ORIGINAL RESEARCH

Are Flowable Restorative Composites Suitable for Orthodontic Bracket Bonding?

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Abstract

Aim: This study aimed to determine if flowable restorative light cure composites can be used effectively for routine orthodontic bracket bonding, thereby reducing 4 in the dental office and preserving the surface enamel.

Materials and methods: Ninety extracted human premolars were divided into three equal groups. Pre-adjusted edgewise (PAE) brackets were bonded to prepared enamel surface using conventional orthodontic resin Transbond XT (control), GC-G-ænial, and Anabond Stedman. Debonding was performed with a shearing force using a universal testing machine to test shear bond strength (SBS). The residual adhesive on the enamel surface was evaluated using the adhesive remnant index (ARI). In addition, representative samples from each group were examined by scanning electron microscopy (SEM) and elemental composition was quantified with energy dispersive X-ray spectrometry (EDX).

Results: There was a statistically significant difference ($p = 0.000$) between all three materials with respect to bond strength and ARI. The SBS values of Transbond XT, GC-G-ænial, and Anabond Stedman were found to be 13.10 ± 3.46, 9.8027 ± 2.05, and 6.2720 ± 1.39 MPa, respectively, signifying acceptable bond strength. The greatest frequency for Transbond XT and GC-G-ænial was observed at an ARI score of 1, whereas Anabond Stedman displayed an ARI score of 2. Morphologically different types of images were observed under the SEM. Similar elements with varied concentrations were detected in EDX. An insignificant amount of calcium was detected in all the samples evaluated under EDX indicating preservation of enamel.

Conclusion: In this study, Transbond XT was found to be relatively better than GC-G-ænial Universal Flo and Anabond Stedman Flowable composite. The use of flowable restorative light cure composites can be advocated for orthodontic bracket bonding as acceptable SBS values were attained.

Clinical significance: The rheological properties and esthetics of the flowable restorative materials make them versatile, economical, and favorable for orthodontic bracket bonding, thereby reducing the in-office armamentarium and the need for an additional orthodontic bonding material.

Keywords: Flowable restorative composites, Orthodontic brackets, Shear bond strength, Transbond XT.

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Introduction

With advances made in material science, more so in a conservative and orthodontic specialty, a vast array of materials are now available. One such material is the flowable restorative light cure composite, with a very subtle difference in the composition between restorative and flowable composite. The content of the inorganic filler is increased almost over 60% by weight in contrast to conventional flowable composites with 20–25% lower filler loading.[1,2]

They present numerous advantages such as optimum adaptation, used for several clinical applications, have good penetration in difficult access areas, and are commercially available with various shade ranges at affordable prices compared to the expensive light-activated adhesive resins. Moreover, they exhibit the property of "controlled fluidity" which ensures ease in application. In addition, it does not necessitate the application of an intermediate bonding agent. Thereby, it becomes time-saving for the clinician as the number of steps during bonding and potential errors are reduced.

Polymerization shrinkage is one of the major disadvantages of any resin composite leading to failure of marginal adaptation between the tooth structure and resin composite more commonly seen when the margins of the restoration are placed at the dentin or cementum. However, the high filled flowable restorative composites are known to contain silane surface-treated ultra-fine strontium glass fillers with an average 200 nm size which provides improved bonding, thereby minimizing the polymerization shrinkage. They also exhibit properties such as lower modulus of elasticity and low volumetric shrinkage which helps the material to withstand masticatory forces and helps to reduce the marginal discrepancies at the tooth–restoration interface. Excellent durability, high wear resistance, and high gloss retention make them esthetic and long-lasting. Due to their thixotropic nature, which is to flow well under pressure, they are recommended in class I, II, III, IV, and V restorations. Moreover, they are bis-GMA free and come in various shades and different opacities for the clinician to choose from.

Flowable restorative composites have paved their way beyond operative dentistry and have found their multipurpose use in

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orthodontics for fabrication of tongue Spikes and Cribs, reactivation of springs, bonded attachments, molar stops, cantilever arches, lingual retainers, and even orthodontic bonding.

In vitro studies help obtain relevant data for evaluating new products and to the best of our knowledge, there has not been any study comparing flowable restorative composites for orthodontic bonding. Hence, the objective of this study was to test the use of flowable restorative light cure composite for routine orthodontic bracket bonding, thereby reducing in-office armamentarium.

Materials and Methods

Ninety premolar teeth extracted for orthodontic purposes were collected and stored in distilled water containing 0.1% thymol solution. Premolars were selected on basis of approximately 6 months elapsed between extraction and investigation and intact buccal surface. Premolars with enamel cracks, carious, hypoplastic, and large restorations were excluded.

The teeth were divided using the random sampling method into three equal groups. Each tooth specimen was mounted in color-coded acrylic cuboidal blocks up to the cemento-enamel junction (CEJ) exposing the crown surface for bonding of brackets. The buccal surfaces were rinsed and dried after polishing for 15 seconds with fluoride-free pumice slurry. Premolar brackets with pre-adjusted edgewise (PAE) prescription were bonded with different adhesives in each group. The bonding adhesives were light-cured with a curing unit (Ivoclar Vivadent, Bluephase N MC). It was a single-blinded study and all bonding procedures were performed in accordance with the manufacturer's instructions and examined by only one investigator (Orthodontist). The study was completed in a period of 6 months.

Bonding Procedure

Group I—Transbond XT (3M Unitek, Monrovia, CA, USA).
Group II—G-ænial Universal Flo (GC Corporation, India).
Group III—Anabond Stedman Flowable composite [Anabond Stedman Pharma Research Pvt Ltd (ASPR), India].

The bonding protocol was done as per the manufacturer's instructions. The enamel was etched with 37% phosphoric acid for a duration of 30 seconds following which it was thoroughly rinsed for 15 seconds. It was then dried with moisture-free air until the surface enamel exhibited a frosty white appearance. Only in the control group (Transbond XT) primer application with Transbond XT primer was done. After the application of composite resin, each bracket was compressed with 300 g using a force gauge for a duration of 10 seconds. A scaler was used to remove excess resin flash. Bracket position was standardized at a distance of 5 mm with 400 to 450 Nm and light-cured for 30 seconds.

Storage after Bonding

The bracketed teeth were kept in sealed containers of distilled water and incubated at 37°C for 72 hours to allow for sufficient equilibration and water absorption.

Debonding

Shear Bond Strength Testing

Shear bond strength (SBS) was evaluated by placing the test specimen on a Universal testing machine Instron (model 3382 100 KN, UK). A shear force was applied on top of each orthodontic bracket using a knife-edged steel blade. The brackets were shear tested to failure with a load cell of 50 kg and a crosshead speed of 1 mm/minute. The force magnitude was recorded in Newton. The conversion of force per unit area (MPa) was done by dividing the measured force values by the bracket surface area. The mean values were recorded with Bluehill 2.0 software coupled to the test machine (Fig. 1).

Adhesive Remnant Index

The amount of adhesive remaining on the bracket was assessed under 30× magnification and graded as per adhesive remnant index (ARI) given by Artun and Bergland in 1984.[3]

Score 0: No adhesive left on the tooth.
Score 1: Less than half of adhesive left on the tooth.
Score 2: More than half of adhesive left on the tooth.
Score 3: All adhesive left on the tooth.

Scanning Electron Microscopy Analysis

Three representative bracket bases from the three groups were subjected to scanning electron microscopy (SEM) analysis (Zeiss, EVO MA15) mounted on SEM studs for qualitative analysis.

Energy Dispersive X-ray Spectrometry

Five bracket samples from each group were subjected to energy dispersive X-ray spectrometry (EDX) to procure quantitative data. The amount of calcium at the bracket base which indicated the damage to enamel was quantified in terms of percentage using EDX mean area scan analysis (Quanta FEG 200 High-Resolution Scanning Electron Microscope).

Statistical Analysis

Statistical analyses were performed by the statistician (double-blinded) using the SPSS software package (SPSS for Windows, version 10.0.1, SPSS Inc., Chicago, IL, USA). The normality and the homogeneity were checked for each variable.

Descriptive statistics including the mean, standard deviation, and minimum and maximum values were calculated for each of the three groups. Comparisons of means were made using analysis of variance (ANOVA) and Tukey *post hoc* significant difference (HSD) tests. The Chi-square test was used to determine significant differences in the ARI scores among the different groups and Kruskal–Wallis for EDX.

Fig. 1: Samples tested using Instron Universal Testing Machine

Results

SBS

The descriptive statistics, including the mean, standard deviation, and minimum and maximum values for each of the three groups, are presented in Table 1.

The results of this study demonstrate that group I had higher SBS values than the flowable composites.

Group I had a mean value of 13.1 ± 3.4 MPa, the highest of all test groups. Groups II and III had mean bond strengths of 9.8 ± 2.0 and 6.2 ± 1.3 MPa, respectively. There was a statistically significant difference ($p = 0.000$) between all three materials with respect to bond strength.

ARI

The residual adhesive on the enamel surfaces was evaluated by the ARI scores, and the results are presented in Table 2. Adhesive remnant index scores indicated that significant differences ($p = 0.000$) were present among the three groups. The bar diagram signifies that in group I and II, the greatest frequency was observed at an ARI score of 1 (66.7 and 40%, respectively), whereas group III displayed the greatest frequency at an ARI score of 2 (50%) (Fig. 2).

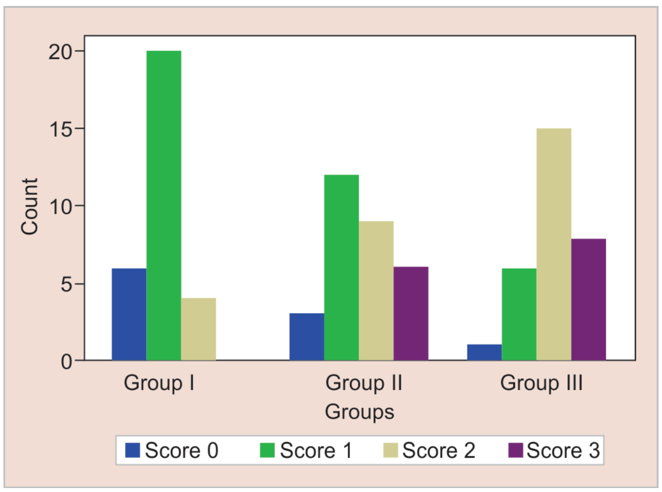


Fig. 2: Adhesive remnant index (ARI) for group I–Transbond XT, group II–GC-G-ænial Universal Flo, group III–Anabond Stedman Flowable composite

SEM Analysis

Morphologically different types of images were observed under the SEM (Fig. 3).

Group I (Transbond XT)

At 30×, the bracket base is evident on the periphery close to the site of shearing leaving a greater area of adhesive retained on the bracket base indicating a good sign of debonding characteristics.

At 500×, the image shows the greater area of resin with resin tags seen minimally.

At 4,000×, the image clearly shows resin with an irregular surface and greater quantum of resin tags which is important for good bond strength (Fig. 3A).

Group II (GC-G-ænial)

At 30×, the bracket base image shows greater coverage of resin. The bracket base design is seen at the periphery close to the point of shearing and the point of peripheral stress.

At 500×, a uniform surface of the resin is evident with the presence of 1 or 2 elevated resin tags.

At 4,000×, the surface of the resin seems to be very irregular with a lot of elevations and depressions signifying the resin tags which are flown into the etched enamel surface for greater retention (Fig. 3B).

Group III (Anabond Stedman)

At 30×, the bracket base showed 70% of the resin retained on the bracket base along with crack lines. At the point of stress, bracket base design is evident with sheared resin surface.

At 500×, the image showed a cracked resin surface owing to the distribution of stress over the entire surface.

At 4,000×, the resin surface shows maximum roughness with greater elevated surfaces. The resin tags are isolated with evident stress lines (Fig. 3C).

X-ray Spectrometry

Although some similar elements were detected with EDX, the concentration was different in each adhesive. The main elements observed were carbon (C), oxygen (O), aluminum (Al), silicon (Si), phosphorus (P), and calcium (Ca).

Table 3 illustrates the descriptive statistics for the different elements present. It was inferred that there was a statistically

Table 1: Mean shear bond strengths (MPa) and descriptive statistics

Flexural load MPA			*95% Confidence interval for mean*		
Group (n = 30 each)	*Mean*	*Std. deviation*	*Lower bound*	*Upper bound*	*p value*
I	13.1085	3.46296	11.8154	14.4016	<0.001
II	9.8027	2.05078	9.0370	10.5685	
III	6.2720	1.39624	5.7507	6.7934	

Tukey's *post hoc* analysis revealed all pairwise comparisons were statistically significant

Table 2: ARI cross tabulation

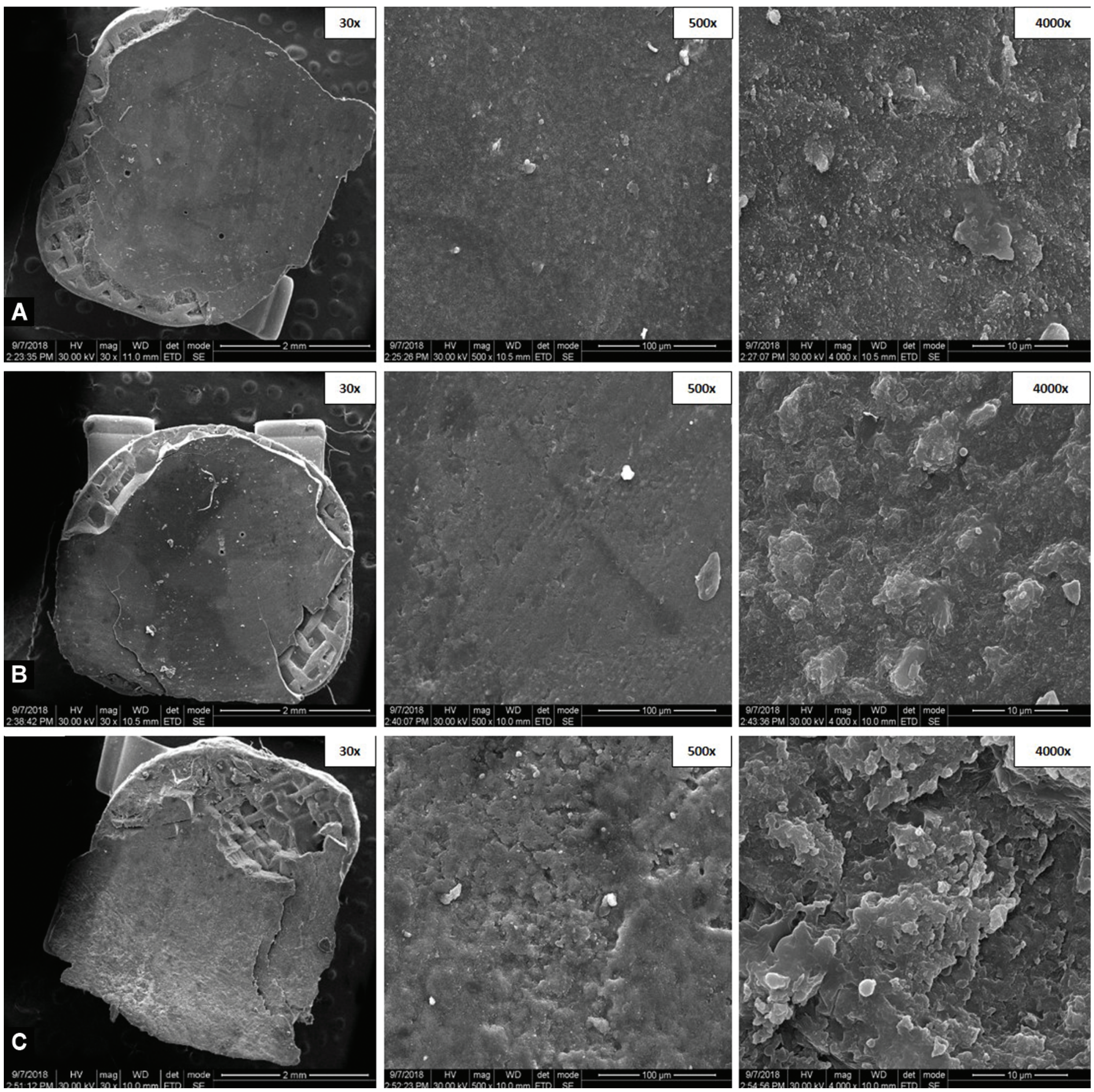
Group count % within ARI	*ARI*					*p value (Chi-square test)*
	Score 0 (%)	*Score 1 (%)*	*Score 2 (%)*	*Score 3 (%)*	*Total*	
I	6 (60.0)	20 (52.6)	4 (14.3)	0 (0.0)	30 (33.3)	<0.001
II	3 (30.0)	12 (31.6)	9 (32.1)	6 (42.9)	30 (33.3)	
III	1 (10.0)	6 (15.8)	15 (53.6)	8 (57.1)	30 (33.3)	

significant difference was found in carbon ($p = 0.001$), oxygen ($p = 0.002$), and aluminum (0.000) in all three groups. However, silicon, phosphorus, and calcium were found to be statistically insignificant (Table 3).

Discussion

Flowable resin composites have been formulated in various compositions and viscosities to meet various procedures in the field of dentistry. This led to the development of flowable restorative composite which was initially considered only for restorative procedures. The acceptance of flowable restorative composites are driven by the benefit of having a resin composite that is easier to place, self-adapting compared to more conventional restorative resin composites. These materials also show sufficient wear resistance and good contact angle for use in both low and high-stress-bearing areas.[2] They have also formulated such a way that it has "controlled fluidity" which overcomes the problem faced in the conventional flowable composites which made bonding of brackets difficult because it tended to slide down due to gravity. The applications of the flowable restorative composites in orthodontics include cases of tongue Spikes and Cribs tip appliance covered with flowable composite to prevent trauma, reactivation of coil springs, molar stops, cantilever arches, and lingual retainers.[4]

Studies have proved that the bond strength of flowable composites is comparable with that of a standard adhesive Transbond XT which is used widely in orthodontics. The SBS from various studies ranges from 6.8 to 34.8 MPa and is clinically



Figs 3A to C: Scanning electron microscopy (SEM) of the bracket base after debonding. (A) SEM of group I (Transbond XT) viewed under 30× showing a greater area of resin coverage on bracket base. Under 500× minimal resin tags are seen. 4,000× reveals an irregular resin surface with multiple resin tags. (B) SEM of group II (GC-G-ænial) viewed under 30× showing good coverage of resin on the base of the bracket. Under 500×, the resin surface is uniform with few elevated resin tags. 4,000× reveals a highly irregular resin surface with elevations and depressions. (C) SEM of group III (Anabond Stedman) viewed under 30× showing greater coverage of resin on the base along with crack lines. Under 500× cracked resin surface seen due to stress distribution. 4,000× reveals a roughened and elevated resin surface with isolated resin tags

Table 3: Descriptive statistics for elemental analysis

Groups (n = 5)		*Carbon*	*Oxygen*	*Aluminum*	*Silicon*	*Phosphorus*	*Calcium*
I	Mean	61.66 ± 1.12	17.97 ± 3.12	0.22 ± 0.09	19.47 ± 1.17	0.36 ± 0.39	0.30 ± 0.27
II	Mean	37.90 ± 8.10	25.55 ± 5.29	5.33 ± 1.0	28.14 ± 4.92	2.39 ± 2.87	0.66 ± 0.69
III	Mean	42.40 ± 2.78	29.94 ± 3.76	3.05 ± 0.47	22.68 ± 4.29	1.26 ± 1.25	0.65 ± 0.82
p value		0.001*	0.002*	0.000*	0.244*	0.200¥	0.289¥

*ANOVA analysis revealed all comparisons were statistically significant

¥Kruskal–Wallis test revealed all pairwise comparisons were statistically significant

acceptable.[5,6] Since many properties of the flowable composites are advantageous in the field of orthodontics, the current study was undertaken to investigate the clinical usefulness of using these materials for routine orthodontic bonding. Further, there have not been any previous studies published regarding the two composite resin materials, GC-G-ænial Flo and Anabond Stedman in orthodontics.

Our investigation revealed that a flowable restorative light cure composite serves as a multipurpose agent and can be used for bonding orthodontic brackets without an additional requirement for orthodontic composite, thereby reducing the armamentarium and making it very economical for the clinician. Further, it can also reduce the potential risk for caries as they contain fluoride. An added advantage of using flowable restorative composites is its diverse shade range. Thus, the adhesive left on a tooth can be easily camouflaged by polishing and maintain its luster. Since the enamel is intact, this, in turn, would avoid enamel loss, roughness and significantly reduce post debonding sensitivity.

In this study, the values obtained for SBS, ARI scores, and X-ray spectrometry proved that Transbond XT, the widely acknowledged orthodontic composite seemed to be a superior material for orthodontic bonding, nonetheless, the results for GC-G-ænial Universal Flo and Anabond Stedman Flowable composite were not far behind and the early *in vitro* SBS seems promising. The *in vivo* performance of the fixed appliances bonded with GC-G-ænial and Anabond Steadman will be assessed in a future clinical trial.

SBS

Retief emphasized that enamel fractures can occur with bond strengths as low as 13.53 MPa.[7] The minimum clinically adequate SBS according to Reynolds was found to be between 5.88 MPa and 7.85 MPa.[8] Thus, we can assume that the optimum range for adequate bond strength lies between 5.88 MPa and 13.53 MPa.

In this study, Transbond XT had a mean value of 13.1 ± 3.4 MPa, the highest of all test groups. GC-G-ænial and Anabond Stedman flowable composites had mean bond strengths of 9.8 ± 2.0 and 6.27 ± 1.3 MPa, respectively. The SBS values of control Transbond XT were less than that obtained by, Tecco et al., D'Attilio et al., and Albaladejo et al. and were higher than those obtained by Owens et al., Ajlouni et al., and Ryou et al.[5,6,9–12] The SBS for flowable composites were less than that obtained by D'Attilio et al., Tecco et al., Viwattanatipa et al., and Albaladejo et al. but greater than those obtained by Pick et al. and Turgut et al.[5,9,10,13–15] Similar results were also cited by Uysal et al. and Ryou et al.[6,16] These variations could suggest the importance of other factors, such as study design, bracket base design, and enamel pre-treatment in determining the SBS. The bond strengths of the three adhesives tested were >5.9 MPa which was considered by Reynolds to be adequate for routine clinical use.

ARI

In the present study, Transbond XT and GC-G-ænial, the greatest frequency was observed at an ARI score of 1, whereas Anabond Stedman displayed the greatest frequency at an ARI score of 2.

In addition, the ARI examination showed that all three composite resins tended to display failure at the adhesive/bracket interface. This shows that the composite penetrated sufficiently into the retentive pores on the enamel surface but not into the metal bracket base. Thus, it is likely to result in a low incidence of enamel fractures. This is in concordance with a study done by Pick et al., who demonstrated a similar ARI score indicating a bonding failure at the bracket–adhesive interface.[14] Therefore, a bond failure at the bracket–adhesive interface would be more desirable to minimize enamel fracture.

EDX

Zachrisson et al. and Mannerberg et al. reported that the normal enamel thickness where the bracket is bonded ranges between 1,500 μm and 2,000 μm. Enamel removal occurs during various processes. A total of 35 μm is removed during the process of bonding and debonding. Slightly more enamel can be removed depending on the type of instrumentation and procedure employed for debonding.[17,18] The advantage of less adhesive on the teeth is a reduced polishing time, the disadvantage might be an increased risk for enamel removal especially with burs.[19–22]

It has been suggested by MacColl et al. that adherence of the adhesive to the bracket shows surface enamel removal during the debonding process, whereas adherence to the tooth assures an intact enamel surface.[23] Thus, it becomes an advantage as enamel can be preserved with help of a simple polishing that will camouflage the resin with the enamel and thereby maintaining an esthetic appearance and reduced post debonding sensitivity.

In the present study, similar elements were detected with EDX with our main focus being calcium content. Calcium was higher in GC-G-ænial and least in Transbond XT. Nevertheless, the minimal concentration of calcium was noted in all the samples evaluated, owing to the ARI score being 1 and 2 indicating there is the preservation of enamel.

Limitations of the Study

The bond strength was not measured under oral conditions, where variables such as mechanical impact like a force of mastication, trauma and orthodontic mechanics and biochemical changes such as intraoral contamination, moisture, temperature, have been found to influence the bond strength and may result in adhesive material fatigue and inadvertent debonding.[24]

Future Scope of the Study

The *in vivo* performance of the fixed appliances bonded with GC-G-ænial and Anabond Steadman will be assessed in a future clinical trial which would determine whether these materials have sufficiently high bond strengths to withstand the stresses of orthodontic therapy and the oral environment, while also providing safe debonding of brackets, without any enamel damage or loss.

Conclusion

New materials that are being introduced in operative dentistry can potentially have orthodontic applications. The versatility of flowable restorative composites due to their inherent properties and esthetics makes them the material of choice to be considered for routine orthodontic practice in the future.

The following conclusions were drawn:

- The two flowable restorative light cure adhesives had favorable mean values of SBS, and thus orthodontic brackets can be successfully bonded with any of these adhesive systems.
- Traditional orthodontic composite Transbond XT showed the highest SBS, followed by GC-G-ænial and least but acceptable bond strength by Anabond Stedman.
- Transbond XT and GC-G-ænial left significantly lower adhesive remnant on the tooth surface than Anabond Stedman.
- All adhesives tended to present bond failure that is favorable for enamel preservation.
- It is cost-effective and also reduces the in-office armamentarium.

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