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Original article

Effect of electrical discharge machining on dental Y-TZP ceramic-resin bonding☆

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ABSTRACT

Purpose: The study determined (i) the effects of electrical discharge machining (EDM) on the shear-bond strength (SBS) of the bond between luting resin and zirconia ceramic and (ii) zirconia ceramic's flexural strength with the three-point bending (TPB) test.
Methods: Sixty 4.8 mm $\times$ 4.8 mm $\times$ 3.2 mm zirconia specimens were fabricated and divided into four groups ($n = 15$): SBG: sandblasted + silane, TSCG: tribochemical silica coated + silane, LTG: Er:YAG laser treated + silane, EDMG: EDM + silane. The specimens were then bonded to a composite block with a dual-cure resin cement and thermal cycled (6000 times) prior to SBS testing. The SBS tests were performed in a universal testing machine. The SBS values were statistically analyzed using ANOVA and Tukey's test. To determine flexural strength, sixty zirconia specimens were prepared and assigned to the same groups ($n = 15$) mentioned earlier. After surface treatment TPB tests were performed in a universal testing machine (ISO 6872). The flexural strength values were statistically analyzed using ANOVA and Tukey's test ($\alpha = 0.05$).
Results: The bond strengths for the four test groups (mean $\pm$ SD; MPa) were as follows: SBG (Control), 12.73 $\pm$ 3.41, TSCG, 14.99 $\pm$ 3.14, LTG, 7.93 $\pm$ 2.07, EDMG, 17.05 $\pm$ 2.71. The bond strength of the EDMG was significantly higher than those of the SBG and LTG ($p < 0.01$). The average flexural strength values for the groups SBG (Control), TSCG, LTG and EDMG were 809.47, 800.47, 679.19 and 695.71 MPa, respectively ($p > 0.05$).
Conclusions: The EDM process improved the SBS. In addition, there was no significant adverse effect of EDM on the flexural strength of zirconia.

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1. Introduction

Since the first days of its introduction zirconia ceramic has been a prevalent material in the dental market. It is possible to use zirconia ceramic in an extensive area of clinical situations, including posts, fixed dental prostheses, implant abutments, orthodontic brackets and resin bonded partial dentures [1]. Zirconia is impregnated with a small amount of yttria (Y_2O_3) to form yttria tetragonal zirconia polycrystals (Y-TZP) a process which enhances its mechanical properties namely flexural strength, fracture toughness and wear resistance, compared to most other metal-free ceramics [2]. However a limitation on the clinical use of Y-TZP ceramic is a deficiency in luting with adhesive resin cements. Due to a lack of silicon dioxide and glass phase, ordinary methods of cementation, including ceramic silanization and hydrofluoric acid etching, do not work effectively for zirconia [3–5]. Current research is therefore focusing on innovative adhesive techniques, coupled with innovative surface roughening procedures [6,7], laser treatments [8,9] and chemical bonding of Y-TZP ceramics. It may not be possible to obtain reliable resin bond strength as the conventional surface roughening technique (airborne particle abrasion) can create an insufficiently coarsened zirconia surface [10]. Many couplers have been included in the process of achieving chemical adhesion to zirconia. An improvement was achieved in the luting of zirconia through the use of various silane coupling substances. It is believed that surface wetting is triggered by silanes and this improves the probability of micromechanical retention with resin cements of low viscosity [11,12]. In spite of these advances, chemical bonding is still susceptible to hydrolytic degradation [13]. For this reason, in addition to these improvements in chemical bonding techniques, the effort to develop surface roughening techniques to achieve micromechanical retention continues.

Electrical discharge machining (EDM) is a nonconventional process, that creates a desired shape by eroding material with electrical sparks in a dielectric medium [14,15]. The process was introduced into dentistry by Rubeling in 1982 to produce precision attachments [16]. In the same year, Windeler AS gained a patent for improving the fit of cast restorations through EDM and since 1990 it has been used widely in implant prostheses [17]. Later this method was implemented the dental laboratory to fabricate precision attachments, telescoping crowns, titanium implant-retained restorations, and bar-retained metal super structures for fixed removable implant prostheses [18,19]. EDM has also been utilized to correct casting inaccuracies in both hybrid-implant prostheses and UCLA-type implant abutments [20].

Any electrically conductive material can be machined via this method, regardless of its hardness, shape or strength [21]. However, it was reported that a resistivity lower than 100 Ω cm is necessary for any material to be machined with EDM [22]. If that is the case, zirconia would be categorized as a nonconductive material for EDM purposes as its resistivity is nearly 10^9–10^{10} Ω cm. Subsequently, Kucukturk and Cogun developed a new method in 2010 (currently underpatent protection) [23] to machine of electrically nonconductive workpieces with EDM. In this method graphite powder is mixed with the dielectric liquid and the maching is achieved via a conductive coating layer (CL) on the workpiece surface. Kucukturk and Cogun further reported the highest material removal rate of material and the most stable machining regime for ZrO_2 (via addition of Y_2O_3) ceramic workpieces [24].

In the literature, there is no published work on the resin bonding to electrical discharge machined zirconia ceramic surfaces due to the impossibility of employing EDM with this electrically nonconductive material. Therefore the purpose of the current research was to develop a new surface treatment for better zirconia-resin bonding; that method was to be based on the EDM technique of Kucukturk and Cogun [24] We hypothesized that; the proposed non-conventional EDM treatment, (1) enhances the shear-bond strength (SBS) between zirconia and resin cements, (2) does not trigger significant internal deterioration of zirconia ceramic.

2. Materials and methods

2.1. SBS tests

The compositions and manufacturers of materials used in this study are listed in Table 1.

2.1.1. Specimen preparation for shear bond strength testing

Sixty Y-TZP specimens (6 mm × 6 mm × 4 mm) were cut from pre-sintered green zirconia blanks with a low-speed saw (Isomet 1000, Buehler) with diamond cutting disk (Series 15 LC Diamond) under water cooling. The specimens were then sintered in a sintering furnace (CeramillTherm) for 2 h at 1500 ± 15 °C, as recommended by the Y-TZP manufacturer. After sintering, the dimensions of the specimens were reduced to 4.8 mm × 4.8 mm × 3.2 mm due to shrinkage (~20 vol.% shrinkage). Forty-five sintered specimens were embedded in acrylic resin blocks while ensuring that one of the surfaces remained exposed for surface treatment and silane application. Finally, all specimens were ground finished with SiC abrasive paper of 600, 800 and 1000 grit and cleaned ultrasonically in deionized water before the surface treatments.

2.1.2. Surface treatments

In present study, forty-five zirconia specimens embedded in acrylic resin blocks were divided into three groups (fifteen specimens in each group) and fifteen zirconia specimens placed on brass molds were subjected to the following, four different surface treatments:

SBG (sandblasted specimens group): Surfaces of the specimens were sandblasted from a distance of 10 mm for 15 s at 2.8 bar pressure with Al_2O_3 particles with average particle size of 110 μm. Subsequent to ultrasonic cleaning with deionized water and drying, Clearfill ceramic primer was applied with a single use brush and curing (hardening) for 4 min.

TSCG (tribochemical silica coated specimens group): Initially, the surfaces of the specimens were air abraded with Rocatec pre-particles for 10 s at a pressure of 2.8 bars and then, air abraded with silica coated Rocatec plus particles for 13 s at the same pressure. Afterwards, the surface was air dried gently and silane 3M Espe SIL was applied to the surface with a single use brush, followed by 4 minutes of curing.

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