

Effect of IR Diode Laser, Photodynamic Therapy, and Erbium-doped Yttrium Aluminum Garnet Laser (Er:YAG)-Assisted Decontamination Techniques on the Adhesion of Lithium Disilicate Veneers to Tooth Surfaces

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Abstract

Purpose To evaluate the effect of different laser-assisted decontamination protocols on the retention of lithium disilicate veneers bonded to prepared tooth surfaces, as assessed by tensile bond strength (TBS).

Materials and Methods Forty extracted human maxillary incisors were prepared for lithium disilicate veneers and artificially contaminated with *Streptococcus mutans*. Specimens were randomly allocated into four groups (n = 10 per group) according to the decontamination protocol applied before cementation: Group 1 (control, alkaline water), Group 2 (808 nm diode laser), Group 3 (photodynamic therapy [PDT] using methylene blue activated by a 635 nm diode laser), and Group 4 (Er:YAG laser, 2940 nm). Veneers were cemented using a dual-cure resin cement according to the manufacturer's instructions. Tensile bond strength was evaluated using a pull-out test. Data were analyzed using one-way ANOVA followed by Tukey's post hoc test ($\alpha = 0.05$).

Results One-way ANOVA revealed significant differences in tensile bond strength among the groups ($P < 0.0001$). The Er:YAG laser group demonstrated the highest retention values, followed by the PDT group. In contrast, the diode laser and control groups exhibited significantly lower bond strength values and did not differ significantly from each other. A progressive increase in retention was observed from the control group to the Er:YAG laser group.

Conclusion Laser-assisted decontamination protocols significantly influenced the retention of lithium disilicate veneers. Er:YAG laser treatment prior to cementation resulted in the highest tensile bond strength, suggesting its potential to improve adhesive retention. Photodynamic therapy also enhanced retention compared with conventional decontamination, whereas diode laser irradiation showed limited effect.

Keywords: Lithium disilicate veneers; Tensile bond strength; Adhesive retention; Er:YAG laser; Photodynamic therapy; Surface decontamination.

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Indirect ceramic restorations have become an integral component of contemporary prosthodontic practice due to their ability to provide highly esthetic and conservative treatment options. The long-term clinical success of these restorations is largely dependent on achieving durable adhesion and adequate retention between the restoration and the dental substrate. Advances in adhesive dentistry have enabled minimally invasive restorative approaches that preserve tooth structure while maintaining favorable mechanical and esthetic outcomes (Warreth and Elkareimi 2020; Hardan et al. 2022). Among the clinical procedures involved in fixed prosthodontics, adhesive cementation plays a pivotal role in restoration longevity, as inadequate bonding may result in debonding, marginal leakage, secondary caries, and eventual restoration failure.

The retention of ceramic restorations is influenced by several factors, including the condition of the tooth surface at the time of cementation. Bacterial contamination, residual organic debris, and smear layer remnants may interfere with resin infiltration and hybrid layer formation, thereby compromising bond strength and adhesive performance (Chen and Wang 2010; Oliveira et al. 2019). Consequently, effective surface decontamination prior to adhesive cementation has become an important consideration in contemporary restorative and prosthodontic procedures.

Conventional cleaning and chemical disinfection methods may reduce microbial contamination; however, their ability to completely eliminate biofilm from prepared tooth surfaces

remains limited (Chen and Wang 2010; Cieplik et al. 2019). These limitations have encouraged the investigation of alternative decontamination approaches capable of providing both antimicrobial activity and beneficial surface modifications. Among these approaches, laser-assisted disinfection has gained increasing attention because of its ability to enhance microbial reduction while minimizing the use of chemical agents (Stájer et al. 2020).

Photodynamic therapy (PDT) is a minimally invasive antimicrobial technique that relies on the interaction between a photosensitizing agent, light of an appropriate wavelength, and molecular oxygen, resulting in the generation of reactive oxygen species capable of damaging microbial cells (Hamblin 2016; Stájer et al. 2020). Several studies have demonstrated the effectiveness of PDT against cariogenic microorganisms, particularly *Streptococcus mutans*, in both planktonic and biofilm forms (Nemezio et al. 2017; Misba et al. 2018; Garcia et al. 2018). Despite its established antimicrobial efficacy, the influence of PDT on adhesive bonding procedures remains controversial. Previous investigations conducted in endodontic and orthodontic applications have reported inconsistent effects on bond strength, ranging from neutral to adverse outcomes depending on the substrate and clinical protocol employed (Ramos et al. 2018a; Ramos et al. 2018b; Shuwaish 2020; Mirhashemi et al. 2021).

Another factor affecting adhesive performance is the smear layer generated during tooth preparation. This layer may obstruct resin penetration and reduce the effectiveness of adhesive systems if not adequately removed (Breschi et al. 2018; Hardan et al. 2022). Although phosphoric acid etching remains the conventional method for surface conditioning, concerns have been raised regarding its potential effects on dentin collagen integrity and long-term bond durability (Mazzoni et al. 2015). Therefore, laser surface treatment has been proposed as a promising alternative or adjunctive conditioning approach capable of improving surface characteristics while simultaneously providing antimicrobial benefits (Alagl et al. 2019).

Lithium disilicate glass-ceramics are widely used for laminate veneers because of their favorable optical properties, biocompatibility, and high mechanical strength, which allow for conservative tooth preparation designs (Silva et al. 2017; Warreth and Elkareimi 2020). The clinical success of lithium disilicate veneers is strongly associated with adhesive cementation, which enhances retention, marginal adaptation, and fracture resistance (Kara and Ozturk 2017). However, adhesion to enamel remains structurally superior to dentin bonding, emphasizing the clinical importance of surface quality and pretreatment protocols (Nada et al. 2016).

Although laser technologies are increasingly incorporated into dental practice, evidence regarding their effect on the retention of lithium disilicate veneers remains limited. Therefore, the present study aimed to evaluate and compare the effects of infrared diode laser irradiation, photodynamic therapy, and Er:YAG laser-assisted decontamination on the tensile bond strength of lithium disilicate veneers bonded to tooth surfaces. The null hypothesis was that the different decontamination protocols would not significantly affect veneer retention.

Methods

Study Ethics and Sample size calculation

All procedures performed in this study were conducted in accordance with the ethical standards of the institutional research committee and the principles of the Declaration of Helsinki. The study protocol was approved by the Ethics Review Committee (Human Research) of the National Institute of Laser Enhanced Sciences (NILES), Cairo University, Egypt (Approval No. NILES-EC-CU 26/04/14(In)). The sample size was calculated based on the results of a previous study by Gomes et al. (2018). Using a continuous response variable from independent groups, a standard deviation of 1.09 and an expected mean difference of 1.836 were considered. A minimum sample size of seven specimens per group was required to achieve a statistical power of 80% at a significance level of 5% ($\alpha = 0.05$). To compensate for potential specimen loss or failure during experimental processing, the sample size was increased to 10 specimens per group. Therefore, a total of 40 specimens were included in the final analysis.

Teeth preparation

A total of 40 extracted intact human maxillary incisors were collected from outpatient dental clinics. All teeth were prepared to receive labial veneers. Tooth preparation was performed using a tapered diamond bur mounted on a high-speed handpiece under continuous water cooling, following a standardized preparation and finishing protocol (Tisler et al. 2022).

Bacterial Contamination of Prepared Dental Surfaces

A standard strain of *Streptococcus mutans* (ATCC 25175) was obtained as a lyophilized vial from the Microbiological Resources Centre (MIRCEN, Cairo, Egypt). To rehydrate the strain, 2 mL of Brain Heart Infusion (BHI) broth (Difco, Detroit, MI, USA) was added. The resulting microbial suspension was then transferred to a Blood Agar culture medium (Merck, Germany). Following 48 hours of incubation at 37°C, the microbial concentration was adjusted to 1.5×10^8 CFU/mL, equivalent to a 0.5 McFarland standard, utilizing a spectrophotometric method at OD_{600nm} (Spectrophotometer DU 730 Life Science, Beckman Coulter, California, USA) (Robati et al. 2022).

Microbial Contamination Protocol

Following incubation, the adjusted bacterial suspension was used as the inoculum for 40 tubes containing BHI broth. A volume of 500 µL of the bacterial suspension (0.5 McFarland standard) was added to each tube. Each prepared tooth was aseptically transferred into an individual tube. All tubes were then incubated anaerobically for 72 hours at 37°C in a 5% CO₂ atmosphere using a shaking incubator (Shaking Mixer SHM-101, AGC Techno Glass Co., Ltd., Shizuoka, Japan) to facilitate biofilm formation (Tisler et al. 2022).

Fabrication of Lithium Disilicate Ceramic Veneers

Impressions of all prepared teeth were obtained using a polyvinyl siloxane impression material (PVS) with a one-step double-mix technique. Type IV dental stone was poured into the impressions to produce master casts, on which standardized veneer wax patterns were fabricated. Following wax-up completion, a prefabricated wax rod was attached to the labial surface of each pattern parallel to the path of insertion. This rod was incorporated into the final restoration design to facilitate subsequent tensile bond strength testing. The veneers were fabricated from lithium disilicate glass-ceramic ingots (IPS e.max Press, Ivoclar Vivadent, Schaan, Liechtenstein) using the heat-pressing technique according to the manufacturer's instructions. After divestment and finishing procedures, the restorations were inspected for defects and dimensional accuracy. To avoid potential alterations in the bonding interface and to allow standardized tensile testing, the restorations were not glazed. The integrated ceramic rods were preserved as part of the monolithic veneer structure throughout the experimental procedures (Al-Dwairi et al. 2022).

Specimen Grouping and Laser Treatment Protocols The contaminated teeth were randomly allocated into four experimental groups (n = 10 per group)

Group 1 (Control Group): The contaminated tooth surfaces were treated with alkaline water only (Hardan et al. 2022).

Group 2 (Diode Laser Group): The contaminated tooth surfaces were treated using an infrared (IR) diode laser (Lasercat 500, Medsolution, Radolfzell, Germany) at a wavelength of 808 nm. The laser was applied in contact mode with the fiber tip positioned 0.5 mm from the surface at a single point, followed by uniform, sequential scanning movements across the entire surface. The total irradiation time was 60 seconds per tooth surface (Alagil et al. 2019).

Group 3 (Photodynamic Therapy Group): The contaminated tooth surfaces were immersed in 3 mL of methylene blue (MB) dye solution (Sigma-Aldrich, St. Louis, MO, USA) at a concentration of 1 mg/mL for 60 seconds of pre-irradiation time. Afterward, the teeth were thoroughly rinsed with

phosphate-buffered saline (PBS) solution (Product No. P3813, pH 7.4, Sigma-Aldrich, St. Louis, MO, USA) to remove excess photosensitizer. The surfaces were then irradiated with a 635 nm diode laser (FotoSan, CMS Dental APS, Copenhagen, Denmark) at an output power of 200 mW for 60 seconds. The laser tip was held at a fixed distance of 1 mm from the specimen surface, covering a spot area of 0.502 0.502 cm² (Eldwakhly et al. 2020).

Group 4 (Er:YAG Laser Group): The contaminated tooth surfaces were treated using an Er:YAG laser system (ONYX-multiwave laser device, Eisenstadt, Austria). The device emitted pulses at a wavelength of 2,940 nm, operating at a frequency range of 5–10 Hz with a maximum output power of 3.0 W. Er:YAG lasers have a high affinity for water and hydroxyapatite, allowing effective surface decontamination and smear layer removal with minimal thermal damage to dental hard tissues (Mancini et al. 2025)

Veneer Cementation

Following the respective decontamination protocols, cementation was performed for all specimens using Breeze™ dual-cure resin cement (Pentron Clinical Technologies, LLC, USA) according to the manufacturer's instructions.

Monobond Etch & Prime (Ivoclar Vivadent, Liechtenstein; self-etching glass-ceramic primer) was applied with a microbrush onto the internal surfaces of the ceramic restorations for 60 seconds, followed by strong oil-free air-drying. The prepared tooth surfaces were etched using a 37% phosphoric acid gel for 15–30 seconds, rinsed thoroughly with a water spray, and dried until the etched enamel exhibited a chalky white appearance. Prime&Bond Universal (Dentsply DeTrey GmbH, Germany) was then applied to the tooth surfaces for 20 seconds, dispersed with a gentle stream of compressed air, and light-curing was performed for 10 seconds.

Following the assigned surface decontamination protocols, veneer cementation was performed according to the manufacturer's instructions. The internal surfaces of the lithium disilicate veneers were conditioned using a self-etching ceramic primer, followed by adhesive treatment of the prepared tooth surfaces. Breeze™ dual-cure resin cement (Pentron Clinical Technologies, USA) was dispensed directly onto the intaglio surfaces of the veneers using an automix tip. The restorations were seated under standardized finger pressure, and excess cement was carefully removed. Light polymerization was performed for 20 s per surface using an LED curing unit positioned approximately 10–15 mm from the restoration margins. Following complete polymerization, residual cement was removed and the margins were polished to obtain a smooth restoration-tooth interface (Aldahlawi et al. 2024; Demirel et al. 2023)

Tensile bond assessment

Tensile bond strength was evaluated using a pull-out test, a method previously used for assessing the retention of adhesively luted indirect restorations (Stawarczyk et al. 2012; Tisler et al. 2022). Each specimen assembly was secured by embedding both ends—the roots of the teeth and the structural ceramic rods of the veneers—into self-curing acrylic resin blocks, leaving the anatomical crown and the cementation margins completely clear of the acrylic matrix. After polymerization of the embedding resin, the assemblies were stored in artificial saliva at 37°C for 24 hours. Pull-out testing was performed using a universal testing machine at a crosshead speed of 0.5 mm/min until debonding occurred. The maximum load at failure was recorded in Newtons (N) and converted to Megapascals (MPa).

Statistical Analysis

Data were tabulated and analyzed using Microsoft Excel® 2016 (Microsoft Corp., Redmond, WA, USA), SPSS® version 24 (IBM Corp., Armonk, NY, USA), and Minitab® version 16 (Minitab LLC, State College, PA, USA). One-way analysis of variance (ANOVA) was executed to compare the mean tensile bond strengths among the four experimental groups. Pairwise multiple comparisons were performed using Tukey's honest significant difference (HSD) post hoc test. The level of statistical significance was established at $P < 0.05$.

Results

Tensile bond strength values revealed distinct differences among the four experimental groups (Table 1, Fig. 1). Group 4 (Er:YAG laser) demonstrated the highest mean bond strength (458.0 ± 45.8 MPa), with individual values ranging from 419.0 to 545.3 MPa, indicating superior adhesive performance. Group 3 (PDT) ranked second with a mean tensile bond strength of 288.0 ± 43.2 MPa, followed by Group 2 (Diode laser), which recorded a mean value of 195.0 ± 39.0 MPa. Group 1 (Control) exhibited the lowest bonding capacity, with a mean tensile bond strength of 151.5 ± 37.88 MPa (range: 90.45 to 214.5 MPa).

Overall, tensile bond strength values increased progressively from Group 1 through Group 4. Standard deviations across all groups were statistically homogeneous, indicating consistent experimental reproducibility within each group.

Table 1: Descriptive statistics of tensile bond strength (MPa) across groups

Metric	Group 1 (Control)	Group 2 (Diode)	Group 3 (PDT)	Group 4 (Er:YAG)
Minimum	90.45	134.50	237.20	419.00
Maximum	214.50	244.60	355.80	545.30

Mean (M)	151.50	195.00	288.00	458.00
Standard Deviation (SD)	37.88	39.00	43.20	45.80
Standard Error (SEM)	12.63	13.00	14.40	15.27

Note: Min = Minimum, Max = Maximum, M = Mean, SD = Standard Deviation, SEM = Standard Error of Mean.

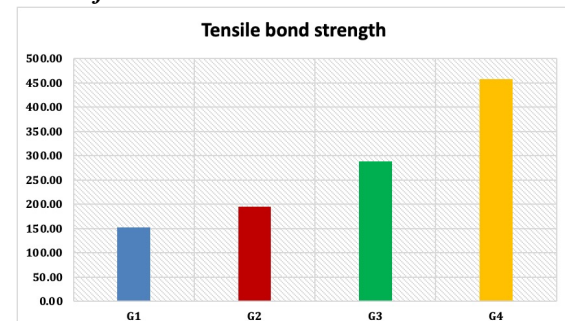


Figure 1: Bar chart displaying the mean tensile bond strength (MPa) with standard error bars across the four experimental groups

The one-way ANOVA summary for tensile bond strength is presented in Table 2. The analysis revealed a highly significant variance among the group means ($F = 95.89$, $P < 0.0001$), establishing that the differences in tensile bond strength among the surface treatments were statistically significant. The coefficient of determination ($R^2 = 0.899$) indicates that approximately 89.9% of the total variability in tensile bond strength can be directly attributed to the surface decontamination protocols, denoting a strong experimental effect size.

Table 2: One-way ANOVA summary of tensile bond strength

ANOVA Parameter	Value
F-statistic	95.89
P-value	< 0.0001
Significant differences among means ($P < 0.05$)?	Yes
R-squared (R^2)	0.899

Tukey's post hoc multiple comparison analysis is summarized in Table 3. No statistically significant difference was observed between Group 1 (Control) and Group 2 (Diode laser) ($MD = -43.50$, 95% CI: -96.62 to 9.63 , $P = 0.1399$). In contrast, Group 1 displayed significantly lower tensile bond strength compared to Group 3 (PDT) and Group 4 (Er:YAG), with mean differences of -136.50 and -306.50 , respectively ($P < 0.0001$). Similarly, Group 2 exhibited significantly lower bond values than

Group 3 (MD = -92.96, $P = 0.0002$) and Group 4 (MD = -263.00, $P < 0.0001$).

Table (3): Tukey's post hoc multiple comparison analysis for tensile bond strength

Tukey's multiple comparisons test	MD	95.00 % CI of diff.	Significant?	P Value
Group 1 vs. Group 2	-43.50	-96.62 to 9.627	No	0.1399
Group 1 vs. Group 3	-136.5	-189.6 to -83.33	Yes	<0.0001
Group 1 vs. Group 4	-306.5	-359.6 to -253.4	Yes	<0.0001
Group 2 vs. Group 3	-92.96	-146.1 to -39.84	Yes	0.0002
Group 2 vs. Group 4	-263.0	-316.1 to -209.9	Yes	<0.0001
Group 3 vs. Group 4	-170.0	-223.2 to -116.9	Yes	<0.0001

A highly significant difference was confirmed between Group 3 and Group 4 (MD = -170.0, 95% CI: -223.2 to -116.9, $p < 0.0001$), confirming the superior bonding outcome of the Er:YAG laser intervention. Overall, the post hoc analysis confirms a progressive and statistically significant increase in tensile bond strength from Group 1 to Group 4, with Group 4 demonstrating the highest bond strength, followed by Group 3, while Groups 1 and 2 showed the lowest and statistically comparable values.

Discussion

The present study evaluated the influence of different laser-assisted decontamination protocols on the tensile bond strength of lithium disilicate veneers bonded to tooth surfaces. Tensile bond strength testing was selected because it provides a reliable in vitro assessment of the retention and resistance to dislodgement of adhesively luted indirect restorations (Tisler et al. 2022). The results demonstrated that the decontamination protocol applied prior to cementation significantly affected veneer retention, highlighting the importance of substrate condition and surface cleanliness in

achieving durable adhesive bonding (Hardan et al. 2022).

Among the tested protocols, Er:YAG laser treatment produced the highest tensile bond strength values. This finding may be attributed to the high absorption of the 2940 nm wavelength by water and hydroxyapatite, which enables effective removal of the smear layer and modification of the dental surface without causing excessive thermal damage (Alagl et al. 2019; Kasakawa et al. 2022). Previous studies have shown that smear layer removal improves resin infiltration and promotes more effective micromechanical interlocking between adhesive systems and dental tissues (Tjäderhane 2015). In addition, laser-induced surface roughening may increase surface energy and wettability, thereby enhancing adhesive interaction with the tooth substrate (Hardan et al. 2022). These factors collectively may explain the superior retention observed in the Er:YAG group.

Photodynamic therapy demonstrated significantly higher tensile bond strength than both the control and diode laser groups. This finding may be related to the well-documented antimicrobial efficacy of methylene blue-mediated photodynamic therapy against *Streptococcus mutans* biofilms (Nemezio et al. 2017; Misba et al. 2018; Garcia et al. 2018). Effective elimination of bacterial contamination before cementation may improve the quality of the adhesive interface by reducing the presence of organic residues that interfere with resin penetration and hybrid layer formation (Oliveira et al. 2019). Furthermore, unlike conventional laser irradiation, photodynamic therapy exerts its antimicrobial effect through reactive oxygen species generation without causing significant thermal alterations to the dental substrate (Hamblin 2016; Stájer et al. 2020). These characteristics may contribute to the improved bond strength observed in the present study.

The findings obtained for photodynamic therapy are consistent with those reported by Tisler et al. (2022), who demonstrated that photodynamic disinfection of tooth surfaces contaminated with *S. mutans* improved the adhesion of ceramic restorations. However, previous investigations evaluating photodynamic therapy in endodontic and orthodontic applications have reported conflicting results, ranging from no significant effect to a reduction in bond strength (Ramos et al. 2018a; Sahyon et al. 2018; Mirhashemi et al. 2021). Such discrepancies may be explained by differences in substrate characteristics, adhesive systems, photosensitizers, irradiation parameters, and testing methodologies.

In contrast, 808 nm diode laser irradiation did not produce a statistically significant improvement in tensile bond strength compared with the control group. This outcome may be explained by the limited interaction of near-infrared

diode lasers with enamel and dentin, as these tissues exhibit relatively low absorption at this wavelength (Stájer et al. 2020). Consequently, diode laser irradiation may provide antimicrobial effects without substantially modifying the smear layer or surface morphology required to enhance adhesive bonding. Additionally, excessive localized heat generation may adversely affect the organic components of dentin and potentially interfere with resin infiltration (Alagl et al. 2019).

The control group exhibited the lowest tensile bond strength values, suggesting that cleaning with alkaline water alone was insufficient to optimize the bonding substrate. Previous studies have demonstrated that residual biofilm and smear layer remnants can compromise adhesive performance by limiting resin penetration and reducing the quality of the adhesive interface (Oliveira et al. 2019; Hardan et al. 2022). The present findings support the concept that effective decontamination prior to adhesive cementation is an important factor for improving restoration retention.

Lithium disilicate veneers depend primarily on adhesive bonding for long-term clinical success because of their minimally invasive preparation design and limited macromechanical retention. Recent evidence has emphasized that the durability of these restorations is strongly influenced by the quality of the bonding substrate and the effectiveness of surface pretreatment procedures prior to cementation (Makhija et al. 2024; Güth and Edelhoff 2025). Therefore, decontamination protocols that optimize the enamel and dentin surface without adversely affecting adhesive interactions may contribute to improved restoration longevity and clinical predictability.

In the present study, laser-assisted decontamination significantly influenced the retention of lithium disilicate veneers. The superior performance observed with Er:YAG laser treatment may be attributed to its ability to effectively decontaminate the tooth surface while promoting favorable microstructural changes that enhance resin infiltration and micromechanical retention. Photodynamic therapy also demonstrated a positive effect on retention, whereas diode laser irradiation produced no significant improvement compared with conventional cleaning procedures.

The findings of this study should be interpreted within the limitations of its *in vitro* design. The experimental conditions could not fully reproduce the complex biological, thermal, chemical, and mechanical challenges encountered in the oral environment. Furthermore, only a single bacterial species (*Streptococcus mutans*), one adhesive system, and one resin cement were evaluated. The specimens were tested after a short storage period without thermocycling, fatigue loading, or long-term aging procedures, which may influence the durability of adhesive interfaces.

Future investigations should incorporate multispecies biofilm models, different adhesive strategies, artificial aging protocols, and long-term clinical trials to better validate the effectiveness of laser-assisted decontamination techniques under clinically relevant conditions.

Conclusion

Within the limitations of this *in vitro* study, laser-assisted decontamination protocols significantly affected the tensile bond strength of lithium disilicate veneers. Er:YAG laser treatment produced the highest bond strength values, followed by photodynamic therapy, whereas 808 nm diode laser irradiation showed no significant improvement compared with the control group. These findings suggest that Er:YAG laser-assisted decontamination may enhance adhesive retention of lithium disilicate veneers; however, further *in vivo* and long-term clinical studies are required to confirm its clinical effectiveness.

List of abbreviations

- **ANOVA:** Analysis of Variance
- **ATCC:** American Type Culture Collection
- **BHI:** Brain Heart Infusion
- **CFU:** Colony Forming Units
- **CI:** Confidence Interval
- **Er:YAG:** Erbium-doped Yttrium Aluminum Garnet
- **IR:** Infrared
- **MB:** Methylene Blue
- **MD:** Mean Difference
- **MIRCEN:** Microbiological Resources Centre
- **NILES:** National Institute of Laser Enhanced Sciences
- **OD:** Optical Density
- **PBS:** Phosphate Buffered Saline
- **PDT:** Photodynamic Therapy
- **ROS:** Reactive Oxygen Species
- **SD:** Standard Deviation
- **SEM:** Standard Error of Mean
- **TBS:** Tensile Bond Strength

Declarations

Ethics Approval and Consent to Participate

All experimental procedures were performed in strict compliance with the ethical regulations of the institutional review boards and the guidelines specified in the Declaration of Helsinki. The study protocol was reviewed and formally approved by the Ethics Review Committee (Human Research) of the National Institute of Laser Enhanced Sciences (NILES), Cairo University, Egypt (Reference Number: NILES-EC-CU 26/04/14(In)).

Consent to Publish declaration: not applicable.

Availability of data and material

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing Interests

The authors declare that they have no conflicts of interest regarding the publication of this research article.

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Authors' Contributions

HE and HAA conceptualized the study. MoR and AZ planned the experimental design. RS and HAA conducted the laboratory experiments and performed the statistical data analysis. HE, HAA, and MaR drafted and structured the manuscript. All authors read, reviewed, and approved the final manuscript and assume mutual accountability for the integrity of the presented work.

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