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COMPARATIVE STUDY OF SHEAR BOND STRENGTH BETWEEN CONVENTIONAL AND FLOWABLE ORTHODONTIC ADHESIVES

Tasneem A. Almohamady[*], Safaa M. Gaballah[**] *and* Nahla E. Gomaa[***]

ABSTRACT

Introduction: Flowable resin composites have been recommended for many clinical uses and have been formulated in a variety of compositions and viscosities to meet various uses.

Aim of the work: To determine if flowable composite with or without primers could be used in orthodontic bracket bonding.

Materials and Methods: Sixty human premolars and sixty metal brackets were randomly and equally divided into four subgroups. 1A subgroup (TXT with primer), 1B subgroup (TXT without primer), 2A (GF with primer) and 2B (GF without primer). After 72 hours, debonding was performed with a shearing force. The SBS (Shear Bond Strength) and the mode of bond failure were examined with ARI. Another twenty eight teeth were bonded by the same protocol to evaluate microleakage after thermocycling and dying with 2% methylene blue dye for 24 hours.

Results: Respective SBS results of the four subgroups were 14.6 ± 5.3, 13.3 ± 6.8, 18.9 ± 6.1 and 12.5 ± 5.9 MPa respectively. SBS value of subgroup 2A were significantly higher than subgroups 1A, 1B and 2B. After debonding ARI scores 0 and 1 were predominant in subgroups 1A, 1B and 2B, where subgroup 2A had ARI scores of 1 and 2. Subgroups 1B and 2B showed microleakage at both bracket-adhesive and enamel- adhesive interfaces, while subgroups 1A and 2A only 43% showed microleakage at bracket-adhesive interface.

Conclusions: Flowable composite (GF) can be successfully used for bonding orthodontic brackets as it provided SBS comparable with conventional composite (TXT), as well as can be used without primer as it gives a clinically acceptable SBS and favorable bond failure pattern. However, from microleakage point of view flowable composite (GF) with primer demonstrated the best performance.

KEY WORDS: Flowable composite, shear bond strength, Adhesive remnant index.

* M.D.S. of Orthodontics, Faculty of Dentistry, Tanta University, Egypt.
** Professor of Orthodontics, Faculty of Dentistry, Tanta University, Egypt.
*** Lecturer of Orthodontics, Faculty of Dentistry, Tanta University, Egypt.

INTRODUCTION

The success of the orthodontic treatment, among other factors, is greatly influence by accurate bracket positioning and long term retention of the accessories[1]. Failure during bracket bonding can disrupt and delay the treatment, increase the cost and hinder correct finalization of the case. Frequent bracket rebonding can also cause damage to enamel structure [2].

In routine orthodontic practice, the minimum bond strength required for bonding brackets range between 6 and 8 MPa [3] and less than the breaking strength of enamel which is approximately 14 MPa to avoid damaging the enamel surface during debonding[4.5]. The continuous research for better adhesives and simpler procedures has led to introduction of nanofilled flowable composites in the 1990[6], which have smaller particles size with wide size distribution and higher filler load which responsible for decreasing polymerization shrinkage and increasing mechanical properties[7].

Flowable composites have great orthodontic attention because of its desirable clinical handling characteristics as nonstickiness and fluid injectability facilitating indirect bonding [8]. In addition to their high flexibility and low modulus of elasticity which act as an "elastic layer" preventing stress concentration[9.10]. Their low viscosity and high wettability of the tooth and the bracket surface ensuring good material penetration in difficult access areas so, thus expected to enhance the level of mechanical retention[11.12], beside that it allows the flowable composite to be applied to acid-etched enamel without the use of primer so, by reducing number of steps during bonding, clinicians can save time and reduce potential errors related to contamination during the bonding procedure[13].

Durability of different bonding agents:

Microleakage is considered as one of the most important factors which has effect on SBS and the durability of bonding [14.15]. Since the difference between coefficient of thermal expansion and contraction between bonding material and tooth surface when they were cured and exposed to changes of temperature of the oral cavity, polymerization shrinkage of composite adhesive was occurred [16.17], causing gap at the enamel-adhesive-bracket complex, thus lead to decalcification, formation of white-spot lesions under bracket base[18] and premature debonding due to adhesive degeneration[19.20].

The purpose of this study, therefore was to test the low viscosity resins, Grandio Flow (GF) flowable composite to determine SBS value in comparison with conventional TXT, the site of bond failure of those materials as evidenced by Adhesive Remnant Index (ARI) score and examine the durability of bonding by evaluation of microleakage at enamel-adhesive and adhesive- bracket interfaces.

AIM OF THE WORK

This study was carried out to:

1- Assess the shear bond strength of flowable composite and conventional composite with and without primer application.

2- Examine the amount of adhesive after debonding on the enamel surface with scaning electron microscope (SEM) and identify the site of bond failure.

3- Determine which type of composite gave the optimal bond strength.

4- Examine the durability of flowable composite and conventional composite.

MATERIALS AND METHODS

Sixty human maxillary premolar teeth were extracted as a part of orthodontic treatment in the Department of Orthodontics, Faculty of Dentistry, Tanta University and private dental clinics after taking consent from patients for extraction.

Exclusion criteria:

The teeth were excluded if they were:

1) Previously restored premolars.
2) Premolars with delamination of the enamel or with enamel defects or cracking.
3) Premolars subjected to any chemical agents affecting the enamel (e.g. Alcohol, Hydrogen Peroxide or Ethanol).

The selected teeth were cleaned and stored in artificial saliva in 37°C for a maximum 6 months after extraction which was changed every two weeks[21].

Teeth preparation for bonding brackets:

- The enamel surface of each tooth was polished with fluoride-free pumice and rubber cup for 10 seconds, sprayed with water and dried with compressed oil-free stream.
- The buccal enamel surfaces of all teeth were etched with 37% phosphoric acid for 30 seconds, rinsed for 15 seconds and dried for 20 seconds until the enamel had a faintly white appearance.
- The teeth were divided into two groups. Each group contained thirty teeth which was divided into 2 equal subgroups (N = 15).
- All the steps were performed according to the manufacturer's instructions.

Group 1: Conventional composite resin, Transbond XT (TXT)*: Its chemical composition was mentioned in **(Table 1)**.

- Subgroup 1A: Teeth were bonded with a thin film of TXT primer, light cured then TXT adhesive paste was applied to the bracket base. (Control)
- Subgroup 1B: TXT adhesive paste was applied without TXT primer.

Each bracket was positioned on the buccal surface at the height of contour mesiodistally, in the middle one third occlusogingivally, parallel to long axis of the tooth using bracket placement tweezers. It was pressed firmly with an instrument to expel the excess adhesive for 10 seconds. Excess bonding resin was removed using a sharp scalar and light cured for 20 seconds from the incisal edge and 20 seconds from the gingival edge of the premolar stainless steel edgewise brackets (0.018" x 0.022") with bracket base area 8.32 mm^2. After bonding procedures, all specimens were stored in artificial saliva at 37° C for 72 hours.

Group 2: Flowable composite resin, Grandio Flow (GF)**: Its chemical composition was mentioned in **(Table 1)**.

- Subgroup 2A: The teeth were bonded with TXT primer, light cured then GF was applied to bracket base.
- Subgroup 2B: GF was applied without TXT primer.GF was applied following TXT protocol.

Teeth preparation for SBS testing:

- The teeth were mounted in color coded acrylic resin blocks which only its crown were exposed, Each sample was mounted on the lower fixed compartment of a computer controlled universal testing machine (Lloyd, Type 500, Lloyd Instrument, England) and subjected to a compressive load at a crosshead speed of 1 mm/min via mono-beveled chisel attached to the upper movable compartment of the testing machine where the chisel tip was positioned to touch only the base of the brackets and parallel to the long axis of each mounted tooth.
- The load required to dislodge each bracket was recorded in newtons N and SBS was calculated in megapascals (MPa) by dividing

* 3M ESPE, St. Paul, Minn.
** Voco, Cuxhaven, Germany.

the load in Newton (N) by the surface area of the bracket base (8.32 mm^2) as given by the manufacture, The maximum load to debond the bracket was thus recorded. Failure manifested by displacement of bracket and confirmed by sudden drop along load-deflection curve recorded by computer software (Nexygen-MT; Lloyd Instruments Ltd).

- After debonding: Teeth were immersed in sealed containers of deionized water and placed in an incubator at 37°C for 72 hours to permit adequate water absorption and equilibration [(22)].

Teeth preparation for SEM examination:

- Qualitative study was carried out to observe with SEM the amount of adhesive remaining on teeth surface and the bracket base.
- The buccal surface of each tooth was polished with fluoride-free pumice and rubber cup for 10 seconds, sprayed with water and dried with compressed oil-free stream.
- The crown of each premolar was sectioned from their roots with low speed double sided diamond disk and continuous water spray irrigation where the buccal surface was retained for the study then all the specimens were mounted on stubs and prepared for SEM by sputtering with gold, then examined in SEM operated at 15 KJ (Jeol, JSM-5200LV scanning microscope, Japan). The buccal surface of the teeth examined at the orthodontic bonding area at 35 X magnification to obtain the representive photomicrographs.
- The amount of adhesive remaining was assessed with ARI scores which developed by Artun and Bergland[(23)] as follows:

▪ **Score 0** = indicates no adhesive remained on the tooth.

▪ **Score 1=** less than 50% of the adhesive remained on the tooth.

▪ **Score 2=** more than 50% of the adhesive remained on the tooth.

▪ **Score 3=** all adhesive remained on the tooth with distinct impression of the bracket mesh on the tooth surface.

- To control operator bias, the results were verified by another two individuals.

Teeth preparation for microleakage testing:

- Another twenty eight teeth were divided as previously 4 subgroups where each subgroup included 7 teeth and the teeth were bonded as previous groups with the same materials and the same method then stored in distilled water at 37˚C for 4 weeks.
- All of the specimens were thermocycled 500 times between two water baths held at 5^0 C and 55^0 C with a dwell time of 30 seconds in each bath[(24)].
- All the specimens were sealed with nail varnish (mesially and distally to the brackets) and immersed in a 2% methylene blue dye for 24 hours.
- SBS testing was carried out for all groups as previously discussed using a universal testing machine. After debonding, all teeth and brackets were examined under 20× magnification with a stereomicroscope (Olymbus SZ 60, Japan) to evaluate microleakage by evaluating the dye penetration qualitatively at two interfaces (enamel-adhesive interface and bracket-adhesive interface).

Statistical analysis

- Descriptive statistics including the mean, standard deviation (SD), maximum and minimum values were calculated for each subgroup.
- Comparison of the means of the SBS values were made with analysis of variance (ANOVA).

Multiple comparisons were undertaken using post hoc Tukey tests.

- The chi-square test was used to evaluate statistically significant difference in the frequencies of ARI scores between the groups. Statistical significance for all tests was predetermined at P ≤ 0.05.
- Using Kappa test to evaluate inter-examiner reliability of adhesive remnant index, where all specimens were re-examined again after one week.
- All statistics results were made with software program (SPSS version 20).

TABLE (1): Chemical composition of the conventional composite and flowable composite used in this study

Product	Composition	Filler weight (%)
Transbond XT Light Cure Adhesive Paste (TXT)	Silane-treated quartz, bisphenol A diglycidyl ether dimethacrylate, bisphenol A bis(2-hydroxyethyl ether) dimethacrylate, silane-treated silica	77%
Grandio Flow (GF)	Bisphenol-A-diglycidyl methacrylate, Ethoxylated bisphenol-A-glycol dimethacrylate, 1,6-Hexanediol dimethacrylate, Triethylene glycol dimethacrylate, SiO2 nanofillers, initiators and stabilizer	80%

RESULTS

1-Shear Bond Strength

a) Descriptive analysis

Descriptive statistics including the mean, SD, maximum and minimum values for each subgroup were shown in (**Table 2).**

b) Analytical Statistics

The results of One way ANOVA showed statistically significant difference among 4 subgroups where p = 0.025 and F value of 3.366 (p ≤ 0.05) as shown in **(Table 2).**

Applying Tukey`s multiple comparisons of SBS tests showed that subgroup 2A had significant difference in mean SBS (P ≤ 0.05) in comparison with subgroup 2B (**Table 3**).

TABLE (2): Descriptive analysis and analytical statistics of SBS of the four studied subgroups in megapascals (MPa)

Sub-groups	Minimum	Maximum	Mean	SD	ANOVA	
					F	P-value
1A	6.0	29.5	14.6	±5.3	3.366	0.025*
1B	2.3	25.8	13.3	± 6.8		
2A	10.2	31.9	18.9	±6.14		
2B	6.2	24.2	12.5	±5.9		

***** **(P ≤ 0.05)***

TABLE (3): Multiple comparisons of shear bond strength between the four studied subgroups.

Tukey's test			
	Subgroup 1B	Subgroup 1A	Subgroup 2B
Subgroup 1A	0.936		
Subgroup 2B	0.983	0.778	
Subgroup 2A	0.063	0.215	0.026*

***** **(P ≤ 0.05)***

2- Adhesive Remnant Index (ARI)

a) Descriptive Analysis

The ARI of the four subgroups were examined under SEM and the data were described using frequencies and percentages as shown in **(Table 4)** where subgroups 1A, 1B and 2B had nearly equal prevalence of bond failure represented mean ARI scores 0 or 1 which revealed that the bond failure at enamel adhesive interface and within the adhesive respectively as shown in **(Figs 1, 2),** where subgroup 2A had mean ARI scores of 1 and 2 represented higher frequency of bond failure within adhesive as shown in **(Figs 3)**. Therefore, score 1 was occurred more frequently than the other scores by 38.3 % and there was no evidence of enamel fracture in any samples during shear bond test.

b) Analytical Statistics

The results of chi-square analysis showed no significant difference between the four subgroups regarding to the ARI scores ($P \leq 0.05$).

Descriptive analysis and analytical statistics of ARI scores of the four studied subgroups were shown in **(Table 4)**.

TABLE (4): Descriptive analysis and analytical statistics of ARI scores of the four studied subgroups.

ARI		**Groups**				
		Subgroup 1A	**Subgroup 1B**	**Subgroup 2A**	**Subgroup 2B**	**Total**
0	N	5	7	0	7	19
	%	33.3	46.7	0.0	46.7	31.6
1	N	5	5	8	5	23
	%	33.3	33.3	53.3	33.3	38.3
2	N	3	0	4	3	10
	%	20.0	0.0	26.7	20.0	16.7
3	N	2	3	3	0	8
	%	13.3	20.0	20.0	0.0	13.3
Total	N	15	15	15	15	60
	%	100.0	100.0	100.0	100.0	100.0
Chi-square	$X^{(2)}$	13.974				
	P-value	0.123				

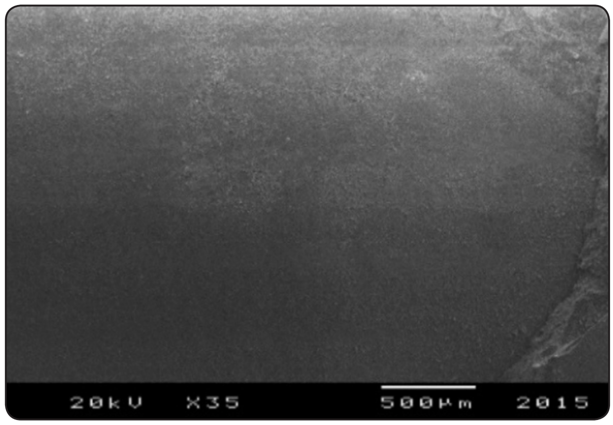

Fig (1): SEM image of enamel surface of subgroup 1B with ARI score 0 where no adhesive remained on the tooth.

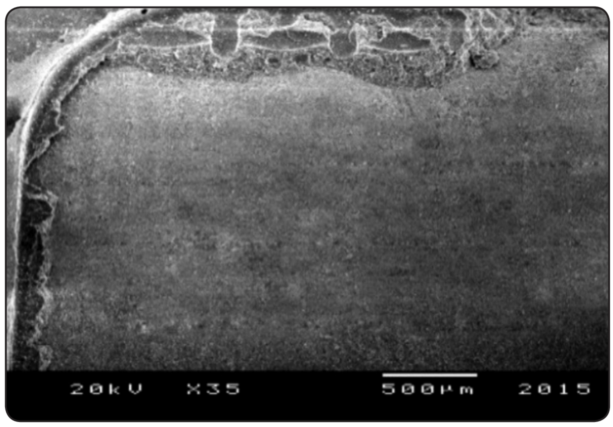

Fig. (2): SEM image of enamel surface of subgroup 1B with ARI score 1 where less than 50% of the adhesive remained on the tooth.

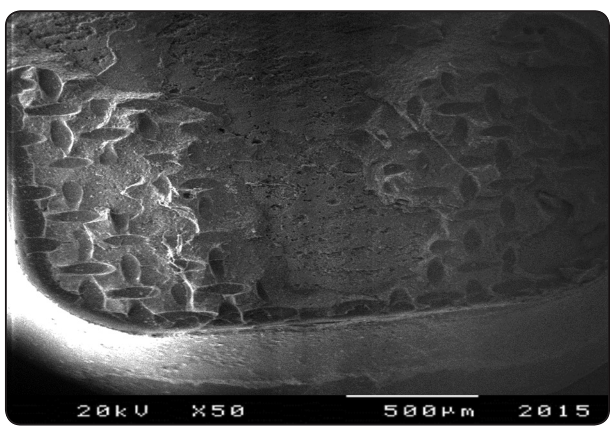

Fig. (3): SEM image of enamel surface of subgroup 2A with ARI score 2 where more than 50% of the adhesive remained on the tooth.

Microleakage test results:

Descriptive analysis

The microleakage of the four subgroups were examined under stereomicroscope and the data were described using frequencies and percentages as shown in **(Table 4 and figs 4-6).**

TABLE (4): Percentages of total microleakage at the enamel-adhesive and bracket-adhesive interfaces.

Microleakage			Subgroup 1A	Subgroup 1B	Subgroup 2A	Subgroup 2B
No		N	4	-	4	-
		%	57	0	57	0
Yes	Tooth adhesive interface	N	-	7	-	5
		%	0	100	0	71
	Adhesive bracket interface	N	3	3	3	7
		%	43	43	43	100

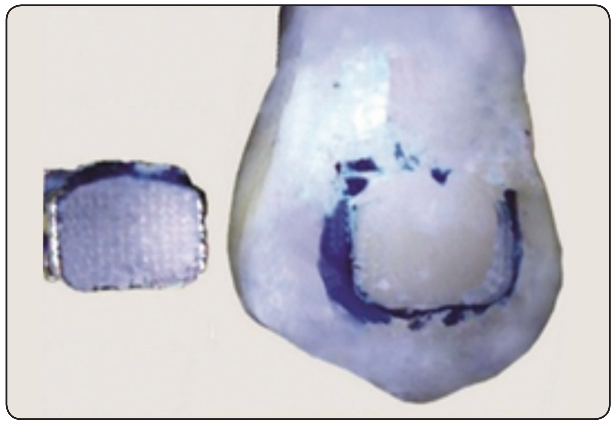

Fig. (4): Subgroup 1A: no microleakage occurred at bracket-adhesive or enamel-adhesive interfaces.

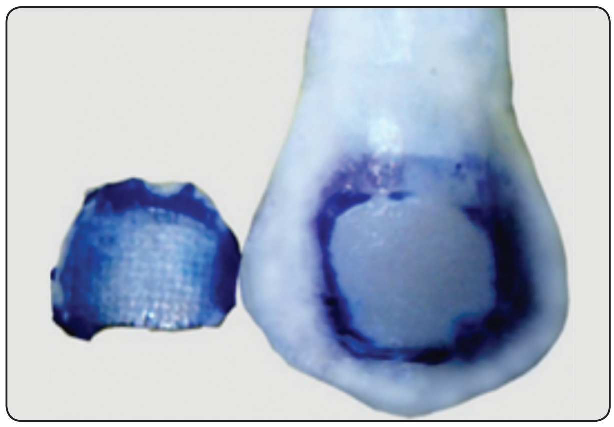

Fig. (5): Subgroup 2A: microleakage is noticed at bracket-adhesive interface.

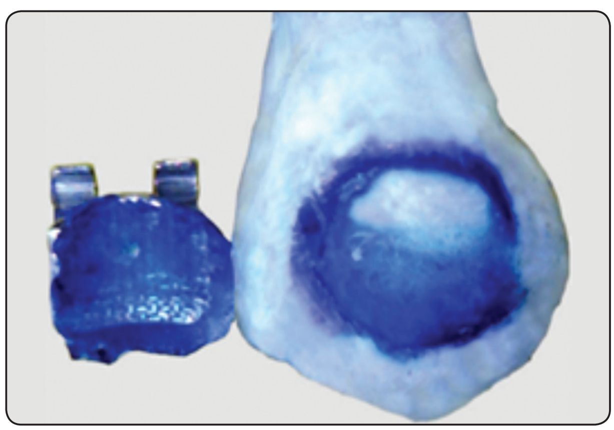

Fig. (6): Subgroup 2B: microleakage is clearly seen at bracket-adhesive and enamel- adhesive interfaces.

DISCUSSION

The quality of orthodontic treatment is constantly improved with increasing sophistication of technique and orthodontic bonding materials[(25)]. In clinical practice, obtaining a successfully long-term bonded bracket depends on achieving a stable and strong interface of the bonding material with the bracket itself and with the tooth structure to withstand the contraction of the adhesive material, normal oral functions and forces generated by the orthodontic movement without premature bracket loss[(26.27)].

Shear bond strength results

It has been supposed that the main contribution of the bond strength of bonded orthodontic brackets are micro-retentive pores formed by acid etching with micromechanical retention by bonding agent forming deep and wide resin tags[(28-30)], while thin and less uniform resin tags are conducive to poor adhesion as recommended by Yap et al.,[31] and Rathke et al.,[32-34]. In contrast with other studies which concluded that there is no correlation between the bond strength and the tag length[35.36].

The finding of this study indicated that the bond strength of subgroup TXT with primer was 14.6 MPa which nearly coincided with that found by Taylor et al.,[19] Park et al.,[37] and Uysal et al.,[38] but it was lesser than that observed in some previous studies[39-42]. Where statistical analysis showed that TXT samples without primer had lower SBS value than with primer (13.3 MPa). This finding was in agreement with the finding of Taylor et al.,[19] and Albaladejoa et al.,[43] although there was no significant difference found between them but this difference in SBS value could be due to TXT has a very large molecular weight and high filler concentration (77% quartz-silica hybrid fillers) which increase the viscosity of the material and reduce the flowability especially without primer where the charged particles in the composite resin limit the free flow of adhesive into the enamel pores, inhibiting the formation of resin tags[44-48], nevertheless it had acceptable SBS value. In contrary with TXT subgroup with primer, primer bonds with the inorganic filler component of the composite, produces small contact angles, good wetting properties which improve the adaptation of the bracket on the tooth surface resulting in high penetration coefficient with the etched enamel surface and also with bracket meshwork[49].

On the other hand GF with primer had the highest SBS value (18.9 MPa) which coincided with the finding of D`Attilio et al.,[17] Tecco et al.,[18] and Park et al.,[37]. Although it was higher than the breaking strength of enamel which is approximately 14 MPa but Bradbum and Pende[50] mentioned up to 20 MPa can be considered the highest acceptable bond strength, while GF without primer subgroup showed the lowest SBS value (12.5 MPa), which coincide with other investigators[19.51.52], with significant difference between them and thus can be explained by the fact that GF without primer has the highest filler load (80 % by weight) which are nano filled and highly irregular shaped particles (0.01 - .005 micron) dispersed in resin matix, its resin to filler ratio is 1:6.7[53] where the liquid phase is present in sufficient amount which responsible for its flowability lead to better infiltration in both etched enamel and in bracket base, that was in contrast with the finding of Park et al.,[37] who demonstrated that the flowability of flowable resins is achieved mainly by lowering the filler loading and that was not in a line with GF that had the highest filler loading and sufficient flowability. Besides, its high wettability, ensuring penetration of the adhesive into enamel pores even without primer. This result was in agreement with Albaladejoa et al.,[34] who found that flowable composites of thinner viscosity may bond to enamel adequately without primer. Its low viscosity allows it to form layers of minimum thickness without air entrapment which responsible for acceptable SBS value of GF without primer while with primer, all these criteria are highly increased resulted in the highest bond strength value.

The results of the present study showed statistically significant difference among 4 subgroups which explained by the effect of primer application, filler size and filler-resin ratio on the viscosity and the flowability of adhesive materials, besides, the finding of Durrani et al.,[52] Faltermeier et al.,[54] and Ostertag et al.,[55] who found that the SBS is increased considerably with increase of the filler loading, so there was a direct relation between them.

According to this SBS results which obtained, GF and TXT composites could be successfully used in bonding orthodontic brackets without the need of intermediate bonding resin as supported by several studies in the literature[18.31.32.43.58].

Adhesive remnant index results

The Chi-square analysis comparing the ARI scores indicated no significant difference between the four subgroups in the type of bond failure.

Specimens of TXT with and without primer and GF without primer had nearly equal prevalence of bond failure exhibited scores 0 or 1 where (score 0: 33.3%, 46.7% and 46.7% respectively, and score 1: 33.3% in all the three subgroups). Although this results were unfavorable for enamel preservation since the enamel fractures and cracking tend to increase with an ARI score of 0[59], on the other hand it would be desirable because debonding and subsequent polishing would become much easier.

In TXT samples without primer, the viscosity was increased as the charged particles in the composite resin limit the free flow of adhesive into the enamel pores, inhibiting the formation of resin tags, lead to weak adhesion with enamel surface which can explain the 0 and 1 scores of TXT without primer subgroup with a percentage 46.7% and 33.3% respectively and demonstrated the importance of traditional applying of primer as a part of the conventional bonding procedures to allow good wetting and penetration of the primer into the etched enamel surface.

Flowable composite (GF) without primer exhibited score 0 with 46.7% which explained by wetting properities and penetration of the composite into the enamel surface were decreased as compared with when primer was used. Some previous studies[60-62] suggesting this result to be due to the mechanical properties of the GF due to its high, smaller and uniformly distributed filler particles create a network within the matrix and increase contact area between the filler and resin matrix with absence of air bubbles.

In contrary, for most of the brackets in GF subgroup with primer, bond failure occurred within the adhesive, indicated by ARI score of 1 and 2 (53.3% and 26.7% respectively). This result may be due to the adhesive strength between GF and enamel is higher than the cohesive strength of the material itself.

Microleakage results

Comparing total microleakage at the enamel-adhesive for different study samples showed the TXT with primer and GF with primer had no microleakage in 57% of their samples, where microleakage was occurred in 43% of their samples at bracket-adhesive interface which ensured that there was strong bond formed between enamel surface and adhesive material with primer, moreover, the high filler loading of GF diminishes the thermal expansion coefficient, bringing them closer to that of tooth enamel which coincide with finding of Uysal et al.,[63] besides, the low modulus of elasticity of flowable composite make it act as an elastic layer preventing microleakage[14.64]. These observation are in agreement with Abdelnaby and Alwakeel.,[65] and Arhun et al.,[66] who stated that there was a significant negative relationship between SBS and microleakage, while James et al.,[67] and Shahabi et al.,[68] contradicting this finding. In contrary, the microleakage was occurred in all samples of subgroups TXT and GF without primer at tooth-adhesive interface (100% and 71% respectively) and at adhesive-bracket interface (43 % and 100% respectively) which could be explained by the quality of adhesion appeared in presence of resin tags prepared at the enamel surface by acid etching and primer that considered as important factors to fight leakage.

CONCLUSION

- The bond strength for the two types of orthodontic adhesives (with and without primer) were clinically acceptable.
- Grandio Flow composite with primer showed statistically significant higher SBS compared with Grandio Flow composite without primer.
- By reducing the number of bonding steps clinicians are able to save time and reduce contamination and technique sensitivity during the bonding procedures.

- ARI score examination showed that the flowable composite without primer tended to display adhesive failure at the enamel-adhesive interface. On the other hand, flowable composite with primer tended to display cohesive failure within the adhesive
- All groups exhibited some amount of microleakage under brackets. However, flowable composite (GF) with intermediate resin demonstrated the best performance.

RECOMMENDATION

Microleakage under orthodontic brackets remains a notable clinical challenge because of polymerization shrinkage of the adhesive with the oral fluid leakage and microbial ingress with consequent enamel decalcification. Further studies are necessary to investigate the microleakage under brackets in a large sample size and the correlation with SBS.

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