ORIGINAL RESEARCH

Effect of Different Light-tip Distances on Shear Bond Strength of Orthodontic Brackets Cured with Light-emitting Diode and High-intensity Light-emitting Diode

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Abstract

Aim: The aim was to find out whether the light-tip distance affected the shear bond strength of orthodontic brackets when cured with light-emitting diode (LED) and high-intensity LED at four different light-tip distances.

Materials and methods: Extracted human premolars were divided into eight groups. Each tooth was embedded in the self-cure acrylic resin block, and brackets were bonded and cured with different lights and different distances. Shear bond strength tests were performed *in vitro* using the universal testing machine. Data were analyzed using one-way ANOVA test.

Results: The descriptive statistics for shear bond strength of orthodontic brackets cured with LED light at 0 mm was 8.49 ± 1.08 MPa, at 3 mm was 8.13 ± 0.85 MPa, 6 mm was 6.42 ± 0.42 MPa, and at 9 mm was 5.24 ± 0.92 MPa, and those cured with high-intensity light at 0 mm was 19.23 ± 4.83 MPa, at 3 mm was 17.65 ± 3.28 MPa, at 6 mm was 13.04 ± 2.36 MPa, and at 9 mm was 11.74 ± 1.4 MPa. Mean shear bond strength was found to decrease as the light-tip distance increased with both light sources.

Conclusion: Shear bond strength is higher when the light source is close to the surface to be cured, and it decreases as the distance increases. The highest shear bond strength was achieved with high-intensity light.

Clinical significance: Light-emitting diode or high-intensity units can be used for bonding orthodontic brackets without compromising the shear bond strength of the brackets, and that shear bond strength is stronger when the light source is close to the surface to be cured, and it decreases as the distance increases between the light source and the surface.

Keywords: Composite resins, High-intensity light curing, Light-curing units, Light-tip distance, Shear bond strength.

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Introduction

Direct bonding of brackets with acid etching has become popular in the field of orthodontics. Light activation of bonding agents has become a popular method of polymerization. Both the characteristics of the composite and the amount of light present during exposure might change due to a variety of factors. One of the variables impacting light intensity that the clinician can manage is the distance between the tip of the activating light source and the surface of the resin to be exposed. This distance needs to be as short as possible to reduce intensity losses.[1]

Curing devices have evolved in tandem with recent advancements in the dental field. Halogen lamps were the principal light source for curing composite resins. Low cost is one of the benefits of halogen lighting, however, low efficiency, a long curing time, and a high temperature are some of the drawbacks. Halogen light filaments quickly overheated, limiting their use for long operations, particularly in Orthodontics.[2] As a result, light-cured materials were developed for bonding brackets in clinical orthodontic practice due to a number of advantages, including a shorter working period and the elimination of excess material with minimal effort.

Solid-state LED technology was used to polymerize light-activated dental materials in 1995, as proven by Mills et al.[3] Light-emitting diodes produce light through junctions of doped semiconductors as opposed to the hot filaments utilized in halogen lamps. Light-emitting diodes are especially vibration-resistant and have a lifespan of over 10,000 hours. Photopolymerization has gained new perspectives, thanks to the advancement of semiconductor-based LED technology.[4] Light-emitting diode-curing systems displayed better mean shear bond strengths when the cure time was raised from 10 to 40 seconds.

Rapid polymerization is a benefit of high-intensity curing, but it also results in considerable polymerization stresses, which weakens the attachment to the tooth structure, according to Ilie et al.[5] Pulpal injury has also been reported with higher-intensity curing units (Plasma arc Curing light), whereas quartz–tungsten–halogen light and LED light were found to cause lower

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Table 1: Comparison of shear bond strength of brackets cured with LED and high-intensity light

Group	*Color coding*	*Curing light*	*Distance*	*Mean (MPa)*	*SD*
Group I	White	LED	0 mm	8.49	1.08
Group II	Blue	LED	3 mm	8.13	0.85
Group III	Red	LED	6 mm	6.46	0.42
Group IV	Green	LED	9 mm	5.24	0.92
Group V	Light pink	High-intensity	0 mm	19.23	4.83
Group VI	Opaque white	High-intensity	3 mm	17.65	3.28
Group VII	Orange	High-intensity	6 mm	13.04	2.36
Group VIII	Pink	High-intensity	9 mm	11.74	1.40

SD, standard deviation; MPa, megaPascal

temperature increase as observed by Ozturk et al.[6] Lindberg et al.[7] and Cacciafesta et al.[8] concluded that the highest light intensity was produced at a distance of 0 mm from the bonding surface, resulting in the greatest increase in pulpal temperature, whereas a distance of 0–3 mm resulted in a negligible increase in pulpal temperature. Oyama et al.[9] recommended that the light guide should be positioned such that the light impact on the adhesive's surface should be as close to perpendicular as possible. The light guide is tipped in clinical practice to maintain the light source as close to the brackets as feasible. The maximum light intensity occurs when the surface of the light guide is perpendicular to the surface of the adhesive that needs to be light-cured. Therefore, the goal of the current investigation was to determine whether the shear bond strength of orthodontic brackets when cured with LED and high-intensity LED at four different light-tip distances is affected by the light-tip distance.

Materials and Methods

Allocation

A total of 112 maxillary first premolar teeth were collected as part of therapeutic extraction from patients being treated in the Department of Orthodontics, MES Dental College, Perinthalmanna. The study period was from 1st August 2020 to 31st July 2021. There were eight groups of 14 teeth. The groups were selected based on light source and the light-tip distance. The roots of the collected teeth were encased in acrylic blocks of various colors – they were color-coded for quick group identification (Table 1).

Sampling Criteria

Exclusion criteria for the study included teeth with caries, visible defects, obvious wear or damage, forceps extraction cracks, malformed teeth, surface defects (erosion, attrition, and abrasion), restored teeth, teeth that had undergone root canal therapy, teeth that had previously undergone chemical treatment, and teeth that had pathological conditions like amelogenesis imperfecta, enamel dysplasia, enamel hypoplasia, and dentinogenesis imperfecta. To get rid of blood, debris, and adhering tissue, the extracted tooth was thoroughly rinsed with tap water immediately.

Bonding

Prior to bonding, the buccal surfaces of the teeth were cleaned, polished for 10 seconds with a rubber prophylactic cup filled with non-oily pumice, and then thoroughly rinsed with water to ensure that all debris, deposits, stains, and calcium were eliminated. About 112 extracted maxillary first premolar teeth were bonded using stainless-steel Mini 2000 brackets (ORMCO 022" MBT), composite – Transbond XT, and etchant – 37% phosphoric acid – Eazetch (Anabond Stedman). The light-curing unit was positioned at 0-, 3-, 6-, and 9-mm using a jig. The teeth in groups I, II, III, and IV at 0-, 3-, 6-, and 9-mm light-tip distance, respectively, were cured for 30 seconds–15 seconds on the mesial and 15 seconds on the distal side with LED light; and in groups V, VI, VII, and VIII at 0-, 3-, 6-, and 9-mm light-tip distance, respectively – 3 seconds on the mesial and 3 seconds on the distal side with high-intensity light.

Table 2: ARI scoring

Score	*Criteria*
0	No adhesive left on the tooth
1	Less than half of the adhesive left on the tooth
2	More than half of the adhesive left on the tooth
3	All adhesives are left on the tooth, with distinct impression of the bracket mesh

The acrylic blocks holding the teeth bonded with orthodontic brackets were kept in distilled water at room temperature. The shear bond strength of these brackets was tested after 1 month using a Universal Testing Machine (Shimadzu Autograph AG-IS). Bond strength was assessed in the shear mode until the bracket was debonded at a crosshead speed of 1 mm/min. A computer attached to the Lloyd machine recorded the stress at the moment the bracket failed. By dividing the force by the area of the bracket base (9.63 mm^2), the shear bond strength values were determined in megaPascals (MPa).

After debonding, the pattern and location of bond failure were examined visually to determine the fracture sites, and the adhesive remnant index (ARI) of Artun and Bergland was used to classify it[10] (Table 2).

SEM Analysis

Representative teeth of each group were prepared for the scanning electron microscopic (SEM) observations to observe enamel surface after debonding. The teeth were dried by heating to remove any moisture and then coated with 3–6 nm layer of gold, mounted on an aluminum stub, and the observations were performed at 15 Kv [Field emission scanning electron microscopy (FESEM), JSM 7610F Plus] at a working distance ranging from 9.5 to 13.5 nm, capturing images at ×3000 magnification (Figs 1 and 2). The images were analyzed by the Image J software, using the thresholding process to showcase its topography.

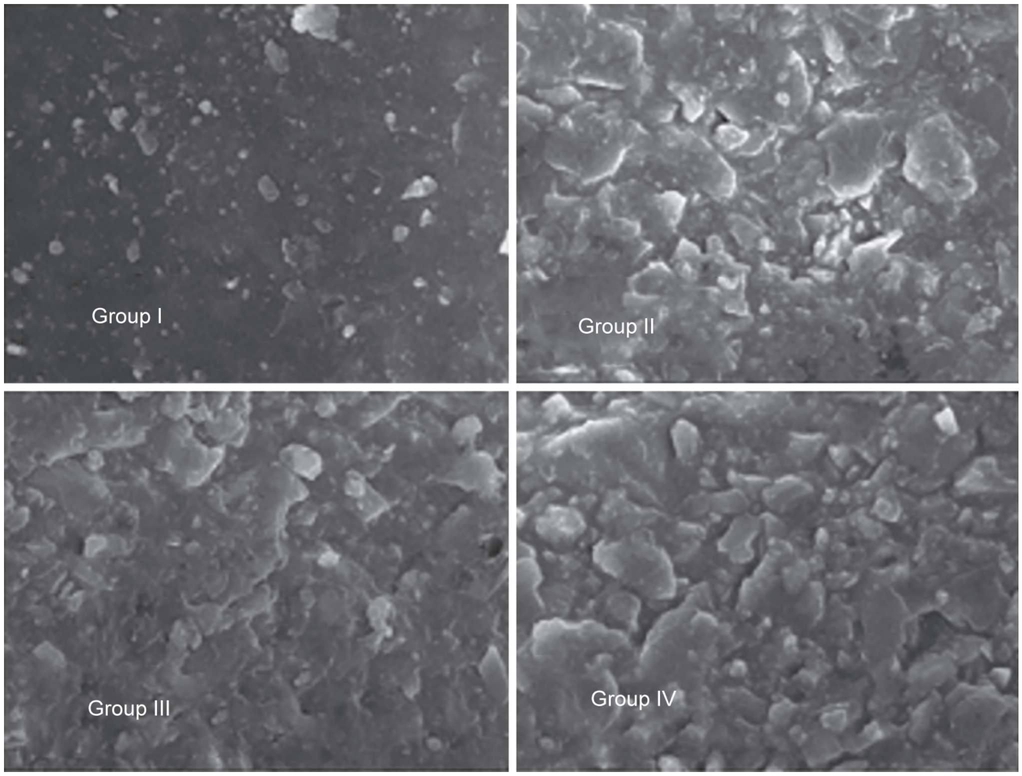

Fig. 1: SEM analysis of teeth cured with LED light. The observations were performed at 15 Kv, at a working distance ranging from 9.5 to 13.5 nm, capturing images at ×3000 magnification

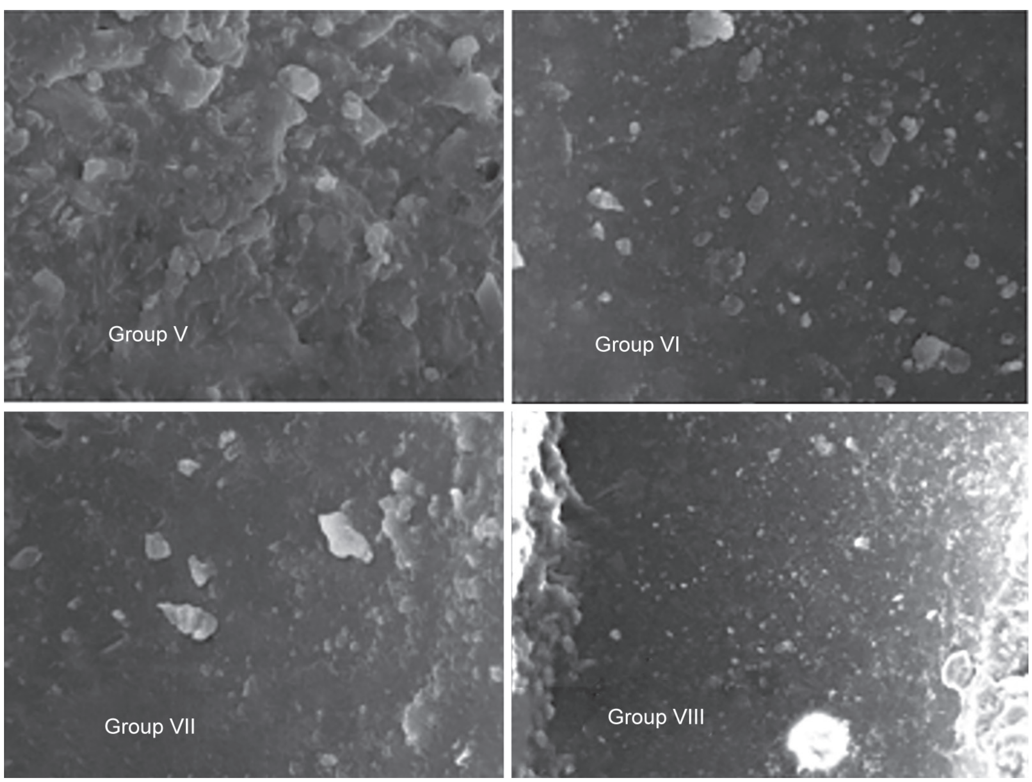

Fig. 2: SEM analysis of teeth cured with high-intensity light. The observations were performed at 15 Kv, at a working distance ranging from 9.5 to 13.5 nm, capturing images at ×3000 magnification

Statistical Analysis

Statistical Package for Social Sciences (SPSS) 20.0 was used for all statistical procedures. The Shapiro–Wilk test was used to determine if the data showed normal distribution. One-way ANOVA and Tukey's *post hoc* test were used in inferential statistics to determine whether there was a difference between the groups. Chi-square test was used to compare ARI scores.

Results

The descriptive statistics for the shear bond strength of orthodontic brackets treated with LED light (Table 1) revealed that, among the four varied light-tip distances, the shear bond strength was determined to be maximum at a distance of 0 mm. ANOVA (Table 3) demonstrated significant differences among the groups I, II, III, and IV when comparing the four different distances in terms of shear bond strength, but little significant difference was detected between 3 mm and 6 mm (Fig. 3).

Descriptive statistics for the mean shear bond strength of orthodontic brackets cured with high-intensity light (Table 1) showed that the shear bond strength was found to decrease as the distance increased. When using the high-intensity light, no significant difference was found between 0 mm and 3 mm, whereas significant difference in bond strength was found when comparing 0 mm and 9 mm. The inference is that when comparing high-intensity light, the light-tip distance significantly affected the shear bond strength at a distance of 0 mm and 9 mm (Fig. 3). A significant decrease can be seen when cured at 9 mm distance. High-intensity light, at a greater light-tip distance, produced lower shear bond strength. A significant increase can be seen when cured at 0 mm distance. Groups V, VI, VII, and VIII revealed significant differences with ANOVA (Table 3) ($p < 0.05$).

When evaluating the effect of the light-tip distance on each light-curing unit, no significant differences ($p < 0.05$) in ARI scores were found among the four distances for all the light-curing units (LED and high-intensity). Groups I, IV, and V showed the highest percentage of score 2 (50%, 41.6%, and 41.6%, respectively), which means that the failure occurred at bracket–adhesive interface leaving more adhesive on the tooth. For orthodontic brackets cured with LED light, highest percentage in score was found at a distance of 3 mm (group II), which means that all adhesive was left on the tooth, with distinct impression of the bracket mesh. When comparing orthodontic brackets cured with high-intensity light, no significant difference in percentage was found among the groups V, VI, VII, and VIII.

The SEM analysis of representative tooth from each group under ×3000 magnification conformed with the ARI score obtained in each group (Table 4). The ARI scores for the two curing

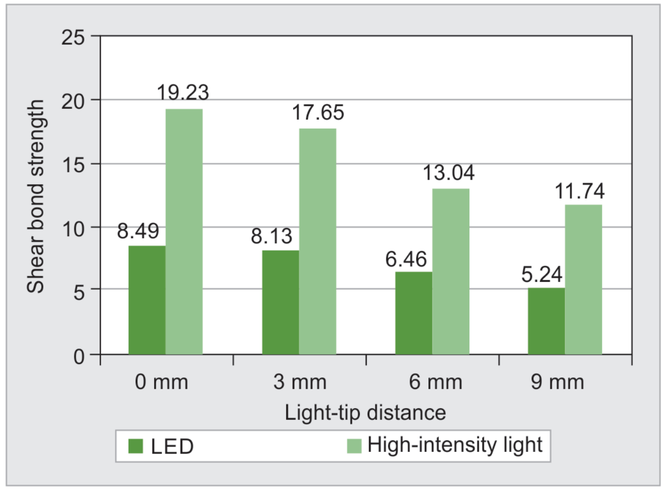

Fig. 3: Shear bond strength of orthodontic brackets bonded with LED or high-intensity light at different light-tip distance

Table 3: One-way ANOVA of shear bond strength of orthodontic brackets cured with LED light and high-intensity light

		Sum of squares	*Df*	*Mean squares*	*F*	*Sig.*
Cured with LED light – Groups I, II, III, IV	Between groups	82.3272	3	27.4424	37.6995	**0.0001***
	Within groups	32.0287	44	0.7279		
	Total	114.3559	47			
Cured with high-intensity light – Groups V, VI, VII, VIII	Between groups	464.3484	3	154.7828	14.876	**0.0001***
	Within groups	457.7859	44	10.4042		
	Total	922.1343	47			

Df, degrees of freedom. *$p < 0.05$ is statistically significant

Table 4: ARI index of brackets cured with LED and high-intensity light

		Score (percentage)					
	Group	*0*	*1*	*2*	*3*	χ^2	*p-value*
LED light	Group I (0 mm)	0	3 (25%)	6 (50%)	3 (25%)	89.03	**0.0001***
	Group II (3 mm)	0	5 (41.6%)	2 (16.8%)	5 (41.6%)		
	Group III (6 mm)	1 (8.4%)	4 (33.3%)	1 (8.4%)	3 (25%)		
	Group IV (9 mm)	1 (8.4%)	5 (41.6%)	5 (41.6%)	1 (8.4%)		
High-intensity light	Group V (0 mm)	1 (8.4%)	4 (33.3%)	5 (41.6%)	2 (16.8%)	77.98	**0.0001***
	Group VI (3 mm)	0	4 (33.3%)	4 (33.3%)	4 (33.3%)		
	Group VII (6 mm)	1 (8.4%)	4 (33.3%)	4 (33.3%)	3 (25%)		
	Group VIII (9 mm)	2 (16.8%)	4 (33.3%)	4 (33.3%)	2 (16.8%)		

ARI, adhesive remnant index. *$p < 0.05$ is statistically significant lights at each of the tested distances did not show very noticeable differences. The failure occurred at the bracket–adhesive contact as seen by Group I's high ARI score. Groups II, IV, VII, and VIII presented the least amount of adhesive remnants on the enamel structure.

Discussion

The importance of bonding of orthodontic brackets cannot be underestimated because the significance of orthodontic bonding lies in obtaining a strong bond between the bracket and tooth surface.[11] Shear bond strength is defined as "the amount of force required to break the connection between a bonded (dental) restoration and the tooth surface with the failure occurring in or near adhesive/adherens interface." Shear testing has been used in several studies to assess the bond strength of orthodontic bonding systems.

Many light-curing devices have been developed over the years, and it is critical to figure out which is more efficient and provides appropriate bond strength. The quality and intensity of light to which these bonding materials are exposed, as well as the curing time, determine the degree to which they cure. Placing a light-tip away from the bonding material may reduce the degree of polymerization due to the reduced light intensity, the intensity of light is inversely proportional to square of the light-tip distance to the enamel surface. According to Rueggeberg and Jordan,[12] the higher the light output, more photons reach the resin, and hence more free radicals are accessible for polymerization. They observed that increasing the light-tip distance reduced the resin polymerization 2 mm below the surface. Hence, the study was undertaken to find out whether the light-tip distance affects the shear bond strength of orthodontic brackets when cured with LED and high-intensity LED at four different light-tip distances, and it was observed that higher shear bond strength was achieved with high-intensity LED light and minimum light-tip distance.

In the present study, when comparing the two light-curing units, light-tip distance of 0 mm showed statistically significant and highest shear bond strengths when compared to other light-tip distances. The highest shear bond strength (19.23 $\pm$ 4.83 MPa) was found for high-intensity LED light at 0 mm. But at a greater distance of 9 mm, high-intensity LED light achieved greater shear bond strength (11.74 $\pm$ 1.40 MPa) when compared with LED light (5.24 $\pm$ 0.92 MPa) (Fig. 3). When using the high-intensity LED light, not much significant difference was found between 0 mm and 3 mm, whereas when comparing 0 mm and 9 mm, a considerable variation in bond strength was found, indicating that it had a significant difference on shear bond strength. Similar bond strength results were obtained for high-intensity LED light (17.35 $\pm$ 5.07 MPa) by Di Nicoló et al.[13] Cacciafesta et al.[8] observed contrasting results, in that, no significant difference was observed in shear bond strength at a light-tip distance of 0 mm when comparing high-intensity halogen light, an LED, and a plasma arc light.

Sakaguchi and Ferracane[14] observed diminished light output at distances more than 2 mm which further reduced to 25% at 4-mm distance. Aguiar et al.[15] observed similar results, in that, samples that were light-cured at 2 and 4 mm showed significantly higher hardness values than those light-cured at 8 mm. Felix and Price[16] and Jain et al.[1] also observed similar results where they observed that light intensity and shear bond strength decreased as distance increased. Barakah[17] in 2021 also concluded that the surface hardness of the restoration increases as the distance from the tip of the LED light-curing unit to the surface of the nanofilled composite resin restoration decreases.

The ARI data in this study revealed a similar pattern of orthodontic bracket failure in all groups. There was a significant difference between the groups (*p*-value = 0.0001). A frequency of score 2 was noted in LED and high-intensity light, indicating more than half of the adhesive was remaining on the tooth. In the LED group, the highest percentage of score 2 was noted in group I. For high-intensity light, the percentage of score among the groups showed no significant difference. The SEM findings conformed to the values of the SBS and ARI. The higher the SBS, the greater the ARI score and deeper the resin tag penetration.

The four light-tip distances are taken in this study because it was noted in the previous studies that, at 0-mm light-tip distance, there was significantly greater shear bond strength and increasing the light-tip distance decreased the shear bond strength. Though a distance of 0 mm is clinically not possible, since it is an *in vitro* study, and we had positioned the light-curing unit on a jig, we used this distance to assess its effect on shear bond strength. Very few studies previously have examined the shear bond strength of orthodontic adhesives using high-intensity LED at different light-tip distances. Considering the importance and the proximity of the light-tip to the resin surface, the present study can be justified to evaluate the shear bond strength of orthodontic brackets using LED and high-intensity light at four different light-tip distances of 0 mm, 3 mm, 6 mm, and 9 mm.

One of the major limitations of this study is that the oral environment cannot be replicated as this was an *in vitro* study, and therefore the findings cannot be generalized to the clinical situation. Therefore for clinical application, *in vivo* studies have to be conducted. Despite the study's limitations, the findings suggest that LED or high-intensity units can be used for bonding orthodontic brackets without compromising the shear bond strength of the brackets, and that high-intensity LED light can be used where a larger area of the enamel surface needs to be cured, with better shear bond strength, without a significant reduction in power output and reduced curing time.

Conclusions

The shear bond strengths of the light-curing units were maximum when they were employed at a distance of 0 mm from the bracket. Significant differences between LED and high-intensity LED light were found at higher distances of 3 mm and 6 mm. At a greater distance of 9 mm, the light-curing units showed lower shear bond strength. As a result, it is possible to draw the following conclusion from the study's results: shear bond strength is stronger when the light source is close to the surface to be cured, and it decreases as the distance increases between the light source and the surface. There was no significant difference in ARI scores between different groups. Scanning electron microscopy analysis confirmed the ARI findings.

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