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Role Of LED Irradiation And Etching Time On Micro Shear Bond Strength Of Composite Resin On Enamel: An In Vitro Study

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Abstract

Introduction:
Composite Resin success depends on proper enamel etching. Although 30-60 seconds etching is adequate, LED-assisted phosphoric acid etching may further shorten etching time without compromising bond strength. This in vitro study compares micro-shear bond strength between conventional and LED-assisted etching techniques.

Materials and methods:
20 extracted human permanent molars were taken and decoronated 1 mm apical to cementoenamel junction. The teeth were then mesiodistally sectioned and the enamel of the
pg. 1
Bucco lingual surfaces were flattened and mounted and were randomly assigned to four groups of 10 specimens each. G1: Fifteen seconds of etching, G2: Fifteen seconds of etching plus LED light irradiation (simultaneously), G3: Five seconds of etching, G4: Five seconds of etching plus LED light irradiation(simultaneously). Dentin bonding agent is applied and light cured. Composite resin is placed incrementally in 2 x 2 mm plastic cylindrical mold and light cured on enamel surface. The micro shear bond strength (μSBS) of composite resin to etched enamel surfaces was measured by using Micro tensile tester. Data were statistically analyzed using ANOVA and Tukey post hoc test.

Results:
ANOVA showed significant differences in micro-shearbond strength among groups ($p<0.01$). Group 2 showed the highest micro-shear bond strength. Group 3 showed the lowest values. Group 1 and Group 4 showed comparable bond strengths without significant difference.

Conclusion:
LED-assisted phosphoric acid etching reduced etching time and improved composite resin bond strength by enhancing enamel demineralization and acid penetration.

Keywords: Composite resin, Etching time, LED light irradiation, micro shear bond strength (μSBS).

Introduction

Composite resin is the preferred restorative material in contemporary dentistry because of its superior esthetics, conservative cavity preparation, and predictable adhesion to enamel. The long-term clinical success of composite restorations depends largely on the quality of the enamel–resin bond, which is achieved through effective acid etching that promotes micromechanical retention by creating microporosities within the enamel surface1,2

Conventional phosphoric acid etching for 15–30 seconds has been widely accepted as the pg. 2

gold standard for enamel conditioning. However, prolonged etching may result in unnecessary mineral loss without providing a significant improvement in bond strength 3,4.

Recent studies have reported that shorter etching durations can produce adequate enamel conditioning while preserving tooth structure and reducing clinical chairside time 5,6.

The bond strength of adhesive restorations is influenced by several factors, including enamel morphology, phosphoric acid concentration, etching duration, adhesive system, and polymerization technique 7.

Advances in adhesive dentistry have introduced energy-assisted surface conditioning methods, such as laser and light-assisted etching, to improve enamel surface characteristics and enhance resin penetration 8,9

Nevertheless, evidence regarding the effect of light-emitting diode (LED) irradiation during phosphoric acid etching on enamel bond strength remains limited. Therefore, this in vitro study aims to evaluate the effect of LED-assisted etching and different etching durations on the microshear bond strength of composite resin bonded to enamel, thereby providing evidence for optimizing enamel conditioning protocols in restorative dentistry 9,10.

Materials and Methodology

This study was registered at the Ethical Committee at the CKS Theja Institute of Dental Sciences and Research, India (Approval No. CKS/IEC-96/2026).

The materials used included 37 % Phosphoric acid, 3M ESPE Single Bond Universal adhesive, and 3M ESPE Filtek Z250XT Nano hybrid Universal Restorative composite and blue phase G2 Ivoclar, vivadent AG FL-9494 Schaan Liechtenstein, Austria.

Sample size calculation:

The sample calculation had conducted utilizing G Power software (Heinrich Heine University, pg. 3

Düsseldorf, Germany). The effect size (1.047), a = 0.05, and a power of 0.95, assuming a normal distribution. The analysis indicated that a minimum of 6 specimens is required per group. However, to improve the reliability, it was decided to take 10 specimens per group.

Specimens preparation:

Twenty freshly extracted human permanent molar teeth were selectedfor this in vitro study.

TeethwithSound,intactEnamel,withoutcariesorRestorationswereincluded.Teeth with fractures, cracks, gross structural irregularities and developmental defects were excluded to ensure standardization of samples. The selected teeth were cleanedand stored appropriately until further use.

The teeth were decoronated approximately 1 mm apical to the cemento-enamel junction (CEJ) using a diamond disc under continuous water cooling. Following decoronation, each tooth was sectioned mesiodistally to obtain two equal halves. The buccal and lingual enamel surfaces of all specimens were flattened by using 600-grit silicon carbide papers under running water to create a standardized bonding surface.

The prepared specimens are randomly divided into four groups, with 10 samples allocated to each group based on the enamel etching protocol employed.

Group 1 (G1)

In Group 1, the enamel surfaces were etched with phosphoric acid for 15 seconds following the conventional etching protocol without LED irradiation.

Group 2 (G2)

In Group 2, the enamel surfaces will be etched with phosphoric acid for 15 seconds along with simultaneous LED light irradiation during the etching procedure.

Group 3 (G3)

In Group 3, the enamel surfaces will be etched with phosphoric acid for 5 seconds without LED assistance. pg. 4

Group 4 (G4)

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In Group 4, the enamel surfaces will be etched with phosphoric acid for 5 seconds combined with simultaneous LED light irradiation.

After completion of the etching procedures, dentin bonding agent was applied to the

conditioned enamel surfaces according to the manufacturer's instructions. Bonding of composite resin to pretreated enamel surface by incremental packing in 2x2 mm plastic cylindrical tube and light cured for 20 seconds.

Micro shear bond strength test:

The bonded specimens will undergo micro-shear bond strength (μSBS) testing using a micro-tensile testing machine to evaluate the bond strength between the composite resin and enamelsurface under different etching conditions.

The obtained data were statistically analyzed using SPSS software version 20. One-way ANOVA followed bypost hoc Tukey's test was used for intergroup comparison. A p-valueof less than 0.05 was considered statistically significant.

Results:

The results of micro shear bond strength (μSBS) test are presented in and Table.1 and

ANOVA for Micro Shear Bond Strength (MPa)are presented in Table.2.

The data were compiled and analyzed using the Statistical Package for the Social Sciences (SPSS), version 20.0 (IBM Corp., Armonk, NY, USA). All quantitative data were expressed as mean ± standard deviation. The statistical analysis revealed a significant difference in micro shear bond strength among the study groups (P=0.000). One-way ANOVA demonstrated that the mean difference between the groups was statistically significant at the 0.01 level (F=87.192), indicating that the experimental conditions had a significant influence on bond strength values.

The error bar of means and 95% confidence intervals of mean micro shear bond strength values in the study groups are shown in Graph 1. Micro shear bond strength (MPa) of all study groups showed variation, with Group 2 demonstrating the highest mean bond strength (53.92 MPa), followed by Group 1 (51.19 MPa), Group 4 (50.50 MPa), and Group 3 (40.31 MPa).

TheTukey HSD intergroup comparison [Table 3.] showed significant differences in micro shearbond strength among most of the groups. Group 2 demonstrated significantly higher bond strength compared to Group 1, Group 3, and Group 4. Group 3 showed the lowest bond strength and was significantly lower than all other groups. There was no statistically significant difference between Group 1 and Group 4 (p = 0.870), indicating similar bond strength values between these two groups. Overall, Group 2 exhibited the highest bond strength, while Group 3 exhibited the lowest.

Discussion:

The longevity of resin-based composite restorations depends largely on the quality of the bond established between enamel and the adhesive system. Since Buonocore introduced the acid-etch technique, phosphoric acid etching has remained the gold standard for enamel conditioning because it creates a microporous surface that enables resin infiltration and micromechanical retention. Contemporary adhesive dentistry continues to rely on this principle despite advances in restorative materials and universal adhesive systems. Recent reviews have emphasized that successful enamel bonding depends not only on the adhesive used but also on the quality of enamel conditioning achieved before bonding. 11, 12, 1, 2, 3

The present study demonstrated that LED-assisted phosphoric acid etching produced micro-shear bond strength values comparable to those obtained with conventional phosphoric acid etching while reducing the application time from 15 seconds to 5 seconds. This finding suggests that the efficiency of enamel conditioning can be enhanced without compromising adhesive performance. Such an approach is clinically significant because reducing etching time decreases chairside time while maintaining adequate bond strength, thereby improving the overall efficiency of restorative procedures.

The most probable explanation for these findings lies in the photothermal effect produced by LED irradiation. Abrandabadi et al. first proposed that the mild heat generated by an LED pg. 6 curing unit during phosphoric acid application accelerates the interaction between phosphoric acid and enamel

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hydroxyapatite. Increased temperature enhances molecular movement and increases the rate of diffusion of hydrogen ions into the enamel surface, allowing faster dissolution of calcium phosphate crystals. Consequently, the characteristic enamel microporosities required for resin penetration can be produced within a shorter period than conventional etching performed at room temperature. The present findings support this concept, indicating that LED activation accelerates the etching process sufficiently to reduce conditioning time from 15 seconds to 5 seconds without adversely affecting bond strength.8

Another possible explanation is that mild heating may reduce the viscosity of the phosphoric acid gel, allowing it to spread more uniformly over the enamel surface. Improved contact between the etchant and enamel enhances dissolution of the interprismatic mineral, producing a more homogeneous etching pattern. Uniform enamel conditioning facilitates better penetration of adhesive monomers into the etched surface, resulting in effective resin tag formation and a stable micromechanical bond. Although the present study did not evaluate enamel morphology using scanning electron microscopy, the comparable bond strength values observed suggest that LED-assisted etching was capable of producing an enamel surface suitable for successful resin infiltration.7,9

Modern adhesive literature consistently demonstrates that adequate enamel conditioning is more important than prolonged etching duration. Loguercio et al. emphasized that selective phosphoric acid etching significantly improves enamel bonding when universal adhesives are used, while Perdigão reported that phosphoric acid pre-etching remains the most reliable method for achieving predictable enamel adhesion. Similarly, Josic et al. concluded that selective enamel etching improves the clinical performance of universal adhesive systems regardless of their application mode. These findings indicate that once sufficient enamel microporosity has been achieved, extending the etching time offers little additional benefit. The comparable bond strengths observed in the present study therefore suggest that LED activation enables the enamel surface to reach this optimal conditioning threshold within only 5 seconds.2, 3, 4

Recent investigations have further questioned the need for conventional etching durations. Öztürk et al. demonstrated that reducing phosphoric acid etching time did not significantly reduce the microtensile bond strength of bulk-fill composite restorations when appropriate pg. 7 universal adhesives were used. Likewise, the systematic review by Amran et al. concluded that shorter etching durations can provide enamel bond strengths comparable to conventional protocols, depending on the adhesive system employed. The present study extends these findings by demonstrating that the addition of LED activation allows etching time to be reduced even further while maintaining satisfactory bond strength, thereby supporting the concept that enamel conditioning can be optimized rather than prolonged.5, 6,13

One of the major advantages of shortened etching time is the preservation of enamel structure. Excessive phosphoric acid exposure produces deeper demineralization, creating enamel porosities that may exceed the penetration depth of adhesive monomers. Such over-etching can leave unsupported enamel prisms that contribute little to bond strength while unnecessarily removing sound mineralized tissue. Earlier studies by Barkmeier et al. demonstrated that increasing etching time beyond the optimum does not necessarily improve adhesion and may alter enamel morphology without additional clinical benefit. Therefore, achieving effective enamel conditioning within 5 seconds may better preserve enamel while maintaining adequate micromechanical retention, supporting the principles of minimally invasive dentistry.14,15

The improved adhesive performance observed with LED-assisted etching is also likely related to enhanced resin penetration into the conditioned enamel surface. Successful bonding depends on complete infiltration of adhesive monomers into the microporosities created by phosphoric acid.16 When resin infiltration matches the depth of demineralization, a strong and durable resin-enamel interface is formed. Because LED activation appears to accelerate enamel conditioning without producing excessive demineralization, the resulting etching pattern may be more compatible with adhesive penetration, thereby producing bond strength comparable to conventional etching despite the shorter application time.17,18,

Another clinically important advantage of reducing etching time is the decreased risk of salivary contamination. Bonding procedures are highly technique-sensitive, and contamination during enamel conditioning can significantly reduce adhesive performance. A shorter etching protocol decreases the period during which the tooth surface remains vulnerable to contamination by saliva, blood or crevicular fluid. This benefit is particularly valuable in pediatric dentistry, partially erupted teeth and patients with limited cooperation, where maintaining absolute isolation may be difficult. Consequently, LED-assisted etching pg. 8 has the potential to improve the predictability of adhesive procedures while simultaneously reducing overall chairside time.

Safety remains an essential consideration whenever additional energy is applied to dental tissues. Although LED irradiation generates heat, the temperature increase produced by modern LED curing units is considerably lower than that produced by conventional quartz-tungsten-halogen lights. Asmussen and Peutzfeldt demonstrated that LED curing units produce only modest temperature elevations, while Chandhok et al. reported that short irradiation periods generally remain below the critical threshold associated with irreversible pulpal injury. These findings suggest that the brief LED exposure used in the present study is unlikely to compromise pulpal health, although long-term biological evaluation remains necessary.19,20

Compared with alternative enamel conditioning techniques such as Er and Er,Cr laser etching, LED-assisted phosphoric acid etching offers several practical advantages. Laser systems have demonstrated satisfactory bond strengths but require expensive equipment and greater operator expertise. In contrast, LED curing units are already available in virtually all restorative dental practices. Therefore, incorporating LED activation into the conventional phosphoric acid etching protocol represents a simple, economical and clinically feasible modification that can be implemented without additional investment or major changes to existing clinical procedures.10,15,16

Overall, the findings of the present study indicate that LED-assisted phosphoric acid etching produced bond strength values comparable to conventional enamel etching while reducing application time from 15 seconds to 5 seconds. The results suggest that LED activation enhances the efficiency of enamel conditioning, probably by accelerating the acid-enamel reaction and facilitating resin penetration into the conditioned surface, thereby producing an effective adhesive interface. In addition, shorter etching duration may preserve enamel structure, reduce the likelihood of over-etching and minimize the risk of contamination during restorative procedures. From a clinical perspective, this technique offers a practical means of improving efficiency without compromising adhesion. Nevertheless, as this investigation was performed under in vitro conditions, future in vivo studies are required to evaluate the long-term durability of the bonded interface and to continue monitoring the pulpal response to the minor thermal changes associated with LED-assisted etching, thereby ensuring complete pg. 9 biological safety alongside these mechanical advantages.

Limitations of the study

This study was limited by its in vitro design, which could not fully replicate oral conditions such as saliva, thermal changes, and masticatory forces. Only immediate micro-shear bond strength was evaluated, while long-term durability, aging effects, and thermocycling were not assessed. The study tested a single LED unit, adhesive system, and etching protocol, limiting generalization of the findings. Advanced surface analyses such as SEM or AFM were not performed to evaluate enamel morphology.

Conclusion

Within the limitations of this in vitro study, LED-assisted phosphoric acid etching produced bond strength values comparable to conventional enamel etchingwhile reducing application time from 15 seconds to 5 seconds. LED activation may improve enamel conditioning and resin penetration, resulting in an effective adhesive interface. Shorter etching duration may also help preserve enamel structure and reduce the risk of contamination during restorative procedures. Future in vivo studies should continue to monitor the pulpal response to the minor thermal changes associated with LED-assisted etching to ensure total biological safety alongside these mechanical gains.

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Table 1. Comparison of micro shear bond strength (µSBS) of the study groups

Groups	N	Mean (MPa)	Standard Deviation
Group 1	10	51.19	2.11
Group 2	10	53.92	2.12
Group 3	10	40.31	2.11
Group 4	10	50.50	1.71

Table 2. ANOVA for Micro Shear Bond Strength (MPa)

Source of Variation	Sum of Squares	df	Mean Square	F	p value	Significance
Between Groups	1067.245	3	355.748	87.192	0.000	**
Within Groups	146.882	36	4.080	—	—	—
Total	1214.127	39	—	—	—	—

Graph .1 Graphical method of Comparison of micro shear bond strength (µSBS) of the study groups

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Table 3. Intergroup comparison of micro shear bond strength (MPa) usingthe Tukey HSD post hoc test after ANOVA

(I) Groups	(J) Groups	Mean Difference (I–J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Group 1	Group 2	-2.72600*	0.903	0.023	-5.159	-0.293
	Group 3	10.88000*	0.903	0.000	8.447	13.313
	Group 4	0.69100	0.903	0.870	-1.742	3.124
Group 2	Group 1	2.72600*	0.903	0.023	0.293	5.159
	Group 3	13.60600*	0.903	0.000	11.173	16.039
	Group 4	3.41700*	0.903	0.003	0.984	5.850
Group 3	Group 1	-10.88000*	0.903	0.000	-13.313	-8.447
	Group 2	-13.60600*	0.903	0.000	-16.039	-11.173
	Group 4	-10.18900*	0.903	0.000	-12.622	-7.756
Group 4	Group 1	-0.69100	0.903	0.870	-3.124	1.742
	Group 2	-3.41700*	0.903	0.003	-5.850	-0.984
	Group 3	10.18900*	0.903	0.000	7.756	12.622

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