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Effects of airborne-particle abrasion protocol choice on the surface characteristics of monolithic zirconia materials and the shear bond strength of resin cement

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Abstract

This study evaluated the effect of several airborne-particle abrasion protocols on the surface characteristics of monolithic zirconia and of protocol choice on the shear bond strength of resin cement. 375 bar-shaped ($45\times4\times3$ mm^3) and 500 disk-shaped (Ø9×1 mm^2) monolithic zirconia specimens were divided into 25 groups. All specimens were abraded with one of three different sizes of alumina particles (25, 50 or 125 μm), two different pressures (2 or 4 bar), two distinct application times (10 or 20 s) and two distinct incidence angles (45° or 90°). The bar-shaped specimens were used for 3-point bending test; Weibull parameters were calculated and transformed monoclinic phase (X_M), surface characteristics were examined. The disk-shaped specimens were used to determine the shear bond strength of resin cement before and after thermocycling. All data were analyzed using 4-way ANOVA and a multiple comparison Scheffé test ($\alpha = .05$). The particle size, pressure and time significantly affected the flexural strength, while the incidence angle was insignificant. The X_M and surface roughness were proportional to the size, pressure, time and incidence angle. The Raman spectrum analysis showed a higher proportion of the monoclinic phase as the depth of the specimen was closer to the abraded surface. In bonding with resin cement, the highest shear bond strength after thermocycling was obtained by the abrasion with 50 μm particles at 4 bar for 20 s, regardless of incidence angle. Surface treatment of monolithic zirconia with 50 μm particle at 4 bar for 20 s at either 45° or 90° incidence angles is recommended.

Keywords: B. Surfaces; C. Strength; D. ZrO_2; E. Biomedical applications; Resin cement

1. Introduction

In response of the high demand for highly esthetic, metal-free and biocompatible restoration materials with high flexural strength, various types of all-ceramic systems have been developed in the last few decades. In a systematic review, all-ceramic crowns showed comparable survival rates to metal–ceramic crowns when used in the anterior and or premolar regions, but had a significantly higher fracture rate when used in the posterior region [1]. Substantial effort has been put forth in the development of more reliable all-ceramic systems. In the early 1990s, yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) was introduced to dentistry as a core material for all-ceramic restorations. Compared to other all-ceramic systems, results with Y-TZP have been encouraging, as it has shown high resistance to fracture [2,3].

Although damage to a zirconia framework has been reported only rarely, chipping or fracturing of the ceramic veneer has been proposed as the most frequent reason for failure of zirconia-based restorations [4–6]. Therefore, in order to increase the success rate of restoration and overcome the chipping problem, zirconia restoration without veneering ceramic, called a monolithic zirconia restoration system, was introduced. Many studies of monolithic zirconia restorations have shown improved

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clinical and laboratory results [7–9]. Their strong bond strength is indispensable for the long-term durability of restorations. Manufacturers also claim that zirconia ceramic restorations can be successfully cemented with either conventional or adhesive cements. Nevertheless, some zirconia fixed partial dentures (FPDs) show reduced retention with abutments. A strong, durable resin bond to dental ceramics is established by the formation of chemical bonds and micromechanical interlocking, and achieving reliable and stable bond to zirconia remains a challenge [10,11]. As zirconia has a polycrystalline structure and limited vitreous phase, neither hydrofluoric acid etching nor silanization can achieve durable zirconia-resin bonding [10]. Thus, various surface treatments have been introduced to establish durable adhesion between zirconia and dental resin cement.

For chemical bonding, many studies have shown that functional monomers containing 4-methacryloyloxyethyl trimellitate anhydride (4-META) and 10-methacryloyloxydecyl dihydrogen phosphate (MDP) act as coupling agents [11–13]. Moreover, recent studies showed that zirconia primers and chemically adhesive resin cements have reliable bond strength [13,14].

For mechanical interlocking, airborne-particle abrasion has been used to clean the surface, removes impurities, increases surface roughness, and modify the surface energy and wettability. In addition, airborne-particle abrasion provides the mechanical impingement of particles on the surface [15–17], which results in a roughened surface and allows the resin cement to flow into these micro-retentions and creates a stronger micromechanical interlock [18]. Airborne-particle abrasion with alumina has been identified as a key factor in achieving a durable bond for zirconia-based ceramics [19–21]. Different sizes of abrasive alumina particles have been used, without evidence of the superiority of one over another [10–12,22]. However, recent *in vitro* studies report that airborne-particle abrasion may have a deleterious effect on the zirconia surface due to the creation of microcracks, which might reduce the flexural strength [23,24]. Moreover, the tetragonal phase of Y-TZP is converted to the monoclinic phase with volume expansion (4–5%) under the high stresses caused by airborne-particle abrasion, and this unique transformation can produce different types of damage that affect the structural integrity and material reliability [25,26]. Specifically, this process may result in an increase in the crack propagation resistance of Y-TZP for a certain period of time, functioning as a toughening mechanism [17,27]. Conversely, since the presence of the monoclinic structure is unstable and stressful, there is a higher tendency for the zirconia ceramic in this phase to be fragile. Thus, it may result in an increase in the fracture tendency over the longer term [23,28,29]. The counteracting effects of airborne-particle abrasion on the flexural strength of Y-TZP are controversial in terms of effective power and duration of abrasion, and the role of surface flaws acting as the stress concentrators relative to the stress-induced surface compressive layer [23,30,31].

Although several surface treatments have been recently described [10,18,32–39], the selection of the most appropriate airborne-particle abrasion protocol on for Y-TZP remains controversial. Moreover, no literature describing the phase transformation of monolithic zirconia under various airborne-particle abrasion protocols could be found. Thus, it is necessary to determine the optimum protocol for airborne-particle abrasion for monolithic zirconia restoration, in order to consistently achieve a more favorable clinical outcome.

This study was aimed to evaluate several airborne-particle abrasion protocols and to determine how they affect monolithic zirconia in terms of flexural strength, surface characteristics, and reliability. The shear bond strength between the abraded monolithic zirconia and resin cement was also evaluated. The null hypothesis to be tested was that there was no difference in flexural strength, surface characteristics or shear bond strength of resin cement before and after thermocycling among groups treated with various airborne-particle abrasion protocols.

2. Materials and methods

2.1. Evaluation of microstructural changes in airborne-particle abraded monolithic zirconia ceramic

2.1.1. Preparation of the specimens

Three-hundred seventy-five specimens ($45\times4\times3$ mm^3) of densely sintered high-purity monolithic zirconia ceramic (Zmatch, Dentaim, Seoul, Korea) – which consisted of 94–95% ZrO_2 and HfO_2, $5\pm0.2\%$ Y_2O_3 and $\leq0.25\%$ Al_2O_3 – were fabricated. The samples, denoted ‘as-received’, were wet ground in sequence, first with 300 grit diamond grinding disk and sequentially with 6, 3 and 1 μm diamond slurry. The grinding and polishing were performed in order to minimize surface defects on the specimens before testing.

2.1.2. Surface treatment with alumina air abrasion

Bar-shaped specimens were randomized into 25 groups ($n=15$), and for each group a different surface treatment was applied to the top surface of the specimens (Group B to Y). Group A was the control group, with the surface remaining in the ‘as-received’ state for comparison. For alumina particle abrasion, the specimens were mounted in a sample holder at a distance of 10 mm from tip of the sandblaster unit (AX-B3, AxianMedical Co., Tianjin, China), equipped with a 5 mm diameter nozzle. Specimens were abraded with 25, 50 or 125 μm alumina particles (Cobra, Renfert GmbH, Hilzingen, Germany) at an air pressure of 2 or 4 bar for 10 or 20 s. The incidence angle of particle delivery was maintained at either 45° or 90°. The airborne-particle abrasion protocols for each group are shown in Table 1.

2.1.3. X-ray diffractometry and Raman spectroscopy analyses

Before and after the airborne-particle abrasion, randomly selected specimens from each group were examined to determine the crystalline phases by X-ray diffractometry (D8 DISCOVER, Bruker, Karlsruhe, Germany). X-ray diffraction data was collected using 2θ diffractometer and Cu-Kα radiation. The diffractogram was obtained from 20° to 40° at a scan speed of 5°/min and a step size of 0.02°, covering the location of the highest peaks of t and m phases. The monoclinic phase peak