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Research article

Shear bond strength of orthodontic brackets bonded to a new version of zirconium all ceramic restoration: An in vitro comparative study

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A R T I C L E I N F O

Keywords:
Shear bond strength
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Surface treatment
Brackets
Extraoral scanning
Bracket surface area
Thermocycle
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Three dimensional (3D)

A B S T R A C T

Objectives: Esthetic restorations such as monolithic zirconia crowns are highly requested for adults nowadays. Bonding orthodontic braces on this type of material became a challenge for orthodontists, because of the special surface treatment needed. This study aims to assess the shear bond strength (SBS) of metal, and ceramic brackets bonded on two types of zirconia ceramics, surface roughness (SR) after different surface treatments for their surfaces, and adhesive remnant index (ARI).
Materials and methods: Brackets' base surface area (BSA) was scanned by an extra-oral scanner, then measured. The doubled labial surface of monolithic zirconia crowns ($n = 30$) and monolithic high translucent zirconia crowns ($n = 30$) were prepared and each was divided into three groups ($n = 10$) depending on surface treatment (hydrofluoric acid etching, no treatment, and rocatec airborne abrasion). Extracted lower central incisors ($n = 20$) were prepared. Each of them was divided into two subgroups depending on the type of bracket bonded on their surfaces (metal and ceramic). The SR, SBS, and ARI were assessed.
Statistical analysis used: Tests used are independent-samples *t*-test, Fisher's exact test, One-Way ANOVA, and Kruskal-Wallis test.
Results: The highest SBS and SR were observed in Enamel/Metal and Zirconia/Metal/Rocatec subgroups, respectively.
Conclusion: Adequate bond strength could be obtained with the high translucent zirconia group if bonded with ceramic or metal brackets even if no treatment was used.
Clinical significance: A proportion of simulation was done like practicing inside the dental clinic to reach the best results regarding the adhesion strength of orthodontic brackets.

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1. Introduction

Nowadays patients seek esthetic ceramic crowns or fixed partial dentures which meet their needs. Zirconium oxide (ZrO_2) is a material that has been developed by dental companies and has several advantages over conventional porcelain fused to metal restorations (PFM), including a more aesthetically pleasing look, enhanced chemical characteristics, and superior mechanical capabilities [1,2]. However, the usage of zirconia as a core presents higher rates of veneering porcelain chipping in comparison to PFM. Porcelain chipping happens mainly due to the firing shrinkage of porcelain and variations in the coefficient of thermal expansion between the core and porcelain [3,4].

Based on the previous, Monolithic zirconia is considered the solution to porcelain chipping [3,5]. Brackets bonded on those surfaces represent a higher bonding failure rate than that with enamel, so bonding on monolithic zirconia is considered a challenge for orthodontists [6,7]. Hydrofluoric acid etching cannot enhance bond strength [3,7], as there is no glass phase for zirconia [8,9], however it may improve the bond strength of new monolithic zirconia that was developed by some companies which added other oxides in zirconia's composition to enhance its esthetic. Airborne particle abrasion is used to roughen a zirconia restoration and has been recommended [8,10,11], as well as silanization [10,11] in previous studies.

With the continuous development of zirconia to new versions for esthetic improvement, it becomes necessary to test the SBS of orthodontic brackets on them in comparison to old zirconia with different surfaces pre-treatment. This may help in studying the influence of new monolithic zirconia versions on the bracket bonding strength.

The purpose of this study is to assess the effect of orthodontic bracket material (metallic or ceramic) and different surface treatments (abrasion of airborne particles, Hydrofluoric acid etching, and No treatment) on the shear bond strength of these brackets bonded to the treated surfaces of monolithic zirconia crowns. The amount of cement that remained on the crowns after failure was also investigated.

Manufacturer companies of the brackets work on developing different designs of the brackets' bases. These designs behave as a mechanical means for different adhesives to enhance brackets bonding on teeth surfaces. Different designs of brackets' bases may affect their surface areas, so in this study, we attended to assess a new three-dimensional (3D) method to calculate the surface area of brackets' bases, and so more precise calculating the shear bond strength using the formula MPa = F/A; where F is the maximum load measured by the machine, and A is bracket base area in mm^2 [12].

2. Material and methods

2.1. Sample

The study was approved by the ethical committee of Mansoura University (no.M11010720). The inclusion criteria were: (1) crowns with no large defects, restoration, or crack line, (2) no chemical agents e.g. formalin or hydrogen peroxide treatment (3) labial and lingual surfaces were not formerly bonded to any orthodontic attachments, and (4) teeth had normal clinical size based on the estimation of crown height and width. These extracted lower central incisors were used as a control group for comparison.

Doubled labial surface monolithic zirconia crowns (n = 30) and monolithic high translucent zirconia crowns (n = 30) were prepared and each was divided into three groups (n = 10) depending on surface treatment (Hydrofluoric acid etching, No treatment, and Rocatec airborne abrasion system). Extracted lower central incisors (n = 20) were prepared. Each of them was divided into two subgroups (A, and B) depending on the type of bracket (metal and ceramic) (Table 1).

The sample size was calculated by G*Power software for Windows (version 3.1.9.4). Based on experience gained from previous studies [11,13], we hypothesize a large effect size (f = 0.4) for each of the three outcome variables particularly SBS between the 14 subgroups in our study. In a one-way ANOVA study, a sample size of 10 per group is required. The total sample size of 140 achieves a power (1-β) of 85.6% to detect this large effect size (f = 0.4) between the mean values versus the alternative of equal means using an F test with a 0.050 significance level (α = 0.05).

2.2. Procedures

The extracted lower central incisors were cleaned and they underwent storage at a 5 °C, in a physiological saline solution, for ≤90 days pre-testing. Their crowns were scanned by an extra-oral 3D scanner (DOF Inc., ASD 180323002Q, Korea) for designing double

Table 1
Sample.

Group	Crown Type	Bracket Type	Surface Treatment	Bonding Material
Natural Teeth (n = 20)	Enamel	Metal or Ceramic	37% Phosphoric acid	Transbond™XT Primer + Transbond™XT paste
1 (n = 10)	(Zirconia or Zolid ht + white)	Metal or Ceramic	Rocatec	RelyX ceramic primer + Transbond™XT Primer + Transbond™XT paste
2 (n = 10)	(Zirconia or Zolid ht + white)	Metal or Ceramic	No treatment	RelyX ceramic primer + Transbond™XT Primer + Transbond™XT paste
3 (n = 10)	(Zirconia or Zolid ht + white)	Metal or Ceramic	9.6% Hydrofluoric acid	RelyX ceramic primer + Transbond™XT Primer + Transbond™XT paste

labial surfaces for the two types of monolithic zirconia crowns and to add artificial roots to increase the length of the design. This was helpful for bonding two brackets on the same crown's labial surfaces with an excellent fit and easy handling and sufficient fixation in epoxy resin block (Fig. 1(C and D)) by a Computer-Aided Devise (CAD) (Exocad DentalCAD Matera 2.3 program).

The monolithic zirconia crowns (Natura Eco HT) (DMAX Co, Ltd, Korea) and monolithic high translucent zirconia crowns (Ceramill ® Zolid ht + White) (Amann Girrbach AG, Herrschaftswiesen 1, Austria) were milled by CORiTEC 250i a Computer-Aided Milling machine (CAM) (imes-icore GmbH, lm Leibolzgraben 16 D-3132 Eiterfeld, Germany). All milled crowns were then sintered in a specific furnace ZIRKON-100 (MIHM-VOGT GmbH & Co. KG, Friedrich-List-StraBe 8, 76,297 Stutensee-Blankenloch, Germany) under 1450 °C for 8 h, and then glazed by applying glazing material (CERABIEN ZR, clear glaze, Kuraray Noritake Dental Inc., 300 Higashiyama, Miyoshi-Cho, Myoshi, Aichi 470–0293, Japan) in a glazing machine; Programat P310 (Ivoclar Vivadent AG, FL-9494 Schaan, Liechtenstein, Austria) under 850 °C for 6 min [14].

The base surface area of each metal and ceramic bracket (Morelli, Sorocaba, Brazil) was scanned by an extra-oral 3D scanner (DOF Inc., ASD 180323002Q, Korea) in consideration of the design of the meshwork of the base. The scanned base was measured in mm^2 by a special program (MeshLab 2020.03) (Fig. 1(E, F, G, H)).

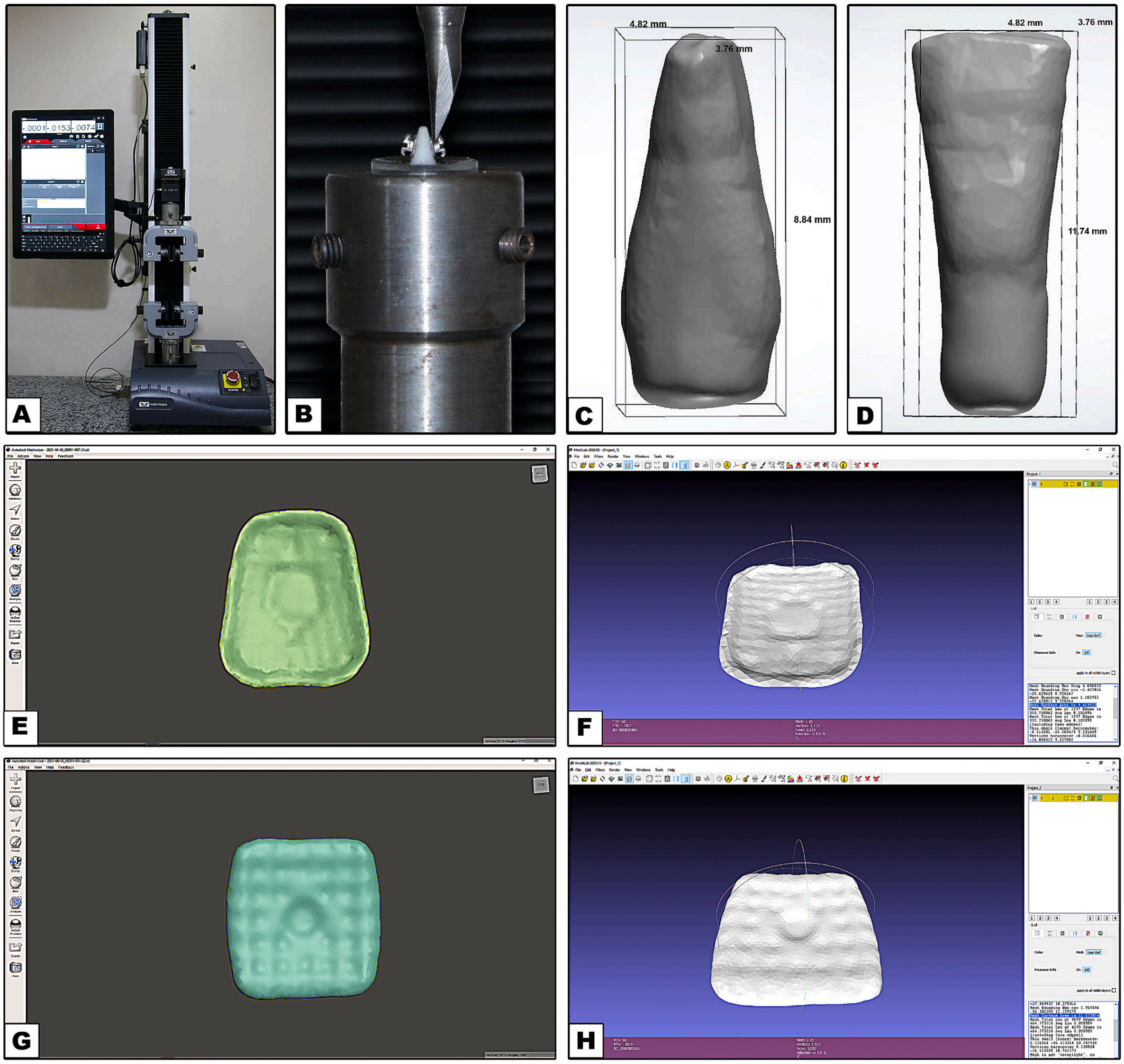

Fig. 1. (A) Instron testing machine (B) Samples was held in epoxy resin blocks to attain the maximum parallel direction of force from blade to the buccal crown surface. (C) Bucco-lingual view of CAD/CAM design (without root extension). (D) Mesio-distal view of CAD/CAM design (with root extension). (E) The base surface area of lower central incisor metal bracket after scanning. (F) Measuring the base surface area of metal bracket in mm^2. (G) The base surface area of lower central incisor ceramic bracket after scanning. (H) Measuring the base surface area of the ceramic bracket in mm^2.

In group I, chemical pretreatment with Hydrofluoric acid 9.6% (HFA) (BISCO, Inc., 1100 W. Irving Park Rd., Schaumburg, Illinois 60,193, USA) was used in a proprietary gel base for 30 s [15,16]. It was washed thoroughly under tap water for over half a minute, and the crowns underwent air-drying for 30 s. In group II, no surface pretreatment was performed. In group III, all labial surfaces underwent abrasion using Rocatec-Pre aluminum oxide powder (3 M ESPE, Seefeld, Germany) using a laboratory air-abrasion device (Renfert GmbH S/N:A1292265, Bj.:2017, Germany) according to manufacturer's instructions at a 2 bar pressure over 15 s from a 10 mm distance, at a 90° angle to the labial surface. Rocatec™ plus then was used in the same manner. In the enamel group, all labial surfaces were etched with 37% Phosphoric acid (PHA) in a proprietary gel base (Meta Biomed Co., Ltd. 414-12 Mochung-Dong, Heungdeok-gu, Chungbuk, Korea) for 20 s, were washed under tab water over half a minute, and then were gently air-dried till the appearance of chalky white color.

Surface roughness was then measured by a profilometer (SURFTEST SJ-201, Mitutoyo Corp., Japan) for all groups before silanization or bonding. The stylus moved backward and forward across the specimens. Five measurements were obtained, and then the average roughness value (Ra) was recorded. A cut-off length of 0.8 mm, at 0.5 mm/s scanning speed was used. The scanning resolution was 0.01 μm.

The labial surfaces of groups I, II, and III were primed with a thin layer of RelyX Ceramic Primer (3 M ESPE, St. Paul, US) for 20 s using an application brush, and underwent air-drying using a moderate, oil-free air spray. A thin uniform layer of universal bond, Transbond™ XT primer (3 M Unitek, Monrovia, California, U.S.) was applied for 5 s using a micro-brush for all groups, then gently air-thinned. Intense exposure to ambient light was avoided, as the primer is photopolymerizable.

A sufficient quantity of Transbond™XT paste (3 M Unitek, Monrovia, California, U.S.) was applied to the base surface of metal and ceramic brackets. The metal brackets were then lightly placed on subgroups' (A) surfaces, while the ceramic brackets were placed on subgroups' (B) surfaces, bracket positioner was used for standardizing the procedure, and then the brackets were firmly pressed down. Excess cement was removed. A curing light device with an intensity of 1200 mW/cm^2 (C02–C LED Premium Plus International Ltd. 1001, Yuen Long Trading Centre No.33, Wang Yip Street West Yuen Long, N.T. Hong Kong) was lastly used to cure brackets for 40 s (10 s from mesial, 10 s from incisal, 10 s from distal, and 10 s from gingival directions). Samples were then held from the root part in epoxy resin blocks.

For aging, according to International Organization for Standardization - ISO [17,18] all samples underwent incubation at 37 °C for 24 h after bonding. They underwent 1000 thermal cycles at 5- 55 °C (±4 °C) in distilled water baths and the dwell time between baths was 20 s [11,19,20]. This was performed by a thermocycler (Robota, Alex, Egypt). Each specimen was aligned in Instron universal testing machine to touch the incisal wings of each bracket. Such a position was to attain the maximum shear stress in a parallel direction to the crown surface at a cross-head speed of 1 mm/min (Fig. 1(A, B)).

Calculation of SBS was in MPa using the equation Mpa = F/A; where F represents the maximum load recorded in N by the Instron machine, while A is the surface area of the bracket base measured in mm^2. After all, 3.5× magnification loupes were used to determine the ARI after failure [21]. Each sample received one of these descriptions: cohesion, adhesion, and mixed.

2.3. Statistical analysis

Data were entered and analyzed using IBM-SPSS software (Version 26.0). Qualitative data were expressed as absolute frequency (N) and percentage (%). Quantitative data were initially tested for normality using Shapiro-Wilk's test with data being normally distributed if $p > 0.050$. The presence of significant outliers was tested for by inspecting boxplots. Quantitative data were expressed as mean ± SD. Categorical data were compared between groups by Chi-Square or Fisher's exact test. Quantitative data between groups were compared by Independent-samples *t*-test (two groups) or One-Way ANOVA/the non-parametric equivalent Kruskal-Wallis H-test (three groups). For any of the used tests, results were considered statistically significant if the p-value ≤0.050.

3. Results

In the enamel group, the Metal bracket subgroup showed statistically significantly higher SBS versus the ceramic subgroup (31.9 ± 15.7 for metal, and 19.7 ± 7.9 for ceramic, $P < 0.05$), however, there was no statistically significant difference in surface roughness of metal and ceramic brackets subgroups (1.007 ± 0.135 for metal, and 0.793 ± 0.366 for ceramic, $P > 0.05$). In the enamel group, all ceramic brackets had an adhesive type, while only 40% were found in the metal bracket subgroup (Table 2).

There were no significant differences in SBS among (Zirconia/Metal) subgroup of the three treatment types ($P > 0.05$). On the other

Table 2
SBS, Surface roughness, and ARI are according to surface treatment in Metal vs. Ceramic subgroups for Enamel group.

Characteristic	Bracket type		Test of significance	
	Metal	Ceramic	Statistic	P value
SBS	31.9 ± 15.7	19.7 ± 7.9	t = 2.190	**0.047**
Surface roughness	1.007 ± 0.135	0.793 ± 0.366	t = 1.737	0.109
ARI	N (%)	N (%)	–	**0.011**
Cohesive	6 (60%)	0 (0%)		
Adhesive	4 (40%)	10 (100%)		

Notes: Data is mean ± SD unless otherwise stated. Test of significance is Independent-Samples *t*-test for SBS and SR and Fisher's exact test for ARI.

hand, (Zirconia/Ceramic) subgroup showed statistically significantly lower SBS in both HF and Rocatec treatments versus No treatment ($P < 0.001$). Additionally, (Zolid ht + white/Metal) and (Zolid ht + white/Ceramic) subgroups showed statistically significantly lower SBS in both HF and Rocatec treatments versus No treatment ($P < 0.001$) (Table 3) (Chart 1).

In (Zirconia/metal) and (Zirconia/ceramic) subgroups, surface roughness was statistically significantly higher in Rocatec more than the other surface treatments that were used However, In (Zolid HT + white/metal) and (Zolid HT + white/ceramic) subgroups, surface roughness was statistically significantly higher in HF more than the other used surface treatments. (Table 4) (Chart 2).

In (zirconia/metal) subgroup, ARI was not statistically significantly different between the three treatment types ($P < 0.05$). On the other hand, in (zirconia/ceramic) subgroup, ARI (cohesive) was statistically significantly higher in the No treatment subgroup ($P < 0.001$), while ARI (adhesive) was statistically significantly higher in the Rocatec subgroup ($P < 0.001$). In addition to this, ARI (cohesive) in (zolid HT + white/metal) subgroup, was statistically significantly higher in the No treatment and Rocatec subgroups ($P < 0.001$), while ARI (adhesive) was statistically significantly higher in the HF subgroup ($P < 0.001$). In (zolid HT + white/ceramic) subgroup, ARI was not statistically significantly different between the three treatment types ($P > 0.05$) (Table 5) (Chart 3).

4. Discussion

This study's goal is to assess the shear strength of metal and ceramic orthodontic brackets attached to two different types of CAD/CAM monolithic zirconia crowns that have had two different treatments applied to their surfaces (Hydrofluoric acid 9.6%, and Rocatec airborne abrasion system), besides No treatment was used in comparison to the enamel control group. Additionally, it was assessed how different zirconia surface treatments and bracket types affected the shear bond strength of orthodontic brackets to those surfaces.

For bonding brackets to zirconia with appropriate SBS, zirconia should be treated by various methods including mechanical or chemical ones as strong acids. Previous studies confirmed that using HF acid as an etchant did not result in effective bond strength [5,22]. However, in this study, HF etching resulted in higher surface roughness for (Zolid ht + white) subgroups, in comparison to other surface treatments used. Subgroups of (Zolid ht + white) treated with HF had higher SBS than ones treated with Rocatec. However, HF had little effect on the other type of zirconia. The difference in the effect of HF on the two types of zirconia may due to their differences in composition and manufacturing.

Some studies included in a systematic review investigated the hydrofluoric acid with different concentrations (9.6%, 5%, and 4% HF) as an etchant on the zirconia samples [11,23–26]. The hypothesis of using HF acid to etch the surface of the crowns we used is that (Zolid ht + white) is not a pure zirconia crown as it had been modified with different oxides ($ZrO2 + HfO2 + Y2O3$: ≥99.0, Y2O3: 6,7 - 7,2, HfO2: ≤5, Al2O3: ≤0.5, Other oxides: ≤1) by the manufacturing company which may be the cause of its higher translucency in combination with high strength in comparison to the other type [27]. The impact of hydrofluoric acid etching on the micro-morphology of different kinds of glassy ceramics varies and is dependent not only on their chemical structure but also on their microstructure arrangement as well [28].

Feldspathic VITA Mark II has the same chemical composition and percentage contribution of components as leucite-reinforced IPS Empress CAD, lithium disilicate IPS e. max CAD, and zirconia-reinforced lithium silicate Celtra Duo; however, the different molecular distribution results in different etching patterns on the surfaces. According to official manufacturer documents, the silica and alumina content of the aforementioned ceramics are as follows: SiO2: 56%, 60%, 80%, 56%; Al2O3: 20–23%, 16%, 5%, and 4%. It should be noted that the silicon dioxide content of all glassy ceramics is around 60%, while the aluminum oxide percentage of feldspar-based and leucite-reinforced ceramics is approximately 20%, and that of lithium-disilicate and zirconia-reinforced lithium silicate is approximately 4%. However, the internal structure and presence of other oxides affect the etching impact of HF acid [28].

Since abrasion with aluminum oxide particles (Al_2O_3) can affect the surface of restorations, multiple studies have demonstrated the advantage of abrasion with airborne particles [8,10,11]. In our study, all ceramic bracket subgroups treated with Rocatec reached the minimal clinically accepted SBS or even less, contrary to all metal bracket subgroups treated by it. Here, the bracket/adhesive interface's mechanical bond strength may play a role in that result which needs extra investigation. Due to the varying grain sizes chosen, moreover, they are silica-coated, which may enhance the chemical retention in addition to a mechanical one, it is challenging to compare the findings of this study with those of past investigations.

Shear bond strength values suitable in clinical situations defined by Reynolds in 1975 [29] are out-of-date because a recent

Table 3
SBS is according to surface treatment in Metal vs. Ceramic subgroups for each three main groups.

Group	Bracket type	Surface treatment			Test of significance	
		HF	No treatment	Rocatec	F/H value	P value
Zirconia	Metal	11.3 ± 3.8	14.7 ± 3.4	14.6 ± 3.7	F = 2.814	0.078
	Ceramic	10.2 (6.8–13.3) [a, b]	15.7 (13.8–21) [a]	3.7 (1.7–6.2) [b]	H = 22.083	**<0.001***
Zolid HT + white	Metal	15.5 ± 5.5 [a]	28.8 ± 9.1 [b]	13.7 ± 6.7 [a]	F = 12.841	**<0.001***
	Ceramic	10.7 ± 4.8 [a]	17.1 ± 3.5 [b]	7.95 ± 5.15 [a]	F = 10.663	**<0.001***

Notes: Data are mean ± SD for zerconia/metal subgroup, and median (25th percentile – 75th percentile) for other subgroups.
Test of significance is One-Way ANOVA for zerconia/metal subgroup, and Kruskal-Wallis H-test for other subgroups.
Pairwise comparisons are presented letter-based (similar letters = no significant difference, different letters = significant difference.).

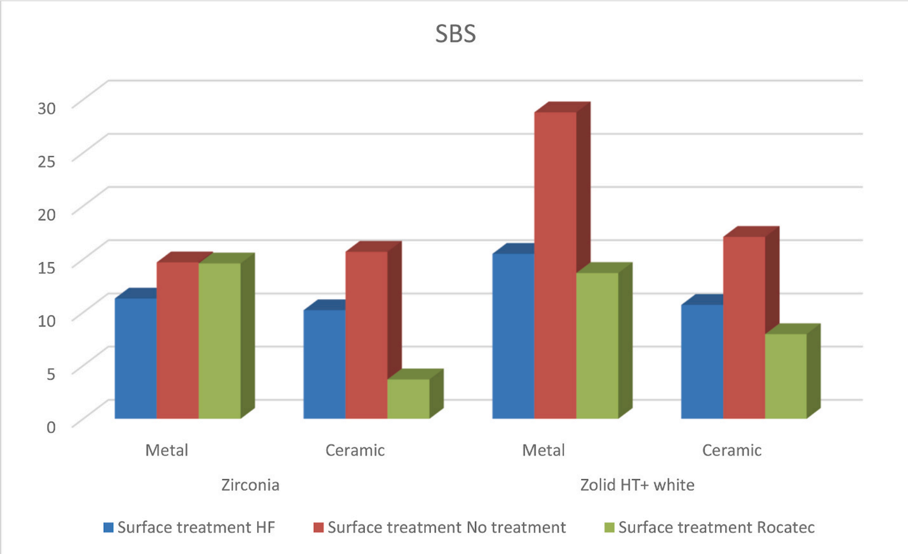

Chart 1. There were no significant differences in SBS among (Zirconia/Metal) subgroup of the three treatment types. On the other hand, (Zirconia/Ceramic) subgroup showed statistically significantly lower SBS in both HF and Rocatec treatments versus No treatment. Additionally, (Zolid ht + white/Metal) and (Zolid ht + white/Ceramic) subgroups showed statistically significantly lower SBS in both HF and Rocatec treatments versus No treatment.

Table 4
Surface roughness is according to surface treatment in Metal and Ceramic subgroups for each of the three main groups.

Group	Bracket type	Surface treatment			Test of significance	
		HF	No treatment	Rocatec	F value	P value
Zirconia	Metal	0.643 ± 0.22 [a]	0.247 ± 0.07 [b]	1.538 ± 0.83 [c]	25.292	**<0.001***
	Ceramic	0.411 ± 0.277 [a]	0.255 ± 0.065 [a]	0.996 ± 0.343 [b]	22.380	**<0.001***
Zolid HT + white	Metal	0.792 ± 0.183 [a]	0.369 ± 0.229 [b]	0.769 ± 0.110 [a]	17.306	**<0.001***
	Ceramic	0.980 ± 0.361 [a]	0.399 ± 0.202 [b]	0.801 ± 0.086 [a]	18.032	**<0.001***

Notes: Data are mean ± SD. Test of significance is One-Way ANOVA for Zolid ht + white/Metal and Welch ANOVA for others. Post-Hoc tests are Tukey HSD for Zolid ht + white/Metal and Games-Howell for others. Pairwise comparisons are presented letter-based (similar letters = no significant difference, different letters = significant difference.).

integrative review showed that most of the authors used only LED photo activators [30]. The clinically acceptable mean SBS revealed after analyzing eleven studies was 16.14 ± 11.13 MPa without causing enamel damage. Hobson et al. [31] stated that the clinically acceptable SBS could be obtained between 5.9 and 7.5 MPa]. In this study, the results showed the mean SBS of metal brackets bonded to enamel surface is 31.89 ± 15.68 MPa, while the mean SBS of ceramic brackets is 19.73 ± 7.91 MPa. Both means of SBS agreed with the results of the Ebert et al. article 2016 [32].

In the current study, the reason for using the same primer and adhesive system was to detect suitable surface treatments for bonding orthodontic brackets on the two types of zirconium crowns. Kwak, J.-Y. et al. explained that if zirconia has a porcelain glaze, a silane primer is recommended for sufficient bonding strength, but a zirconia primer is used for the exposed bare zirconia surface [11]. Our study agreed with Kwak, J.-Y. et al. one, as our findings revealed that even though no surface treatment was used, we got clinically acceptable SBS for almost all the zirconium groups.

The variations in SBS in our study, with respect to the type of primer, zirconia, and the method of surface treatment, were contrary to an evidence from literature suggesting that the SBS of ceramic brackets was greater compared to the SBS of metallic brackets when they bonded to different ceramic surfaces [33–35]. However, our results match with the findings of Mehmeti et al. who showed that metallic brackets when compared to ceramic brackets produced superior bond strength with zirconia [22,25]. This explains that maybe the superiority relays on the base surface design of the metal bracket.

In our study, the control enamel group showed higher SBS mean values than other groups, however, it did not show the highest surface roughness mean values. These findings mean that increasing the surface roughness does not enhance the shear bond strength which matches with findings of a recent study [36]. Moreover, a study from 1993 revealed that the use of polyacrylic acid for enamel

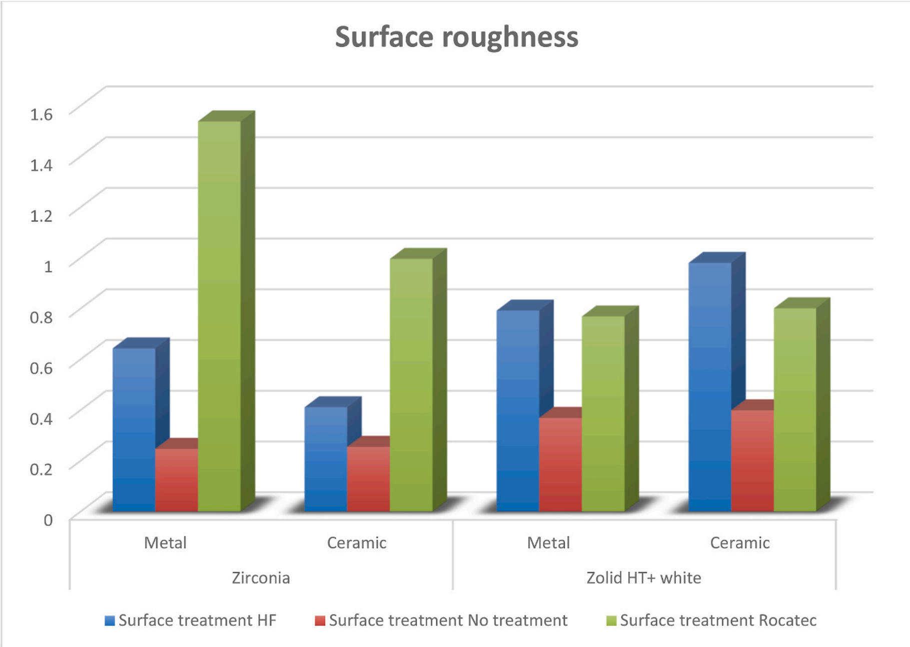

Chart 2. In (Zirconia/metal) and (Zirconia/ceramic) subgroups, surface roughness was statistically significantly higher in Rocatec more than the other surface treatments that were used However, In (Zolid HT + white/metal) and (Zolid HT + white/ceramic) subgroups, surface roughness was statistically significantly higher in HF more than the other used surface treatments.

Table 5
ARI is according to surface treatment in Metal and Ceramic subgroups for each three main groups.

Group	Bracket type	Surface treatment			Test of significance
		HF	No treatment	Rocatec	P value
Zirconia	Metal				0.151
	Cohesive	10 (100%)	7 (70%)	6 (60%)	
	Adhesive	0 (0%)	3 (30%)	4 (40%)	
	Ceramic				**<0.001***
	Cohesive	7 (70%) a, b	9 (90%) b	2 (20%) a	
	Adhesive	0 (0%) a	1 (10%) a	8 (80%) b	
	Mixed	3 (30%) a	0 (0%) a	0 (0%) a	
Zolid HT + white	Metal				**<0.001***
	Cohesive	1 (10%) a	10 (100%) b	10 (100%) b	
	Adhesive	9 (90%) a	0 (0%) b	0 (0%) b	
	Ceramic				0.286
	Cohesive	7 (70%)	9 (90%)	10 (100%)	
	Mixed	3 (30%)	1 (10%)	0 (0%)	

Notes: Data are N (%). Test of significance is Fisher's exact or Chi-Square test. Pairwise comparisons are presented letter-based (similar letters = no significant difference, different letters = significant difference.).

conditioning resulted in lower bonding forces as compared with the use of the phosphoric acid enamel conditioner, and so the mean debonding strength values of metal and ceramic brackets bonded onto enamel surfaces ranged between a low of 40 kg/cm2 and a high of 194 kg/cm2. Also, that study mentioned that using polyacrylic acid on an enamel surface resulted in crystal growth of the enamel surface, under (×1000) magnification, contrary to etching an enamel surface with 37% phosphoric acid, as it gave a different configuration of etched enamel surface under the same magnification [37]. All that findings figure out that the configuration of surface roughness affects the SBS.

Zolid ht + white monolithic zirconia has Young's modulus of 200 GPa and bending strength of 1100–150 MPa. There is thus very little chance of creating fractures while debonding the bracket from the prior crown surfaces. The bond between the prosthetic restoration and the tooth must be carefully considered since some variables, including the type of cementation used, can affect how strong the bond is. To avoid the crown, attached to the bracket, from debonding, the proper equilibrium must be achieved. Studies on the subject have not established a specific upper strength limit for zirconia crowns [38].

When we want to debond a bracket, it's necessary to keep the enamel or zirconia surface's structure intact and leave as little adhesive residue as possible on the surface. To avoid any cohesive breakdown inside the zirconia, a low ARI score is necessary [39]. In

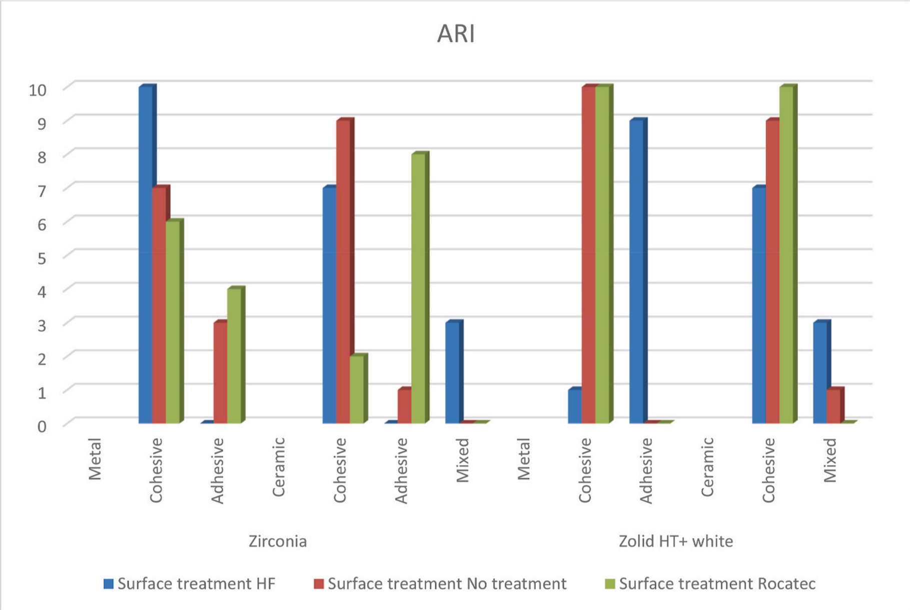

Chart 3. In (zirconia/metal) subgroup, ARI was not statistically significantly different between the three treatment types. On the other hand, in (zirconia/ceramic) subgroup, ARI (cohesive) was statistically significantly higher in the No treatment subgroup, while ARI (adhesive) was statistically significantly higher in the Rocatec subgroup. In addition to this, ARI (cohesive) in (zolid HT + white/metal) subgroup, was statistically significantly higher in the No treatment and Rocatec subgroups, while ARI (adhesive) was statistically significantly higher in the HF subgroup. In (zolid HT + white/ceramic) subgroup, ARI was not statistically significantly different between the three treatment types.

this study, the Zirconia/Metal/HF, Zolid ht + white/Metal/No treatment, Zolid ht + white/Metal/Rocatec, and Zolid ht + white/-Ceramic/Rocatic subgroups displayed the lowest mean ARI score. In general, the subgroups with ceramic brackets had higher mean ARI scores than the subgroups with metal brackets.

Thermo-cycling is the in vitro procedure of exposing an extracted tooth with a restoration to oral cavity-like temperature extremes. In general, thermal stress may be pathogenic in two ways: first, mechanical stresses caused by temperature fluctuations can directly cause the development of cracks across bonded interfaces. Second, the fluctuating gap diameters are related to the pathogenic movement of oral fluids into and out of the gaps. The linear coefficient of thermal expansion of material has been identified as a significant determinant in micro-leakage [40]. Since thermo-cycling could be considered to represent the worst-case scenario for aging. According to a systematic review and meta-analysis [41], only non-thermo-cycled and thermo-cycled groups were utilized for data extraction. The number of cycles also varied greatly, ranging from 500 to 37,500. Consequently, the results presented there exhibited large standard deviations. In general, thermo-cycling appears to reduce bond strength, so the selection of 1000 cycles for this study because they came in the range mentioned by previous systematic review. Furthermore, the extreme range of the available thermo-cycler in our university is 1000 cycles per day.

The frequency of cycling in vivo is undetermined and requires formal assessment at this time. In the absence of this knowledge, and based on the idea that these cycles may occur between 20 and 50 times each day, it is postulated that 10,000 cycles may be typical of one year of in vivo behavior [42,43]. No records have been identified about the number of heat cycles per unit time in vivo, which certainly advocates more research.

4.1. *Limitations*

1 Using static shear bond strength which is not completely simulating the forces falling on the braces intra-oral, so further studies are needed with using cyclic shear bond strength which depends on cyclic stresses in lower magnitude till failure happens, a condition referred to as fatigue.
2 Further studies also are needed with a longer term of storage and extended periods of water thermal cycling.
3 Future investigations are also needed on the high translucent zirconia (Ceramill ® Zolid ht + White) with a zirconia primer.

5. Conclusion

1 The Enamel/Metal and Zolid ht + white/Metal subgroups had the greatest SBS sequentially.
2 Zirconia/Metal/Rocatec subgroup was found to have the greatest SR.
3 The Zirconia/Metal/HF, Zolid ht + white/Metal/No treatment, Zolid ht + white/Metal/Rocatec, and Zolid ht + white/Ceramic/Rocatec subgroups had the lowest average ARI scores.

Even with using the silane, bonding agent, and without surface treatment, enough bond strength may be produced with the zolid ht + white group when bonded to ceramic or metal brackets.

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Author contribution statement

Assem Abd EL-wahab: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Shaza Hammad: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data.

Noha El-Wassefy and Ahmed Hafez: Conceived and designed the experiments; Wrote the paper.

Marwa Shamaa: Analyzed and interpreted the data; Wrote the paper.

Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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