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The shear bond strength of orthodontic brackets after surface conditioning of Zirconia, Ceramic and E. max models

Amina R. Khalid[1], Enas T. Al Jwary[2*]
[1,2]College of Dentistry, University of Mosul, Mosul, Iraq; enastallb@uomosul.edu.iq (E.T.A.J).

Abstract: The current study aims to evaluate the shear bond strength (SBS) of metal orthodontic brackets after surface conditioning by hydrofluoric acid (HF) and aluminum oxide air abrasion (Al_2O_3) and using two prime types and to determines the adhesive remnant index (ARI). We compared the bond strength of different types of models (full glazed zirconia, ceramic faced zirconia and E. max faced zirconia) with different surface conditioning methods for attaching metal orthodontic brackets. The study used 60 models for each material, divided into subgroups based on the type of prime material and surface preparation method. The bond strength was measured using a universal testing machine and the results were analyzed using statistical software. Shear bond strength of the Aluminum oxide was statistically ($p<0.05$) higher than the hydrofluoric acid and control groups in all groups (full glazed zirconia, ceramic faced zirconia and E. max faced zirconia). The Assure® Plus primer with Aluminum oxide surface treatment give rise to the highest shear bond strength than 3M™ Transbond™ XT, while there was no significant difference between Assure® Plus and 3M™ Transbond™ XT primer for both control and hydrofluoric acid groups. The highest shear bond strength was obtained with Aluminum oxide conditioning method for all types of ceramic materials used in this study.
Keywords: *Ceramic, E. max, Orthodontic brackets, Shear bond strength, Surface roughness, Zirconia.*

1. Introduction

The number of adults seeking orthodontic care increased from 14% to 27% between 2010 and 2014, based on a survey conducted by the American Association of Orthodontics back in 2015, meaning that the number of orthodontic adult patients has almost doubled in four years and likely to continue growing as time passes. Possible reasons for the increasing popularity of orthodontics include an overall increase in public demand for aesthetic procedures, dentists finding orthodontic treatments lucrative, and the perception that orthodontic treatments have been greatly simplified because of technological advancements (1,2).

Because the bonding of orthodontic brackets directly to the crowns have shown a high degree failure rate when compared to enamel surface bonding. Therefore, increasing the bond strength between the orthodontic brackets and various types of all-ceramic materials is one of the challenges that orthodontist has to deal with (3). Numerous options to improve bracket bonding to such substrates have been suggested, these methods encompassed a range of techniques, such as using various concentrations of orthophosphoric acid and hydrofluoric acid, applying monomers and silane, performing sandblasting or air abrasion with aluminum oxide, roughening with diamond burs, and employing different types of lasers, including Er:YAG and CO_2 lasers (4–7).

Due to the clinical difficulty in distinguishing between lithium disilicate, zirconia and other glass ceramics to the orthodontist, a universal bonding protocol that achieves a good bond strength would be of great benefit (8). Transbond XT (3M Unitek, Monrovia, California): It is a hybrid resin of Bis-GMA and TEGDMA in a proportion of 1:1, with 82% of silica particles of 3μ. Previous studies show

* Correspondence: enastallb@uomosul.edu.iq

Transbond XT had an acceptable bond strength of 9 MPa to 14 MPa. However, its bond strength on zirconia surfaces not adequate (1.2-2 MPa)(9). Recently, manufacturers have introduced different primers for ceramic and zirconia crowns, like Assure® Plus adhesive systems; which has the ability to bond to porcelain and zirconia differentiates this bonding agent from its previous generation (10).

It claims that it provides adequately high bond strength to normal as well as hypo-calcified and flurosed enamel, primary teeth, dentin and bond to irregular metal surfaces such as amalgam, gold, stainless steel, porcelain, zirconia, composite restorations, temporary restorations or acrylic pontics (10). So, it is crucial to know what are the best materials or instruments are required to bond brackets to each type of artificial surface (1). This study will be aimed to investigate the effects of different surface conditioning methods of full glazed zirconia, ceramic faced zirconia and E. max faced zirconia on the shear bond strength of metal orthodontic brackets.

2. Materials and Methods

2.1. Study Sample Grouping

The models were divided according to the types of material into three groups and each group consist of 60 models as follow:

1. Full zirconia models (Zirconia group).
2. Ceramic faced zirconia (Ceramic group).
3. E. max faced zirconia (E. max group).

And then each group subdivided into two subgroups of 30 models according to the types of prime materials as follow (Figure 1):

1. Assure® Plus.
2. 3M™ Transbond™ XT.

Furthermore, each one of these groups subdivided into three subgroups according to the surface conditioning methods and as follow:

1. Control group: Consisted of 30 models (10 ceramic, 10 zirconia and 10 E. max) without any surface conditioning procedure.
2. Hydrofluoric acid group (HF group): Consisted of 30 models (10 ceramic, 10 zirconia and 10 E. max) and the labial surface etch by 9.6% hydrofluoric acid.
3. Aluminum oxide group (AL_2O_3 group): Consisted of 30 models (10 ceramic, 10 zirconia and 10 E. max) and the labial surface etch by air-particle abrasion with50μm aluminum oxide particles.
4.

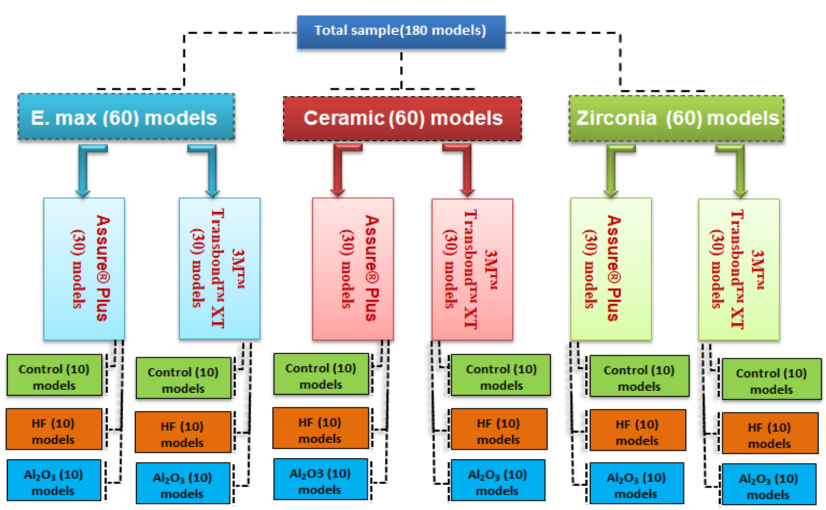

Figure 1.
Study sample grouping.

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2.1.1. Control Groups

The middle part of the labial surface of the sixty models (20 ceramic,20 zirconia and 20 E. max) received no surface treatment(11,12).

2.1.2. Hydrofluoric Acid Groups

The middle part of the labial surface of the another sixty models(20 ceramic,20 zircon and 20 E. max) treated with 9.6% HF acid for 1minute then rinsed for 30 seconds, and air-dried as described by Riowruangsanggoon *et al.*, (2022) and Jassim and Majeed, (2023)(6,14)

2.1.3. Aluminum Oxide (AL_2O_3) Groups

The last sixty models (20 ceramic,20 zircon and 20 E. max) fixed in a special design base to ensure standardization of distance and direction between micro etcher (Ortho Technology, Emergo Europa) and models' surface. The profilometric test was used to assess the surface roughness of specimens after surface treatment using the profilometer device (Surfatest SJ-201 p, Mitutoyo, Japan).

2.2. Shear Bond Strength Measurement

The SBS test was measured by using the Universal testing machine at with a crosshead speed of 0.5mm/min. A prefabricated holder for the specimens has been constructed to ensure proper and secure seating of the specimen so that the bracket base was parallel to the direction of the shear force.

2.3. Adhesive Remnant Index (ARI) Measurement

After debonding of the brackets, the labial surface of the crown of the models were examined under Stereomicroscope at 10X magnification power, to assess the amount of the adhesive material left on the models' surfaces.

2.4. Statistical analysis

The data of the present study were analyzed using computerized statistical program SPSS statistic, version 19. The statistical results were considered significant at $P \leq 0.05$. All the variables were checked for their normal distribution by Kolmogorov-Smirnova and Shapiro-Wilk test, as well as statistical analysis was conducted which includes the following:
Descriptive statistics, One Way Analysis of Variance (ANOVA), Duncan's Multiple Range Test, Kruskal-Wallis Test, Mann-Whitney test between two groups for surface roughness values, the ARI scores and to evaluate the reliability of the researcher's work (intra and inter examiner calibration). Independent t-test was used to evaluate the SBS between the two primer types.

3. Results

3.1. Results for Surface Roughness

Regarding results of surface roughness, the Chi-square test showed a significant difference between each two experimental groups at $p<0.05$. These significant differences were applicable to all experimental groups (Table 1).

3.2. Results of SBS

In the AL_2O_3 groups, there was a significant difference between Assure® Plus and 3M™ Transbond™ XT primer while in the HF group, there were no significant difference between Assure® Plus and 3M™ Transbond™ XT primer materials. In the AL_2O_3 group, there was a significant difference between Assure® Plus and 3M™ Transbond™ XT while in the HF and control groups, there were no significant difference between Assure® Plus and 3M™ Transbond™ XT primer materials. In the AL_2O_3 group, there was a significant difference between Assure® Plus and 3M™ Transbond™ XT primer while in the control and HF groups, there were no significant difference between Assure® Plus and 3M™ Transbond™ XT primer materials (Table 2).

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Table 1.
Surface roughness (μm) for ceramic, Zirconia, E. max groups.

Group	Priming	mean±SD	P value	Chi²
Ceramic	HF	0.5±0.070	0.001	23.7
	Al_2O_3	0.64±0.10		
	control	0.111±0.010		
Zirconia	HF	0.44±0.06	0.001	26.298
	Al_2O_3	0.72±0.06		
	control	0.11±0.01		
E. max	HF	.4±0.050	0.001	26.612
	Al_2O_3	.67±0.050		
	control	.11±0.010		

Data expressed as mean±SD, n=10, p<0.05 is significant using Chi-square test.

Table 2.
SBS (MPa) for ceramic, E. max and zirconia groups according to primer types.

Priming	Group	Type (n=10 each)	Mean±SD	P value
Ceramic	Control	Assure® Plus	2.4460±0.32080	0.19
		3M™ Transbond™ XT	2.1454±0.18384	
	HF	Assure® Plus	4.1316±0.34192	0.2140
		3M™ Transbond™ XT	3.9490±0.289460	
	Al_2O_3	Assure® Plus	16.9406±0.76870	.0001*0
		3M™ Transbond™ XT	14.3699±0.42528	
E. max	Control	Assure® Plus	2.3523±0.34103	0.9700
		3M™ Transbond™ XT	2.3470±0.27964	
	HF	Assure® Plus	4.0331±0.14655	0.6170
		3M™ Transbond™ XT	4.0027±0.11950	
	Al_2O_3	Assure® Plus	16.6471±0.41969	0.000*0
		Trans bond 3M	13.8350±0.20950	
Zirconia	Control	Assure® Plus	3.3039±0.31672	0.3490
		3M™ Transbond™ XT	3.1865±0.22104	
	HF	Assure® Plus	4.0989±0.14546	0.1750
		3M™ Transbond™ XT	4.0182±0.10698	
	Al_2O_3	Assure® Plus	17.6450±0.257790	0.0001*0
		3M™ Transbond™ XT	15.0527±0.294350	

Data expressed as mean±SD, n=10, p<0.05 is significant using independent t-test for

3.3. Results of ARI

The distribution of ARI scores for ceramic groups and showed that the AL_2O_3 with Assure® Plus had a score 2 and 3, the HF with Assure® Plus had mostly score1, while control with Assure® Plus group had score 0 and 1. On other hand, the AL_2O_3 with 3M™ Transbond™ XT had score 1 and 2, while HF with 3M™ Transbond™ XT had score 0 and 1. The control group with 3M™ Transbond™ XT had score 0.

The AL_2O_3 with Assure® Plus had mostly score 2 and 3 while HF and control with Assure® Plus had score 0 and 1. Furthermore, the AL_2O_3 with 3M™ Transbond™ XT had score 1 and 2, but the control and HF with 3M™ Transbond™ XT had mostly score zero and 1. The AL_2O_3 with Assure® Plus had mostly score 2 while the control and HF with Assure® Plus group had score 0 and 1. For 3M™ Transbond™ XT primer, the AL_2O_3 groups had score 1 and 2 but the control and HF group had score 0 and 1 (Table 3, Table 4, Table 5, and Table 6).

Table 3.
Kruskal Wallis Test for ARI for ceramic, E. max and zirconia groups.

	Ceramic Assure® Plus	**Zeramic 3M™ Transbond™ XT**	**Zirconia Assure® Plus**	**Zirconia 3M™ Transbond™ XT**	**E. max Assure® Plus**	**E. max 3M™ Transbond™ XT**
Chi-Square	20.152	20.558	19.262	14.783	18.723	19.669
df	2	2	2	2	2	2
Asymp. Sig.	0.0001	0.0001	0.0001	0.001	0.0001	0.0001

a. Kruskal Wallis Test , b. Grouping Variable: VAR00019

Table 4.
Mann–Whitney Test for ARI score between control and HF group

	Ceramic Assure® Plus	**Ceramic 3M™ Transbond ™ XT**	**Zirconia Assure® Plus**	**Zirconia 3M™ Transbond ™ XT**	**E max. Assure® Plus**	**E. max 3M™ Transbond ™ XT**
Mann-Whitney U	23	15	45	20	40	40
Wilcoxon W	78	70	100	75	95	95
Z	-2.368-	-3.199-	-0.438-	-2.669-	-0.890-	-1.090-
Asymp. Sig. (2-tailed)	0.018	0.001	.661	.008	0.374	0.276
Exact Sig. [2*(1-tailed Sig.)]	0.043[a]	0.007[a]	0.739[a]	0.023[a]	0.481[a]	0.481[a]

Note: a. Not corrected for ties., b. Grouping Variable: VAR00019

Table 5.
Mann–Whitney Test for ARI score for control and Al_2O_3.

	Ceramic Assure® Plus	Ceramic 3M™ Transbond ™ XT	Zirconia Assure® Plus	Zirconia 3M™ Transbond ™ XT	E. max Assure® Plus	E. max 3M™ Transbond ™ XT
Mann-Whitney U	2	0.0001	2.5	8	3	2.5
Wilcoxon W	57	55	57.5	63	58	57.5
Z	-3.764-	-4.147-	-3.725-	-3.460-	-3.713-	-3.853-
Asymp. Sig. (2-tailed)	0.0001	0.0001	0.0001	0.001	0.0001	0.0001
Exact Sig. [2*(1-tailed Sig.)]	0.0001[a]	0.0001[a]	0.0001[a]	0.001[a]	0.0001[a]	0.0001[a]

Note: a. Not corrected for ties., b. Grouping Variable: VAR00019.

Table 6.
Mann–Whitney Test for ARI score for HF and Al_2O_3.

	Ceramic Assure® Plus	Ceramic 3M™ Transbond™ XT	Zirconia Assure® Plus	Zirconia 3M™ Transbond ™ XT	E. max Assure® Plus	E. max 3M™ Transbond ™ XT
Mann-Whitney U	8	24.5	3	26	5	7.5
Wilcoxon W	63	79.5	58	81	60	62.5
Z	-3.414-	-2.387-	-3.702-	-2.068-	-3.555-	-3.425-
Asymp. Sig. (2-tailed)	0.001	0.017	0.0001	0.039	0.0001	0.001
Exact Sig. [2*(1-tailed Sig.)]	0.001[a]	0.052[a]	0.0001[a]	0.075[a]	0.0001[a]	0.0001[a]

4. Discussion

According to surface treatment methods, the AL_2O_3 group had the highest value of SBS among group while the control and HF groups had a SBS which is so low and not reach to the acceptable clinical range of bonding strength that the reasonable clinical bond strength values were 5.9 to 7.8 MPa and this result due to the fact that sandblasting creates a rough surface and improves surface characteristics like surface energy and wettability(15).

Shear bond strength of all groups (ceramic, zirconia and E. max) treated by air abrasion by AL_2O_3 had a highest mean than HF and control groups and these results coincide with (16) who showed that sandblasting of zirconium surface led to higher bond strength values than HF acid etching. Also, (17), evaluated the effect of different surface conditioning methods and reported that sandblasting yielded the highest bond strength of bracket bonded to zirconia and these findings were in agreement with our results. Meanwhile, (18) revealed that a clinically acceptable shear bond strengths achieved when the E. max specimens sandblasted and bonded by either Z-prime plus or monobond etch and prime.

The effectiveness of sandblast in increasing the SBS between the bonding materials and the zirconia specimens are study by (19) and showed that air abrasion increases surface roughness and wettability of the zirconia materials and the contact angle increased, increasing the mechano-retention and enhance the bond strength. (20) in his study concluded that bonding brackets to sandblasted zirconia surfaces with Reliance Assure plus resulted in a higher shear bond strength. On the other hand, a research on E. max material by (21) showed that the higher SBS was achieved in the sandblasted group for lithium disilicate and found that there was appositive correlation between the surface roughness and SBS.

Also, Ferreira *et al.*, (2023) found that sandblasting group yielded a satisfactory SBS with ceramic surfaces(22). The present study indicated that mechanical abrasion using aluminum oxide creates a greater SBS than HF and control groups and this agree with (23), who found that among all surface treatments, aluminum oxide particle abrasion produced significantly higher SBS than hydrofluoric acid etching and tribochemical silica coating particle air abrasion. Based on the results obtained by Mageet *et al.*, (2024), who concluded that the use of sandblasting method without etching has shown the strongest SBS compared with all the acids that they have used because the sandblasting increases the surface area(24). Also, El-Farag et al. (2024) used aluminum oxide particles size for sandblasting (40, 80 and 110 μm) and observed that the use of coarser AL_2O_3 particles lead to an increase in surface irregularities and then increased the surface area available for adhesive improving the micro-mechanical retention and finally increasing the bond strength values(25).

On the other hand, Kwak *et al.*, (2016) demonstrated that hydrofluoric acid etching provided no significant difference in SBS values (15.24 ± 3.36 and 15.78 ± 2.39 Mpa, respectively) compared to the air abrasion by AL_2O_3 on glazed monolithic zirconia attached to metal brackets and this result not coincide with our finding(26).

Several studies were controversy to our results such as Stella et al (2015) concluded that etching of porcelain surface by 10% hydrofluoric acid result in higher SBS of (16.42MPa)(27). Moreover, results obtained by Yassaei *et al.*, (2013)(16) and Lyons et al. (2019) (28) showed that etching of felspathic ceramic by HF 9.6% for 2 minutes result in SBS of 7.4MPa and 8.84MPa, respectively. The literature review done by Alzainal *et al.*, (2020) mentioned that the HF 9.6% consider as golden methods of surface treatment of ceramic prosthesis(1). In another study by Mageet *et al.*, (2024), they note a higher SBS when porcelain surface etching by HF for 1 minutes(24). Furthermore, the present study not coincide with (29) who found that the higher bond strength obtained when the orthodontic bracket bonded to ceramic surface treated by HF than surface treated by AL_2O_3 air abrasion. Also, Mokhtarpur *et al.*, (2020) (30)and Zhang *et al.*, (2014) (31) showed that the surface treatment with HF acid demonstrated higher values of SBS compared with the AL_2O_3 sandblasting-treated zirconia specimens. Ferreira *et al.*, (2023) showed that the conditioning of the three different ceramic groups (feldspathic, lithium disilicate, and zirconia) by hydrofluoric acid were produced a significantly higher SBS than those obtained by sandblasting methods(32).

While (33) showed that the use of HF for surface conditioning of zirconium or lithium disilicate samples were not provide a significant increase in SBS of metal brackets. Also, Oldham *et al.*, (2020) showed that the sandblasting etching protocol does not effective for E. max materials.

According to (34), the hydrofluoric acid provides no effect on the zirconia surface but provides adequate adhesive strength on glass ceramics and this due to difference in the composition of ceramics materials which produce distinct topographical features after etching. While (35) founded that the used of high concentration of HF 40% is appropriate for conditioning of zirconia specimens because it leads to uniform and fast etching. Also, our result in contrast with Zhang *et al.*, (2020) who considered that the HF acid is a promising surface conditioning method to promote bracket-zirconia bonding without excessive zirconia damage and (36) concluded that when the E. max surface was pre-treated with hydrofluoric acid etch, it provides a bond strength that is within an acceptable clinical range.

The contrary in there our results with these studies mentioned above should be related to use of different types of ceramic materials which differ in particle size and the form of their crystalline structure which may be responsible for different values of bond strength and also due to heterogeneity of their methodology related to concentration and application protocol of HF acid.

The result of the present study revealed that the Assure® Plus primer with AL_2O_3 conditioning methods in all groups (ceramic, zirconia and E. max) give rise to the highest SBS than 3M™ Transbond™ XT bonding system and this due to that Assure® Plus adhesive is one of 10-Methacryloyloxydecyl dihydrogen phosphate (MDP) containing primers, which is a bifunctional phosphate monomer that allows for the formation of a chemical bond between the resin of the adhesive and the ceramic and also due to higher flowability of Assure® Plus prime compared with 3M™ Transbond™ XT prime and this result agreement (37) found that the application of Assure® Plus on feldspathic porcelain yielded a higher SBS than those treated by 3M™ Transbond™ XT. The finding of (38) reported that the application of Assure® Plus on ceramic, amalgam or enamel surface provided a bonding strength values within acceptable clinical mean and considered Assure® Plus as a multipurpose prime. Similar results obtained by (39) who reported that a high shear bonding strength (17.29MPa) was recorded when Assure® Plus bonding ceramic brackets to feldspathic ceramic. Also, Pulido *et al.*, (2023) found that the SBS obtained when bonding metal orthodontic brackets using the Assure® Plus adhesive systems were significantly higher than 3M™ Transbond™ XT adhesive system for E. max and zirconia groups(40). Naseh *et al.*, (2018) compared between the Assure® Plus and 3M™ Transbond™ XT primes on bonding metal brackets to porcelain and lithium disilicate specimens after sandblasting and etching and revealed that the Assure® Plus prime had a higher bonding strength.

Furthermore, Polineti *et al.*, (2023) concluded that the Assure® Plus give raised to a strong adhesion to porcelain and zirconium surfaces so they considered Assure® Plus primer as a better bonding agent for repeated bonding failure. The study by Goracci *et al.*, (2022) on E. max specimens without surface conditioning and concluded that the Assure® Plus and 3M™ Transbond™ XT primer provided inferior bonding strength than that considered for clinical application and these findings support our results.

A controversy result by Mehta *et al.*, (2016) (41) and Douara *et al.*, (2019) (42) reported no significant differences in SBS between 3M™ Transbond™ XT and Assure® Plus bonding agent. Kocadereli et al. (2001) (43) and Türkkahraman et al. (2006) (44) also reported low bonding strength (5.46 MPa) when the feldspathic porcelains sandblasted by AL_2O_3 particles and bonded by Assure® Plus primer. Also, El- Ramly *et al.*, (2022) which showed that the air abrasion with Reliance Assure Plus yielded a lower SBS value(1.84MPa) of orthodontic brackets bonded to porcelain surfaces.

The finding of the present study showed that there no significant difference between the Assure® Plus and 3M™ Transbond™ XT primer system in all groups treated with HF and this result is disagree with Pulido *et al.*, (2023) who found that the application of hydrofluoric acid and Assure® Plus adhesive system is adequate for bonding brackets to the feldspathic ceramics, lithium disilicate ceramics and zirconia(40). A contrast result also achieved with Ferreira *et al.*, (2023) who revealed that the hydrofluoric acid treatment produced a favorable SBS for all three examined ceramic types when bracket bonding with Assure® Plus(32).

On the other hand, Goracci *et al.*, (2022) found that the SBS of metal brackets bonded with 3M™ Transbond™ XT primer on glazed zirconia specimens without surface treatment was stronger than that obtained by Assure® Plus and this result was contrary to our finding which showed that no significant difference between Assure® Plus and 3M™ Transbond™ XT on control zirconia models(45).

A universal bonding (3M™ Transbond™ XT prime) revealed a high SBS (14.369MPa) with AL_2O_3 surface treatment while a low SBS (4.30 and 2.39 MPa) values with HF etching and control groups respectively. A research by (46) evaluated the bonding strength of brackets bonded to porcelain surface using universal bonding agent after etched by 10% HF and showed a high bonding strength of 29MPa. Furthermore, (47) tested the SBS of metal brackets to ceramic bonded by universal prime and the results found that the SBS values were 4.4MPa and the author reported that the universal prime did not provide acceptable SBS and these findings were contrary to our results.

For Zirconia group, The adhesive failure in control and HF group bonded by 3M™ Transbond™ XT or Assure® Plus had a score 0 and 1 which was designated to adhesive zirconia interface failure

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which mean that the bonding strength of adhesive to zirconia surface is weaker than the mechanical interlocking between adhesive and bracket base and this result agree with Pulido *et al.*, (2023) (40) who found that in zirconia samples etched by HF and bonded by 3M™ Transbond™ XT showed adhesive zirconia interface failure while a controversy result with Pulido *et al.*, (2023) achieved with Assure® Plus because they found that zirconia samples etched by HF and bonded by Assure® Plus was designated as mixed-type failures Another contrarily to our result, Mehmeti *et al.*, (2019) showed that the when the metallic brackets bonded to zirconia specimens after HF etching using 3M™ Transbond™ XT have shown mixed adhesive-cohesive failures(48). Furthermore, most of the models in AL_2O_3 group bonded with Assure® Plus had a score 2 and 3 which was designated to adhesive bracket interface failure while in AL_2O_3 group bonded with 3M™ Transbond™ XT had a score 1 and 2 which was designated as mix type, indicating a favorable failure mode. A similar result achieved by Mehta *et al.*, (2016) who found that the ARI scores were mostly score 3 in Assure® Plus with sandblasting surface treatment and concluded that the physiochemical bond between adhesive materials and zirconia surface was greater than the micromechanical retention between the bracket base and adhesive.

For ceramic group, The adhesive failure in control and HF group bonded by 3M™ Transbond™ XT or Assure® Plus had a score 0 and 1 which was designated to adhesive-ceramic interface failure and this indicates low adhesion between ceramic surface and adhesive materials and this result similar to the finding of (49) and disagree with Pulido *et al.*, (2023) who found that the ceramic samples etched by HF and bonded by 3M™ Transbond™ XT or Assure® Plus primer was designated as mixed-type failures(40).

While the models in AL_2O_3 group bonded by 3M™ Transbond™ XT had a score 1 and 2 which is a mixed failure, showing a favorable failure mode. Controversy, most of the models in AL_2O_3 group bonded with Assure® Plus had a score 2 and 3 which was appointed to adhesive-bracket interface failure and this mean that the mechanical interlocking between adhesive and brackets was lower than that bonding strength between ceramic surface and adhesive material and this findings similar to Tahmasbi *et al.*, (2020) who utilizing the same protocol and concluded that most of failure occurred at bracket adhesive interface(50) and Abou shady *et al.*, (2021) (8) who have been utilizing the same protocol and concluded that most of failure occurred at bracket adhesive interface. Also, A cohesive porcelain failure of the specimens was reported by Isolan *et al.*, (2014) (51)and Mehta *et al.*, (2016)(41). Controversy to present study, Karan *et al.*, (2007)(52) and El-Ramly *et al.*, (2022)(53) showed that the samples which treated with air abrasion by AL_2O_3 and bonded by Assure® Plus prime failed at the adhesive porcelain interface and this controversy in the results attributed to different in methodology used in these studies like variety in bracket materials and their base designs.

For E.max group, the adhesive failure in control and HF group bonded by 3M™ Transbond™ XT or Assure® Plus had a score 0 and 1 which was designated to adhesive- E. max interface failure and this indicates low adhesion between E. max surface and adhesive materials while the models in AL_2O_3 group bonded by 3M™ Transbond™ XT had a score 1 and 2 which is a mixed failure, showing a favorable failure mode. Controversy, most of the models in AL_2O_3 group bonded with Assure® Plus had a score 2 and 3 which was appointed to adhesive-bracket interface failure and this mean that the strongest attachment occured between E. max surface and adhesive than that attachment between brackets and adhesive materials. A similar result achieved by Naseh *et al.*, (2018) who found that when the lithium disilicate bonded by Assure® Plus, 40% of the samples had adhesive remain in the specimen surface while the samples bonded by 3M™ Transbond™ XT, 90% of the samples had no adhesive remain on the surface of the specimens(10). Also, Juntavee *et al.*, (2020) found that for HF group bonded by 3M™ Transbond™ XT, the ARI scores were mostly 0 and 2. (54) in their study found a low ARI scores of the E. max. materials(55). While, Mehmeti *et al.*, (2019) showed that the samples with metallic brackets bonded to lithium disilicate specimen after HF etching using 3M™ Transbond™ XT have mixed adhesive-cohesive failures(48).

In other hand, a contrary result achieved with Pulido *et al.*, (2023) who found that when lithium disilicate treated HF and bonded by Assure® Plus was designated as mixed-type failures for all the

specimens, indicating a favorable failure mode while with 3M™ Transbond™ XT most of the samples showed mixed-type failures and the other showed adhesive E. max interface failure(40). Also, Aboushady et al. (2021) (56) showed that in the samples receiving sandblasting by AL_2O_3 and bonded by Assure® Plus displayed better debonding characteristic which is a mixed cohesive adhesive failure pattern while the samples receiving sandblasting by AL_2O_3 and HF acid etching and bonded by 3M™ Transbond™ XT showed a failure at the bracket adhesive interface.
These in vitro studies applied to evaluate the effect of two types of primer material and two surface treatment methods on SBS but the effect of other factors that intervene in oral environment were not considered in our investigation. These contributing variables that affect the SBS values in the oral environment like pH level of saliva, complex microflora, temperature, stress generated by the orthodontic arch wire and masticatory force.

5. Conclusion

The air abrasion with Al_2O_3 particles provide a higher surface roughness than etching by HF acid. With an increased in degree of surface roughness, A higher SBS was obtained. The air abrasion with Al_2O_3 particles provide an acceptable value of SBS in the all types of ceramic materials while the bonding strength obtained after HF acid etching not reach to acceptable range values that determined for clinical used. The present study concluded that the bonding strength obtained when using the Transbond™ XT or Assure plus primer system with AL_2O_3 air abrasion is satisfactory of all types of ceramic used, although the Assure plus primer give raised a higher value. Inadequate bonding strength obtained when using the Transbond™ XT or Assure plus primer system with control or HF acid etching so the surface conditioning method is the most effect variable than the type of bonding material used. As it is difficult clinically to distinguish which types of ceramic materials used in prostheses so it is a pertinent to choose a surface conditioning method and the bonding types that are effective with different types of ceramics materials so our study concluded that the Transbond™ XT or Assure plus with AL_2O_3 surface conditioning is a suitable method for use with ceramic restorations.

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