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BONDING OF CERAMIC ORTHODONTIC BRACKETS TO FELDSPATHIC CERAMIC RESTORATIONS - ORIGINAL ARTICLE

БОНДИРАЊЕ НА КЕРАМИЧКИ ОРТОДОНТСКИ БРЕКЕТИ НА ФЕЛДСПАТНИ КЕРАМИЧКИ РЕСТАВРАЦИИ

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Abstract

Aim of the study: To determine a conditioning protocol of feldspathic restorations in order bonding ceramic orthodontic brackets during fixed orthodontic treatment. **Material and method:** 45 ceramic specimens were obtained from feldspathic CAD/CAM blocks which were divided into five groups according to the performed conditioning method: 1. deglazing with a fine diamond bur (control group); 2. etching with 4% hydrofluoric acid (HF); 3. sandblasting with 29 µm alumina (Al2O3); 4. HF acid etching followed by conditioning with a universal primer - silanization (HF + S) and 5. alumina sandblasting followed by silanization (Al2O3 + S). A shear bond strength (SBS) test was performed after storing the samples in a water bath for 7 days. All of the fractured samples were analyzed with an optical microscope to determine the mode of fracture. **Results:** Etching with 4% hydrofluoric acid followed by silanization resulted in the highest bond strength - 9.68±1.19 MPa (95%CI 8.4-10.9), while alumina sandblasting followed by silanization – 6.62 MPa, which was non-significantly higher than HF acid etchingalone-5.62 MPa. Adhesive types of fractures were observed in the samples where only mechanical conditioning methods were used. In contrast, cohesive and mixed fractures were noted in samples treated with mechanical and chemical methods. **Conclusion:** Authors suggest that the optimal conditioning method when bonding ceramic brackets to restorations made of Mark II feldspathic ceramic is etching with 4% hydrofluoric acid, which ensures adequate bond strength during the fixed orthodontic treatment and prevents damage to the restoration during debonding of the brackets at the end of the orthodontic treatment. **Key words:** Ceramic brackets; Feldspathic ceramic; Conditioning methods; Hydrofluoric acid; Sandblasting; Silanization; Shear bond strength.

Апстракт

Цел на трудот: Главната цел на трудот е одредување на протокол за кондиционирање на фелдспатни керамички реставрации пред бондирањето на керамички ортодонтски брекети во текот на фиксен ортодонтски третман. **Материјал и метод:** 45 керамички примероци добиени од фелдспатни CAD/CAM блокови беа поделени во пет групи според извршениот метод на кондиционирање на бондирачката површина: 1. Деглазирање со фин дијамантски борер (контролна група); 2. Нагризување со 4% флуороводородна киселина (HF); 3. Песочење со 29 µm алуминиум триоксидни зрна (Al2O3); 4. Нагризување со 4% HF киселина проследено со силинизација со универзален прајмер (HF + S); 5. Песочење со Al2O3 проследено со силанизација (Al2O3 + S). Тестот за одредување на силата на смолкнување (SBS) беше спроведен по складирање на примероците во водена бања (37°C) во траење од 7 дена. Сите бондирачки површини по дебондирањето на брекетите беа анализирани со оптички микроскоп со цел да се одреди типот на фрактура. **Резултати:** Нагризувањето со 4% флуороводородна киселина проследено со силанизација оствари највисока јачина на врзување (SBS) - 9,68±1,19 MPa (95%CI 8,4-10,9), додека песочењето проследено со силанизација - 6,62 MPa, што е несигнификантно повисоко од нагризувањето со HF киселина - 5,62 MPa. Атхезивниот тип на фрактура беше доминантен кај примероците каде кондиционирањето се спроведе користејќи исклучиво механички методи, додека зголемен процент на кохезивни и мешани фрактури беше забележан кај примероците каде што се користеа механички и хемиски методи за алтерирање на керамичките бондирачки површини. **Заклучок:** Авторите сугерираат дека оптималниот метод на кондиционирање на реставрации изработени од Mark II фелдспатна керамика при бондирање на керамички ортодонтски брекети, е нагризување со 4% флуороводородна киселина, што обезбедува соодветна јачина на бондирање од една страна и оневозможува оштетување на реставрацијата при дебондирање на брекетите на крајот од ортодонтскиот третман од друга страна. **Клучни зборови:** Керамички брекети; Фелдспатна керамика; Методи за кондиционирање; Флуороводородна киселина; Воздушна абразија; Силанизација; Сила на смолкнување.

Introduction

With the increased number of adult orthodontic patients, clinicians often have to bond orthodontic brackets to teeth that have different types of restorations. One of the materials that have particularly presented problems to both the operative dentists and the orthodontists is ceramic due to its inert nature. Therefore, many attempts have been made to determine the conditioning method for altering the ceramic bonding surfaces, which will enable optimal bonding of orthodontic brackets[1]. There are different conditioning methods, which may be classified as mechanical, chemical, or mechanical-chemical methods.

In cases of natural teeth, the enamel surfaces on which the brackets will be bonded are etched using 37% phosphoric acid. However, in the presence of ceramic restorations, different protocols are required for etching the ceramic bonding surfaces due to their greater resistance to acids[2]. One of the mechanical methods for altering the ceramic surfaces is by etching with hydrofluoric acid. Clinicians should be very cautious when manipulating doing manipulations with this type of acid due to its corrosive and toxic effects on human tissues, including oral mucosa[3]. In addition, other conditioning methods can also be performed: sandblasting with 29 or 50 µm alumina particles, silicatization - sandblasting with silica-coated alumina particles.

Enhancing the bond between the ceramic brackets and ceramic restorations can be achieved by changing the nature of the bonding surface, using coupling agents such as ceramic primers or universal primers that contain silanes (chemical method). The silane contains two different functional groups: the hydrolyzable group that reacts with the inorganic ceramic, whereas its organofunctional group reacts with the resin, thus enhancing adhesion. Silanes are also known as adhesion promoters as they are adsorbed onto, altering the surface of a solid material (in this case ceramic) by either a chemical or physical process. The portion of the silane molecule that is not adsorbed presents a free surface that is wetted easily by adhesives. It is found that the silane coupler actually forms a chemical bond with both the resin and the porcelain, thus forming a bridge between the two materials[4]. In order to achieve a strong chemical bond with the adhesive resin, the process of silanization should be performed after altering the porcelain surfaces with mechanical conditioning methods[5].

The third method provides chemo-mechanical alteration of the ceramic bonding surfaces, which is performed with silica-coated alumina particles, known as silicatization.

The desired outcome of bonding the brackets to teeth previously restored with ceramic restorations is to provide an optimal bond that will be able to withstand the forces produced during the orthodontic treatment, as well as mastication, without displacement/debonding the brackets. On the other hand, the achieved bond strength should not be too strong so it can prevent any damage to the ceramic restoration during the debonding process of the brackets at the end of the orthodontic treatment when the detachment is preferred to occur at the bracket–adhesive interface[6]. The aim of this study was to determine a conditioning protocol of feldspathic restorations in order to bond ceramic orthodontic brackets during fixed orthodontic treatment.

Material and method

Feldspathic CAD/CAM ceramic blocks Vita Mark II (VITA Zahnfabrik, Germany) (Fig. 1a) were cut by a precision cutting machine - Minitom (Struers, Denmark) using diamond blades, into 2 mm thick ceramic sections (Fig. 1b). Cutting was performed with permanent water cooling to prevent overheating of the ceramic material that may cause micro-cracks. The ceramic sections had rectangular shapes with a flat bonding surface, unlike ceramic restorations' vestibular surface designed with slight convexities imitating the morphology of the natural teeth. The anatomo-morphology of the restoration may influence the bond strength due to the unequal contact of the bracket and the bonding surface.

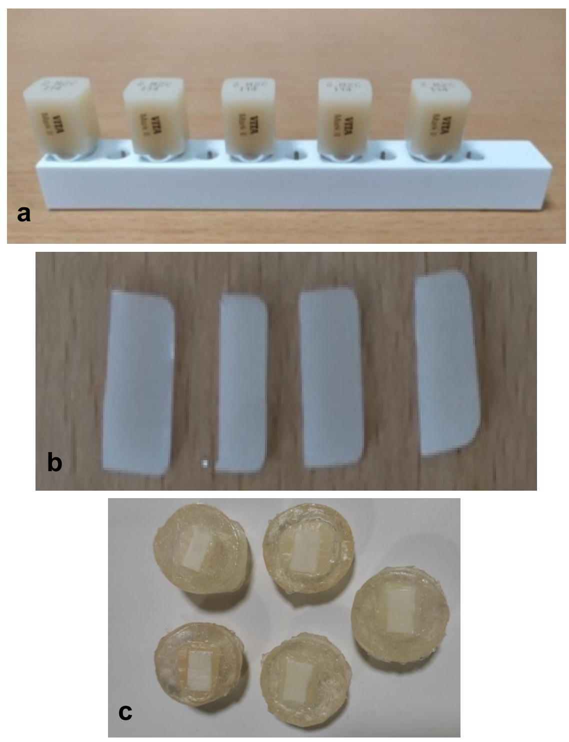

Figure 1. a) Feldspathic CAD/CAM ceramic blocks; b) Ceramic sections; c) Prepared acrylic molds with ceramic samples.

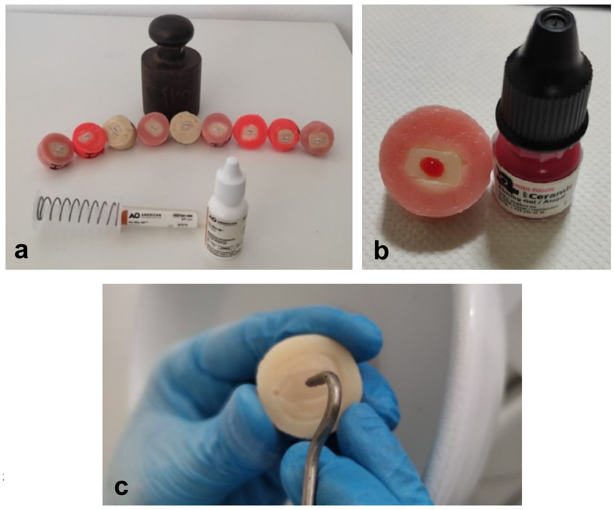

Figure 2. a) Control group; b) Etching the samples with 4% hydrofluoric acid; c) Sandblasting.

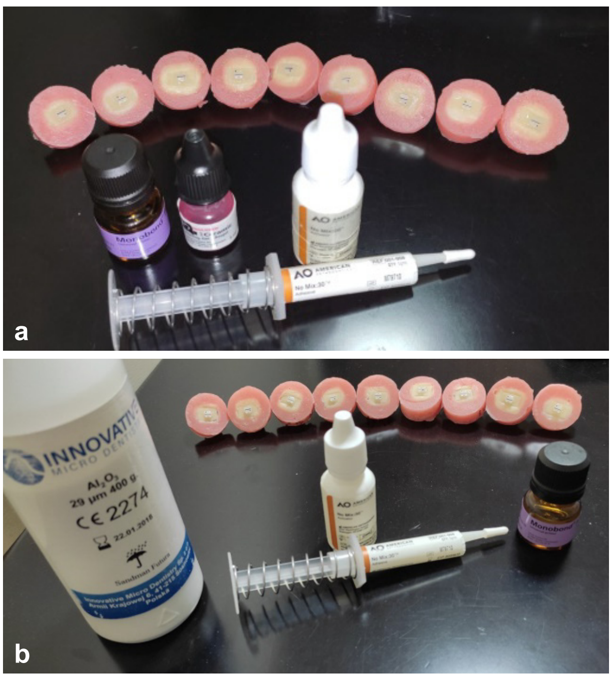

Figure 3. a) Prepared samples - group 4; b) Prepared samples -group 5.

Acrylic molds were prepared in the next step: the ceramic sections were immersed in the middle of the metal ring molds (d =30 mm) filled with freshly mixed auto-polymerizing acrylate – PoliTEMP (PoliDent, Slovenia), with an exposed ceramic surface that was used as a bonding surface for the ceramic brackets (Fig. 1c). Before the beginning of the conditioning treatments, the bonding surface of all samples was grinded using fine diamond burs. The prepared 45 samples were randomly divided into five groups:

1. **Control group** – no treatment (Fig. 2a).
2. **HF** - the ceramic samples were treated with 4% hydrofluoric acid - IPS Ceramic etching gel (Ivoclar Vivadent, Shaan Liechtenstein) for 60 seconds followed byrinsing for 60 seconds with copious water, and air dried with compressed air (Fig. 2b).
3. **Al_2O_3** - the bonding surfaces were sandblasted with 29-µm Al_2O_3 particles – Sandman (Innovative Micro Dentistry, Poland), perpendicular to the bonding surface, for 10 seconds, under a pressure of 1 bar and at 10 mm distance (Figure 2c). Surfaces were cleaned with air blowing for 5 sec.
4. **HF+S** - the bonding surfaces were etched with 4% hydrofluoric acid for 60 s, rinsed, and dried. A universal primer, Monobond Plus (IvoclarVivadent, Shaan Liechtenstein), was applied in a thin coat and left to react for 60 seconds (Fig. 3a).
5. **Al_2O_3+S** - the bonding surfaces were sandblasted with 29-µm Al_2O_3 particles using a blasting procedure as in Group 3. After that, a universal primer, Monobond Plus, was applied in a thin coat and left to react for 60 seconds (Figure 3b).

Bonding procedure

Ceramic brackets for maxillary central incisors – Cosmetic 20/40 UR Central (American Orthodontics, USA) were bonded to treated surfaces using orthodontic composite luting cement (self-curing adhesive) No Mix:30TM One step Adhesive – (American Orthodontics, USA) with a constant vertical load of 1 kg, for 1 min. The samples were stored in distilled water at 37°C for 7 days – Biobase Water Tank WT-42 (Biobase Biodustry, Shandong, China), thus imitating the conditions in the oral cavity (moisture and temperature) (Fig. 4a).

Shear bond strength test

The shear bond strength test (SBS) was performed using a universal testing machine – Shimadzu AGS-X (Shimadzu Co., Japan), at a speed of 0.5 mm/min until

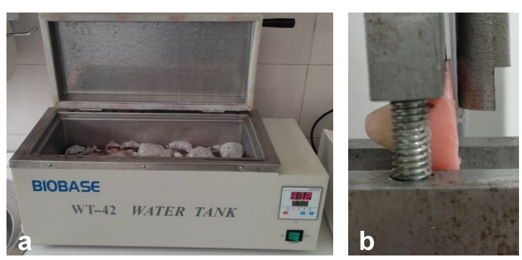

Figure 4: a) Samples stored in a water bath, b) Performing of shear bond strength (SBS) test.

fracturing occurred, to determine the bond strength between the orthodontic brackets and the ceramic surfaces (Figure 4b). The SBS was expressed in megapascals (MPa), derived by dividing the imposed force (N) at the time of fracture by the bonding area of the ceramic bracket (mm2) (MPa = N/mm^2).

Mode of fracture

The mode of fracture (adhesive, cohesive in luting cement or ceramic bracket or mixed) for each specimen was determined using optical microscopy – Levenhuk Zeno Cash ZC6 (Levenhuk Inc., USA) at a magnification of 60x.

Statistical Analysis

The categorical variables were analyzed by determining the coefficient of relationship, proportions, and rates. Continuous variables were analyzed using measures of central tendency (mean, median, minimum, and maximum values) and by measuring dispersion (standard deviation). Shapiro-Wilk W test was used to determine the normality of the frequency distribution of the studied variables. Pearson's chi-squared test was used to determine the association between certain attributive dichotomous features. The One-way ANOVA test was used to compare the Shear bond strength (SBS) values for multiple independent continuous variables with correct frequency distribution. In addition, Tukey post hoc (HSD) was used in order to determine the size of the effect of the determined significance between the variables.

Results

The mean values of the shear bond strength (SBS) after the various treatments of the ceramic bonding surfaces are shown in Figure 5, and the percentage values of the mode of fracture after the debonding areshown in Table 1.

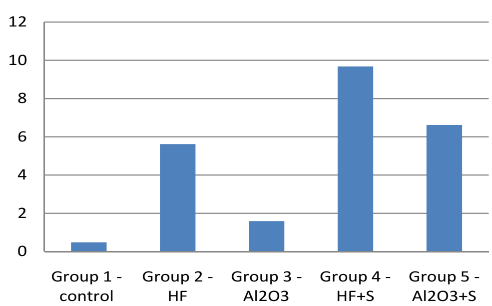

***Figure 5.** Mean SBS (MPa) after different conditioning treatments.*

Table 1. Mode of fracture after debonding.

Mode of fracture			
	Adhesive (%)	Cohesive (%)	Mixed (%)
Group 1	100	/	/
Group 2	77.7	11.1	11.1
Group 3	100	/	/
Group 4	/	85.7	14.3
Group 5	22.2	66.6	11.2

The highest mean SBS of 9.68±1.19 MPa (95%CI 8.4-10.9) with min/max values of 8.1/11.5 MPa was recorded in Group 4 (HF+S), which was significantly higher compared to all other groups. The mean SBS value of Group 5 (Al2O3+S) was 6.62 MPa,which shows a non-significantly higher value (p=0.6856) than Group 2 (HF) with a mean value of SBS of 5.62 MPa. Group 3 (Al2O3) provided a low mean SBS value of 1.59 MPa, which is not significantly higher (p=0.3629) compared to the control group.

An adhesive mode of fractures can be observed in the samples of the first three groups where only mechanical conditioning methods were used. An increased percentage of cohesive and mixed fractures is noted in Groups 4 and 5, where mechanical and chemical methods were performed to alter the ceramic bonding surfaces.

Discussion

The aim of this study was to investigate the SBS between orthodontic ceramic brackets and monolithic CAD/CAM ceramic Vita Mark II after different conditioning methods of the feldspathic bonding surface and mode of fracture after debonding the brackets. High SBS values were achieved in the ceramic samples that were altered using mechanical and chemical methods (etching with hydrofluoric acid or alumina sandblasting, with the additional application of a universal primer) and in the ceramic samples that were etched with HF acid only. Lower SBS was observed when sandblasting was the only conditioning method without the application of a universal primer, while the lowest SBS values were found in the control group; that means that if the ceramic bonding surfaces are not altered and conditioned, then sufficient bond strength between the orthodontic brackets and the ceramic bonding surfaces cannot be expected.

When bonding orthodontic brackets to ceramic restorations, it is necessary to change the inert ceramic surface to achieve clinically acceptable bond strength. The maximum bond strength that may be achieved is not usually required for orthodontic purposes. The ideal bond strength should be sufficiently strong to endure a course of orthodontic treatment and, at the same time, be sufficiently weak so not to cause any damage to the restoration during the debonding process when the orthodontic treatment is finished[7]. If the SBS exceeds 13 MPa, fracture of the ceramic surface can be expected. According to Schmage et al., the SBS value of 6 to 10 MPa is sufficient to ensure adequate bond strength between the orthodontic brackets and the ceramic surfaces[8].

The results of Türkkahraman's study show that the highest SBS values are detected when porcelain surfaces are treated with hydrofluoric acid followed by the application of a silane coupling agent. When ceramic materials are etched with 9.6% HFA, a double reaction occurs: primary - between the acid and the glassy phase, and secondary - between the acid and the crystalline phase, leaving the larger crystals intact. This creates an irregular surface with microscopic pores that enable the micromechanical retention of the adhesive resin[9]. There is a greater resistance of the ceramic to the acid etching when the crystalline phase is more present than the glassy phase in the composition of the ceramic material[2]. Ajouni et al. proved that etching with hydrofluoric acid and primer conditioning provided the strongest bond of orthodontic brackets to ceramic, but at the same time caused the greatest damage to the ceramic surfaces during debonding[1]. According to Bishara et al., the most reliable bonding procedure of orthodontic brackets to porcelain surfaces is micro-etching with hydrofluoric acid and conditioning with a silane coupler; this combination also produces the greatest damage to the porcelain surface[10].

Sandblasting as a method for mechanical alteration of the bonding surfaces of ceramic restorations causes an irregular surface required for micromechanical retention of the adhesive resin. On the other hand, sandblasting can cause irreversible damage to the ceramic restorations. Therefore, it is recommended that sandblasting should be performed under low pressure (1-2 bar), using aluminum oxide grains with a size smaller than 50 μm and at a distance of 10 mm from the surface being treated. In Türkkahraman's study, it was concluded that silane application to sandblasted ceramic provides poor results in vitro, and clinical trials are needed to determine its reliability for bonding ceramic brackets to ceramic crowns[9]. Also, Zachrisson reported that silane application to sandblasted ceramic did not provide clinically acceptable bond strength and suggested abandoning this technique[11].

The application of a silane coupling agent may produce such high bond strength with a tendency for cohesive fractures of ceramic surfaces during the debonding process, especially when the bonding surfaces have been acid-etched[12]. Newman reported that the bond strength between the resin and porcelain, achieved by using a silane, was sufficient to cause fracturing of the porcelain. Such an occurrence is undesirable when associated with the removal of orthodontic brackets from porcelain crowns on restored teeth[4]. On the other hand, literature data show that the use of a silane coupling agent as the only conditioning method of the ceramic surfaces does not provide long-term bond strength due to the susceptibility of the chemical bonds to hydrolysis[13].

Determining the optimal conditioning treatment for ceramic restorations is largely dependent on the analysis of fracture mode after debonding. The adhesive mode of fracture usually occurs when weaker bond strength is present between ceramic restorations and orthodontic brackets. During the optical microscopy analysis of the ceramic surfaces, no residue of the adhesive resin was observed on the bonding surfaces. The cohesive type of fracture, on the other hand, was often present in the samples that were treated with methods that achieved higher bond strength with the orthodontic brackets, whereby residue from the adhesive resin was observed on the ceramic surfaces. In some cases, parts of the fractured ceramic brackets that remained bonded to the ceramic surface could also be observed.

Despite the significance of this topic for the success of orthodontic treatment, there remains a noticeable gap in the existing literature. The limited number of studies addressing this issue highlights the need for further investigation to develop a more comprehensive understanding and guide future research, with an emphasis on clinical trials.

Conclusions

The authors suggest that the optimal conditioning method when bonding ceramic brackets to teeth restored with Mark II feldspathic ceramic is etching with 4% hydrofluoric acid, which ensures adequate bond strength and most adhesive modes of fracture during the debonding process.

As an alternative conditioning method, the authors suggest the use of alumina sandblasting followed by chemical conditioning with a universal primer.

Additional clinical trials are needed to verify which suggested conditioning method offers an optimal bond.

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