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Research article

Advancement in orthodontic bonding: comparing 1-second and 5-second light emitting diode (LED) curing lights

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Abstract: Recent advancements in dentistry have introduced new light-curing units such as 1-second and 5-second LED curing lights to orthodontics. We aimed to evaluate the shear bond strength and Adhesive Remnant Index (ARI) of stainless-steel orthodontic brackets cured with 1-second, and 5-second LED curing lights. Ninety human extracted upper premolars were selected based on the inclusion and exclusion criteria. The selected teeth were randomly divided into 2 groups - Group I and Group II. In Group I, the teeth were bonded with Standard pre-adjusted edgewise upper premolar brackets (Orthox, JJ Orthodontics) using Transbond XT and cured with Woodpecker iLED 1-second curing light. In Group II, the same brackets and composite were used to bond and light-cure with 5-

seconds Woodpecker LED-D unit. The shear bond strength and the Adhesive Remnant Index (ARI) of brackets in both groups were evaluated. Student t-test was used for the statistical analysis of the data. In Group-I (1-second LED curing light), the shear bond strength was 6.62 MPa, whereas it was 10.32 MPa in group II (5-second LED curing light). A highly significant difference was observed in the shear bond strength between the groups. The ARI scores further revealed that the 5-second curing light resulted in a safer failure mode, with adhesive remaining mostly on the bracket. We found that the 5-second Woodpecker LED-D curing light demonstrated higher shear bond strength compared to the 1-second iLED curing light, although both sets of bond strength values are clinically acceptable.

Keywords: orthodontic brackets; premolar teeth; composite resin; shear bond strength; light emitting diode

1. Introduction

Introduction of acid etching technology into dentistry by Buonocore [1] has revolutionized the field of orthodontics by enabling direct bonding of brackets to teeth. A variety of orthodontic composites have since emerged, including both self-cured and light-cured types. Light-cured composites require a curing light to achieve optimal bond strength between the bracket and the tooth surface, which is crucial to minimize the risk of accidental debonding and prevent treatment delays [2,3].

Researchers have reported the bonding of orthodontic brackets using visible light cure composite [4]. Light-polymerized composites facilitate easier bracket placement and removal of excess resin [5]. The delivery of visible blue light for curing composite resins can be achieved using different technologies, including Quartz-Tungsten-Halogen (QTH) lights, plasma arc (xenon) lights, and argon lasers. Recent advancements have introduced Light Emitting Diode (LED) curing lights, marking a significant development in curing light technology.

In 1995, light-emitting diodes (LEDs) were introduced as a polymerization source for light-cured composite resins. These solid-state light sources use semiconductors to produce light. LED curing lights offer several advantages, including a long lifespan of approximately 10,000 hours [6], minimal degradation of output, reduced energy waste, and lower heat generation. Their efficiency also allows them to operate on rechargeable batteries due to their low power consumption.

Researchers assessed the effects of different exposure times and intensities of a high-power LED device on pulp chamber temperature and cooling time during orthodontic bracket bonding. The results showed that the quick curing group (QCG) with a 3-second exposure had a significantly lower temperature increase (1.28 °C) and shorter cooling time (9.97 seconds) compared to the traditional curing group (TCG) with a 20-second exposure (3.52 °C and 38.83 seconds). Thus, reducing the exposure time to 3 seconds with a higher intensity is safer for the pulp chamber [7].

A new generation of high-intensity LED curing lights has recently been introduced, featuring multiple LEDs or larger emission areas. These advancements will reduce curing times due to their increased intensity. Notably, the development of 1-second and 5-second LED curing lights aims to further decrease chairside time for orthodontists. However, the clinical efficacy of these ultra-fast curing lights in achieving acceptable bond strengths has not been thoroughly investigated. Therefore, we aim to assess the shear bond strength of stainless-steel orthodontic brackets when cured with the newly introduced 1-second and 5-second LED curing lights.

2. Materials and methods

2.1. Sample size calculation

The sample size for the study was calculated using GPower software (v. 3.1.9.4, Universitat Dusseldorf, Germany) with an alpha (α) error of 0.05, a statistical power (1−β) of 80%, and a significance level of 0.05. An equal allocation ratio (N2/N1) of 1 was applied, meaning participants were evenly distributed across the two groups. Based on these parameters, a total of 90 participants were included in the study, with 45 samples assigned to each group.

2.2. Ethics approval and study design

The study was conducted in the Department of Orthodontics & Dentofacial Orthopaedics, Kamineni Institue of Dental Sciences, Telangana, India following an approval from the Institutional Ethics Committee (KIDS/IEC/2019/21).

Ninety extracted upper 1st premolars were selected based on the inclusion criteria, teeth with normal buccal surface area, no caries and cracks, and without restorations. The selected teeth were cleaned to remove blood, periodontal soft tissue, calculus and debris, and stored in distilled water. The teeth were fixed in self-cured acrylic using block-shaped metal plates. Once the acrylic had set, the ninety premolar blocks were randomly assigned to two groups (Group I and Group II), with forty-five teeth in each group.

2.3. Methods

Acid etching was performed on the buccal surfaces of the premolar teeth in both groups using a 37% phosphoric acid solution for 30 seconds. The teeth were then rinsed with water and dried until a chalky appearance was achieved. Ninety standard edgewise upper premolar brackets (Orthox, JJ Orthodontics), each with a surface area of 11.80 mm^2, were selected for the study. Following a standard bonding protocol, each bracket was bonded to the teeth using a layer of adhesive primer (Transbond XT Primer, 3M Unitek Dental Products, CA, USA), followed by Transbond XT Light Cure Orthodontic Adhesive (3M Unitek Dental Products, CA, USA). After applying the adhesive, the brackets were centered on the buccal surfaces of the teeth and gently pressed into place. Excess adhesive was carefully removed.

In Group I, 45 premolar brackets were bonded according to the protocol and light-cured using the Woodpecker i-Led (intensity of 2300 mW/cm^2, Woodpecker, China) from the incisal direction for 1 second. In Group II, the remaining forty-five premolar brackets were bonded and light-cured using a 5-second LED curing light (Woodpecker LED-D, China). In both groups, the distance between the light-curing tip and the bracket edge was consistently maintained at 1mm.

2.4. Shear bond strength test and Adhesive Remnant Index (ARI)

The shear bond strength was measured using a Universal Testing Machine (Mecmesin OmniTest-25, UK) at the MSME Testing Station, Hyderabad, India. The testing was conducted with a crosshead speed of 1 mm/second. The force required to debond the brackets was recorded and then divided by the bracket surface area to calculate the shear bond strength in Megapascals (MPa). The Adhesive Remnant Index (ARI) was evaluated using a stereomicroscope of 10X magnification (Lynx, EVO Dynascope®) for all 90 samples post-debonding to assess the mode of bond failure.

2.5. Statistical analysis

The statistical analysis was performed using the Statistical Package for Social Sciences (SPSS, Version 22.0, SPSS Inc., IBM Corporation, New York, USA). An independent Student's t-test was conducted to compare the groups' mean shear bond strengths and differences in the ARI. The significance level (p-value) was set at $P < 0.05$.

3. Results

A highly significant difference in shear bond strength was observed between the two groups (Table 1). In Group I, where the 1-second LED curing light was used, the shear bond strength was 6.62 MPa. In contrast, Group II, which utilized the 5-second LED curing light, showed a shear bond strength of 10.32 MPa.

Table 1. Comparison between group I and group II.

Parameter	Group I (1-second LED) mean (SD)	Group II (5-second LED) mean (SD)	t-test value	df	p-value
Shear bond strength (Mpa)	6.62 (1.34)	10.32 (2.28)	27.44	61	0.001

Abbreviations: MPa: Mega Pascals, SD: standard deviation, df: degrees of freedom.

ARI scores indicated a statistically significant difference between the two groups ($p = 0.04$). In Group I (1-second LED curing light), the ARI scores were predominantly 3, suggesting that 10% to 90% of the adhesive remained on the bracket after debonding. In Group II (5-second LED curing light), the ARI scores were predominantly 4 and 5, indicating that most adhesive remained on the bracket after debonding. This suggests that bond failure primarily occurred at the adhesive-bracket interface rather than the enamel-adhesive interface.

4. Discussion

Recent advancements in material science and dental equipment have led to significant innovations, including the development of 1-second and 5-second LED light curing lights by several manufacturers. Given the importance of clinicians' time, these rapid-curing devices offer the potential for more efficient procedures. Achieving optimal bracket bond strength is crucial to prevent accidental debonding. Although manufacturers claim these new orthodontic curing lights are effective, it is essential to verify if they provide adequate bond strength. Therefore, this study was designed to evaluate whether these new curing lights deliver satisfactory shear bond strength for orthodontic brackets.

Our results suggest that the new intensive LED curing units reduce the time necessary to bond orthodontic brackets. The shear bond strength of the group II was 10.32 Mpa whereas for Group-I it was 6.62 Mpa. The bond strength measurements should not be directly compared among various experiments as they could be influenced by many experimental variables.

Bond strength values depend on several factors, including the power of the light curing unit, curing time, the total energy emitted by the unit, the distance between the bracket and the curing light tip, and the type of brackets used [8]. Researchers have consistently found a direct correlation between curing time and shear bond strength, which is attributed to the increased rate of monomer-to-polymer conversion with longer curing times [9−14]. However, it is generally accepted that shear bond strengths below 6–8 MPa are insufficient to withstand clinical stresses.

Researchers have found that the exothermic reaction during polymerization and heat output from LED curing units can increase intra-pulpal temperature, which is influenced by factors like radiation time and material thickness. Comparisons of different curing lights, including LED and halogen, reveal varying thermal effects, highlighting the importance of carefully managing exposure time and intensity to minimize the risk of pulp damage. Alsafadi et al., assessed the effects of different exposure times and intensities of a high-power LED device on pulp chamber temperature and cooling time during orthodontic bracket bonding. The results showed that the quick curing group (QCG) with a 3-second exposure at 2500 mW/cm² had a significantly lower temperature increase (1.28 °C) and shorter cooling time (9.97 seconds) compared to the traditional curing group (TCG) with a 20-second exposure at 1200 mW/cm² (3.52 °C and 38.83 seconds). Thus, reducing the exposure time to 3 seconds with a higher intensity is safer for the pulp chamber [7].

Swanson et al., reported that longer curing times resulted in higher bond strengths. While they found that a 10-second cure was adequate, they recommended longer polymerization periods for optimal results [15]. Similarly, Fujibayashi et al. observed that LED sources with the same irradiance as halogen sources achieved a significantly greater depth of cure than halogen sources [16]. Nonetheless, in orthodontics, a high depth of cure is less critical since orthodontic materials are applied in relatively thin layers.

In this study, Group II (5-second LED curing light) demonstrated a higher shear bond strength compared to Group I (1-second LED curing light), with both values remaining within acceptable ranges for clinical stress despite the reduced curing time. Researchers found that brackets cured with LED curing lights for 3 seconds showed the highest shear bond strength, followed by those cured for 1 second. The LED groups in that study exhibited clinically acceptable shear bond strength compared to halogen lights, allowing for reduced bonding times without compromising shear bond strength [17]. In this study, the curing power of the LED-D curing light ranged from 600 mW/cm² to 850 mW/cm², whereas the iLED light had a power of 2300 mW/cm². Uşumez et al., noted that higher light power results in a greater number of photons reaching the composite material, which leads to an increased generation of free radicals that facilitate the conversion of monomers into polymers [10].

The Adhesive Remnant Index (ARI) analysis revealed a statistically significant difference between the groups ($p = 0.04$) regarding bracket failure modes. In the 5-second curing group, a higher proportion of teeth exhibited ARI scores of 4 and 5, indicating that most of the adhesive remained on the bracket post-debonding. This pattern suggests that bond failure in this group occurred primarily at the adhesive-bracket interface, reducing the likelihood of damage to the enamel surface during debonding. The findings align with the clinical goal of preserving enamel integrity at the end of orthodontic treatment, as most of the adhesive remained on the bracket than the enamel. In contrast, the 1-second group exhibited ARI scores of 3 and 4, indicating a more variable distribution of adhesive remaining on the bracket post-debonding. This suggests that bond failure in this group occurred more frequently within the adhesive layer, with 10% to 90% of the composite remaining on the bracket surface. While this does not compromise the bond's clinical acceptability, it points to a greater risk of bond failure occurring closer to the enamel surface than the 5-second group.

The ARI findings, in conjunction with the shear bond strength results, suggest that while the 1-second curing light is a viable option for bonding, the 5-second curing light offers greater bond strength and a safer failure mode, as evidenced by the adhesive remaining on the bracket in most cases. This could be clinically advantageous by minimizing the risk of enamel damage during debonding, especially in high-risk cases where enamel preservation is critical.

It should be noted that the absence of thermocycling in this study is a limitation. Thermocycling simulates the temperature fluctuations that occur intraorally, which could influence the bond strength and failure mode over time. Future studies should incorporate thermocycling to better simulate clinical conditions and further validate these findings.

It has been reported that halogen lights utilize only a small portion of their emission spectrum for activating photo-initiator molecules, whereas LED units are more efficient at delivering light that activates camphorquinone. The absorption spectrum of camphorquinone extends from 360 to 520 nm, with a peak at 465 nm. The optimal emission bandwidth for light sources is between 450 and 490 nm. LED curing lights emit 95% of their spectrum between 440 and 500 nm, closely matching the absorption peak of camphorquinone. Although LED curing lights generally offer higher light intensity, their short exposure times can result in insufficient energy delivery. Nonetheless, in this study, the 1-second LED curing light, with an intensity of 2300 mW/cm^2, achieved a clinically acceptable shear bond strength of 6.62 MPa, although it was lower than that of the 5-second curing light.

5. Limitations and future scope

This study has a few limitations, including its in-vitro nature, single bonding protocol with specific adhesive systems, and small sample size. Therefore, the results should be cautiously compared with clinical research findings and validated with a larger sample size. By addressing these limitations and exploring these future directions, we can gain deeper insights into optimizing LED curing technology and its applications in orthodontic bonding. Due to practical constraints and the focus on comparing curing lights, thermocycling was not performed in this study.

6. Conclusions

We evaluated the shear bond strength of stainless-steel orthodontic brackets using two newly introduced 1-second and 5-second LED curing lights. Our findings indicate that the 5-second LED curing light resulted in a significantly higher shear bond strength (10.32 MPa) compared to the 1-second LED curing light (6.62 MPa). Both curing times were within clinically acceptable ranges, demonstrating that even the shorter curing time of 1 second can achieve a satisfactory bond strength. The ARI scores further revealed that the 5-second curing light resulted in a safer failure mode, with adhesive remaining mostly on the bracket, which could help minimize the risk of enamel damage during debonding.

Overall, our results suggest that high-intensity LED curing lights, particularly the 5-second curing time, offer the potential to reduce chairside time without compromising the shear bond strength of orthodontic brackets. The 1-second curing light also showed promise as a viable option for bonding.

However, further research with larger sample sizes and varied clinical conditions is recommended to confirm these findings and optimize curing protocols.

Use of AI tools declaration

We declare the Artificial Intelligence tools are not used in the preparation of this article.

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Conflict of interest

All authors declare no conflicts of interest in this paper.

Author contributions

Praveen Kumar Neela conceptualized the study, designed the methodology, conducted data analysis, and contributed to writing and revising the manuscript. Prathyusha Dasari assisted with the literature review, performed experiments, collected data, and manuscript preparation. Pavan Kumar Mamillapalli supported data collection and statistical analysis. Mahamad Irfanulla Khan A N analyzed the data, prepared the manuscript and tables, and participated in revisions and proofreading. Udayini Monica conducted fieldwork and gathered relevant data. Naresh Mangalapu coordinated research activities and ensured compliance with ethical standards. Shahistha Parveen Dasnadi provided critical insights during the review process and edited the manuscript.

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