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Comparison of Shear Bond Strength of Orthodontic Buccal Tube Bonded to Zirconia Crown after Using Two Different (10-MDP)-Containing Adhesive Systems

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ABSTRACT

Background: *Use of zirconia in cosmetic dentistry has expanded which coincided with a new trend of adult orthodontics; therefore it is very important to find an accepted method and material of bonding orthodontic appliances affectively to zirconia surface.* ***Materials and methods:*** *The sample was composed of 30 monolithic zirconia crowns of the lower right first molar. All samples were treated first by sandblasting with aluminum oxide particle 50 µm, then they were divided into 3 equal groups (the 1st group was the control, while 2nd and 3rd were the test groups), containing 10 crowns each, according to the type of adhesive system used; conventional light cure orthodontic bonding system (Transbond™ XT Primer/ Transbond™ XT composite resin) was used in the control group, while 2 different (10-MDP)-containing adhesive systems (Single Bond Universal adhesive/ TransbondTM XT composite resin, TheraCem dual-cured self-adhesive resin cement) were used in the test groups, buccal tube of lower right first molar (Ortho-Cast M-Series, Dentaurum, Germany) was bonded on the buccal surface of each zirconia crown in all the groups using one of the adhesive systems.* ***Results:*** *The Single Bond Universal group had the highest mean value of shear bond strength (16.299 MPa), followed by TheraCem group (15.373 Mpa), while the control group had the least value (5.337 ± 1.274Mpa); however, a highly significant difference in the shear bond strength was found between control and Single Bond Universal, and control and TheraCem groups, while non-significant difference was found between Single Bond Universal and TheraCem groups.* ***Conclusions:*** *The two types of (10-MDP)-containing adhesive systems provide good value of shear bond strength for buccal tubes bonded to zirconia surface, however, Single Bond Universal adhesive/composite resin is the best.*

Keywords: Shear bond strength, Adhesive remnant index, Zirconia, 10-MDP, Single Bond Universal adhesive, TheraCem

INTRODUCTION

Modern fixed orthodontic appliances include bonding of teeth from the first molar to second molar [1]. Bonding of attachments to molars is more convenient than banding method for both the clinician and patient, amongst the advantages which include the elimination of additional appointment time for placement of separators, easier maintenance of gingival health and elimination of post-orthodontic space in between the molars [2]. But it is a less frequently adopted practice [3]. Brackets bonded to molars have lower bond strength and a higher clinical failure rate than those brackets bonded to teeth located more anteriorly, due to larger masticatory forces in the molar region [4-6]. At present, the number of adults seeking orthodontic treatment is increasing. Many of them present to orthodontic clinics with restorations such as crowns and bridges in their mouth, were made of yttrium-stabilized tetragonal zirconium (Y-TZP) ceramics or in short, zirconia crowns. These crowns are widely used and favored for their advantages incorporating biocompatibility, aesthetics, cost effectiveness, fracture resistance and accurate fabrication [7]. The approaches suggested improving bond strength to zirconia surfaces can be grouped into 3 broad categories, namely mechanical, chemical, or a combination. The purpose of mechanical alteration of the zirconia surface is to remove the glaze and roughen the surface to provide sufficient mechanical retention for the adhesive, allowing for the successful placement and retention of the orthodontic bracket [8]. The glaze is translucent, low-fusing porcelain which may be applied to the surface of zirconia as the final stage in the firing cycle and has the effect of filling surface defects and to improve their esthetic appearance [9]. Chemical bonding to zirconia can be done by adhesive functional monomers, which are supposed to have the capability to form chemical bonds with metal oxides at the resin/zirconia interface and improving the wettability [10]. One of the phosphate monomers is 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP) monomer that can react chemically with the zirconia oxides, promoting a water-resistant bond to zirconia ceramics, it can be included both in resin cement and adhesives or applied directly over the zirconia surface [11].

The aim of the current study was to evaluate and compare the shear bonding strength and adhesive remnant index pattern of buccal tubes bonded to monolithic zirconia crowns after using two different 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP)-containing adhesive systems, one of them containing Multi-mode adhesive (Single Bond Universal adhesive) with Transbond™ XT composite resin, while the other is Self-adhesive resin cement (TheraCem).

PATIENTS AND METHODS

Sample

A dentoform mandibular right first molar tooth (Dentoform, Nissin, Kyoto, Japan) was used in this study as an *in vitro* model, the dentoform tooth received preparation for monolithic zirconia crowns according to the guidelines recommended for inCoris TZI C blank [12]. Then, 30 monolithic CAD/CAM zirconia crowns of lower right first molar were made of identical size and shape by using a CAD/CAM system. The samples were cured in a special oven according to manufacture instruction, after that the samples were painted with a glaze layer and fired at 840°C for 18 min. Each crown had been inspected by using a 10X magnifying eye lens to check if there is any manufacturer defect including cracks, roughness or irregularities on the surfaces of each zirconia crown [13].

Fabrication of Resin Dies

Resin dies were fabricated from PMMA blank (Aidite, China) by using the CAD/CAM system in order to be used for seating the fabricated crowns. Then the completed zirconia crowns were seated on their respective dies and were fixed by using ethyl cyanoacrylate.

Fabrication of the Acrylic Blocks

A silicone mold that was especially made by a technician with a cubic hole (20 mm) in dimensions and a tooth like hole of the same shape and dimensions of the buccal surface of the zirconia crown with its respective die (15 mm length, 10 mm width, 3 mm depth) was made in the bottom of the cube, so that the glazed buccal surface of the crown would be inserted inside the hole in order that no acrylic material would come in contact with the surface. Each specimen was placed in the silicone mold after that powder and liquid of the cold cure acrylic were mixed according to manufacturer instructions and poured into each mold. Then after the setting of the cold cure acrylic resin, the acrylic block with the specimen was taken out from the mold. After mounting, the specimens were cleaned and polished with non-fluoridated pumice and rubber cup for 10 seconds, washed and air dried for another 10 seconds.

Sandblasting Surface Treatment

By using Twin-Pen sandblaster machine (EASYBLAST, BEGO, Germany), the glazed buccal zirconia surface of all specimens was sandblasted by 50 µm aluminum oxide powder for 10 seconds at 10 mm distance with 40 Psi pressure [14]. For standardization, a ruler was fixed at the tip of the sandblaster pen. All specimens were ultrasonically cleaned with distilled water for 10 minutes to remove the factors that inhibit adhesion and then was air dried for 30 seconds [15,16].

Bonding Procedures

Control group: A thin coat of Transbond™ XT Primer (3M Unitek, Monrovia, CA, USA) was applied on the buccal surface of zirconia crown by using a disposable brush, as standardization one disposable brush was used for each specimen with a single stroke in gingival-occlusal direction and exposed to curing light for 10 seconds according to the manufacturer instructions.

Single Bond Universal adhesive group: A thin coat of the Single Bond Universal adhesive (3M ESPE, St. Paul, MN, USA) was applied to the same position and standardization of the previous groups, but after application it was rubbed in gingival-occlusal direction for 20 seconds, and also air dried for 5 seconds, and then light cured for 10 seconds according to the manufacturer instructions. After the use of different adhesives agents in the previous groups, an equal amount of the Transbond™ XT light cure adhesive paste (3M Unitek, Monrovia, CA, USA) composite resin was applied to the buccal tube base. Then the tube was positioned in the middle third of the buccal surface and parallel to the long axis of the zirconia crown using a tube holder. For standardization a constant load was placed on the top of the tube at 90° for 10 seconds (by fixing 200 gm load on the upper part of the vertical arm of the surveyor), to ensure that each tube was seated under equal force and to ensure a uniform thickness of the adhesive [13,17]. The adhesive paste was exposed to curing light for 20 seconds, 10 seconds from the mesial side and 10 seconds from the occlusal side of the buccal tubes according to manufacturer instructions, at a distance of 3 mm [18], for standardization we fixed a ruler at the tip of the light cure unit and at an angle of 45° to the surface of the buccal tube [19].

TheraCem group: The bonding procedure of buccal tube using TheraCem (Bisco, Schaumburg, IL, USA) was done in the same way as described with the previous groups except that no priming or bonding agent to the zirconia surfaces was needed according to manufacturer instructions. The cement was dispensed using disposable mixing tips supplied with the cement kit and applied directly as a thin even layer into the base of the buccal tube and directly the tube was positioned in the middle third of the buccal surface and parallel to the long axis of the zirconia crown using a tube holder, then initially cured for 2-3 seconds to aid in the removal of the excess cement, and then cured for 20 seconds according to manufacturer instructions, 10 seconds from the mesial side and 10 seconds from the occlusal side of the buccal tubes. The same standardization of pressure on the buccal tube, light intensity, the direction of curing that was used previously with the cement. After the completion of the bonding procedure, the specimens were immersed in distilled water and stored in an incubator at 37°C for 24 hours [20].

Shear Bond Strength Test

The shear test was accomplished using a Tinius-Olsen universal testing machine, with loading cell 50 kilograms and a crosshead speed of 1 mm/min and a custom made chisel rod [21-23]. The specimen was placed in the lower jaw of the machine. An occluso-gingival load was applied at the buccal tube base/zirconia surface interface from a knife-edge rod until debonding occurs. The shear bond strength values were calculated in megapascal (MPa) by dividing the force value by the area of the tube base (13.15 mm^2) (Figure 1).

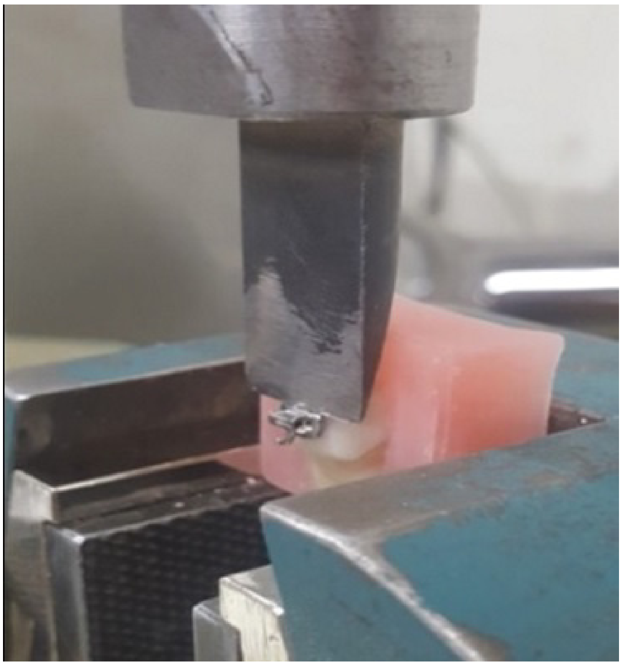

Figure 1 Shear bond test of the specimen by the universal testing machine

Estimation of Adhesive Remnant Index

The debonded buccal tube and zirconia surface of each sample was inspected under a stereomicroscope (10X magnifications) to determine the predominant site of bond failure [24-27]. The site of bond failure is scored as follow [28]:

The score I: Adhesive failure occurred between the tube base and adhesive

Score II: Cohesive failure within the adhesive itself, with some of the adhesive, remained on the zirconia surface and some remained on the tube base

Score III: The failure was between adhesive and zirconia surface.

Score IV: Zirconia detachment

Statistical Analysis

All statistical tests and calculations were made using statistical package for Social science software version 15 for windows XP Chicago, USA. Maximum, minimum, mean values, standard error, and standard deviations were calculated as part of the descriptive analysis. Statistical significances were measured using one way (ANOVA) to discover the differences among the 3 groups and in regard to the adhesive remnant index, statistically significant differences among the groups were done by using chi-square test, while means Yate's correction test was used to compare the adhesive remnant index scores between every two groups.

RESULTS

Shear Bond Strength Test

The mean shear bond strength (SBS), standard deviation (S.D.), minimum (Min.), and maximum (Max.) values of all groups are shown in Table 1. The highest value of the mean shear bond strength was in group Single Bond Universal (16.299 ± 2.201 MPa), followed by that of group TheraCem (15.373 ± 1.575 Mpa), while the control group had the lowest value (5.337 ± 1.274 Mpa). One way analysis of variance (ANOVA) showed that there was a statistically highly significant difference ($p \leq 0.01$) among the mean values of the shear bond strength of all groups. The Tukey honest significant difference (HDS) test was performed to compare the mean difference between each two tested groups (Table 2). It showed the following:

- Highly significant differences ($p \leq 0.01$) were found between control and each of Single Bond Universal, TheraCem groups
- The non-significant difference (p-value>0.05) was found between Single Bond Universal and TheraCem

Table 1 Descriptive statistics of the shear bond strength (MPa) for different groups

Groups	N	Mean	S.D.	Min.	Max.
Control	10	5.337	1.274	3.33	7.27
Single Bond Universal	10	16.299	2.201	13.41	19.51
TheraCem	10	15.373	1.575	13.87	18.91

Table 2 Comparing the shear bond strength between every two groups using Tukey HSD test

Groups		Mean Difference	p-value
Control	Single Bond Universal	-10.962	0.000 (HS)
	TheraCem	-10.036	0.000 (HS)
Single Bond Universal	TheraCem	0.926	0.599 (NS)

Adhesive Remnant index

The sites of bond failure of all tested groups are shown in Table 3. The ARI scores showed the following:

- Score (I) was noticed in a high percentage (70%) in Single Bond Universal group, while noticed in a low percentage (20%) in TheraCem group
- Score (II) was noticed in a high percentage (80%) in TheraCem group, followed by Single Bond Universal group (30%), while the lowest was in the control group (10%)
- Score (III) was noticed in the highest percentage (90%) in the control group
- Score (IV) was not noticed in any of the tested groups

Statistically, Chi-square test of the ARI scores showed a highly significant difference among all groups. Means

Yate's correction test was used to compare the ARI scores between every two groups and showed highly significant differences between the control and Single Bond Universal groups, control, and TheraCem groups, while the non-significant difference between Single Bond Universal and TheraCem groups (Table 4).

Table 3 Frequency distribution of the ARI scores in different groups

Groups		Scores				
		I	II	III	IV	Total
Control	No.	0	1	9	0	100
	%	0%	10%	90%	0%	100%
Single Bond Universal	No.	7	3	0	0	10
	%	70%	30%	0%	0%	100%
TheraCem	No.	2	8	0	0	10
	%	20%	80%	0%	0%	100%
Total	No.	**0**	12	9	0	30
	%	30%	40%	30%	0%	100%

Table 4 Comparison of ARI scores among all groups and between each two groups

Comparison	X^2	Likelihood ratio	d.f.	p-value
Among all groups	37.846	42.631	6	0.000 (HS)
Control vs. Single Bond Universal	17.000	23.227	2	0.000 (HS)
Control vs. TheraCem	16.444	21.447	2	0.000 (HS)
Single Bond Universal vs. TheraCem	5.051	3.232*	1	0.072 (NS)

DISUSSION

Shear Bond Strength

Generally, the high mean shear bond strength value does not necessarily refer to better clinical performance [29]. Consequently, the serious issue about the shear bond strength in clinical orthodontic practice is to attain sufficient bond strength value that permits safe detachment of fixed appliance components than to get the highest potential value [30]. Therefore, the bond has to withstand the forces that occur in the moist oral environment and at the end of the orthodontic treatment must be capable of being removed without causing damage to the enamel or ceramics crowns as cracks or chipping [31].

In this study, the mean shear bond strength in all groups except the control group was higher than the clinically adequate bond strength (6-8MPa) that is sufficient to withstand the masticatory and orthodontic force as proposed by Reynolds [32], which means that the adhesive systems that were used in the experimental groups can resist shear stress to adequate level. To evaluate the effectiveness of different (10-MDP)-containing adhesive systems on the shear bond strength of stainless steel buccal tubes bonded to monolithic zirconia crowns as follow:

Control group: These samples had the lowest value of the mean shear bond strength among all the groups. This result was less than the clinically accepted range of mean shear bond strength value (6-8 Mpa) as proposed by Reynolds, such values are insufficient to support orthodontic forces [32]. Similar results were recorded by Lee, et al., and Byeon, et al., [19,23]. Although, air-abrasion with aluminum oxide particles is one of the common methods used to increase the surface roughness of zirconia which increases the surface area, improves the wettability by diminishing the surface tension, and produces micromechanical retention [33-35]. However, such roughness was not enough to provide a reliable bond strength between the adhesive resin and zirconia surface when it is used alone without additional chemical treatments and that came in consistent with many studies [36-39].

Single Bond Universal group: These samples showed the highest value of the mean shear bond strength among all the groups. Statistically, its shear bond strength showed highly significant differences when compared to control, while had no significant difference when compared to TheraCem group. These results could be attributed to the chemical composition of Single Bond Universal adhesive. It contains multiple adhesion promoters, such as 10-MDP, Silane, Vitrebond™ copolymer and methacrylate monomers [40]. In addition to 10-MDP monomer, silane monomer may promote adhesion to silica-based ceramics, such as porcelain [41]. Moreover, depending on previous studies in the literature like Zachrisson, et al., who reported that, sandblasting with aluminum oxide particles (50 μm) to remove the glaze layer (low-fusing porcelain rich in silicone oxides) is better than other methods like using burs or stones as revealed by scanning electron microscope [42], without mentioning that the removal of the glaze was partial or complete. In addition to that, Valentino, et al., found that the subsequent use of airborne particle abrasion with aluminum oxide particles (50 µm) on glazed zirconia surfaces was responsible for partial removal of the vitreous layer of the glaze as inspected by (SEM) [43]. Based on this, silane might promote adhesion to the part of glaze that still covers the zirconia surface after sandblasting and form a chemical bond with its silica content. This finding agreed with the finding of Lee, et al., who found that, the application of MDP-containing zirconia primer with porcelain primer (saline coupling agent) on sandblasted glazed zirconia surfaces, showed significantly higher shear bond strength value than the application of only MDP-containing zirconia primer, and coincided with the result of Kim, et al., who reported that, single bond universal adhesive showed the highest bond strength value than other tested primers including Z-Prime Plus on silica coated zirconia surface [44,45], while disagreed with the finding of Byeon, et al., who found that there was no significant difference between MDP with saline primer and MDP-based primer on sandblasted zirconia surfaces and this could be due to the use of different types of primers on non-glazed zirconia surfaces [19]. Furthermore, Vitrebond copolymer (polyalkenoic acid copolymer), which has acidic carboxylic group might be also helped in bonding to zirconia surface as reported in a study conducted by Lee, et al, [46-48].

TheraCem group

Bonding buccal tubes on sandblasted zirconia surfaces using TheraCem self-adhesive resin cement with no primer or bonding agent to the zirconia surfaces was used (according to manufacturer instructions), resulted with samples showed the 2nd highest value of mean shear strength among all groups in the present study with a highly significant differences when compared to control, and this could be attributed to calcium silicate (alkaline component) present in the chemical composition of TheraCem in addition to acidic monomer (10-MDP), which enabled TheraCem to had an acidic to alkaline conversion system. Although the initial acidic pH due to acidic monomer helped in bonding to zirconia surface, while alkaline calcium silicate component neutralized the acidic monomer within 30 minutes after polymerization due to calcium ions release and this could be desirable in strengthening the bond with more stability as reported by Chen, et al., who declared that shear bond strength of calcium silicate-based self-adhesive resin cement (TheraCem) was higher than other cement contain phosphate monomer or resin-modified glass ionomer cement to zirconia surface [49].

However, this could be due to the fact that when acidic monomer present in self-adhesive resin cement, the cement becomes more hydrophilic and absorbs more water if its acidic pH maintained, that lowers the physical and mechanical properties of the cement and this may decrease its bond strength [50-52].

Additionally, Yoshida, et al., found that MDP can chemically bond to Ca^{++} ions and form stable MDP-Ca salts, the salt deposits at the adhesive interface form 'self-assembled nano-layers', which strengthens the adhesive interface and may be responsible for the good long-term performance of MDP-containing adhesives [53]. For this reason, MDP in TheraCem might form a chemical bond to calcium ions released from calcium silicate component of the cement that strengthen the adhesive interface. On the other hand, there was no significant difference in shear bond strength between TheraCem and Single Bond Universal groups but there was little difference in mean value of bond strength between them which could be due to the differences in chemical composition as mentioned in both groups and differences in type of adhesive system like adhesive agent with composite resin in Single bond universal, while only self-adhesive resin cement in TheraCem groups. There was no previous data in the literature concerning the use of TheraCem in bonding orthodontic attachment to zirconia surface in order to compare, so the present study showed that more studies should be performed to confirm the evaluability of these data.

Failure Site

Concerning the adhesive remnant index scores which gave the indication about the site of bond failure for each group, it appeared that there was a highly significant difference in ARI among all groups. Regarding the control group, occurrence of score (III) which indicates failure at adhesive zirconia interface represented 90% of this group and this might be due to that bond failure which occurs usually at the area of least resistance which means that the bond strength between the adhesive-buccal tube base interface and the cohesive bond strength of the adhesive itself were stronger than the bond strength between the adhesive and zirconia. This could be attributed to the hardness glossy surface of zirconia, so the mechanical retention might not be sufficient enough, and this agreed with the result reported by Lee, et al., and Byeon, et al., [19,23]. However, the occurrence of a cohesive failure within the adhesive itself score (II) in a low percentage (10%) of this group, could be negligible.

According to Single Bond Universal group, score (I) was noticed in a high percentage (70%) of this group, while score (II) was noticed in a low percentage (30%). ARI Score (I) indicates failure at the adhesive-buccal tube base interface, since the bond failure occurs usually at the area of least resistance which means that bond strength between the adhesive-zirconia interface and the cohesive bond strength of the adhesive itself were stronger than the bond strength between adhesive and buccal tube base and this might be due to the effect of multiple adhesion promoters, and this agreed with the result of Lee, et al., but did not match the result of Hellak, et al., [48,54].

While regarding TheraCem group, Score (II) was predominant and represented 80% of this group indicates cohesive failure within the adhesive itself, with some of adhesive remained on the zirconia surface and some remained on the buccal tube base, this means that adhesive bond to the buccal tube base and to the zirconia was greater than cohesive bond within the adhesive itself. In addition to the high bond between the adhesive and zirconia surface, the viscosity of TheraCem that allowed it to be engaged into the mesh of the buccal tube base produced high mechanical interlock without any weak point between buccal tube base adhesive links. However, Score (II) noticed in a low percentage of 20% in this group and this could be negligible. Smith, et al., found that, surface-adhesive interface failure Score (III) is desirable, because the problem of residual adhesive is not encountered [55], while Harari, et al., and Sarac, et al., reported that, cohesive failure within the adhesive itself Score (II) or adhesive bracket failure Score (I) is preferable to avoid surface damage during debonding which clinically leads to the long term integrity of the restorations [56,57], but this kind of residual adhesive may require further treatment to remove it from the zirconia surface, a procedure that could cause additional damage to zirconia restoration surface and this coincided with the finding of Trakyali, et al., [58]. None of the tested samples showed Score IV which usually indicates surface detachment, this may be attributed to exceptional strength of the zirconia surface, which might reach to (1000 Mpa).

CONCLUSIONS

- Bonding buccal tubes with the 2 types of (10-MDP)-containing adhesive systems in combination with sandblasting on zirconia crowns provide a good rate of shear bond strength values.
- Bonding with Single Bond Universal adhesive (multi-mode adhesive) that was not specialized as zirconia primer resulted with the highest shear bond strength value without an additional primer; therefore it might be helpful in reducing orthodontic equipment costs.
- No significant statistical differences were found between TheraCem (one-step bonding material) and Single Bond Universal adhesive groups, which simplifies bonding procedure saving of chair-side time better than applying multi-steps procedure.
- The occurrence of ARI Score (II), which indicates cohesive failure within the adhesive itself was the predominant mode of bond failure in TheraCem groups, while Score (I) which indicates failure at the adhesive-buccal tube base interface was predominant in Single bond universal group, both are considered preferable to avoid surface damage during debonding that clinically leads to the long-term integrity of the restorations, and none of the samples showed fractures within the zirconia itself during debonding score IV.

DECLARATIONS

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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