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Effect of surface treatments on the bond strength between resin cement and differently sintered zirconium-oxide ceramics☆

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ABSTRACT

Purpose: This study investigated the effects of surface treatments on bond strength between resin cement and differently sintered zirconium-oxide ceramics.

Methods: 220 zirconium-oxide ceramic (Ceramill ZI) specimens were prepared, sintered in two different period (Short = Ss, Long = Ls) and divided into ten treatment groups as: GC, no treatment; GSil, silanized (ESPE-Sil); GSilPen, silane flame treatment (Silano-Pen); GSb, sandblasted; GSbSil, sandblasted + silanized; GSbCoSil, sandblasted + silica coated (CoJet) + silanized; GSbRoSil, sandblasted + silica coated (Rocatech-Plus) + silanized; GSbDSil, sandblasted + diamond particle abraded (Micron MDA) + silanized; GSbSilPen, sandblasted + silane flame treatment + silanized; GSbLSil, sandblasted + Er:Yag (Asclepion-MCL30) laser treated + silanized. The composite resin (Filtek Z-250) cylinders were cemented to the treated ceramic surfaces with a resin cement (Panavia F2.0). Shear bond strength test was performed after specimens were stored in water for 24 h and thermocycled for 6000 cycles (5–55 °C). Data were statistically analyzed with two-way analysis of variance (ANOVA) and Tamhane's multiple comparison test ($\alpha = 0.05$).

Results: According to the ANOVA, sintering time, surface treatments and their interaction were statistically significant ($p < 0.05$). The highest bond strengths were obtained in GSbCoSil (Ss = 13.36/Ls = 11.19 MPa) and lowest values were obtained in GC (Ss = 4.70/Ls = 4.62 MPa) for both sinter groups.

Conclusions: Sintering time may be effective on the bond strength and 30 μm silica coating (Cojet) with silane coupling application technique increased the bond strength between resin cement and differently sintered zirconium-oxide ceramics.

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1. Introduction

The yttrium stabilized polycrystalline tetragonal zirconia (Y-TZP), a high-strength/crystalline content ceramic, was recently introduced as a core material for single crowns and fixed dental prosthesis due to its relatively esthetic, good biocompatibility and excellent mechanical properties; high flexural strength (700–1200 MPa) and fracture toughness (7–10 MPa $m^{1/2}$) [1–4]. Zirconium-oxide is a polymorphic material and has three allotropes; monoclinic, tetragonal and cubic. The monoclinic phase is stable from room temperature to 1170 °C, tetragonal in 1170–2370 °C and cubic phase exist over 2370 °C up to melting point of 2680 °C [3,5–8]. In order to obtain more stable and stronger tetragonal zirconia in room temperature, small amounts of stabilizing oxides (Y_2O_3 or CeO_2) use to control the tetragonal (t) to monoclinic (m) phase transformation and take advantages of the transformation-toughening [7–9]. This transformation is associated with 3–4% volume expansion that induces compressive stresses and making zirconia a potentially superior material compared with other dental ceramics. The tetragonal form of zirconia in room temperature is "metastable" and some external stresses factors like sandblasting, grinding, impact or thermal aging can initiate the tetragonal to monoclinic phase transformation [5–8].

With the widespread use of computer-aided design/computer-assisted manufacture (CAD/CAM) technology, it was possible to produce more stable and strong zirconia ceramic substructures for complete coverage single crown and FPD's [5–7,10]. Two types of zirconia milling processes are currently available: soft-milling (partially sintered state) and hard-milling (full sintered). Soft-milled frameworks are subsequently sintered to full density and a linear dimensional shrinkage of 20–25% occurs during sintering process. Whereas, fully sintered zirconia frameworks does not require any heat treatment, sintering process and can be milled to the final dimensions [6,7]. Variations at sintering conditions like final sintering temperature or heating method may influence the physical or mechanical behavior of the material [3,6]. In particular the final temperature and the holding time may possibly affects the translucency and also direct determinants of density, porosity and grain size of zirconia [3,4,6,9,11]. It was indicated in recent studies that, the grain size of zirconia ceramics was also an important factor on phase stability as well as the stabilizing oxides [9,12]. Increase in the grain size of zirconium oxide stimulates the spontaneous t–m phase transformation and thus reduces the stability and strength of material. Nevertheless, reduction in the grain size adversely affects the phase stability and strength of the material [13,14]. The grain size of zirconium oxide can vary, depends on both raw material and fabrication process like sintering conditions (time and/or temperature) [15]. Higher sintering temperatures as well as long sintering time yield larger the grain size [3,4,6,11]. However, in order to avoid spontaneous t–m phase transformation, which may result in enhanced crack formation, ultrafine grains are required [16]. In a recent study, the influence of the grain size on the flexural strength of Y-TZP ceramics respectively exposure to additional sintering procedures was investigated. It was reported that the grain size of specimens were increased in proportion to the increased sintering temperature, whereas biaxial flexural strength of specimens were showed tendency to decrease [9]. This result was also acknowledged by another related study and declared that the flexural strength and contrast ratio of zirconia ceramics were significantly decreased when the specimens sintered above 1550 °C [6]. It was concluded that increased in grain size would propagate the amount of micro-pores and cavitation thus reduced the mechanical properties of the material [6,17]. However, the effects of sintering conditions on the mechanical properties of partially sintered zirconia ceramics should be further investigated.

A strong, stable bonding of a ceramic restoration is essential factor for long-term success rate and it can be achieved by either micromechanical interlocking and/or chemical bonding of luting cement to ceramic surface [10,18–21]. There is a common thought that conventional surface conditioning methods are not enough to produce significant topographic alterations in ceramics with high crystalline content [2,18,19,21]. Because of the Y-TZP ceramics does not have silica and glass phase, neither acid etching with hydrofluoric/phosphoric acid nor silane coupling will not be sufficient to increase bond strength [8,18–23]. Therefore a great many surface conditioning methods such as airborne particle abrasion, are suggested to achieve a strong and durable bonding between resin based cements and zirconium-oxide ceramics [8,18,20,21]. The airborne-particle abrasion (sandblasting), which is one of the most popular surface treatment technique, creates micro undercut areas, increases the surface roughness of the ceramic surface on the ceramic surface and thus improve the micro-mechanical retention of bonding agent [2,5,8,10,18,19,21,23]. Nevertheless, airborne abrasion also cleans the surface, removes impurities, modifies the surface energy and wettability [21,24,25]. The most commonly used airborne particles in dental applications are aluminum oxide (Al_2O_3) or silica-coated aluminum particles (tribochemical silica coating) in different grain sizes ranging from 30 to 110 μm [12,14–17]. According to the alumina particles, silica-coated alumina particles could buried into the ceramic surface and provide an additional chemical retention with resin bonding agents [19,21]. The silica coating systems have showed superior bond strength values in several studies [18,26]. Nevertheless, nano-sized synthetic diamond particles have also been used as an airborne abrasive particle to modify the surface of dental materials and create more uniform and smaller cavities [27]. But, further studies must be performed to evaluate the effects of synthetic diamond particle abrasion on bonding strength of zirconium oxide ceramics. It was indicated in some related studies that the excessive airborne-particle abrasion may leads to crack formation and strength degradation on zirconia ceramics [5,8,10]. Furthermore, airborne-particle abrasion was shown as responsible to trigger the phase transformation from tetragonal to monoclinic, which subsequently emerges compressive stress and enhance fracture tendency [5,8,23,25]. These unfavorable potential results lead to improve new alternative surface treatment techniques for zirconia ceramics.

While laser technology become widely used in medicine and dentistry, laser irradiation techniques were also used for roughening the surface of ceramics to create micro-mechanical retention [23,28]. Today there are many types of laser devices