

Effect of Chitosan Nanoparticles on Composite Bond Strength to Enamel Following Laser and Non-laser assisted Bleaching: An In-vitro Study

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ABSTRACT

Introduction: Bleaching is a popular treatment used to enhance the appearance of stained anterior teeth with resin-based restorations. However, additional interventions may be required following bleaching, as the application of peroxide gel can adversely affect bond strength. The present study focuses on gaining valuable insights into the use of novel chitosan nanoparticles to overcome the challenges of post-laser-assisted bleaching bond strength.

Aim: To comparatively evaluate the adhesive bond strength between composite resin and enamel pretreated with chitosan nanoparticles after both non laser and laser -assisted bleaching.

Materials and Methods: The laboratory-based in-vitro study was conducted at the Department of Conservative Dentistry and Endodontics, Panineeya Institute of Dental Sciences, Hyderabad, Telangana, India in March 2026. The study included 50 anterior intact teeth and devoid from caries, fractures or any prior dental fillings. "Samples were randomly allocated into five groups of ten samples each." Group 1 -no bleaching-no antioxidant, Group 2-chemical bleaching-composite restoration after 2 weeks, Group 3-chemical bleaching-chitosan

nanoparticles - immediate composite restoration, group 4- laser assisted bleaching - composite restoration after 2 weeks, Group 5- laser assisted bleaching - chitosan nanoparticles - immediate composite restoration. The bond strength of these samples was evaluated using universal testing machine at crosshead velocity of 1 mm per minute. Data were analysed using one-way Analysis of Variance (ANOVA) with Tukey's post-hoc test for group comparisons and "Student's t test" for correlating antioxidant and non antioxidant groups, with significance set at $p < 0.05$.

Results: Significant differences in mean shear bond strength were noted among the groups ($p < 0.05$). The highest value was recorded in Group 1 (control: 22.0 ± 0.73 MPa), followed by Group 5 (21.1 ± 1.11 MPa) and Group 4 (20.5 ± 1.13 MPa), while Group 2 (bleaching without antioxidant) showed the lowest (19.3 ± 1.23 MPa). Tukey's post-hoc analysis indicated significant differences between Group 1 and all other groups ($p = 0.0001$), and between Group 2 and Groups 4 ($p = 0.03$) and 5 ($p = 0.002$).

Conclusion: 0.2% chitosan nanoparticles have the ability to restore adhesive bonding to laser-bleached enamel surfaces, enabling immediate bonding of composite resin and reducing the waiting time for adhesive restorative procedures.

Keywords: Antioxidants, Dental enamel, Nanochitosan, Teeth whitening, Tooth-coloured restorative material

INTRODUCTION

Tooth discoloration is a common aesthetic concern, often resulting in an unappealing appearance and causing mental distress for patients. Tooth whitening procedures are popular options as they provide a more conservative alternative compared to other procedures, such as direct or indirect restorative veneers and full-coverage restorations [1].

The bleaching process depends on redox reactions, which generate free radicals like, nascent oxygen, superoxide anion, perhydroxyl and hydroxyl ions. These oxygen radicals are highly reactive due to unpaired electrons and break down large pigmented molecules into smaller ones there by reducing discoloration [2]. To enhance these bleaching processes heat and light can be used which reduce treatment time and improve whitening efficiency. Common light sources used include infrared lamps, plasma arc lamps, CO₂ lasers, Potassium Titanyl Phosphate (KTP) lasers, and diode lasers [2-4]. Sultan MS and Elkorashy ME found that the use of a diode laser improved the bond strength of resin composite to enamel surfaces following bleaching procedure [5].

Dental restorative procedures including space closure and replacement of resin-based restorations may be needed in addition to bleaching to obtain more acceptable shades. The most frequently

used whitening gels contain carbamide peroxide at concentrations of 10% and hydrogen peroxide at concentrations of 35% which can adversely affect the bond strength after bleaching [6].

The oxygen free radicals released can pass through the enamel prisms and penetrate the tooth structure, reaching the dentin [2]. This further weakens the bond strength by inhibiting the resin-tooth interaction or preventing the resin polymerisation of the adhesives. The reduced shear bond strength may be caused by alterations in the microstructure of bleached enamel surfaces following acid etching. These changes involve a loss of calcium in the enamel, a reduction in microhardness, and the dissolution of enamel prisms [7].

Hence, several approaches aimed to reverse the decreased bond strength post bleaching. In general, it is suggested to wait 24 hrs to 3 weeks before performing composite restoration after bleaching, as this waiting period is essential to allow bond strength values to return to normal [6]. However, this approach carries risks such as dental hypersensitivity, leakage at the interface, structural failure of the crown, and post-treatment staining, which are undesirable for both the dentist and the patient [8]. Other methods include removing the outer enamel layer, treating the enamel with adhesive-based organic solvents and using antioxidant agents designed to eliminate free radicals from the enamel surface [9-11].

While traditional antioxidants such as sodium ascorbate, green tea extract, and proanthocyanidins have been extensively researched for reversing the reduction in bond strength post-bleaching, recent focus has shifted toward biocompatible nanoparticle-based antioxidants [12].

Chitosan is a novel biomimetic material used in various areas of dentistry, serving multiple roles. Its major properties include biocompatibility, safety, biodegradability, antibacterial activity, oxidation inhibition, and the capability to form films and gels. Chitosan nanoparticles exhibit high surface area-to-volume ratio, improved penetration, enhanced mucoadhesion, and greater cellular uptake. These properties contribute to their superior bioactivity compared to bulk chitosan [13]. Despite its promising potential, limited data are available on its efficacy in restoring bond strength after bleaching, particularly in laser-assisted protocols.

Hence, the primary objective was to evaluate and compare shear bond strength of composite resin to enamel after bleaching and subsequent application of 0.2% nanochitosan as an antioxidant. Secondary objective: To compare the effectiveness of nanochitosan in reversing bond strength reduction after chemical versus laser-assisted bleaching. Null hypothesis (H_0): No significant difference in shear bond strength between bleached enamel with or without nanochitosan treatment. Alternate hypothesis (H_1): Nanochitosan treatment significantly affects the shear bond strength of composite resin to bleached enamel.

MATERIALS AND METHODS

The present laboratory-based in-vitro study was carried out at the Department of Conservative Dentistry and Endodontics, Panineeya Institute of Dental Sciences and Research Centre, Hyderabad, Telangana, India over a period of one month, March 2026. Ethical clearance for the study was obtained from the Institutional Ethical Committee (IEC No: PND/IEC/2024/03/07).

Sample size calculation: The sample size was determined to be 50 based on, Sultan MS and Elkorashy ME [5] study using G*Power software. The calculation considered a statistical power of 80% and a significance level of 5%.

Inclusion and Exclusion criteria: The study included 50 anterior intact teeth and devoid from caries, fractures or any prior dental fillings which were extracted for periodontal and orthodontic reasons are collected from Department of Oral Maxillofacial Surgery, Panineeya Institute of Dental Sciences. Teeth previously subjected to bleaching, Structural defects, storage in chemical preservatives, or prior experimental use were excluded from the study.

Study Procedure

Using a diamond abrasive disc, the specimens were sectioned 2 mm below the cemento-enamel line. Each crown was placed in a self-curing acrylic resin mold (4 cm in length, height and width), with the labial surface positioned upward. To standardise the exposed enamel surface, all samples were polished using 600-grit silicon carbide abrasive paper under running water to obtain a smooth and flat enamel surface. This provided a standardised bonding substrate for all specimens.

Chitosan Gel Preparation: A total of 0.2 g of nanochitosan (Nano Wings Private Limited and VL Products) was liquefied in 100 mL of a 1% aqueous acetic acid. A magnetic stirrer was used to create a uniform mixture at 60°C for 2 hrs to prepare a nanochitosan gel. Study by Mohamed AM et al., [14] showed that the application of 0.2% chitosan before restoration with composite resin resulted in a higher microtensile strength than 2.5% chitosan, hence 0.2% solution is chosen in present study.

Sample Distribution: Total specimens (N=50) were sub-divided into five random groups by simple random sampling (n=10).

Group 1 (Control n=10)

No bleaching treatment, no antioxidant treatment was performed on the specimen surfaces. These specimens were kept in synthetic saliva (commercially available brand name Biochemazone Aritech Chemazone Pvt. Ltd. Urban Estate, Kurukshetra, Haryana) during the duration of the study.

Group 2 (Conventional bleaching n=10)

The samples were treated with Opalescence Boost 40% hydrogen peroxide gel according to the manufacturer's instructions. This gel is specifically formulated for conventional chemical bleaching, with stabilisers and pH buffers optimised for effective and safe use. Two applications of the bleaching gel, each lasting 20 min. were performed. Before the second application, the samples were rinsed with distilled water [Table/Fig-1a].

Group 3 (Conventional bleaching+Antioxidant application)

The samples were bleached in the same manner as Group 2. Then, 0.02 mL of the nanochitosan antioxidant gel was carried in a syringe and evenly applied to the buccal surface of the enamel using a microbrush for 10 min. Afterward, the enamel was rinsed with distilled water for 30 sec [Table/Fig-1b]. According to Rath DN et al, 0.02 mL of chitosan antioxidant was placed and dispersed onto the enamel surface using a sponge pellet for 10 min- which showed similar bond strength were composite is applied directly after 2 weeks waiting period. Hence 10 min time interval have been chosen [14,15].

Group 4 (Diode laser bleaching)

The samples were bleached with 45% hydrogen peroxide (Laser 20 Whitening Gel, Biolase), and the Epic X Diode Laser (Biolase) were used. However, this gel is specifically formulated for activation with a diode laser, containing photoactive agents that help accelerate peroxide breakdown. Using the manufacturer-recommended gels for each technique ensured consistent performance, standardised procedures, and reliable, reproducible results. Previous studies (Sultan et al.) have shown that slightly higher peroxide concentrations with laser activation can be used safely without harming the enamel [5]. The prepared enamel blocks were coated with a thin layer, approximately 1 mm thick, of Laser 20 Whitening Gel (Biolase), was applied using a syringe [Table/Fig-1c]. The diode laser (Epic X, Biolase) was set to deliver power for a specified interval of 30 sec in continuous mode, providing a total energy of 200 J. [Table/Fig-1d,e] Afterward, the excess gel was wiped off using cotton swab, and a second layer of gel was applied in a similar manner. The gel was then removed by rinsing with distilled water for 30 sec.

Group 5 (Diode Laser Bleaching+Antioxidant Application)

Samples were bleached similar to group 4 followed by application of antioxidant gel. Using a syringe, 0.02 mL of nanochitosan gel was applied to each sample and spread onto the buccal surface of the outer enamel with a microbrush for 10 min. Subsequently, the surface was rinsed with distilled water for 30 sec [Table/Fig-1b].

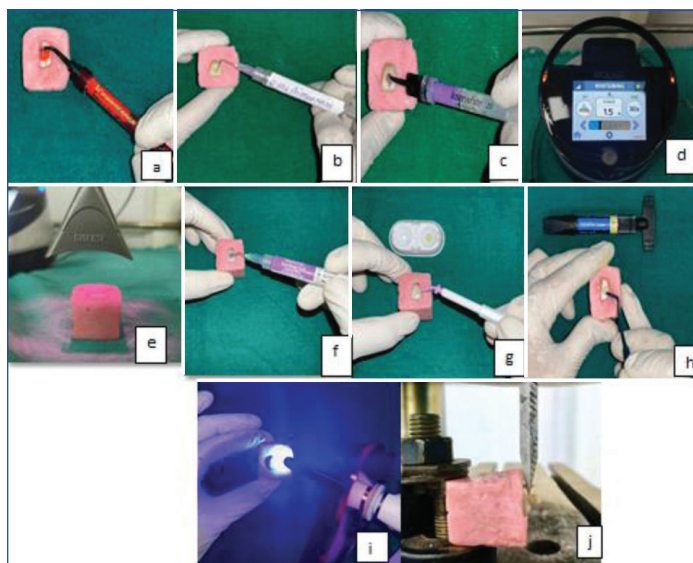
Bonding and Composite Restoration Procedure

After bleaching, direct nanohybrid composite restorations (tetric-N-ceram) were performed immediately in groups 3 and 5, while samples in groups 2 and 4 were kept in synthetic saliva substitute for a 14 day time interval. The buccal surface of the enamel was exposed to 37% phosphoric acid (Prime-Dent® Etchant Gel) for 20-30 sec [Table/Fig-1f], and was subsequently rinsed with water for 30 sec. Afterward, it was carefully blow-dried for 10 sec until a frosty appearance was seen. Following this, a fourth-generation bonding agent (Dentsply Sirona Prime&Bond® NT) was applied [Table/Fig-1g], evenly spread using a three-way air syringe, and polymerised with an Light-emitting Diode (LED) light curing unit for 10 sec (LEDition, IvoclarVivadent AG, Schaan/Liechtenstein). Then, composite resin (Tetric® N-Ceram) was placed using a cylindrical plastic mold 3 mm (diameter)x2 mm (height) to standardise the

bonded surface area. This ensured a consistent and uniform bonding area across all specimens for accurate bond strength testing [Table/Fig-1h,i]. Then cured for 20 sec at 3000 mW/cm². Salivary substitute was replenished for storage of every sample at 37°C in an incubator for one day. After this, the samples were subjected to 500 thermocycles in a thermocycling unit, cycling for 5°C and 55°C consequently.

Shear Bond Strength Evaluation

The bond strength of these samples was evaluated using universal testing machine at crosshead velocity of 1 mm per minute. The blade edge was positioned at the interface between the enamel surface and the resin material. Each specimen was subjected to stress until failure occurred, and the bond strength measurements in MPa were determined by dividing the force necessary to detach the resin composite by the bonded tooth-surface area of the sample (mm²) to calculate the MPa values for adhesive strength [Table/Fig-1j].



[Table/Fig-1]: a) Opalescence boost 40 bleaching gel was dispensed and applied to groups 2 and 3; (b) A 0.2% nanochitosan gel was applied to groups 3 and 5; (c) Biolase laser whitening gel was applied to groups 4 and 5 for 30 sec; (d) The Epic X Biolase unit was used with specific power settings; (e) The diode laser and its application were utilised for whitening; (f) Etching was done with 37% phosphoric acid; (g) A bonding agent was applied; (h) Incremental composite build-up was performed following the bonding protocol; (i) Curing was done using LED curing unit for 20 sec; (j) Shear strength evaluation was done using a universal testing device.

STATISTICAL ANALYSIS

The data were reviewed using IBM Statistical Packages of Social Sciences (SPSS) software version 23.0 (IBM SPSS, IBM Corp., Armonk, NY, USA). A one-way ANOVA was conducted for within the group analysis, followed by Tukey's post-hoc test for pair-wise comparison among the group. A student t-test was applied to correlate the group with antioxidant bonding to the group without antioxidant bonding. The limit for statistical significance was set as p-values <0.05.

RESULTS

The one-way ANOVA f-value indicated statistically significant variations in mean shear bond strength across the groups ($F=11.34$, $p=0.01<0.05$). Group 1 exhibited the highest mean shear bond strength (22.0 ± 0.73 MPa; 95% CI: 21.48-22.52), followed by Group 5 (21.1 ± 1.11 MPa; 95% CI: 20.31-21.89) and Group 4 (20.5 ± 1.13 MPa; 95% CI: 19.69-21.31), and Group 3 (19.9 ± 1.08 MPa; CI-19.13-20.67) while Group 2 showed the lowest mean value (19.3 ± 1.23 MPa; 95% CI: 18.42-20.18) [Table/Fig-2].

The pair-wise comparison from Tukey's post-hoc test revealed marked significant differences between Group 1 and all other groups. Specifically, Group 1 demonstrated a significantly higher bond strength compared to Groups 2, 3, 4, and 5 ($p=0.0001$, $p=0.0001$, $p=0.002$, and $p=0.004$, respectively). Statistically

Group	Mean±SD	Min	Max	p-value	95% CI
Group 1	22±0.73	18.6	25.1	0.01*	21.48-22.52
Group 2	19.3±1.23	17.8	24.3		18.42-20.18
Group 3	19.9±1.08	17.2	24.9		19.13-20.67
Group 4	20.5±1.13	18.1	23.4		19.69-21.31
Group 5	21.1±1.11	17.4	25		20.31-21.89

[Table/Fig-2]: A one-way ANOVA is used to assess the differences in mean shear bond strength in MPa across groups. One-way ANOVA test applied; f value- 11.34 p-value <0.05 considered statistically significant*

significant differences were also observed between Group 2 and Group 4 ($p=0.03$) and between Group 2 and Group 5 ($p=0.002$). However, no significant differences were found between Groups 2 and 3, 3 and 4, or 4 and 5, as the p-values for these comparisons were all greater than 0.05 [Table/Fig-3].

Group comparison	Mean difference	Standard error	p-value	
Group 1	Group 2	2.7	0.452	0.0001*
	Group 3	2.1	0.412	0.0001*
	Group 4	1.5	0.425	0.002*
	Group 5	0.9	0.420	0.004*
Group 2	Group 3	0.6	0.513	0.2615
	Group 4	1.2	0.528	0.03*
	Group 5	1.8	0.524	0.002*
Group 3	Group 4	0.6	0.524	0.245
	Group 5	1.2	0.490	0.024*
Group 4	Group 5	0.6	0.452	0.267

[Table/Fig-3]: Tukey's post-hoc test was conducted for pair-wise comparisons of shear bond strength (MPa) of composite resin to enamel following laser-assisted or chemical bleaching, with and without antioxidant application. Tukey's post-hoc test, Statistical significance is considered when p-value <0.05

In comparison, antioxidant-treated groups (Groups 3 and 5) with their respective non antioxidant counterparts (Groups 2 and 4), a slight increase in mean bond strength was observed in both chemical and laser-assisted bleaching protocols. Specifically, Group 3 showed higher values than Group 2, and Group 5 showed higher values than Group 4. However, these differences were not statistically significant ($p>0.05$), indicating that while chitosan nanoparticle application tended to improve immediate bond strength, the effect was not large enough to reach statistical significance within the present sample size [Table/Fig-4].

This demonstrates that, among the bleaching techniques, laser-assisted bleached enamel exhibited improved bond strength. Furthermore, laser-assisted bleached enamel with chitosan pretreatment showed a substantial improvement in immediate bonding to enamel. Although both antioxidant-treated groups demonstrated slightly higher bond strength than their respective non antioxidant groups that underwent delayed composite restoration after a two-week waiting period, these differences were not statistically significant ($p>0.05$).

DISCUSSION

The whitening mechanism of Hydrogen Peroxide (HP) occurs in three phases. First, hydrogen peroxide diffuses through the enamel and dentin, circulating within the tooth for up to two weeks. Second, hydrogen peroxide interacts with organic chromophores, creating free radicals that break down the chromophore chains, lightening the tooth color. In the third phase, changes in the tooth's surface reflect light differently, contributing to the perception of increased whiteness [16].

Like any procedure tooth whitening also has its drawbacks in a clinical setting. Despite the excellent results achieved with bleaching gels such carbamide peroxide and hydrogen peroxide, numerous

	Chemical bleaching (Group 2 and 3)			Laser bleaching (Group 4 and 5)			Mean Deviation (MD)	Standard error	p-value	t -value
	Mean±SD	Min	Max	Mean±SD	Min	Max				
Group	(Group 3)	17.6	24.2	(Group 5)	18.2	25.2	1.2	0.452	0.024*	2.65
	19.9±1.08			(Group 4)						
	(Group 2)	17.2	23.9	(Group 4)	18.4	24.8				
	19.3±1.23			20.5±1.13						
p-value	0.2615			0.267			-	-	-	-

[Table/Fig-4]: Comparison of shear bond strength between with antioxidant bonding and without antioxidant bonding for chemical and laser bleaching using student's test. Student's test, p- value <0.05 considered statistically significant*

studies have observed changes in surface properties, reduced micro-hardness, and lessened bond strength at the resin composite interface post bleaching [17,18].

The residual peroxide and oxygen free radicals gradually dissipate over time, eventually restoring the composite bond strength affected by bleaching process. The suggested waiting period for resin-bonded restorations after bleaching ranges from a 24 hrs to 3 weeks [6], which can be time-consuming for both professionals and patients. Therefore, antioxidant substances have been studied to expedite the process.

Consequently, to restore the post bleaching reduced bond strength, bleached surfaces were treated with antioxidants, as they neutralise the remaining free radicals, as also noted by Lai SCN et al., that the use of antioxidants can help reverse the damage caused by the presence of peroxide ions [19].

Chitosan is a large polysaccharide made up of repeated D-glucosamine units, which is produced through the deacetylation process of chitin sourced from the shells of marine crustaceans, especially crabs and shrimp. Being a natural, safe, biodegradable and biologically compatible, and, nanochitosan exhibits both antimicrobial and antioxidant characteristic [13].

The ongoing research was conducted to examine the immediate bond strength of composite restorations to enamel that had been pretreated with 0.2% nanochitosan, following both laser and non laser bleaching procedures.

In the current study, Group 1 had a statistically significant improvement in bond strength in comparison to test groups. The results of the study align with previous research, which indicated that the use of a bleaching agent reduced shear strength in all samples [20,21]. possibly due to the byproducts resulting from the breakdown of hydrogen peroxide, which are known to have a low molecular weight and can penetrate the enamel more easily. These free radicals may influence the polymerisation of resin composites and adhesive systems.

In the current study chemical bleaching i.e Group 2 and 3 showed reduced bond strength might due to Reactive Oxygen Species (ROS) interfere with resin penetration into bleached enamel and impede resin polymerisation [22-24], leading to the formation of bubble-like spheres along the resin-enamel interface ultimately weakening the bond strength between enamel and resin-based fillings [23,25,26].

In the current study, laser assisted bleaching Group 4 and Group 5 resulted in statistically significant higher shear bond strength compared to chemical bleaching Group 2 and 3 [Table/Fig-4]. This could be attributed to the faster removal of residual free oxygen radicals due to the temperature increase from laser use previously thought to be a key factor in the reduction of bond strength following bleaching. De Moor RJ et al., [27] and Dostalova T et al., [28] found that diode laser bleaching did not lead to morphological changes on the dental enamel surface. Mirhashemi AH et al., [22] it was suggested that bond strength could be restored in as little as one hour after investigating the effects of laser-enhanced bleached enamel at various time intervals.

However, the difference in hydrogen peroxide concentration (45% for laser bleaching, 40% for conventional) was due to the commercially available systems used. The present study compared manufacturer-recommended protocols rather than equalising concentrations. Although higher peroxide in the laser group could affect bleaching and bond strength, heat activation shortens exposure time and may offset this effect. Brand-specific formulation factors (pH, stabilisers, viscosity) may also influence outcomes and should be considered when interpreting results. According to Dostalova T et al., diode laser activation enhances the efficacy of bleaching even at slightly higher peroxide concentrations, without causing structural enamel damage. Additionally, Sultan MS and Elkorashy ME used 45% HP with diode laser and 40% for conventional chemical bleaching in their comparative study on antioxidant effects [5,28].

In the present study, no statistically significant difference was observed within Groups 2, 3, and Groups 4, 5 [Table/Fig-3]. This suggests the impact of bleaching substance is short termed, with enamel surface adhesiveness is often regained within two weeks. After this period, peroxide ions may break down and replace hydroxyl radicals, re-entering the apatite lattice and reversing the morphological alterations due to inclusion of peroxide ions [29]. These results align with previous studies, which demonstrated that immersing samples in artificial saliva or distilled water resulted in the restore of reduced enamel bond strength. Additionally, a two-week time interval prior applying resin composite bonding is suggested to produce a similar effect to the use of antioxidants [12,15,19,20].

Based on the findings of the present study, chitosan application on specimens subjected to both chemical and laser bleaching i.e, in Group 3 and Group 5 showed slight increase in bond strength. Therefore, the null hypothesis was rejected, confirming that nanochitosan had a significant positive effect on restoring bond strength after bleaching. The antioxidant activity of nanochitosan primarily depends on the presence of its hydroxyl (OH) and amino (NH₂) groups. However, because of chitosan's semi-crystalline structure and strong hydrogen bonding, it is challenging to separate these hydroxyl and amino group [12,15].

Furthermore, chitosan's effects can be attributed to two mechanisms: its antioxidant properties and its ability to promote remineralisation by preventing enamel demineralisation [30]. The antioxidant capacity of chitosan is directly related to its low molecular weight and viscosity. Chitosan helps prevent enamel demineralisation, reduces mineral loss, and maintains hydroxyapatite [15,31]. Chitosan increases hydrophilicity, reduces the contact angle of the fluid with the superficial enamel surface, and enhances wettability, leading to uniform distribution on the enamel surface [32].

However certain drawbacks such as Chitosan nanoparticles-potential limitations in clinical application include: Limited commercial availability of standardised dental-grade nanochitosan formulations. Possible variability in antioxidant efficacy due to differences in nanoparticle size, degree of deacetylation, and formulation pH. Need for additional chairside time for application and rinsing. Unknown long-term effects on enamel optical properties and surface integrity.

While the differences in mean shear bond strength between groups were statistically significant, the magnitude of difference (ranging from 0.6–2.7 MPa) may or may not be clinically perceptible, depending

on the restorative scenario. In most clinical settings, a minimal threshold of bond strength is required for restoration longevity, and all tested groups exceeded this threshold. Therefore, while laser-assisted bleaching with nanochitosan pretreatment produced higher immediate bond strength, the practical benefit must be weighed against factors such as cost, equipment availability, and patient comfort.

Future perspectives include determining the optimal concentration and application time of nanochitosan to maximise its clinical efficacy. Since this was a laboratory-based in-vitro design, assessing the long-term longevity of restorations was beyond its scope. Nevertheless, we acknowledge that clinical follow-up would provide valuable insights. It is recommend conducting longitudinal in-vivo studies to evaluate restoration performance over time, assess the potential impact on bleaching outcomes or staining, and compare different delivery forms to identify the most effective and user-friendly option.

In summary, within in the limitations of the study, chemical bleaching has an adverse impact on the strength of microshear bonds. The study results indicate that pretreating with 0.2% nanochitosan enhances the bond between composite resin and enamel immediately following laser-assisted bleaching, thereby eliminating the conventional two-week waiting period before restoration and mitigating this negative effect.

Limitation(s)

This laboratory-based in-vitro study evaluated only the immediate bond strength of composite resin to bleached enamel, without assessing delayed bonding or long-term clinical performance. Additionally, variations in hydrogen peroxide brand and concentration between bleaching techniques, as well as the absence of in-vivo conditions, may limit the direct applicability of the findings to clinical practice.

CONCLUSION(S)

Within the study's limitations, it was found that 0.2% chitosan nanoparticles have the potential to restore the bleached enamel bond strength. This suggests that chitosan nanoparticles could serve as an effective alternative to enhance the bonding of enamel especially weakened by the bleaching process. Furthermore, laser-assisted bleaching could facilitate immediate bonding procedures by being paired with a nanochitosan antioxidant. This approach could provide a more efficient solution for dental restorations, shortening the waiting time between bleaching and restorative procedures while also reducing the risk of dentinal hypersensitivity microleakage and crown fractures.

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