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Lifetime prediction of zirconia and metal ceramic crowns loaded on marginal ridges

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ABSTRACT

Objective. To evaluate the fatigue life of zirconia-veneered and metal-ceramic crowns comprised by an even thickness or a modified framework design when loaded on marginal ridges.

Methods. Eighty marginal ridges were present after fabrication of forty molar crowns cemented onto composite-resin replicas and divided (n = 20/each), in the following groups: metal-ceramic with even thickness (MCev) or with a modified framework design (MCm, lingual collar with proximal struts); porcelain-fused to zirconia with even thickness (PFZev) or with the modified framework design (PFZm). Each marginal ridge (mesial and distal) was subjected to cyclic loading separately with a lithium disilicate indenter for 10^6 cycles or until fracture. Kruskal–Wallis and Wilcoxon matched pair test ($p < 0.05$) evaluated both marginal ridges. Every 125,000 cycles, the test was interrupted for damage inspection. Weibull distribution (90% confidence bounds) determined the probability of survival (reliability).

Results. Weibull 2-parameter contour-plot showed significantly higher fatigue life for PFZev compared to MC, and comparable with PFZm. A significant decrease in reliability was observed between groups from 625,000 until 10^6 cycles. Metal-ceramic groups presented significantly lower probability of survival at 10^6 cycles (MCev = 0.66% and MCm = 4.73%) compared to PFZm (23.41%) and PFZev (36.68%). Fractographic marks showed a consistent fracture origin and direction of crack propagation. Reliability was higher for porcelain-fused to zirconia than for metal ceramic crowns, regardless of framework design.

Significance. Zirconia-veneered crowns presented decreased fracture rates compared to metal ceramics, even when loaded at marginal ridges, regardless of framework design.

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1. Introduction

All-ceramic materials continue to be investigated in both laboratory and clinical settings in a constant quest to accumulate supportive data for their safe use. In general, these materials are still prone to fractures of multiple nature including bulk fractures or chipping within the veneering porcelain [1–5] given their inherent brittleness. The most common complications include veneering material fractures, loss of retention, endodontic treatment, and bleeding on probing. However, for crown applications and material such as porcelain fused to zirconia, it seems that the rates of such complications are comparable to those of metal ceramics, according to a recent systematic review [6]. Yet, such observations have been made on a relatively small number of studies, seldom of randomized controlled design that warrants further investigation in the field.

It is unequivocal that inconsistencies are present in reporting the extent of failures occurring clinically in all-ceramic materials, even when standardized evaluation systems are used (e.g., USPHS), which eventually results in uncertainties upon decision making towards replacement or repair for continued function [7]. In spite of its extension, a finding of clinical significance comprises where the failure is located. When at any free surface area (e.g., buccal, lingual or occlusal) access for repair is straightforward and may allow for successful repair. However, when at the proximal areas, not only access, but proper isolation may be hindered by adjacent teeth. Interestingly, a clinical study has shown that when occlusal contacts are present on mesial or distal ridges, fractures in porcelain-fused to zirconia prostheses demand restoration replacement due to their extension leading to esthetics and/or function impairment [8].

Because the marginal ridges are a common location for occlusal contacts in natural dentition in maximal intercuspation, regardless of Angle occlusal scheme (class I, II, and III), it is speculated that such areas may be more prone to failures when compared to contacts at the central fossa [9]. Finite element analysis investigations evaluating the stresses in marginal ridges and proximal areas have shown a high tensile stresses specially in molars [10] and second premolars [11,12].

The prevalence of contacts between the cusp and marginal ridge is 34.60% [13]. It may be present at only one marginal ridge [13,14] or two simultaneously [13]. Teeth that have the widest range of these contacts are the first molars, presenting up to six simultaneous occlusal contacts [15–17]. Furthermore, one to three contacts are common at molars [16] in intercuspal position. The explanation for this variety is given by the largest occlusal surface compared to other teeth [18].

Factors associated with failure rates of porcelain fused to polycrystalline zirconia crowns are multifaceted and attempts to reduce failures include modification of core design [19–22], improved CTE matching between core and porcelain [23–25], cooling rate of the porcelain [25,26], and others. By core design modification, an additional support for veneering ceramic is provided when compared to the standard design core with implications including an increase in probability of survival and and a reduction in the extent of porcelain veneer fracture [27,28]. However, virtually all investigations simulate the occlusal contact at the cusp inclines where the lingual collar provided additional support, rather than on marginal ridges where some failures have shown to occur clinically [7,29–45]. Therefore, whether failure rates can be decreased or not at the marginal ridges when a framework is designed to improve support is yet to be investigated.

The present study sought to investigate the fatigue life and failure modes of porcelain fused to zirconia (Y-TZP—yttria-stabilized tetragonal zirconia polycrystal) and metal-ceramic crows with an even thickness or a modified framework design. The following null hypotheses tested were that fatigue life would not be improved: (1) by framework design modification and (2) by material used to fabricate crowns.

2. Materials and methods

An artificial mandibular first molar was positioned in a mannequin for full crown preparation that included 2.0 mm occlusal reduction, 1.5 mm axial reduction and a 1.2 mm shoulder margin with rounded internal angles [21]. Replicas of the prepared tooth (n = 40) were obtained by an impression with polyvinyl siloxane material (Express—3 M Oral Care, St. Paul, MN, USA) followed by incremental packing and light-curing (Ultralux, Dabi Atlante, Ribeirão Preto, SP, Brazil) of composite resin (Z100, 3 M Oral Care, St. Paul, MN, USA). These replicas were stored into a distilled water recipient for 30 days to provide hygroscopic expansion and minimize dimensional alteration [21,46]. The replicas were removed from the recipient, vertically positioned into a polyvinyl siloxane matrix (Express—3 M ESPE) to standardize embedding and pouring of acrylic resin (Jet, Clássico Artigos Odontológicos, São Paulo, SP, Brazil) in a 25 mm diameter PVC tubes.

Replicas were randomly assigned to two groups (n = 20 each) according to the crown system used; metal ceramic (MC) or porcelain fused to zirconia (PFZ). Subsequently, each group was subdivided (n = 10 each) according to framework design comprising either a core with an even thickness (MCev and PFZev) or a modified design (MCm and PFZm). The even thickness groups presented a 0.5 mm thickness coping (Fig. 1A and C) and the modified core design comprised a 0.5 mm even thickness with a 1 mm thick lingual collar and 2.0 mm of height, connected to proximal struts of 3.5 mm height (Fig. 1B and D) [19,21,26].

For fabrication of MC crowns, an impression of each composite resin replica was made (Pentamix—3 M Oral Care, St. Paul, MN, USA) with polyether material (Impregum F—3 M Oral Care, St. Paul, MN, USA) and poured, resulting in a total of 20 stone dies. The even thickness and modified metal cores (cobalt–chromium, Fit Cast Cobalto, Metal Talmax, Curitiba, PR, Brazil) were manufactured by means of lost wax technique and cast according to manufacturer. The IPS d.SIGN Transpaneutral (Ivoclar Vivadent AG, Schaan, Liechtenstein) veneering ceramic was hand layered and the firing schedule followed the manufacturer's recommendation. The veneering ceramic transparency was chosen to facilitate crack inspection throughout fatigue cycles.

The Y-TZP cores (IPS e.max ZirCAD—Ivoclar Vivadent AG, Schaan, Liechtenstein) were milled from pre-sintered