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Original scientific paper

Air abrasion or silicatization – optimal conditioning method for zirconium dioxide prosthetic restorations due to the bonding of ceramic orthodontic brackets

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Abstract

According to the results obtained from the survey of the American Orthodontic Society conducted in 2015, the number of adult patients that requested orthodontic treatment was increased from 14% to 27% between 2010 and 2014. Because of the increased age of the patients, fixed orthodontic treatment is expected to be performed on restored teeth as well. The aim of the present study was to evaluate the bond strength of the ceramic brackets bonded to the zirconium dioxide ceramic surfaces after air abrasion or silicatization as a single method of mechanical conditioning and their combination with the use of a universal primer. In this research, zirconium dioxide CAD CAM blocks were used for the experimental phase. The following conditioning treatments were performed: group 1 - direct bonding of the ceramic brackets, group 2 – air abrasion with 29 μm aluminum oxide (Al_2O_3), group 3 – silicatizaion with 30 μm aluminium oxide coated with silicium dioxide (Al_2O_3 x SiO_2), group 4 - air abrasion combined with universal primer, group 5 – silicatization combined with universal primer. It was observed that the treatment from group 5 achieved the highest average value of shear bond strength SBS (MPa): 30 μm Al_2O_3 x SiO_2 + universal primer - 9.32±1.29 (95%CI 8.3-10.3) MPa with min/max values of 7.6/11.1 MPa. In group 1, the lowest average value of SBS was established by 0.51±0.12 (95%CI 0.4-0.6) MPa with min/max values of 0.4/0.8 MPa. After evaluation of the obtained results, it was concluded that air abrasion followed by the application of a universal primer can be considered as an adequate method for conditioning the zirconium dioxide ceramic bonding surfaces.

Key words: ceramic brackets, conditioning methods, zirconium restorations, air abrasion, silicatization

Introduction

Text In daily clinical practice, orthodontic treatment with orthodontic brackets can be expected in some situations to be performed on dentition previously treated with fixed-prosthetic restorations - metal-ceramic or all-ceramic crowns or veneers. On the other hand, debonding of the brackets is an often problem encountered by orthodontists, which is why dental appointments are scheduled more often and associated with re-implementing the entire procedure for rebonding the brackets. According to the results obtained from the survey of the American Orthodontic Society conducted in 2015, the number of adult patients that requested orthodontic treatment was increased from 14% to 27% between 2010 and 2014 implying on the fact that the number of adult orthodontic patients has doubled in just 4 years (Alzainal et al., 2020). Because of the increased age of the patients, fixed orthodontic treatment is expected to be performed on restored teeth as well. It can be concluded that with the increase in the number of adult patients in need of orthodontic treatment, the presence of fixed-prosthetic restorations to which the orthodontic brackets will have to

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be bonded could be expected. Obtaining an adequate bonding between the restorations and the brackets is of primary importance for the successful implementation of the entire orthodontic treatment. At the same time, the bond strength should not be too strong in order to avoid damage to the ceramic surfaces during the debonding process of the brackets at the end of the orthodontic treatment (Alzainal et al., 2020). Zirconium dioxide ceramics are not susceptible to etching by acids like glass ceramics, due to the absence of a glass phase which makes it impossible to build an efficient bond during the process of adhesive cementation (in the case of bonding ceramic brackets). For those reasons, it is necessary to find the most efficient method and establish a standard protocol for adhesive cementation of ceramic brackets to zirconium dioxide ceramic restorations (Scaminaci Russo et al., 2019). Air abrasion using aluminum oxide is a method for mechanical conditioning of the bonding surfaces of zirconium dioxide ceramic restorations. After air abrasion treatment, an irregular surface is created with microscopic pores, which are required for micromechanical retention of the bonding agent. On the other hand, air abrasion can cause irreversible damage to the zirconium dioxide ceramic restorations. Therefore, it is recommended that sandblasting should be performed under low pressure (1-2 bar), using aluminum oxide grains with a size of less than 50 μm and at a distance of 10 mm from the ceramic surface (Kern et al., 2009). Because of the resistance to etching, some authors have proposed applying a silica-rich layer to the zirconia surface; in that way the ceramic would acquire the glass phase that is absent and behave as a glass ceramic. Silication (tribochemical silica coating – TBS) is a method for conditioning zirconium dioxide ceramics in order to obtain better adhesion, and is based on sandblasting with aluminum trioxide grains coated with silicon dioxide. When the grains hit the ceramic surface, silicon dioxide particles are released and due to the generated heat, the particles are getting incorporated into the surface, or in other words, they become an integral part of the zirconium dioxide ceramic. The creation of the glass layer on the zirconium dioxide ceramic surface allows the use of silane as a conditioning and bonding agent to the cement. The silane molecule has two different functional groups: the -SiOH group that bonds to the hydroxyl groups of the silica layer and another functional group that bonds to the methacrylate resin of the composite cement (Lung et al., 2015). The use of a universal primer, which contains both silane and 10-MDP monomer, allows obtaining a better connection during bonding procedure, because in some areas of the zirconium dioxide ceramic surface where silicate particles have not been incorporated, the connection with the composite cement is achieved through the mediation of the primer based on 10-MDP (Xie et al., 2016)

The aim of the present study was to evaluate the bond strength of the ceramic brackets bonded to the zirconium dioxide surfaces after different conditioning methods of the ceramic surface using air abrasion or silicatization as a single method of mechanical conditioning and their combination with the use of a universal primer, mechanical –chemical method of conditioning.

Material and methods

Zirconium dioxide CAD/CAM blocks were used for the experimental phase of the research (Fig. 1a). In the first phase of the experiment, using a Minitom precise cutting machine and diamond cutting discs, the CAD/CAM blocks were cut into 2 mm thick ceramic samples, imitating the surface of an average ceramic restoration (Fig. 1b). Cutting was performed with permanent water cooling to prevent overheating of the ceramic material that could cause microcracks. The ceramic samples had a flat bonding surface, in contrast to the convex vestibular surfaces of the ceramic restorations (where the brackets are bonded), thus it may have an impact on the bond strength due to the unequal contact of the bracket and the bonding surface. The CAD/CAM blocks were in presintered form and therefore, after obtaining the ceramic samples, they were sintered in order to acquire all physical and mechanical characteristics (primarily the hardness). The experimental phase continued with the preparation of acrylic molds in which the ceramic samples were fixed. Dimensionally identical metal ring molds (d = 30 mm) were filled with cold-polymerizing acrylate. During the working phase of the acrylate polymerization, the ceramic samples were placed in the middle of the ring molds and immersed in the acrylate, leaving one surface exposed; that surface, in the further experiment, was used as a bonding surface for the ceramic brackets (Fig. 1c). Before the beginning of the treatments, the bonding surfaces of all the samples was deglazed using a diamond drill with fine granularity of the grains - marked with a red ring. The bonding of the ceramic brackets was achieved by controlled pressure of 1 kg.

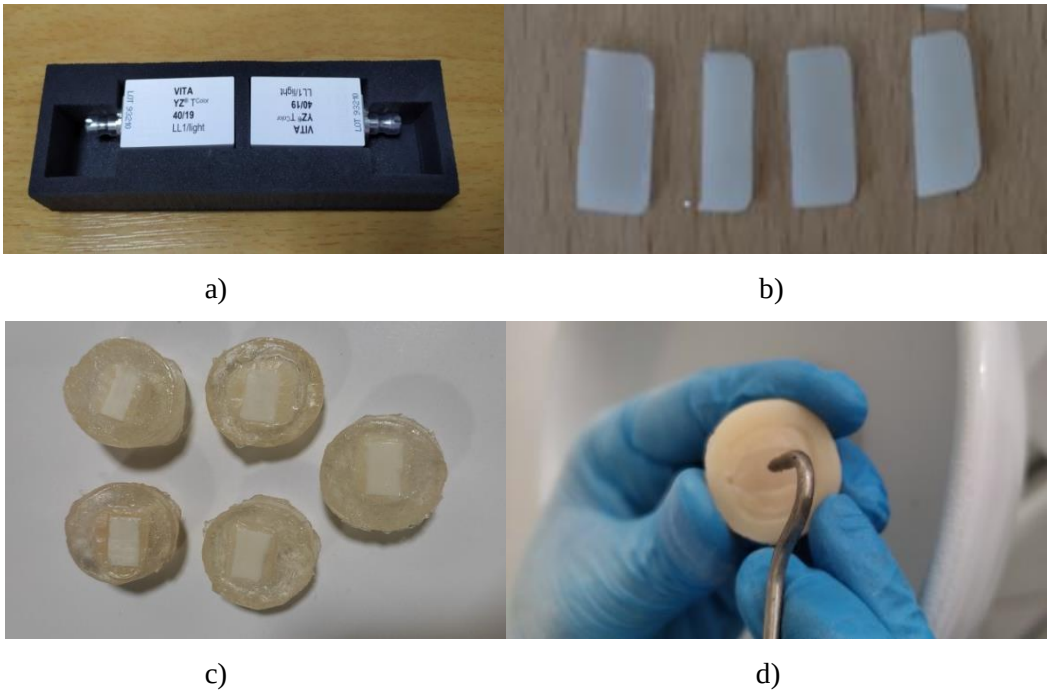
In the samples from the first group or control group, direct bonding of the ceramic brackets was carried out on the deglazed areas of the bonding surfaces.

In the second group, the ceramic samples were sandblasted with aluminum oxide grains (Al_2O_3) with a size of 29 μm, for 10 seconds, under a pressure of 1 bar and at a distance of 10 mm from the bonding surface (Fig. 1d).

In the third group, the process of silicatization was perfomed where the samples were sandblasted with aluminum oxide grains coated with silicon dioxide ($Al2O_3$ x SiO_2) – CoJet, with a size of 30 μm, for 10 seconds, under a pressure of 1 bar and at a distance of 10 mm from the bonding surface.

In the fourth group, the ceramic samples were sandblasted with aluminum oxide grains (Al_2O_3) with a size of 29 μm, for 10 seconds, under a pressure of 1 bar and at a distance of 10 mm from the bonding surface. After that, conditioning with a universal primer - Monobond Plus was performed for 60 seconds (Fig. 2a).

In the fifth group, the process of silicatization was



a) b)

c) d)

Fig. 1. a) Zirconium dioxide presintered CAD/CAM blocks; b) Ceramic samples after sintering; c) Prepared acrylic molds with ceramic samples; d) Air abrasion.

perfomed where the samples were sandblasted with aluminum oxide grains coated with silicon dioxide (Al2O3 x SiO2) – CoJet, with a size of 30 μm, for 10 seconds, under a pressure of 1 bar and at a distance of 10 mm from the bonding surface. After that, conditioning with a universal primer - Monobond Plus was performed for 60 seconds (Fig. 2b).

After the conditioning treatments were done, all samples were stored in a water bath at a temperature of 37°C for 7 days. In this way, the conditions in the oral cavity (moisture and temperature) were imitated in order to observe their influence on the bond strength created between orthodontic brackets and ceramic surfaces.

In the last stage, the shear bond strength test (SBS) was conducted, thus determining the bond strength between the orthodontic brackets and the ceramic surfaces (Fig. 3). The test was carried out using a universal testing machine – Shimadzu, at a speed of 0.5 mm/min.

a) b)

Fig. 2. a) Prepared samples from group 4; b) Prepared samples from group 5.

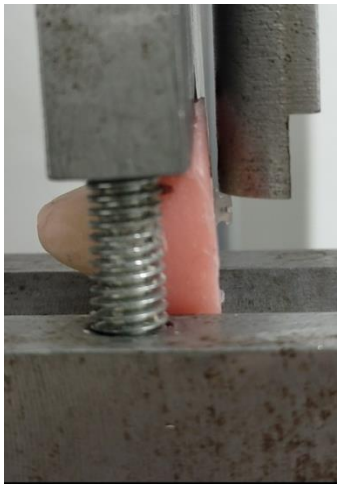


Fig. 3. Shear bond strength test.

The type of fracture (adhesive, cohesive or mixed) was determined by analyzing the fracture surfaces after SBS test and debonding of the ceramic brackets, using a light microscope and a magnification of 60 times.

Results and discussion

The analysis of categorical variables was done by determining coefficient of relationships, proportions and rates. Continuous variables were analyzed with measures of central tendency (mean, median, minimum and maximum values), as well as with measures of dispersion (standard deviation). Shapiro-Wilk W test was used to determine the normality of the frequency distribution of the studied variables. Pearson Chi square test was used to determine the association between certain attributive dichotomous features.

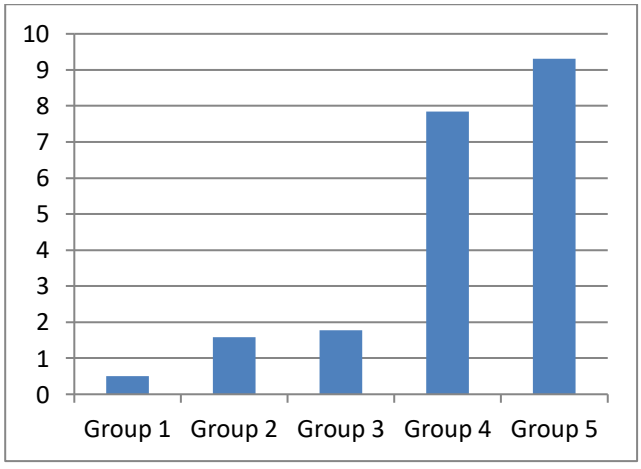


Fig. 4. Mean SBS in mega Pascals (MPa).

It was observed that Group 5 had the highest average value of SBS (MPa): 30 μm Al_2O_3 x SiO_2 + universal primer - 9.32±1.29 (95%CI 8.3-10.3) MPa with min/max values of 7.6/11.1 MPa. The mean value of SBS (MPa) for Group 4 was 7.85 MPa with min/max values of 6.9/9 MPa. The mean value of SBS (MPa) for Group 3 was 1.77 MPa with min/max values of 1.43/2.11 MPa. The mean value of SBS (MPa) for Group 2 was 1.58 MPa with min/max values of 1.1/2.3 MPa. In Group 1, the lowest average value of shear bond strength - SBS was established by 0.51±0.12 (95%CI 0.4-0.6) MPa with min/max values of 0.4/0.8 MPa (Fig. 4).

Table 1. Types of fracture after debonding

	Adhesive (%)	Cohesive (%)	Mixed (%)
Group 1	100	/	/
Group 2	100	/	/
Group 3	100	/	/
Group 4	/	71,4	28,6
Group 5	/	100	/

From the obtained results, it can be observed that high bond strength was achieved in the groups where mechanical-chemical methods for alteration of the ceramic bonding surfaces (air abrasion or silicatization, combined with the application of a universal primer) were performed. Lower bond strength was achieved in samples that were subjected only to mechanical alteration methods (air abrasion or silicatization), without primer conditioning. The lowest mean values for bond strength were observed in the control group, meaning that if the zirconium dioxide ceramic bonding surfaces are not altered and conditioned, then sufficient bond strength cannot be expected.

The chemical inertness of the zirconium dioxide ceramic and the resistance to etching due to the lack of silicon dioxide molecules in its composition are reasons why there is a general opinion in the literature that the only way to activate the surface of the zirconium dioxide restorations is through air abrasion performed either with aluminum oxide or aluminum oxide coated with silica.

According to Yang et al. (2010), air abrasion with aluminum oxide without the use of a primer achieves significantly low bond strength. On the other hand, air abrasion of zirconium dioxide ceramics with Al_2O_3 followed by primer conditioning provides adequate bond strength to composite cements. The authors in the same research proved that the primers used as the only conditioning method for the zirconium dioxide ceramics provided initially adequate bond strength with the

composite cement, but the acquired bond was proved to be non-water resistant, which resulted in drastically decreased bond strength over time. Hence, the authors concluded that although chemical conditioning methods (primers) are responsible for making the bond with zirconium dioxide ceramics, such a bond can only be made after previous mechanical conditioning of the ceramic surface by means of air abrasion. In the process of air abrasion the surface roughness increases, it gets cleaned of organic molecules and it becomes receptive for making a connection with chemical agents (Yang et al., 2010)

The silicatization combined with silanization (silane-based primers) makes the surface of the zirconium dioxide ceramic reactive for bonding with composite cements. Heikkinen proves that the higher kinetic energy during silicatization allows a greater part of the silicate particles to be incorporated on the surface of the zirconium dioxide ceramic, whereby the surface becomes chemically active with the possibility of establishing a bond with chemical agents (primers); thus increasing the bond strength between zirconium dioxide ceramics and composite cements (Heikkinen et al., 2007). The greatest advantage of the use of aluminum oxide grains coated with silicon dioxide – Al_2O_3 x SiO_2 (CoJet), is the reduced risk of creating cracks on the ceramic surface due to a rounded shape and no sharp edges (Kelch et al., 2019).

Schmage et al. (2003) suggest that bond strength of 6 to 10 MPa is sufficient to provide an adequate bond between orthodontic brackets and ceramic restorations. The conditiong method of the ceramic surface that provides the strongest bonding connection simultaneously may lead to its damage during debonding; if the bond strength exceeds 13 MPa, fracture of the ceramic surface can be expected (Schmage et al., 2003).

Determining the optimal conditioning treatment for zirconium dioxide ceramic restorations is largely dependent on the analysis and determination of fracture type after debonding of the ceramic brackets. The adhesive type of fracture usually occurs when weaker bonding forces are created between ceramic surfaces and orthodontic brackets and when analyzing the ceramic surface with light microscopy, no residue of the bonding cement is observed on the bonding surface. The cohesive type of fracture, on the other hand, is more often observed in those samples that have been treated with methods that achieve stronger bonding forces with the orthodontic brackets, whereby a residue of the bonding cement is observed on the ceramic surface (in some cases, parts of the fractured ceramic brackets that remains bonded to the ceramic surfaces could be observed). From the obtained results it was obvious that the adhesive fractures are mostly represented in the groups where no primer was used to build chemical bonds, but the treatment consisted only of methods for achieving mechanical retention (air abrasion or silicatization). Similarly, cohesive fractures are most prevalent in the groups where mechanical and chemical retention was acquired (air abrasion or silicatization combined with use of primer) (Table 1).

The conditioning method that provides the strongest bond strength of the brackets to ceramic restorations does not always represent an optimal conditioning treatment due to the appearance of cohesive fractures after the debonding of the orthodontic brackets. Removing the fractured bracket or bonded cement (which remains adherent to the ceramic surface) may result in irreversible damage to the prosthetic restoration.

Conclusion

When fixed orthodontic treatment with ceramic brackets is required in patients with zirconium dioxide restorations, air abrasion of the bonding surface with 29 μm aluminum oxide followed by conditioning with a use of universal primer is considered the optimal treatment. Although the largest percentage of fractures are of the cohesive type and in a smaller percentage of the mixed type, due to the inert nature and resistance to etching, air abrasion followed by the application of a universal primer is considered an adequate method for conditioning the zirconium dioxide ceramic bonding surfaces.

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Резиме

Воздушна абразија или силикатизација – оптимален метод за кондиционирање на цирконium диксидни протетички реставрации поради бондирање на керамички ортодонтски брекети

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Клучни зборови: керамички брекети, методи за кондиционирање, циркониумски реставрации, воздушна абразија, силикатизација

Според резултатите добиени од истражувањето на Американското ортодонтско здружение спроведено во 2015 година, бројот на возрасни пациенти кои побарале фиксен ортодонтски третман забележува пораст од 14% на 27% во периодот од 2010 до 2014 година. Поради зголемената возраст на пациентите кај кои е потребен фиксен ортодонтски третман, истиот би се очекувал да се изведува и на реставрирана дентиција со фиксно протетски реставрации. Целта на оваа студија беше да се евалуира јачината на врската на керамичките брекети бондирани за цирконium диоксидни керамички површини по спроведена воздушна абразија или силикатизација како единствени методи на механичко кондиционирање и нивна комбинација со употреба на универзален прајмер. Во истражувањето, за експерименталната фаза беа користени CAD/CAM цирконium диоксидни керамички блокови. Спроведени беа следните третмани за кондиционирање: група 1 - директно бондирање на керамичките брекети за цирконium диоксидните керамички површини, група 2 - воздушна абразија со 29 μm алуминиум оксидни зрна (Al_2O_3), група 3 - силикатизација со 30 μm алуминиум оксидни зрна обложени со силициум диоксид (Al_2O_3 x SiO_2), група 4 - воздушна абразија во комбинација со употреба на универзален прајмер, група 5 - силикатизација во комбинација со употреба на универзален прајмер. Беше забележано дека третманот од групата 5 постигна највисока просечна вредност на силата на смолкнување SBS (MPa): 30 μm Al_2O_3 x SiO_2 + универзален прајмер - 9,32±1,29 (95%CI 8,3-10,3) MPa со min/max вредности од 7,6 /11,1 MPa. Во групата 1, беше утврдена најниската просечна вредност на SBS од 0,51±0,12 (95%CI 0,4-0,6) MPa со мин/макс вредности од 0,4/0,8 MPa. По евалуацијата на добиените резултати, беше констатирано дека воздушната абразија проследена со нанесување на универзален прајмер може да се смета како адекватен метод за кондиционирање на цирконium диоксидните керамички бондирачки површини.