Adhesion between orthodontic bracket and dental ceramics

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Abstract: The strength of the connection between orthodontic brackets and sandblasted dental ceramics was evaluated. The strength of the bracket-ceramics connection was determined in four time intervals. Based on the obtained results, basic statistics were calculated. For the comparative analysis of average values, the following were used: ANOVA analysis of variance and Tukey's HSD post-hoc test at the significance level of α = 0.05. The statistical analysis performed did not show any influence of the method of surface treatment (with sanding, without sanding) between orthodontic brackets and ceramics. At the same time, it has been shown that with samples storing time in aqueous environment, the quality of the connection decreases significantly, regardless of the surface treatment method used.

Keywords: orthodontics, dental ceramics, adhesive system, shear bonding strength.

Adhezja pomiędzy zamkiem ortodontycznym a ceramiką dentystyczną

Streszczenie: Zbadano wytrzymałość połączenia zamków ortodontycznych z ceramiką dentystyczną poddaną piaskowaniu. Wytrzymałość połączenia zamek-ceramika wyznaczono w czterech przedziałach czasowych. Do analizy porównawczej wartości średnich zastosowano m.in. analizę wariancji ANOVA oraz test post - hoc Tukeya HSD na poziomie istotności α = 0,05. Przeprowadzona analiza statystyczna nie wykazała wpływu metody obróbki powierzchni porcelany dentystycznej (z piaskowaniem, bez piaskowania) na jakość połączenia zamków ortodontycznych z ceramiką. Jednocześnie wykazano, że wraz z upływem czasu przechowywania próbek w środowisku wodnym, istotnie zmniejsza się jakość połączenia, niezależnie od stosowanej metody obróbki powierzchni.

Słowa kluczowe: ortodoncja, ceramika dentystyczna, system adhezyjny, siła połączenia.

Orthodontic treatment of adults constitutes a challenge for the doctor, both in terms of meeting patients' expectations regarding aesthetics of their teeth and obtaining optimal clinical results. It should be remembered that achieving an optimal result in such cases is often hampered by completed growth process, which prevents modification of the size and spatial relationships of mandibular and maxillary bones. Dentition in adults is often affected by missing teeth reconstructed by extensive prosthetic restorations. It is therefore necessary to use other therapeutic methods combined with orthodontic treatment, such as maxillofacial surgery or implant-prosthetic treatment.

Another difficulty that the orthodontist must face when treating adult patients with prosthetic restorations made of dental ceramics is the need to adhesively secure elements of orthodontic appliances to porcelain bridges, crowns, or veneers. Patients increasingly choose restorations of this type due to their excellent aesthetics, similar color to natural tooth tissues, high biocompatibility, mechanical strength and chemical stability [1]. Thanks to the growing popularity of CAD/CAM systems, they are more often made without a metal framework [2].

Bonding forces obtained when fixing orthodontic elements to smooth ceramic surfaces are often characterized by low values [3]. Due to ceramics' resistance to etching with orthophosphoric acid, which is used as standard when conditioning tooth enamel surfaces, preparation of surfaces in restorations made of dental porcelain requires a different methodology [4,5]. Ceramic surfaces are characterized by high resistance to penetration by adhesive systems used in dentistry [6]. Results of studies published in available literature indicate that effectiveness of the bond is determined to a greater extent by appropri-

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ate method of preparing the surface to which orthodontic brackets are attached, rather than by the type of adhesive system used [7–9]. Some authors recommend combining mechanical and chemical techniques for conditioning of ceramics [10, 11].

The specificity of securing elements of orthodontic appliances to tooth surfaces and prosthetic restorations also requires that they can be safely removed after completion of therapy. Application of an adhesive procedure that ensures too strong connections between brackets and enamel surface results in enamel chipping off when an appliance is removed. Damaged elements of ceramic prosthetic restorations, observed after completion of orthodontic treatment, require polishing. Unfortunately, the aesthetic effect achieved in the oral cavity is often unsatisfactory [6]. In many cases, prosthetic restorations need to be replaced. This process is not only time-consuming, but also expensive, and therefore reluctantly accepted by patients.

Mechanical processing, which roughens the layer of fired glaze on ceramics, increases retention surface for adhesive substances. In clinical practice, surface preparation with diamond drills or corundum stones is used. Aluminum oxide abrasive blasting techniques with grain diameters ranging from 25 to 50 μm are also commonly applied. Preparing ceramic surfaces with corundum stones, drills made of sintered carbides or with diamond grit increases the bonding strength of orthodontic adhesive systems. However, such a process generates a risk of microcracks and damage to prosthetic restorations [12].

The use of an abrasive sandblaster minimizes the risk of damaging prosthetic working surfaces in the area of future brackets. Sandblasting of porcelain restorations with aluminum oxide causes surface damage to a much lower degree and also results in a desired increase in retention of adhesive system at the ceramics-adhesive system-bracket junction [13, 14].

Studies described in available literature, which are devoted to assessment of shear strength of orthodontic brackets cemented to ceramic surfaces, have shown that the method of ceramic surface sandblasting combined with subsequent application of silane yields the highest values of bonding strength compared to other clinical treatment protocols [15, 16].

The silanization process often uses preparations based on strong acids, such as hydrofluoric acid. While the use of the above-mentioned chemical compounds in technical laboratory environment, taking into account the principles of safety and protection of employees, is not questionable, direct use of this type of compounds in a dental office may contribute to chemical burns of the mucous membrane, damage to skin or eyes in both the patient and the staff, as well as to adverse effects of acid vapors on their respiratory system.

It seems that the procedure of sandblasting of ceramics with aluminum oxide in clinical conditions is a safe method of mechanically developing its surface before implementation of an orthodontic adhesive system [17–19].

The aim of the study was to assess the strength of bonds between orthodontic brackets and dental ceramics subjected to the sandblasting process in laboratory conditions in comparison to material whose surface has not been subjected to the above-mentioned modification.

EXPERIMENTAL PART

Materials and preparation

The study included 32 samples of Ceramill Zi ceramics (Amann Girrbach AG, Koblach, Austria) made in the shape of cubes with minimum dimensions of 6×6×6 mm. Then, using a Programat EP 5010® furnace (Ivoclar Vivadent AG, Schaan, Liechtenstein), Vintage Art glaze (Shofu Inc., Kyoto, Japan) was fired on one of the surfaces of each sample. The prepared material was embedded in Duracryl® Plus acrylic (SpofaDental a.s. Jiczyn, Czech Republic), in PVC rings (Usmetrix Inc., Baltimore, USA) with a diameter of ½ inch and a length of 15 mm in such a way that the fired surface was approximately 1 mm above the plane of the acrylic material.

In the next stage, the samples were divided into two groups of sixteen samples each. The first group was left without additional processing, and the second group was subjected to sandblasting of the glaze surface using a PrepStart H_2O sandblaster (Danville Materials/Zest Dental Solutions, Carlsbad, USA) and aluminum oxide with grain size of 27μm (Danville/Zest Dental Solutions, USA), for 5 seconds at a pressure of 2.5 bars. The incidence angle of the abrasive substance stream was 45°, and the distance of sandblaster nozzle tip from the sample surface was 15 mm. The abrasive blasting process is presented in Figure 1.

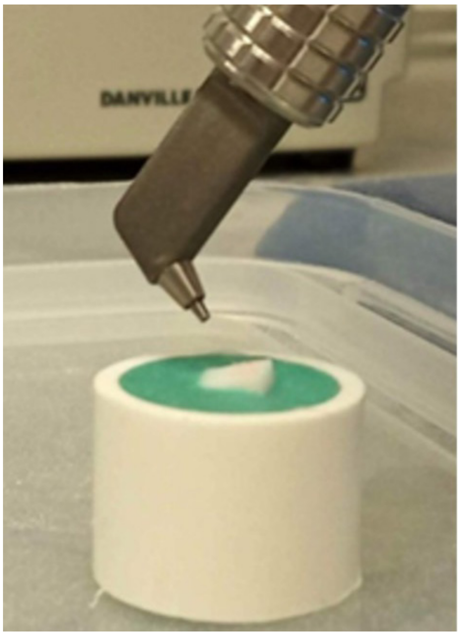

Fig. 1. The sandblasting process of ceramic sample surface

Then, all tested samples were subjected to surface cleaning by etching with orthophosphoric acid in the form of gel with concentration of 37% (Cerkamed Blue Etch, Cerkamed, Poland). Then, Transbond XT Light Cure Adhesive Primer bonding system (3M Oral Care, Monrovia, United States) was applied to the conditioned surface, the excess was removed with a stream of compressed air and then the resin was polymerized using Mini L.E.D. OEM curing light (Acteon Satelec, Bordeaux, France). The procedure of application and polymerization of the orthodontic adhesive system was repeated twice.

In the next stage of the experiment, a portion of Transbond XT Light Cure Adhesive (3M ORAL CARE, Monrovia, United States) was applied to the bases of orthodontic brackets (Pinacle, Ortho Technology, United States) intended for lower incisors. Then, using laboratory tweezers, they were placed on the surface of porcelain with a previously applied bonding system. Excess glue was collected using an applicator and polymerized from a distance of approximately 1 cm for 60 seconds with the use of Mini L.E.D. OEM curing light.

The samples prepared in the manner described above were divided into subgroups and subjected to testing to assess the strength of the bonding between orthodontic brackets and ceramics after 15 minutes and after 1, 7, and 28 days of storage in distilled water at 37°C in a CLW 115 STD incubator (Pol-Eko - Aparatura, Wodzisław Śląski, Poland).

Methods of testing

The strength of the bracket-ceramics bonding was determined using the Zwick/Roell Z020 universal testing machine (Zwick GmbH & Co. KG, Ulm, Germany) presented in Figure 2 with a traverse feed speed of 1 mm/min. A diagram of the applied test system is shown in Figure 3.

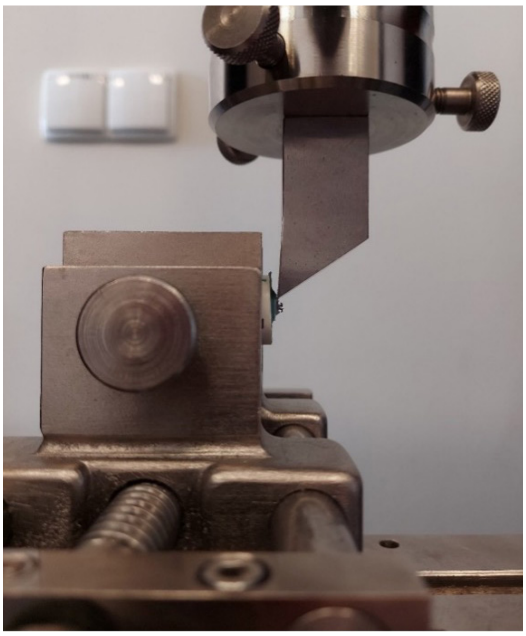

Fig. 2. Testing of bracket-ceramics bonding strength

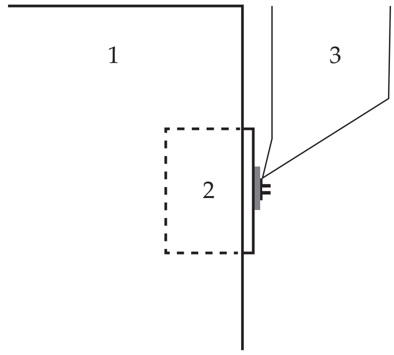

Fig. 3. Diagram of the test system: 1 – machine holder, 2 – sample, 3 – shearing blade

To determine the stress value, the contact surface area S = 8.4mm^2 was assumed, determined based on image analysis using MetIlo graphic program (Janusz Szala, Lodz, Poland).

Based on the analysis of data obtained for each of the samples, mean values and standard deviation were calculated. A comparison of the means was conducted based on one-way ANOVA analysis of variance and Tukey post – hoc test.

Before performing the analysis of variance, its assumptions were verified - normality of distribution of variables in the groups was confirmed with Shapiro-Wilk W test, and the assumption of homogeneity of variance was verified with Levene's test. The correlation between the averaged values was expressed using the Pearson linear correlation coefficient (r).

All significance tests were two-tailed, and the significance level was (α) = 0.05. The analysis was performed using TIBCO Statistica 13.3 (TIBCO Software Inc., Palo Alto, USA) and IBM SPSS Statistics 24 (IBM Corporation, Armonk, USA) programs.

RESULTS AND DISCUSSION

15 minutes after application of the bonding material in the bracket-dental ceramics system, the average bonding strength was 11.58 MPa, with 10.95 MPa for the surface not previously sandblasted and 11.58 MPa for the surface treated with an abrasive agent.

After 24 hours of sample storage in water, the average bonding strength calculated for all assessed samples dropped to 5.28 MPa, after 7 days the average value was 5.72 MPa, and after 28 days of the experiment it equaled 2.17 MPa on average.

The lowest bonding strength at an average level of 0.87 MPa was recorded for ceramic samples not subjected to sandblasting after 28 days of storage in aqueous environment.

The values of basic statistics showing average bonding strength in subsequent observation periods are presented in Table 1 and Figure 4.

A statistical analysis did not show any influence of the method of dental porcelain surface treatment on the qual-

T a b l e 1. Bonding strength between orthodontic brackets and ceramics for individual types of samples in subsequent observation periods

Material	Time	Number of samples	Bonding strength MPa	Standard deviation
Dental ceramics not sandblasted	15 min.	4	12.22	4.12
	24 h	4	4.24	1.11
	7 days	4	4.33	1.04
	28 days	4	0.87	1.33
	Total	16	5.41	4.77
Dental ceramics sandblasted	15 min.	4	10.95	1.02
	24 h	4	6.31	2.69
	7 days	4	7.12	2.07
	28 days	4	3.48	3.07
	Total	16	6.96	3.46
Total	15 min.	8	11.58	2.86
	24 h	8	5.28	2.20
	7 days	8	5.72	2.13
	28 days	8	2.17	2.60
	Total	32	6.19	4.18

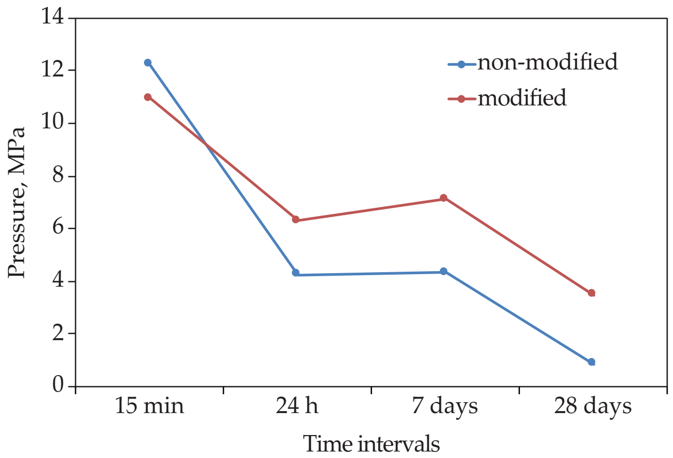

Fig. 4. Bonding strength of the orthodontic bracket with ceramics in subsequent observation periods depending on the type of surface preparation

ity of bonding between orthodontic brackets and ceramics. In subsequent time periods, both methods used in the experiment were comparable.

The statistical analysis showed that the quality of the bonding decreased significantly with sample storage time, regardless of previously performed surface treatment method. The results of the ANOVA analysis are presented in Table 2.

A comparison of the results of adjacent measurements showed that during the adopted observation periods, the bonding strength of the bracket-adhesive-ceramics system decreased significantly in subsequent time intervals, except for the period 1 day – 7 days for samples subjected to treatment with an abrasive material. The results of the statistical analysis confirming the above-mentioned observation are presented in Table 3.

Orthodontic adhesive systems are based on composite materials or glass-ionomer cements. The standard adhesive procedure used for fixing orthodontic brackets to the enamel surface includes etching the enamel tissue with orthophosphoric acid, which develops its surface, creates micro-retention for adhesive resin and increases its ability to penetrate deep into the material [20].

Many authors and clinicians believe that modern orthodontic bonding systems should guarantee a bonding strength of 3–10 MPa throughout entire treatment period, which lasts about two [21–23].

A meta-analysis of literature conducted by Ahmed *et al.* [24] presenting a comparison of bonding strength values of various adhesive systems and brackets to tooth enamel surfaces in vivo showed that the values range from 4 to 20 MPa.

As mentioned earlier, in the case of patients with permanent prosthetic restorations made of dental ceramics,

T a b l e 2. ANOVA analysis of variance values in relation to the impact of time and method of ceramic surface preparation on bonding strength with the orthodontic bracket

Effect	Probability	Corrected R^2
Time	0.000	
Method	0.070	0.692
Time · Method	0.282	

T a b l e 3. Comparison of individual observation periods for both methods of ceramic surface preparation

Method of ceramic surface preparation	Compared time intervals	Probability
Total	15 min vs 24 h	0.000
	24 h vs 7 days	0.013
	7 days vs 28 days	0.000
Etching	15 min vs 24 h	0.000
	24 h vs 7 days	0.017
	7 days vs 28 days	0.001
Sandblasting and etching	15 min vs 24 h	0.016
	24 h vs 7 days	0.313
	7 days vs 28 days	0.005

achieving a sufficiently durable and long-lasting bonding involving the bracket, adhesive system and porcelain constitutes a challenge for the clinician.

The available literature contains publications whose authors evaluate the bonding strength of orthodontic systems consisting of a bracket, an adhesive system, and dental ceramics in laboratory conditions.

In the study reported by Hu *et al.* [20], the authors assessed the bonding strength between zirconia ceramics samples which were sandblasted and conditioned with Ivoclean preparation (Ivoclar - Vivadent, Lichtenstein) and orthodontic brackets secured with the use of various bonding systems. For this purpose, they used the shear test. Depending on the bonding system, 24 hours after the adhesion procedure, the average bonding strength values ranged from 4 to 16 MPa. The above values were similar to those obtained in the current study.

After sample aging with the use of the thermocycling method (3000 cycles), the values illustrating the shear resistance of the system reported by Hu *et al.* [20] ranged from 0.28 to 11.11 MPa. The results noted by the cited authors indicate that under the conditions of the experiment, only one of the adhesive systems used with 2 different primers met the assumptions determining its use in clinical conditions in a long-term perspective.

A decrease in performance of orthodontic adhesive systems over time was also observed in the current study.

The publication by Pinho *et al.* [25] contains information on assessment of average bonding strength between orthodontic brackets and dental ceramics conducted in laboratory conditions. Before application of an orthodontic adhesive system, surfaces of porcelain samples were treated with dental drills and then with 9% hydrofluoric acid. According to the cited authors, bonding strengths determined by the shear resistance test ranged from an average of 5.7 to an average of 8.1 MPa, depending on the adhesive system, which is the range also observed in the current experiment.

Similar values of bonding strength between orthodontic brackets and ceramics to those obtained in the current study were also observed by Di Guida *et al.* [23]. The cited authors assessed the bonding strength between metal orthodontic brackets and dental ceramic samples undergoing various adhesive procedures. After 48 hours of storing the samples in distilled water, they recorded average bonding strength values ranging from 1.14 to 6.98 MPa, respectively for ceramics used only with a bonding system without additional surface treatment and for ceramics conditioned with hydrofluoric acid in combination with silane.

In the study by Amer and Rayyan [26] conducted in laboratory conditions, much higher values of average bonding strengths were noted than in the studies cited above. According to the mentioned authors, the values ranged from 16.7 to 20.8 MPa, immediately after the adhesion procedure. However, it should be noted that the protocol described in the mentioned publication included not only sandblasting of the ceramic surface, but also application of Clearfil Ceramic Primer (Kuraray, Noritake, Japan). As a bonding resin the authors used Panavia F2.0 cement (Kuraray, Japan) intended for prosthetic restorations. Although the values of bonding strengths between orthodontic brackets and dental ceramics reported by Amer and Rayyan [26] are impressive, the described protocol does not appear to be appropriate for clinical practice. Too strong bonding could cause considerable damage to prosthetic restorations when removing elements of the orthodontic appliance. Moreover, Clearfil Ceramic Primer containing both ethanol and 3-trimethoxysilylpropyl methacrylate [27] is a preparation whose use in clinical conditions should not be recommended.

The glazed surface of dental ceramics is not only devoid of porosity and smooth, but is also characterized by low chemical reactivity. Therefore, achieving proper adhesion using generally available procedures and materials that are safe for patients and medical staff is a challenge for the industry, independent research teams and clinicians.

The available literature contains descriptions of methods intended to increase strength and stability of bonds between porcelain prosthetic restorations and elements of fixed orthodontic appliances [28–30]. The purpose of dental ceramics surface modification is to provide appropriate conditions for reliable performance of orthodontic adhesive systems. The most frequently used methods for conditioning surfaces of porcelain prosthetic restorations include: etching with orthophosphoric, maleic or hydrofluoric acid, sandblasting using aluminum oxide particles, applying various adhesive systems or roughening surfaces with drills, dental stones or abrasive discs.

None of the methods presented above is free from weaknesses, which include:

– insufficient modification of the material surface to which a bracket is attached, resulting in reduction of bonding strength,

– reduction of bonding strength of the adhesive system over time, i.e., aging of the bonding,

– irreversible damage to prosthetic restorations during modification of their surface and removal of orthodontic brackets,

– risk to the health of the patient and staff related to cytotoxic or carcinogenic effect of chemicals used during treatment of porcelain surfaces in the conditions of a dental office (chairside).

However, both in clinical and laboratory conditions, we can observe a significant decrease in the strength of adhesive bonds over time. This phenomenon is most likely related to degradation of dental adhesive systems based on composite materials [31–33] caused by, among others, their insufficient chemical stability and water sorption. This process is observed in many materials used in the oral environment. The above issue requires further, detailed research to develop adhesive systems resistant to degradation.

CONCLUSIONS

The procedure of sandblasting of dental ceramics combined with its surface etching using orthophosphoric acid may be a method that allows obtaining satisfactory adhesion strength of orthodontic brackets to the surface of porcelain prosthetic restorations.

The long-term strength of the bonding obtained by this method should be the subject of further research.

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