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Original Article

Effect of High Irradiance and Short Exposure Times on the Shear Bond Strength of Metal and Ceramic Brackets

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Abstract

Background: Orthodontic brackets are bonded to the tooth surface using adhesive systems, and the quality of this bonding plays a critical role in the success of orthodontic treatment. Light-cured composite resins are widely used for this purpose, and their effectiveness depends on several factors, including light intensity, wavelength, and exposure time. High-intensity LED curing units have been reported to provide adequate polymerization even with short exposure times. This study

aimed to compare the shear bond strength (SBS) values of metal and ceramic brackets bonded using three different LED curing units (Q6 Corded, Valo X, and Dentac Vega) at various exposure times (3, 5, and 10 seconds).

Methods: 112 intact premolars extracted for orthodontic reasons were randomly divided into 16 groups ($n=7$). Groups were formed based on bracket type, LED unit, and exposure time. Brackets were polymerized with the respective devices for the specified times, and light intensities were controlled with a radiometer. All samples were subjected to SBS testing after all samples were stored in water for 24 hours and thermocycled 500 times between 5 and 55°C. Data were analyzed using ANOVA.

Results: Light-curing time had a significant effect on SBS ($p < 0.001$), whereas bracket type did not ($p = 0.765$). The Vega and Q6 Corded 3-second groups exhibited the lowest strength, and no statistically significant difference was found between the other groups ($p=0.272$).

Conclusions: 5-second curing with high-intensity LED units significantly shortens clinical time while maintaining bond security. Regardless of bracket type, no significant difference was found in SBS among the Q6 Corded, Valo X, and Dentac Vega devices.

Key Words: LED devices; Orthodontic bracket; Shear bond strength

Background

The bonding of orthodontic brackets to the tooth surface using adhesive systems is a critical factor influencing the success of fixed orthodontic treatment. Reynolds defined the clinically acceptable range of shear bond strength (SBS) as 5.9 to 7.9 MPa. Adhesion within this range ensures bracket retention during treatment and allows for safe removal without damaging the enamel surface.¹

Light-cured composite resins are commonly used for bonding orthodontic brackets because they offer ease of application, controlled working time, and suitable mechanical properties. The effectiveness of these resins depends on the technical characteristics of the light-curing unit and the specific application parameters. Light intensity, wavelength range, exposure time, and the distance between the curing unit and the bracket surface each influence the degree of resin polymerization. These factors ultimately determine the mechanical properties of the resin and the bond strength achieved between the bracket and the tooth.^{2,3}

Recent advances in light-emitting diode (LED) curing units have reduced the duration of clinical bonding procedures and improved bracket adhesion. Third-generation LED units emit light within the 390 to 490 nm range, which activates multiple photoinitiators and results in more effective

polymerization.^{4,5} Studies indicate that LED units with an intensity of 1000 mW per square centimeter achieve satisfactory results with exposure times of 8 to 10 seconds.^{6,7} Devices with a light intensity of 3200 mW per square centimeter can achieve approximately 90 percent polymerization of orthodontic bonding composites in 3 seconds.⁸ Manufacturers and several studies report that high-intensity curing lights provide adequate bracket bonding with exposure times of 3 to 6 seconds.^{2,4}

The type of bracket selected significantly influences the outcome of orthodontic bonding. Orthodontic brackets are classified as either metal or ceramic.⁹ Ceramic brackets were introduced to address the aesthetic preferences of adult patients. Studies have reported several limitations associated with ceramic brackets, including their brittleness, increased risk of enamel damage during debonding, and variability in bond strength performance, all of which may present clinical challenges. Despite these limitations, the rising demand for adult orthodontic treatment has led to increased clinical use of ceramic brackets. This trend underscores the need for continued research in this area.^{10,11}

Accordingly, the aim of this in vitro study was to comparatively evaluate the shear bond strength of metal and ceramic orthodontic brackets bonded to human teeth using three different LED light curing units (Q6 Corded, Valo X, and Dentac Vega) with varying exposure times (3, 5, and 10 seconds). The findings may provide evidence-based guidance for optimizing clinical light-curing protocols used in orthodontic bonding. The null hypotheses tested in this study were as follows: (1) The type of LED light curing units (Q6 Corded, Valo X, or Dentac Vega) has no significant effect on the shear bond strength of metal and ceramic brackets; (2) Different polymerization times (3, 5, and 10 seconds) do not lead to significant differences in bracket bond strength.

Materials And Methods

This research was approved by the Suleyman Demirel University Health Sciences Ethics Committee (Ethics Committee Decision No: 26, Meeting No: 96, Date: 12.05.2025). In this in vitro study, a total of 112 human premolar teeth extracted for orthodontic reasons, free of caries, fillings, and cracks, were used. The sample size calculation was performed using G*Power software (Heinrich-Heine-Universität Düsseldorf), based on previous studies with a similar methodology.¹² Extracted teeth were stored in a 0.5% chloramine-T solution at +4°C and used in the study within a maximum of 3 months. The teeth were confirmed to be free of cracks or structural defects by examination with a stereomicroscope (S4E; Leica Microsystems, Wetzlar,

Germany). After the buccal surfaces of the teeth were cleaned with fluoride-free pumice and a rubber cup, they were placed in autopolymerizing acrylic resin blocks. A total of 112 teeth were randomly divided into 16 groups, each consisting of 7 samples. The groups were formed based on the illumination time of the light device used and the bracket type (metal/ceramic) (Table 1) (Figure 1).

The buccal enamel surface of the lower right tooth was etched with 37% orthophosphoric acid (Transbond XT Etching Gel; 3M Unitek, Monrovia, CA, USA) for 15 seconds, then rinsed with water for 10 seconds and dried with oil-free air for 5 seconds. Then, a thin layer of a light-cured adhesive agent (Transbond XT Primer; 3M Unitek) was applied to all samples and gently dispersed with air. Orthodontic premolar metal brackets (Victory Series™, 3M Unitek, Monrovia, CA, USA; bracket base area: 8.97 mm²) and ceramic brackets (Clarity™ Advanced, 3M Unitek, Monrovia, CA, USA; bracket base area: 11.69 mm²), both with a 0.022-inch MBT prescription, were bonded to the center of the buccal surfaces using a light-cured composite resin (Transbond XT; 3M Unitek) according to the manufacturer's instructions, and excess adhesive was removed with a dental probe. Polymerization of the brackets was performed using three different LED light devices (Valo X, Vega, and Q6 Corded) and the specified irradiation times for each (Table 1) (Figure 2). Light curing was performed with the light tip 1 mm from the bracket margins using the LED light-curing unit. The light output intensities of the light devices were verified with a radiometer before each application. After polymerization, all samples were soaked in distilled water at 37°C for 24 hours. All samples were subjected to shear bond strength (SBS) testing after all samples were stored in water for 24 hours and thermocycled 500 times between 5 and 55°C. The tests were positioned with the bracket base parallel to the occlusogingival cutting load and applied at a speed of 1 mm/min using a universal testing machine. The maximum load at fracture (in Newtons) was recorded and divided by the bracket base area (in mm²) to calculate the SBS value in MPa. After the brackets were removed, the amount of adhesive remaining on the enamel surfaces was examined using a 20x magnification stereomicroscope (S4E; Leica Microsystems, Wetzlar, Germany) and evaluated using Adhesive Remnant Index (ARI) scores. For the ARI assessment, the 4-point scale by Årtun and Bergland was used:¹³

0 = no adhesive remaining;

1 = less than 50% adhesive remaining;

2 = more than 50% adhesive remaining;

3 = 100% adhesive remaining.

Prior to SBS testing and ARI evaluation, all specimens were coded by an independent researcher. The examiner performing the measurements was blinded to the group allocation. Data were analyzed using SPSS software (Version 29; IBM Corp., Armonk, NY, USA). Normality of data distribution was assessed using the Shapiro–Wilk test, and homogeneity of variances was evaluated using Levene's test. The effects of bracket type and curing protocol on shear bond strength were analyzed using two-way analysis of variance (ANOVA). When significant main effects were identified, pairwise comparisons were performed using Tukey's honestly significant difference (HSD) post hoc test to account for multiple comparisons. Interaction effects between bracket type and curing protocol were also evaluated. Statistical significance was set at $p < 0.05$.

Results

The two-way ANOVA test results are detailed in Table 2. The mean and standard deviations of shear bond strength values for different experimental groups are presented in Table 3 and Figure 2. The distribution of ARI scores is shown in Figure 3. Chi-square analysis revealed no significant difference in ARI score distribution among the experimental groups ($\chi^2 = 59.55$, $df = 45$, $p = 0.095$). The light-curing mode was statistically effective on the shear bond strength ($p < 0.001$). The bracket type did not influence the shear bond strength ($p = 0.765$). The Vega and Q6 Corded 3-second groups exhibited the lowest shear bond strength values, with no significant difference between the two light-curing modes ($p = 0.116$). The shear bond strength of other experimental groups was not statistically different ($p = 0.272$).

Discussion

In this study, the bond strengths of two different orthodontic brackets, metal and ceramic, were compared using various light-curing units and polymerization protocols. One of the hypotheses of our study was that there was no significant difference in shear bond strength between metal and ceramic brackets based on the type of LED light-curing units (Q6 Corded, Valo X, or Dentac Vega); this hypothesis was confirmed. Another hypothesis was that variations in curing time within the tested light-curing protocols would not significantly affect bracket bond strength. However, the results demonstrated significant differences among certain curing-time groups; therefore, this hypothesis was rejected.

Metal and ceramic brackets are the most commonly preferred bracket types in orthodontic treatments. Although the use of ceramic brackets has increased due to aesthetic expectations, it is reported that metal brackets continue to be more widely preferred.^{14,15} In the current study, no statistically significant difference in bond strength was observed between metal and ceramic brackets. This suggests that the adhesive system used is compatible with both bracket types and that there are no significant differences between the types in terms of SBS in clinical practice. However, it has been reported in the literature that ceramic brackets may exhibit higher bond strengths depending on factors such as surface morphology and light transmittance.^{16,17} This difference may be due to the different base surfaces of the ceramic brackets used in the study.

It has been noted that short-term application of high intensity and long-term application of low intensity can achieve similar polymerization efficiencies.^{18,19} This allows for the selection of different devices and protocols in clinical applications.

Today's widely used LED-based light-curing units reduce thermal irritation that may occur in pulpal and gingival tissues due to their lower heat generation, offering significant clinical advantages. Furthermore, third-generation multi-wavelength LED based units offer more homogeneous and higher polymerization rates in materials.^{20,21} Therefore, the high light intensity and multiple polymerization modes of current third-generation LED based units increase clinical efficacy and contribute to treatment success.²²

Currently, high-intensity light sources and light-cured composites are preferred for direct bracket bonding techniques; these offer advantages such as shorter clinical time and deeper polymerization.²³ It is reported in the literature that a bond strength of 5.4 MPa results in 5% debonding, and that bond strengths in the range of 6–8 MPa are considered sufficient for clinical success.^{24,25} In the present study, SBS values were observed with the 3-second curing protocol of the Dentac Vega unit, measuring 5.24 ± 1.99 MPa for metal brackets and 5.10 ± 1.97 MPa for ceramic brackets, whereas the highest SBS value was recorded for metal brackets cured with the 10-second mode of the Valo unit (9.90 ± 2.78 MPa). The reduced bond strength observed with shorter curing times likely reflects a lower degree of monomer conversion and is consistent with previous findings. Although these minimum SBS values approached the lower limit generally considered clinically acceptable, they may provide a reduced safety margin against bracket failure under functional orthodontic forces. Therefore, despite the potential improvement in clinical efficiency, the routine use of very short curing protocols should be approached with caution.^{26,27}

In contrast, the SBS values obtained during the 5- and 10-second applications were within clinically acceptable limits, with no significant differences between them. Furthermore, all tested light devices and mode combinations were found to provide clinically adequate bond strengths. This finding suggests that a minimum 5-second polymerization time may represent a safe threshold for orthodontic bracket bonding.¹⁶

The need to shorten this time in clinical practice has highlighted the optimization of bracket bonding procedures.^{28,29} In this context, LED technology stands out as an effective alternative to halogen light sources. In a study by Krishnaswamy and Sunitha, the clinical performance of 10-second LED polymerization compared to 40-second halogen polymerization was evaluated, and similar results were reported between the two methods.²⁸ Indeed, a separate study compared the adhesive performance of 10-second and 3-second LED polymerization times; no statistically significant difference was found between the two methods in terms of bracket breakage rates or in vitro bond strength.³⁰ These findings demonstrate the clinical success of short polymerization times. In the current study, bracket bond strength was found to be sufficient with 5-second LED applications.

ARI scores, evaluated according to different light sources, exposure times, and bracket types, have been shown to increase with longer exposure times.^{12,31} This suggests that increased exposure time may lead to greater resin polymerization, resulting in more adhesive residue on the tooth surface. Conversely, the higher frequency of ARI scores of 0 and 1 with shorter exposure times suggests that adhesive resins are removed with lower bond strengths and leave less residue on the tooth surface. However, the lack of statistical differences between the groups suggests that the findings have limited clinical significance.^{32,33} Nevertheless, increased resin residue may prolong the clinical post-debonding cleaning time and increase the risk of potential damage to the enamel surface. Therefore, the ideal irradiation time and selection of bracket material should be evaluated not only in terms of bond strength but also in terms of ease of clinical application.

The Tranbond XT adhesive system, widely used for bracket bonding, is preferred for its high bonding performance in both clinical and laboratory studies.^{34,35} In this study, Tranbond XT was used to ensure that differences in adhesive performance were primarily due to the light device and application modes.

Shear testing was preferred for assessing bond strength due to its high reproducibility and ability to reflect clinical forces.³⁶ The ideal bracket connection should remain stable on the tooth surface throughout treatment and provide adequate resistance to both orthodontic and masticatory forces. Although each experimental subgroup consisted of seven specimens, this sample size is comparable to those used in previous in vitro orthodontic bond strength studies. Furthermore, a post hoc power analysis indicated that the study had sufficient statistical power to detect the observed effect size. Nevertheless, the possibility of a Type II error cannot be entirely excluded, as smaller differences between groups may have remained undetected. Therefore, future studies with larger sample sizes are warranted to validate and expand upon the present findings.

Several limitations of this study should be acknowledged. First, the in vitro design did not allow for the simulation of clinical factors such as saliva contamination, intraoral temperature fluctuations, masticatory forces, pH variations, and biofilm accumulation, all of which may influence the clinical performance of orthodontic bonding materials. Second, the curing protocols were selected in accordance with the manufacturers' recommendations and were not identical across all light-curing units. Future research incorporating standardized exposure times across different light-curing units and a wider range of experimental and clinical conditions would enhance the generalizability of the findings.

Conclusions

Regardless of bracket type, a 5-second curing protocol with high-intensity LED units has been shown to significantly reduce chairside time while maintaining bond security. Furthermore, no significant differences in shear bond strength were found between Q6 Corded, Valo X, and Dentac Vega LED curing units for metal and ceramic brackets. These results strongly support the potential for restructuring clinical protocols to incorporate short-term curing, thereby enhancing treatment efficiency.

Authors contributions: E.A. and G.C. contributed to Research, Software, Visualization, Validation, *Roles/Writing* (original draft), while M.U. and M.H.B. contributed to Formal analysis, Project management, Methodology, Conceptualization, and Data curation. All authors contributed equally to the project and read and approved the final manuscript.

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Availability of data and materials: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Declarations

Ethics approval and consent to participate: Ethical approval was obtained from the Clinical Research Ethics Committee of Süleyman Demirel University, Isparta, Türkiye (Ethics Committee Decision No: 26, Meeting No: 96, Date: 12.05.2025). All procedures involving human participants were in compliance with the ethical standards of the 1964 Helsinki Declaration and its subsequent revisions, or similar ethical norms. Informed consent was obtained from all participants.

Consent for publication: Not applicable.

Competing Interests: The authors declare no competing interests.

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FIGURE LEGENDS

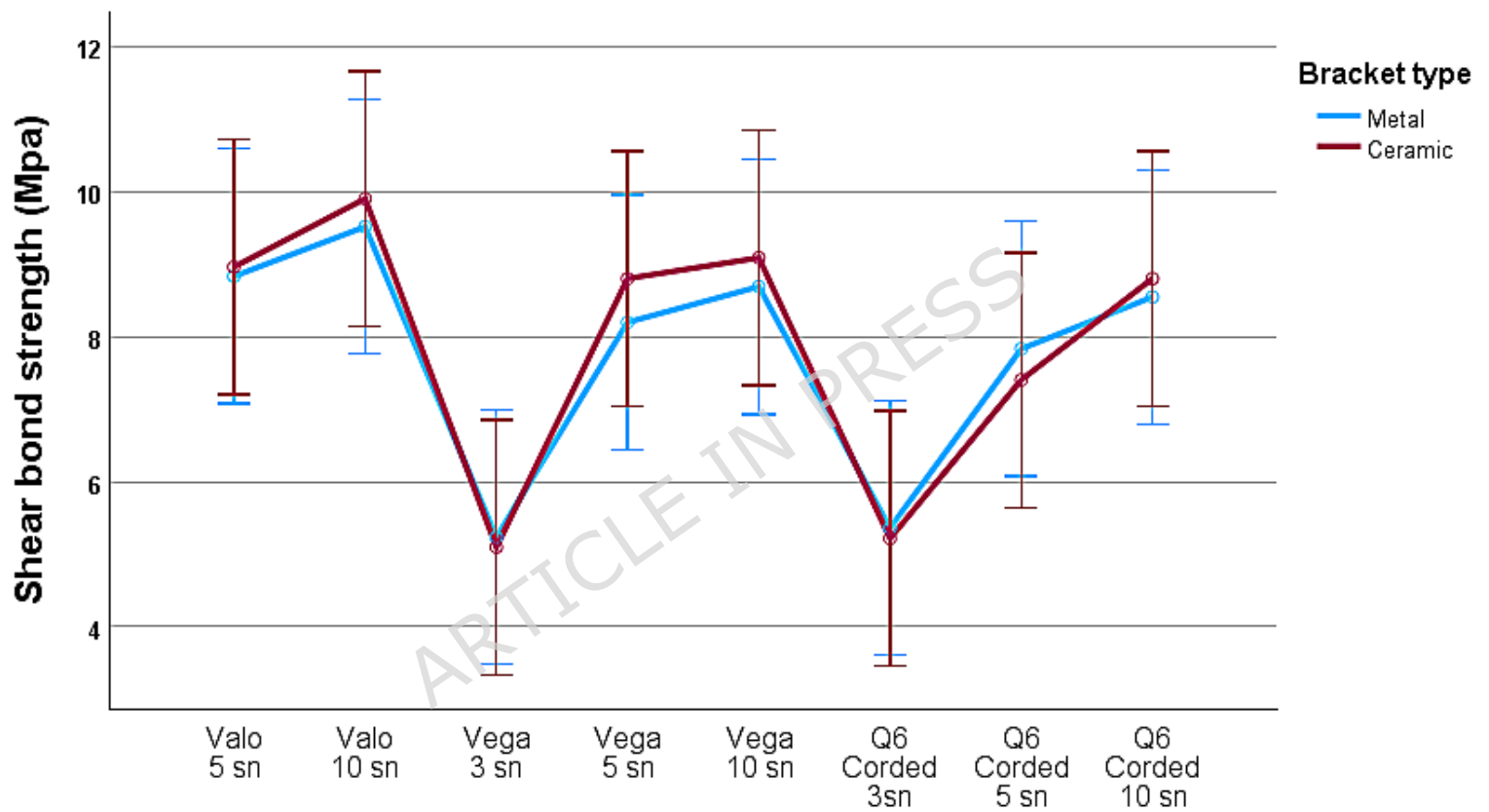
Figure 1. Groups, light devices used, light durations and bracket types

Figure 2. Curing of brackets with three different LED light devices and the light durations specified for each

Figure 3. Adhesive remnant index scores

Workflow Diagram





Adhesive remnant index scores

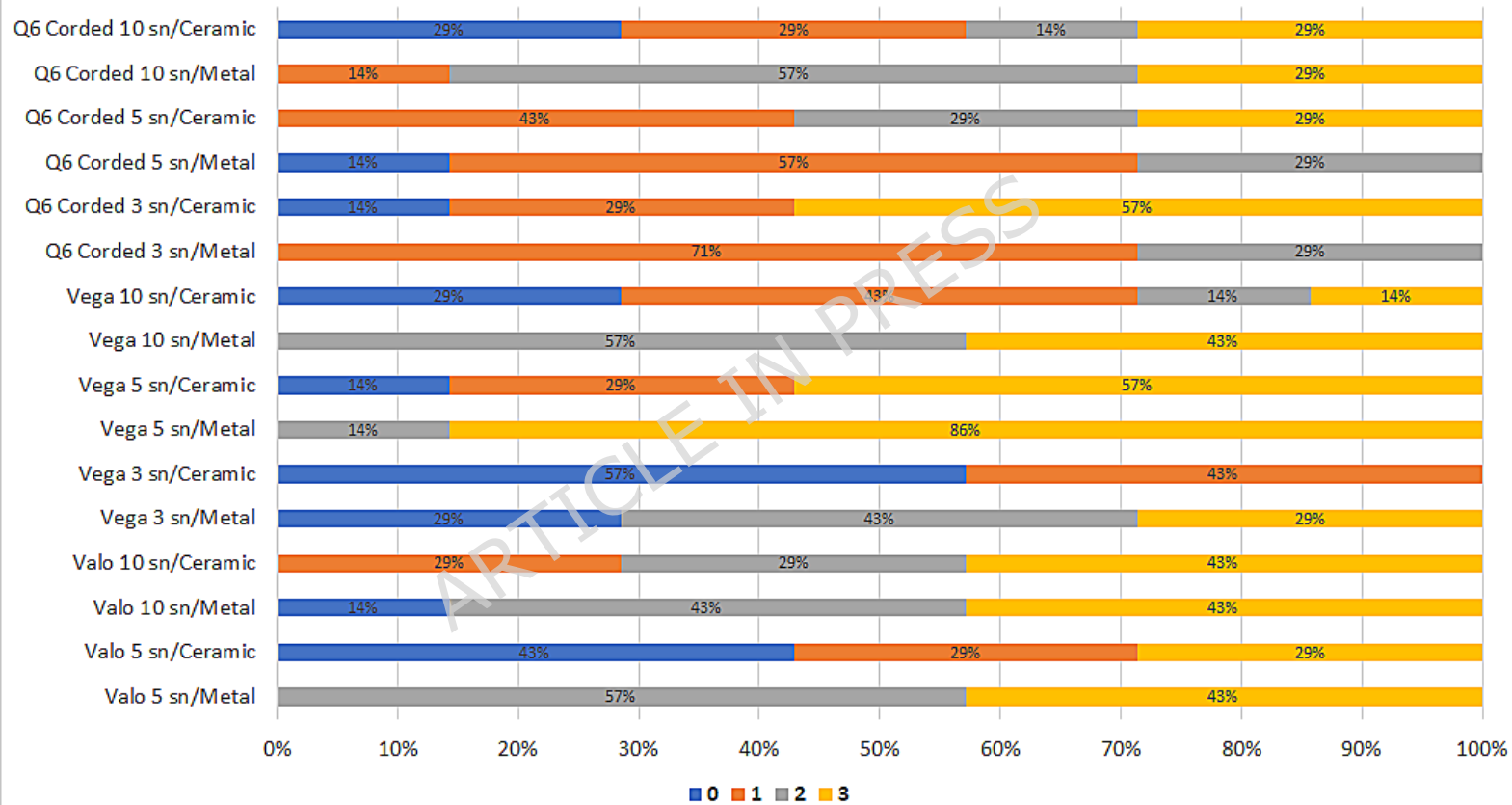


Table 1: Distribution of experimental groups based on light-curing unit, exposure time, light intensity, and bracket type

Light-curing Unit	Time (s)	Light Intensity (mW/cm ²)	Bracket Type
ValoX (Ultradent, South Jordan, UT, ABD)	5	2755	Metal
	5	2755	Ceramic
	10	1370	Metal
	10	1370	Ceramic
Vega (Dentac, Turkey)	3	3000	Metal
	3	3000	Ceramic
	5	2000	Metal
	5	2000	Ceramic
	10	1200	Metal
	10	1200	Ceramic
	3	3000	Metal
	3	3000	Ceramic
Q6 Corded (Siger, China)	5	2000	Metal
	5	2000	Ceramic
	10	1200	Metal
	10	1200	Ceramic
	10	1200	Metal
	10	1200	Ceramic

Table 2. Two-way ANOVA results for shear bond strength test

Source	Type III Sum of Squares	df	Mean Square	F	p
Light curing mode	287.084	7	41.012	7.487	0.000
Bracket type	0.492	1	0.492	0.090	0.765
Interaction	2.917	7	0.417	0.076	0.999

Table 3. Mean shear bond strengths of the experimental groups. Values are presented as mean $\pm$ standard deviation (SD).

Light curing mode	Bracket type	MPa
Valo 5 sn	Metal	8.83 $\pm$ 2.77
	Ceramic	8.96 $\pm$ 2.90
	Metal	9.51 $\pm$ 2.51

Valo 10 sn	Ceramic	9.90±2.78
Vega 3 sn	Metal	5.24±1.99
	Ceramic	5.10±1.97
Vega 5 sn	Metal	8.20±2.09
	Ceramic	8.80±2.23
Vega 10 sn	Metal	8.69±2.55
	Ceramic	9.08±2.39
Q6 Corded 3 sn	Metal	5.36±2.14
	Ceramic	5.22±2.01
Q6 Corded 5 sn	Metal	7.83±2.13
	Ceramic	7.40±2.12
Q6 Corded 10 sn	Metal	8.54±2.40
	Ceramic	8.80±2.17