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Original Research Article

Comparative evaluation of shear bond strength for indirect bonding systems – An in-vitro study

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Abstract

Aims: In–vitro comparison and measurement of bond strengths between the direct bonding technique and the three different indirect bonding systems (Single vacuum form, Glue gun, polyvinyl siloxane)

Materials and Methods: 120 extracted human premolar specimens were mounted on acrylic stubs. These were equally divided into four groups: Direct bonding group, Single vacuum form (Bioplast) group, Glue gun group, and polyvinyl siloxane (Putty) group. The shear debonding force was measured using an Instron universal testing machine and comparatively evaluated for all the groups.

Results: One-way ANOVA showed a statistically significant difference in the mean bond strength values in various groups with the highest bond strength in Direct bonding and the least in Glue Gun with P-value < 0.001 and F-value = 15.343. Post-Hoc Tukey also presented a statistically significant difference in the bond strength between Direct bonding and Glue gun, Single vacuum form and Glue Gun, and PVS and Glue Gun (P<0.001).

Conclusion: The in-vitro shear bond strengths of all the indirect bonding techniques (Thomas Technique, Glue gun technique and modified polyvinyl siloxane tray technique) were adequate and comparable to direct bonding technique.

Keywords: Indirect bonding, Bond strength, Vacuum form, Glue gun, Poly-vinyl siloxane

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1. Introduction

Early orthodontists had to be good wire benders but modern orthodontists should be good bracket positioners. With the profound use of pre-adjusted straight wire appliances and the concept of minimal wire bending, the accuracy of bracket positioning determines the result. After accurate diagnosis and treatment planning the most important step is execution. The first step is bonding of teeth. Achieving Andrew's six keys of normal occlusion has gained importance from 1972.[1] till date. Before the straight wire appliances, all these goals were achieved with the 1st, 2nd and 3rd order bend. With the straight wire appliances, these goals can be achieved with accurate bracket positioning. Errors in bracket placement at the start of treatment persist throughout its duration. Incorrectly positioned brackets can lead in-out alignment problems, improper tooth angulation, and an inability to fully achieve the desired torque. Thus, clinical success and a well-finished result depend on the skill of the operator to accurately position the brackets on the tooth.

Earlier with the use of chemically cured resins, the working time for the operator was fairly limited.[2] Glass ionomer cement, acrylic epoxy adhesives, and cyanoacrylates were also used apart from resins. The light-cured resins have eliminated the limitations of chemically cured composites like the limited working time and polymerization shrinkage. The chemical cured composites are supplied as a two-component system and so the chances of air incorporation

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and contamination of material increase which can be avoided by using light-cured composite adhesives.

Bonding in orthodontics is semi-permanent which means that the strength of the bonded bracket should resist debonding of the bracket during treatment either due to masticatory forces or during wire engagement. Also, it should be low enough to allow the debonding with light forces without damaging the tooth surfaces.

Bonding in orthodontics is done by two methods i.e direct bonding and indirect bonding. The method of direct bonding of orthodontic brackets is implied by clinicians from the foundation. It begins with the isolation, preparation of the tooth surface, etching, priming, application of uncured composite resin on the bracket mesh, and placement of the individual bracket onto the tooth surface. Curing of the composite resin is initiated once the ideal bracket position is obtained. Direct bonding technique has its own limitations like difficulty in visualizing the long axis of moderately to severe malpositioned teeth intra-orally, limited access, patient comfort and clinician’s fatigue. Direct bonding technique is a chairside time-consuming technique. It is cumbersome for both the patient and the operator. Clinician’s fatigue can many times lead to inaccuracy in bracket positioning. Direct bonding is mostly based on the clinician’s judgement because three-dimensional visualization is difficult with that of direct bonding technique. Direct bonding has a limitation of customised bracket positioning. In an indirect bonding technique, as every individual tooth can be visualized, customised bracket positioning becomes easy for the operator. To overcome the disadvantages of direct bonding, indirect method to bond full arch brackets onto the dentition. The indirect bonding procedure involves bracket placement on patient model followed by preparation of custom tray or transfer tray. After the enamel surface preparation in patient, custom tray is placed and the bonding procedure is commenced. The advantages of indirect bonding include accurate bracket placement, less chair-side time and patient’s comfort. Despite of the obvious advantages of indirect bonding procedure, increased laboratory time and technique sensitiveness are the disadvantages of this procedure.[2,3]

Many methods of indirect bonding and newer techniques are presented in the literature. Most of these techniques are the modification of Thomas technique.[2] The difference between various indirect bonding techniques is mainly related with the adhesives during the entire procedure. Indirect bonding techniques are more commonly used for lingual appliances because of the limitation of direct visualization. CAD-CAM systems have been used for indirect bonding of orthodontic brackets in recent times. The process mainly involves the designing of the virtual model to prepare transfer jigs. This transfer jig facilitates the bracket bonding on the target tooth. Also, Stereolithography and intraoral scanners have reduced laboratory time and increased the accuracy of bracket placement and the manual errors are completely removed.

The studies conducted till date evaluated the effect of different resins used for bonding or the different etching and priming agents on bond strength. But, none of those studies evaluated the effect of tray thickness and amount of light penetration as the factors affecting bond strength.

The purpose of the present study is to evaluate and compare the in-vitro bond strengths of three different indirect bonding transfer trays (Single vacuum form[2], Glue Gun[4] and Polyvinyl siloxane[5]) with the direct bonding group.

2. Materials and Methods

A total of 120 extracted premolars were collected from patients undergoing orthodontic treatment and purposive sampling was done. Approval of the ethical committee was obtained before commencement of any procedure. Teeth with fluorosis, carious lesions, restorations and enamel defects were excluded.

Samples were divided into four groups equally (n = 120):

1. Direct bonding group (Control group n = 30)
2. Single vacuum form (Bioplast®) group (n = 30)
3. Glue gun group (n = 30)
4. Polyvinyl siloxane (Putty) group (n= 30)

The samples were mounted on acrylic stubs with buccal surface perpendicular to bracket base respectively and were cleaned with fluoride-free pumice using a rubber cup. After rinsing with the three-way syringe for 15 seconds, the specimens were dried with oil-free compressed air for 10 seconds and later stored in distilled water at room temperature (37◦C) to prevent dehydration.[6]

2.1. Bracket placement and bonding procedure

Brackets in all the groups were bonded on the labial surface at the intersection of long axis of the clinical crown (LACC) and midpoint of the clinical crown known as the LA point (**Figure 1**).

2.2. For direct bonding group

Acid etching was done with 37% phosphoric acid for 15 seconds followed by application of a thin layer of primer (Orthosolo™). Then after, the adhesive (Enlight®) was applied to the bracket base. The brackets were then cured using a Supra Blue LED curing light for 40 seconds, with 10 seconds each for the proximal, occlusal, and gingival aspects, as per the method described by Bishara.[7] The diameter of the curing tip was 8mm with the light intensity of 1000 mW/cm2 and wavelength of 420 – 480 nm. Intensity meter was used for the frequency calibration of emitted light.

*2.3. For the indirect bonding group (**Figure 2**)*

For the fabrication of indirect bonding trays, the mounted specimens were duplicated with alginate impression material and poured into Orthokal. A separating medium was applied to the model specimen and then the brackets were bonded on the model specimen. Undercuts were blocked with patient relief wax for easy retrieval of the tray.

BIOSTAR® machine of great lakes dental technologies was used for the fabrication of a vacuum-formed tray (**Figure 3**). Thomas Technique,[2] Glue gun technique[4] and modified polyvinyl siloxane tray technique[3,4,5] were used for indirect bonding tray fabrication (**Figure 4**). After tray fabrication trays were cleaned, sandblasted and enamel preparation was done.

Acid etching was done with 37% phosphoric acid for 15 seconds followed by application of a thin layer of primer (Orthosolo™). Then after, the adhesive (Enlight®) was applied to the bracket base. After ensuring proper tray seat, curing was performed. Curing time was same for all the techniques. Trays were removed with a curved explorer in a peeling motion. In the glue gun technique, the tray was immersed in lukewarm water to soften the glue for easy removal of the tray.

Instron universal testing machine (Model-5982) at Ahmedabad Textile Industry's Research Association (ATIRA), Ahmedabad was used for measuring the shear debonding force (**Figure 5**). The models were placed on a mounting jig such that the bracket base was parallel to the force applied.

A shear force at a crosshead speed of 5mm/min was applied in a direction perpendicular to the long axes of the tooth directing at the bracket base and composite interface. A stainless-steel blade of 1mm thickness was used with a 45-degree tip inclination (**Figure 6**a,b, **Figure 7**).

The shear bond strength was recorded in Newton and was converted to Megapascal (Mpa) by the formula (Ferrando et al, 1983):[8]

Shear bond strength (Mpa) = Force (Newton)/Area (Newton per millimeter square)

The area of the bracket base (AO mini-master) used in the present study is 9.6 mm^2.

3. Results

3.1. Data were analysed using SPSS version 23.

For the in-vitro bond strength measurement One-way ANOVA (Analysis of variance) with Post hoc Tukey was used.

The results of the one-way ANOVA revealed a statistically significant difference in the mean bond strength values among the various groups. The highest bond strength was observed in the Direct Bonding group, while the Glue Gun group exhibited the lowest bond strength, with a P-value of less than 0.001 and an F-value of 15.343 (**Table 1**).

Further analysis using a post-hoc Tukey test showed significant differences in bond strength between the Direct Bonding group and the Glue Gun group, as well as between the Glue Gun group and the Single Vacuum Form group, and between the Glue Gun group and the PVS group ($P < 0.001$). The bond strength followed an ascending order, starting with the Glue Gun group, followed by the PVS group, the Single Vacuum Form group, and culminating with the Direct Bonding group, which demonstrated the highest bond strength values (**Table 2**, **Table 3**). These findings showed a comparable bond strength of the Direct Bonding method to the other techniques evaluated.

Figure 1: Top view of bonded sample

Figure 2: Indirectly bonded model specinems

Figure 3: BiostaR® Great lakes dental technologies

		Technique	Material/Equipment used	Modifications
Trays for Indirect Bonding	**Single vacuum form (Bioplast®)**	Thomas technique	- 1.5 mm thick, clear ethyl vinyl acetate sheets (Bioplast®, *Great lakes orthodontics*) - BIOSTAR® machine (*Great lakes dental technologies*)	Not Applicable
	Glue gun tray	Larry white technique	- GT-10 Hot glue gun(110-240V,100W) - Glue Stick. (Ethyl vinyl acetate)	Not Applicable
	Polyvinyl siloxane tray	Modification of Klange Tray Design and Technique	- Kerr's Take 1® Advanced™ type O very high consistency putty impression material	It is not possible to use light-cured adhesive with an opaque material like putty. So, after mixing an equal proportion of the base and catalyst, the material was adapted to the model on the facial (bracket side) and palatal side. The occlusal/incisal surface was covered with thin rope made up of putty connecting the facial and the palatal surface. This modification allowed the penetration of curing light through the occlusal/incisal surface.

Figure 4: Indirect bonding trays and techniques used for tray fabrication

Table 1: Intergroup comparison of bond strength (One-way ANOVA)

Group	N	Minimum	Maximum	Mean	Std. Deviation	F value	P value
Direct Bonding	30	10.36	13.26	11.5499	.62630	15.343	<0.001**
Single vacuum form (Bioplast)	30	10.24	12.76	11.1650	.59322		
PVS	30	9.93	12.46	11.0468	.58013		
Glue gun	30	8.34	13.17	10.1876	1.22598		

**-Highly significant (p<0.001)

Table 2: Individual pair-wise comparison of Bond strength (Post Hoc Tukey test)

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.
Direct Bonding	Single vacuum form	.38490	.20751	0.253 NS
	PVS	.50309	.20751	0.078 NS
	Glue Gun	1.36226*	.20751	<0.001**
	PVS	.11819	.20751	0.941 NS
	Glue Gun	.97736*	.20751	<0.001**
PVS	Glue Gun	.85917*	.20751	<0.001**

NS-Not significant (p> 0.05), **-Highly significant (p<0.001)

Table 3: Ascending order of bond strength

Group	N	Subset for alpha = 0.05	
		Low	High
Glue Gun	30	10.1876	
PVS	30		11.0468
Single Vacuum Form	30		11.1650
Direct Bonding	30		11.5499
Sig.		1.000	.078

Figure 5: Instron universal testing machine

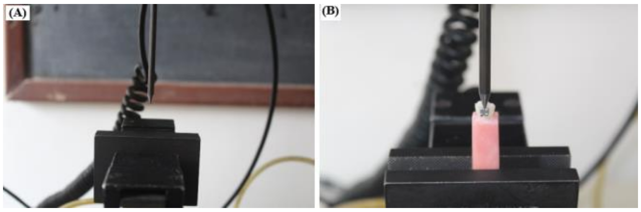

Figure 6: Stainless steel blade; (**A**): and its adaptation to the composite-bracket interface (**B**)

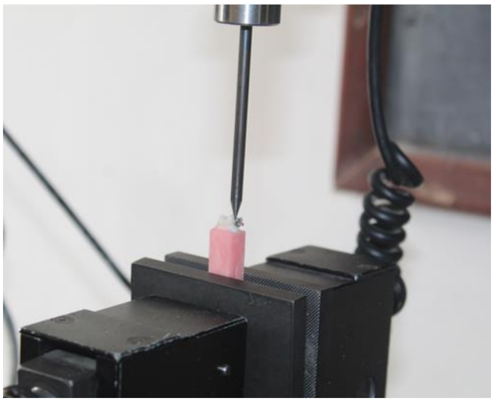

Figure 7: Direction of force

4. Discussion

Silverman and Cohen.[9] were the pioneers to present the technique of indirect bonding in 1972. The concept was, to attach the brackets to the diagnostic model of the patient, prepare a plastic transfer tray and when the plastic tray was removed the brackets ware separated from the model and attached to the tray. Bonding is then performed by placing the transfer tray in the patient's mouth. Further in 1976[10] they stated that maximum bonding time with indirect technique is twenty minutes. Thomas[11] (1979) discussed the modified Silverman and Cohen technique. In this technique a vacuum formed tray was used. For bonding of brackets, custom composite bases and a two-part liquid sealant ware used. Thomas further modified his technique by using 1.5mm thick ethyl vinyl acetate sheet for the fabrication of an indirect bonding transfer tray.

Indirect bonding methods have allowed the orthodontist to place brackets accurately and reliably. Indirect bonding is advantageous for both the orthodontist and the patient. The advantages are shorter bonding time - A study by Guenthner TA et al.[12] showed that the total time spent for bonding was reduced by 30 minutes for the indirect bonding technique.

A Clinical comparison was done by Aguirre MJ, King GJ & Waldron JM.[13] (1882) to address the short comings of both the bonding techniques. Direct and indirect bonding techniques were evaluated on the basis of bond strength, failure rate of bonded brackets and the bonding time for each technique. The bond failures, recorded after 3 months of bonding, were 4.5 % for the indirect bonding and 5.3% for the direct bonding.

An in-vitro shear bond strength was performed to evaluate the effect of indirect bonding tray thickness on bond strength. Specimens were prepared by mounting teeth on the acrylic stubs. The brackets were directly bonded to the specimens and the specimens were subjected to a shear debonding force in the direct bonding group. For indirect bonding groups, Alginate impressions were recorded of the specimens and model specimens were poured with Orthokal. After the application and drying of separating medium, the brackets were bonded on to the model specimens. Individual transfer trays were prepared for the model specimens (Bioplast, Glue gun, PVS), after the enamel preparation of the tooth specimen. The indirect bonding trays were transferred from the model specimen to the tooth specimen. In the present study, the highest bond strength was of direct bonding group, followed by nearly equal bond strengths for Bioplast and modified PVS tray technique. Glue gun tray technique had the least bond strength with maximum standard deviation as the trays prepared with glue gun had a varied thickness which was not possible for us to standardize.

Shear bond strength of the specimens was measured after 24 hours and stored in distilled water at room temperature which in turn does not reflect clinical practice and allows the adhesive to mature to its optimal bond strength.[14]

According to Reynolds.[15] the adequate bond strength for orthodontic brackets should be between 5.88 – 7.85Mpa. Thus, in the present study the result was adequate. The direct bonding group had the highest bond strength. Also, the bond strength of indirect bonding groups was sufficient and comparable to that of direct bonding (**Table 1**, **Table 2**l **Table 3**). The results are comparable with the studies done by Polat et al.[16] and M Swetha et al.[17] in 2015. A study by Shaik et al.[18] in 2015 found that the shear bond strength of Enlight adhesive (13.92 ± 3.92) aligns with the findings of the present study. Shear bond strength and adhesive remanent index was significantly different when a comparative study was carried out by Demirovic et al in 2018.[19]

Jungbauer et al.[11,20] found that, in vitro, the accuracy of transfer trays could be more influenced by rigid printing materials than by flexible ones. While rigid materials may result in an incomplete fit on the teeth or even immediate bracket debonding upon tray removal, more elastic materials can deform under the clinician's finger pressure.[21] This deformation may lead to excessive seating of the tray and misalignment of bracket placement. These findings align with previous studies indicating that material properties significantly affect transfer tray performance and bond strength. The findings of the present study are consistent with these results, as the highest bond strength was observed with the single vacuum-formed tray. The glue gun tray exhibited an uneven thickness and was generally thicker than the vacuum-formed tray. Additionally, if the glue gun material does not adequately soften during tray removal, it can generate excessive pressure, potentially compromising bond strength. Furthermore, the dimensional stability of the PVS tray also influences bond strength. Although variations in bond strength were observed across different tray materials, all measured values remained within clinically acceptable limits.

However, in clinical scenarios, the stresses experienced by the enamel-adhesive interface, such as those from mastication or the application of orthodontic forces, are not purely shear forces. Instead, these stresses are multi-directional. Therefore, evaluating shear bond strength in vitro alone is not sufficient to fully represent the complex biomechanical interactions that occur in the oral environment.

The further scope of this study is to evaluate the thickness of composite resin base by scanning electron microscopy studies and the discrepancies caused because of uneven base thickness. Evaluating the accuracy of bracket positioning by CAD-CAM and stereolithography is also the scope of further research.

5. Conclusion

The in-vitro shear bond strengths of all the indirect bonding techniques (Thomas Technique, Glue gun technique and modified polyvinyl siloxane tray technique) were adequate and comparable to direct bonding technique.

6. Sources of Funding

None.

7. Conflict of Interest

None.

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