually prepared to receive anatomically shaped metal-ceramic ($n = 10$) or veneered Y-TZP all-ceramic crowns ($n = 10$). All steps in production were equivalent to clinical situations. Resistance to fatigue fracture was tested under compressive cyclic loading using a universal testing machine, with a loading frequency of 12 Hz using a spherical tungsten carbide indenter (6 mm diameter) in distilled water. The maximum compressive load was increased as the number of cycles increased (600,000 cycles at 400 N, 200,000 cycles at 600 N, 200,000 cycles at 800 N and 200,000 cycles at 1000 N). The specimens were inspected after each loading sequence for initial failures such as infractions. Final failure was considered as any loss of material which automatically ended the test and the number of cycles until final failure was recorded. Fractographic analysis of the fractured specimens was performed with scanning electron microscopy (SEM).

Results: The two types of crowns exhibit similar fatigue resistance ($P = 0.87$) to compressive cycling loading under wet conditions. The failure modes as observed with SEM were similar in the two groups and were found in the veneer ceramic, except that three veneered Y-TZP all-ceramic crowns displayed a complete framework fracture.

Conclusions: Within the limitation of this study using simulated oral masticatory function, the results revealed that the fatigue resistance was similar for the two crown types.

Clinical significance: In this study metal-ceramic crowns and veneered Y-TZP all-ceramic crowns showed similar fracture resistance to compressive cycling loading in water. The test conditions were simulating clinical conditions. Thus, the result may predict the long-term clinical performance of these types of crowns.

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1. Introduction

The increasing demand for aesthetically pleasing restoration of teeth, and concerns about metal containing restorations, have been the force behind the evolution of new materials and techniques, such as all-ceramic materials for crowns and fixed dental prostheses (FDPs).[1,2]

Metal-ceramic restorations have been used for more than four decades and are considered reliable.[3,4] For many dentists this represents the gold standard for restoring teeth with single crowns and small gaps in the dental arch with FDPs.[5,6] When replacing metal-ceramic restorations with all-ceramic systems, especially posteriorly in the mouth, a key aspect to consider is their susceptibility to fracture.[7] Fractures are often preceded by the propagation of subcritical cracks in the material and this is accelerated in the presence of water.[7,8] The propagating crack reduces the strength of the ceramic, leading to failure at occlusal loading which normally would not have been expected to induce failure.[1] Fatigue degradation caused by cyclic loading enhances the water-assisted subcritical crack propagation.[7–10] Clinical studies concerning metal-ceramic and veneered Y-TZP all-ceramic posterior crowns and FDPs are available.[4,11–20] Some studies report an increased occurrence and severity of fractures of veneering ceramic with veneered Y-TZP all-ceramic restorations compared to metal-ceramic restorations, especially in the posterior areas.[12,15,18,20]

Yttria tetragonal zirconia polycrystal (Y-TZP) is a ceramic core material with excellent mechanical properties such as high toughness and strength.[9] Stress induced phase-transformation of Y-TZP from the tetragonal crystalline structure to the more voluminous monoclinic structure limits crack propagation and enhances the strength and toughness of Y-TZP ceramics.[21] Y-TZP is the strongest and toughest of all dental ceramics and is widely used as framework material for posterior crowns and FDPs.[9,22] The appearance of Y-TZP and metal frameworks is not aesthetically pleasing; consequently, both frameworks must be veneered with a more translucent ceramic to obtain the appearance of a natural tooth.[7,22] The ceramic veneer is predisposed to chipping.[7] Despite these clinical drawbacks, there has been an increase in the use of all-ceramic systems in the last two decades in the posterior region of the mouth, owing to significant improvement in their mechanical properties, especially the development of the Y-TZP framework material.

Several previous *in vitro* studies have investigated the failure modes, failure origins and crack propagation of the veneer and framework material separately, thus providing valuable information on the parameters for crack growth of the individual components of a crown or a FDP.[23] However, lifetime prediction of a restoration requires a knowledge of the properties and behaviour when all components are assembled and treated as the finished restoration would be for clinically use. Studies on veneer-framework compositions can give information regarding failure mode, fracture origin and overall combined strength, which cannot be assessed by investigating the materials separately.[23] Furthermore, crown-shaped test specimens cemented on preparations of tooth-like material[10] may bring the test conditions even closer to the clinical situation.

Many *in vitro* tests have been based on static loading, where the loads that ultimately caused failure generated contact stresses much higher than those experienced in the oral cavity under occlusal loading, mastication and parafunctional behaviour.[24] On the other hand, cyclic loading causes failure of the material at loads lower than static loading of the same material.[25] Thus, fatigue tests with lower loads (using compressive cyclic loading) can prove more clinically relevant, since this test better imitates some of the stresses a material will be exposed to during a lifetime in function.[7,8] Additionally, the aqueous environment of the mouth and cyclic loading during mastication are evidently favourable conditions for subcritical crack propagation in ceramic restorations.[8] Thus, the evaluation of crack propagations and fracture behaviour in dental ceramics under such conditions is desirable.

Consequently, the aim of this study was to compare the fatigue resistance and fracture mode of high-precious gold metal-ceramic crowns with veneered Y-TZP all-ceramic crowns when subjected to compressive cyclic loading in water.

2. Materials and methods

2.1. Specimen preparation

Twenty cylinders in the approximate size of a human molar (height 21 mm, diameter 9 mm) were cut from the same piece of elephant tusk. The ivory was kept moist in distilled water throughout the preparation and testing of the samples. Ten cylinders were randomized to receive metal-ceramic crowns and ten to receive veneered Y-TZP all-ceramic crowns with a CAD–CAM Y-TZP framework. Preparation was carried out by the same operator using standard approaches and following the manufacturer's guidelines. A high-speed hand-piece with copious water irrigation and new diamond burrs were used for each preparation. The angle of convergence was 15°, namely 7.5° to the long axis of the cylinder. For the metal-ceramic crown preparations, a 1 mm shoulder was prepared on the facial aspect and a 0.6 mm deep chamfer on the remaining axial walls. The veneered Y-TZP all-ceramic crown preparations were made with a circumferential 0.8 mm deep chamfer. The height of the preparation was 4 mm on the walls representing the proximal surfaces and 5 mm on the walls representing the buccal and lingual surfaces (Fig. 1). The finish line was given a curvature similar to a molar crown preparation, with the finish line 1 mm more occlusally placed on the proximal surfaces than on the buccal and lingual surfaces.

Impressions of the prepared specimens were made with a single-step, two-phase technique with silicone impression materials (Extrude, Kerr, KaVo Kerr Group, Romulus, MI, USA). The impression materials were mixed in accordance with the manufacturer's instructions.

The impressions were poured in stone (Nova Die Stone, BK Giulini, Ludwigshafen, Germany). The metal frameworks were cast from high noble Au–Pt alloy (BioPontoStar, BEGO, Bremen, Germany) using the lost wax technique. To facilitate the CAD–CAM fabrication of the Y-TZP frameworks, the stone dies of the veneered Y-TZP all-ceramic crown preparations were

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