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Comparative evaluation of shear bond strength of metallic orthodontic brackets bonded to enamel prepared with Laser etching and conventional etching after bleaching: An in Vitro Study

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Abstract

Objectives: *Comparing effect of Er:YAG (Erbium:Yttrium–Aluminum–Garnet) laser versus typical phosphoric acid etching on the shear bond strength of orthodontic brackets after office bleaching.*

Materials & Methods: *Eighty freshly extracted premolars were randomly divided into four groups (n=20) as follows; Group I: conventional acid etching, Group II: Er:YAG laser etching. Group III: bleaching followed by conventional etching, while Group IV: bleaching followed by laser etching. The brackets were bonded to the enamel surfaces, and Shear Bond Strength (SBS) was measured using a universal testing machine. Adhesive remnant index (ARI) scores were determined after debonding under a stereomicroscope. Statistical analysis was performed using the t-test and ANOVA, with significance set at $p < 0.05$.*

Results: *The bleaching/laser etching group exhibited significantly higher SBS (mean 18.08 MPa) compared to the bleaching/acid etching group (mean 4.15 MPa), indicating superior bonding performance with laser etching. No significant difference was observed between the laser etching group (mean 16.13 MPa) and the conventional etching group (mean 18.54 MPa).*

Conclusion: *Laser conditioning significantly improves SBS in orthodontic brackets applied after bleaching compared to conventional acid etching. Both laser and conventional etching are effective methods, but laser conditioning offers additional benefits for bonding post-bleaching.*

Keywords:
Shear bond strength, laser etching, orthodontic brackets, bleaching, phosphoric acid etching, Er:YAG laser.

Introduction

Nowadays, enamel bleaching has become a popular cosmetic procedure, in the dental practice and many patients who undergo tooth bleaching seek subsequent orthodontic treatment.

But the effects of bleaching on orthodontic bonding have raised concerns. Bleaching agents, commonly composed of hydrogen peroxide or carbamide peroxide, are widely used in aesthetic dentistry to enhance tooth whiteness. However, bleaching has been shown to reduce the SBS of orthodontic brackets [1, 2], likely due to alterations in the enamel's organic matrix and the formation of residual oxygen as a by-products that interfere with

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adhesive polymerization [3-6]. Achieving optimum SBS is crucial for resisting the forces exerted by the orthodontic appliance and the ones present during daily activities such as mastication and speech This poses a challenge for achieving clinically acceptable orthodontic bracket bond strength. Consequently, clinicians are often challenged with finding suitable methods to bond orthodontic brackets immediately after bleaching.

Conventional bonding protocols typically utilize 37% phosphoric acid etching to produce micro-retentive patterns on the enamel, thereby enhancing the mechanical interlocking of orthodontic adhesives and increasing SBS. [7] However, acid etching is not without limitations, such as the potential for over-etching, which can lead to enamel weakening and increased post-operative sensitivity, prompting researches are ongoing to find alternative etching methodologies. Recent advancements in laser technology have identified Er:YAG lasers as a promising alternative for enamel etching.

Operating at a wavelength of 2940 nm, Er:YAG lasers specifically target water and hydroxyapatite, inducing micro-explosions that generate an irregular surface topography akin to that produced by acid etching. This laser-based approach has been proposed to offer several advantages, including enhanced control over etching depth, reduced patient discomfort, and a diminished risk of over-etching when compared to traditional phosphoric acid etching methods [8].

Researches have also shown that Er:YAG lasers induce a lesser reduction in calcium levels compared to traditional acid etching with decreasesed the carbon-to-phosphate ratio, which may reduce susceptibility to tooth sensitivity and acid-induced demineralization. Furthermore, laser technology has been proposed as a means to neutralize free radicals and enhance bond strength in teeth that have undergone bleaching procedures. However, the effectiveness of laser etching on shear bond strength (SBS), particularly when combined with bleaching treatments, remains an area of ongoing investigation [9, 10].

Since, the Er:YAG laser, in particular, has been found to produce a more uniform etching depth, reducing the risk of enamel over-etching while improving bond strength with orthodontic adhesives [11], it has been used as etching agent.

Many studies comparing Er:YAG laser etching with conventional acid etching post-bleaching, have reported conflicting results, with some demonstrating superior bond strength for laser-etched surfaces and others showing no significant difference [12-14].

Recent studies have highlighted the advantages of laser etching over conventional acid etching, especially in post-bleaching scenarios. Research has shown that Er:YAG laser etching significantly improves shear bond strength (SBS) compared to traditional etching techniques after bleaching. In particular, laser etching has been found to mitigate the reduction in bond strength typically observed with conventional etching after bleaching. Additionally, laser-treated enamel retains more adhesive during debonding, offering better enamel protection. The rougher and more uniform surface created by laser etching enhances bonding potential, and it has been demonstrated to counteract the adverse effects of bleaching on SBS. These findings emphasize the clinical potential of laser etching in orthodontic bonding applications.

In addition to bond strength, the adhesive remnant index (ARI) is often used to assess the quality of bonding and debonding in orthodontic treatments. ARI scores provide insight into where bond failures occur (i.e., at the bracket-adhesive interface or the adhesive-enamel interface), which is crucial for determining the clinical performance of bonding methods [15, 16]. Studies have shown that laser-etched enamel surfaces tend to result in lower ARI scores, indicating more adhesive retention on the enamel surface, which may reduce the risk of enamel damage during debonding. However, more research is needed to fully understand the clinical implications of these findings.

Materials and Methods

The sample size estimation was conducted using Power and Sample Size Calculation software (Epi-Info 7, Atlanta, GA, USA), targeting a significance level (α) of 0.05 and a statistical power of 0.95. Based on these parameters, the calculated minimum required sample size was determined to be 80 premolar teeth, ensuring sufficient power to detect significant differences across experimental groups.

Ethical approval for the study was obtained from the Ethics Committee of the Faculty of Dentistry, KafrelSheikh University, Egypt (IRB:KFSIRB200-405). A total of 80 sound human premolars, freshly extracted for orthodontic purposes, were collected. Teeth presenting with visible cracks or signs of decalcification were excluded to ensure the integrity of the sample. Following extraction, the teeth were initially cleansed under running tap water, subjected to pumicing, and subsequently stored in a saline solution (0.9% NaCl) until collecting the required sample size.

Prior to experimental procedures, each tooth was assigned a unique identification number (1 to 80) and were embedded in acrylic blocks to facilitate handling and ensure stability during testing, Fig.1. They were stored in labeled containers filled with artificial saliva composed of 20 mmol/L $NaHCO_3$, 3 mmol/L NaH_2PO_4, and 1 mmol/L $CaCl_2$, at a pH of 7.0. The artificial saliva, prepared at the Faculty of Pharmacy, Alexandria University, was changed daily to simulate dynamic oral conditions. Storage in artificial saliva throughout the study was deemed more consistent and appropriate for mimicking in vivo conditions compared to an initial saline storage phase [17].

The specimens were randomly and equally allocated into one of the four groups, 20 per group, ensuring unbiased distribution across the treatment conditions. The groups were defined as follows:

- **Group A (Control Group)**: Teeth underwent conventional etching using 37% phosphoric acid before bonding, serving as the control for comparison.
- **Group B**: Teeth were treated with Er-YAG laser etching before the bonding procedure.

- **Group C**: Teeth were subjected to bleaching, followed by a 24-hour immersion in artificial saliva, after which conventional acid etching was performed prior to bonding.
- **Group D**: Teeth were subjected to bleaching, followed by a 24-hour immersion in artificial saliva, after which laser etching was performed for the facial surface prior to bonding.

Figure.1. Specimen fabrication in blocks.

Conventional Acid Etching group (Group A)

The labial surfaces of the Group (A) specimens were prepared by applying a 37% phosphoric acid gel for 15 seconds to etch the enamel. The etching was confined to the designated bonding area, centrally positioned on the tooth surface both occlusocervically and buccolingually. After the acid application, the teeth were thoroughly rinsed with water to remove residual etchant and subsequently air-dried using oil-free, moisture-free compressed air until a characteristic dull, frosty appearance was observed on the enamel surface. Following the etching procedure, a bonding agent (Transbond) was applied uniformly to the conditioned enamel using an applicator tip in accordance with the manufacturer's guidelines. Stainless steel premolar brackets (Gemini, 3M Unitek, Monrovia, CA, USA with 0.022-inch slot), with a mesh base surface area of 9.806 mm^2) were then positioned on the enamel. A uniform layer of adhesive resin (Transbond XT, 3M Unitek) was applied to the etched surfaces to ensure optimal bonding. The brackets were placed in their final positions and pressed onto the enamel with a standardized force of 300 g, verified using a dynamometer. Excess adhesive was meticulously removed from the periphery of the bracket base to prevent interference, then, light cured for 40 seconds per bracket to ensure adequate polymerization.

Laser etching group (Group B)

The enamel surfaces were irradiated using an Er-laser operating at a wavelength of 2940 nm (Fotona, Slovenia, EU), equipped with an H14 handpiece and a cylindrical sapphire tip (1 mm diameter, 8 mm length). The laser was configured to operate in quantum-square-pulse (QSP) mode, delivering energy settings of 120 mJ, 1.2 W, at a frequency of 10 Hz, Fig.2. To ensure optimal etching conditions, the laser was used with concurrent air and water cooling. The handpiece was positioned perpendicularly to the buccal surface of each tooth, maintaining a distance of 1 mm from the enamel surface. The laser treatment was conducted by scanning the area intended for bonding with horizontal movements for a duration of 10 seconds, ensuring uniform exposure and etching under the air-water spray. Following laser etching, the same bonding agent and adhesive resin were applied in the same manner of control group. [18, 19]

Both conventional and Laser groups were stored in artificial saliva at ambient temperature for a period of 24 hours to simulate oral conditions before further testing

Figure.2. Laser etching of the specimens

Bleaching of Group C and D

The 35% hydrogen peroxide gel (*Beyond Solo* single treatment kit) was mixed according to manufacturer's instructions. The gel was applied to the buccal surface of the samples of groups C & D (about 1mm thickness of bleaching gel was applied for each tooth) and 5 teeth were bleached per session, Fig.3. Activation of the bleaching gel was made with LED curing unit (Roson, China) for 15 minutes, Fig.4. After each bleaching session, the teeth were washed thoroughly with air-water syringe then immersed in artificial saliva for 24 hours to be ready for the next step of the experiment.

Figure.3. (a) Bleaching kit, (b) Bleaching gel application on the specimen

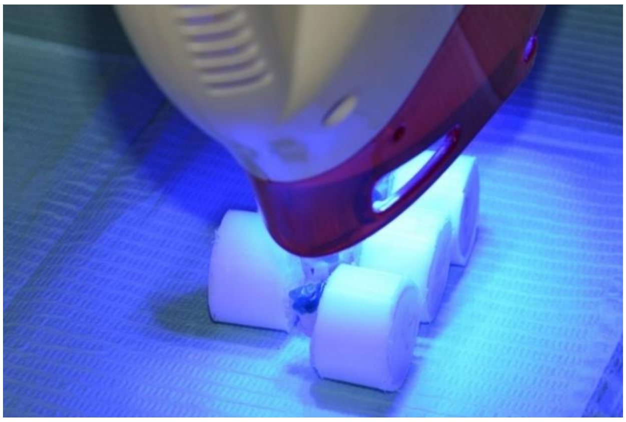

Figure.4. Blue LED light during bleaching process being applied to dental specimens.

After 24 hours storage in artificial saliva, specimens in group C were etched using the conventional acid etching technique, while specimens in group D were etched using Er-YAG laser etching. Bonding procedures were done for both groups (C and D) in the same manner with the same materials as in group A and B.

Shear Bond Strength Testing

The shear bond strength (SBS) evaluation was performed utilizing a Universal Testing Machine (Biomaterial Department, Faculty of Dentistry, Alexandria University) equipped with a chisel-edged attachment, positioned on the crosshead, Fig.5. The machine applied a unidirectional load along the longitudinal axis of the tooth, specifically targeting the bracket-enamel interface. The loading rate was maintained at a constant crosshead speed of 1 mm/min to ensure standardized testing conditions.

The force required to debond each specimen was recorded in Newtons (N), and the SBS was calculated by converting this force to Megapascals (MPa). The conversion involved dividing the recorded shear force (N) by the cross-sectional area of the bracket base (mm^2), using the formula:

$$\text{SBS (MPa)} = \frac{\text{Shear Force (N)}}{\textit{Cross sectional area}\ (mm^2)}$$

This calculation provided a quantifiable measure of bond strength, allowing for comparisons across different etching and treatment groups.

The adhesive remnant index (ARI)

Following debonding procedure of all the specimens, the Adhesive Remnant Index (ARI) was assessed by examining each specimen under stereomicroscopic magnifications of 25X and 50X (Olympus SZ-CTV, Japan) to accurately evaluate the residual adhesive on the enamel surface and to identify the bond failure mode, whether the adhesive failure occurred predominantly at the bracket-adhesive interface, within the adhesive itself, or at the adhesive-enamel interface, providing insights into the bonding performance and integrity [19]. The ARI scoring system, ranging from 0 to 4, was employed to categorize the extent of adhesive remnants: a score of 0 indicated no adhesive residue on the tooth surface, a score of 1 signified that less than 50% of the bonding site retained adhesive, a score of 2 denoted more than 50% adhesive coverage, a score of 3 indicated complete adhesive coverage across the bonding site with a clear impression of the bracket base on the remaining adhesive layer and a score of 4 indicated thesame as score 3 but accompanied by enamel fracture. [20]

For intraexaminer reliability, all specimens were scored again by the same examiner after two week. No difference was found between the scores in the first and second time.

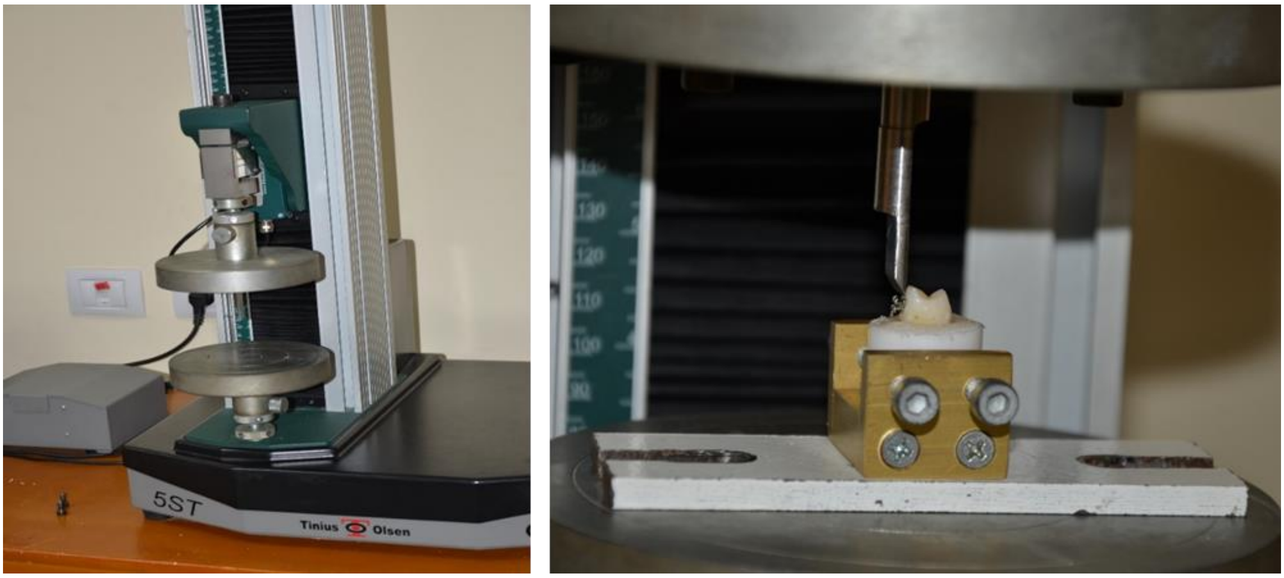

Figure.5. (a) Universal testing machine used for SBS testing, (b) Orientation of the specimen on the universal testing machine

Statistical Analysis

Descriptive statistics including mean, standard deviations, and minimum and maximum values were calculated for each group. Comparisons of shear bond strengths of different surface treatments were performed using ANOVA test (multiple comparisons, Tukey's correction). Comparison of the ARI scores was done using Chi-square test. The level of significance was set at $P < 0.05$.

Results

The results of SBS and ARI were presented in Table (1) and Fig.6.

Results were highlighted the differences in shear bond strength (SBS) among the four groups with varying etching and bleaching treatments. In this study, the mean SBS values of the 4 groups were: group A, 18.54±3.9, group B, 16.13±5.01, group C, 4.15±2.03 and group D, 18.08±5.11. However, One-Way-ANOVA revealed no statistical significance difference between groups A, B and D, while there was a significant lower SBS in group C (bleaching and conventional etching).

While the ARI scores revealed no significant difference among groups A, B and D only, with average 2.7 except for group C, 0.7 which indicating the weakest bond failure between adhesive and enamel surface. It was assured by using Stereomicroscope on enamel surface after debonding, Fig.7, showing a comparison among the 4 groups with the smoothest surface detected in group C.

The consistency in ARI scores between these groups suggested that both etching methods provide comparable outcomes for adhesive distribution. Thus, laser etching appears more effective than conventional methods for bonding immediately after bleaching.

Group #	Group Description	Mean SBS ± *SD*	ARI	0	1	2	3	4	Mean ARI	*Significant $p \leq 0.05$*
Group A	Conventional Acid Etching	18.54 ± 3.9	20	0	0	4	16	0	2.8	0.07
Group B	Er:YAG Laser etching	16.13 ± 5.01	20	0	0	5	15	0	2.75	0.07
Group C	Bleaching/ Acid Etching	4.15 ± 2.08	20	10	8	2	0	0	0.7	0.0002*
Group D	Bleaching/ Laser Etching	18.08 ± 5.11	20	0	1	2	16	1	2.7	0.07

Table 1: comparison between SBS and Mean ARI for different groups.

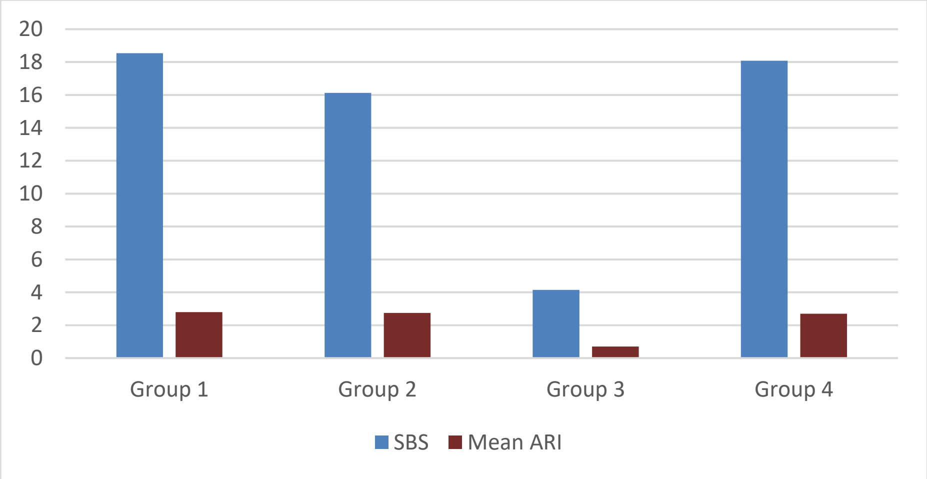

Figure.6. Comparison between SBS and Mean ARI for different groups

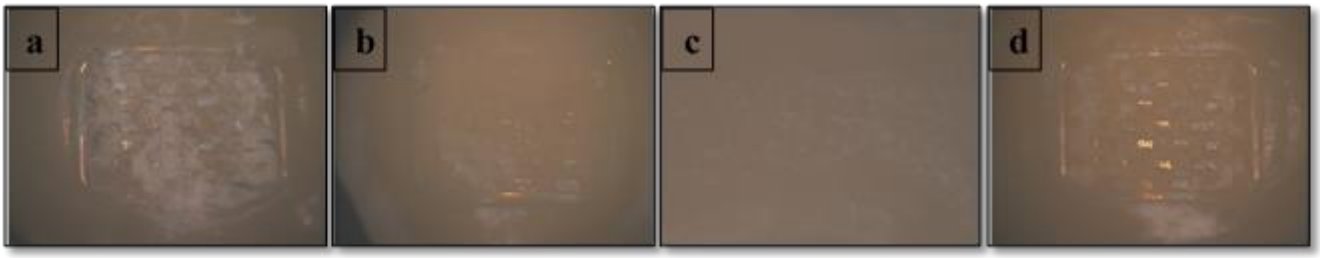

Figure.7. A stereomicroscope pictures after debonding showing ARI among groups, (a) Group A, Conventional etching, (b) Group B, Laser etching, (c) Group C, Conventional etching after bleaching, and (d) Group D, Laser etching after.

Discussion:

Sağır et al. (2013) concluded that Er:YAG laser etching in QSP (Quasi-Continuous Wave Super Pulse) mode, utilizing settings of 120 mJ, 10 Hz, and 1.2 W, presents a successful alternative to traditional acid etching for the bonding of orthodontic brackets. This study highlights several advantages of the QSP mode, which is characterized by its ability to achieve a high ablation volume while minimizing heat deposition and reducing vibrations during the etching process. The ability of the QSP mode to optimize energy delivery facilitates effective enamel modification without the thermal damage often associated with conventional methods. The minimal heat generation is particularly advantageous as it helps preserve the integrity of the dental hard tissues, thereby mitigating potential adverse effects such as enamel softening or damage. Additionally, the reduced vibration enhances patient comfort during the procedure, making it a more tolerable option for those undergoing orthodontic treatment. The findings indicate that Er:YAG laser etching not only achieves comparable, if not superior, bonding conditions compared to acid etching but also enhances the overall efficiency of the bonding process. This approach aligns well with contemporary trends in minimally invasive dentistry, where the preservation of tooth structure and patient comfort are of paramount importance. As such, the adoption of Er:YAG lasers in clinical orthodontics may represent a significant advancement in bonding techniques, warranting further exploration and validation in clinical settings [21,22].

Several studies have compared different laser types for their effectiveness in enhancing the acid resistance of enamel. In a specific analysis between Er:YAG (6 J/cm²) and Er,Cr:YSGG (8 J/cm²), findings indicated that neither laser was recommended for clinical application due to the potential initiation of fine cracks in the enamel. In another study involving four experimental groups, a reduction in calcium loss was observed in two specific groups: those treated with fluoride following Er:YAG application and those treated with CO_2 following Er:YAG application.

Additionally, Castellan et al.[23] suggested that both Nd:YAG and Er:YAG lasers could serve as viable alternatives for increasing the acid resistance of deciduous enamel. Chen et al. proposed that laser-activated fluoride therapy could enhance acid resistance, demonstrating this with CO_2 and Nd:YAG lasers at an energy density of 83.33 J/cm², which resulted in melted surfaces and crater-like formations in the enamel samples. In a study evaluating the acid resistance effects using MHN, Correa-Afonso assessed the performance of CO_2 (0.4 W, 20 Hz), Nd:YAG (1 W, 10 Hz), and Er:YAG (80 mJ, 2 Hz) lasers. The results indicated that the CO_2 laser was the most effective option for enhancing pit and fissure resistance to acid [24].

Another recent study by Milan et al. [25] examined the impact of bleaching on bond strength, focusing on enamel pretreated with different etching methods. Their study found that SBS was significantly reduced after bleaching when conventional acid etching was used, but this reduction was less pronounced when laser etching was applied. Our study corroborates this finding, as the laser etching group maintained higher SBS values post-bleaching compared to the acid-etched group. The role of laser etching in mitigating the negative effects of bleaching appears to be well-supported by these more recent investigations.

In the context of laser etching of enamel, various studies have indicated that this technique can create microspaces conducive to remineralization, effectively trapping free ions and resulting in a surface that exhibits enhanced acid resistance and reduced susceptibility to caries. Notably, laser etching eliminates the need for water spraying or air drying, thereby conserving valuable clinical time (Sawan et al. 2015; Aglarci et al. 2016) [26, 27].

Conversely, while phosphoric acid etching has established itself as a reliable method for bonding resin materials to enamel, it presents potential drawbacks, particularly concerning the demineralization of the superficial enamel layer. This phenomenon raises significant concerns for orthodontic practitioners, as demineralization can render the enamel surface more vulnerable to acid attacks and the development of caries (Nalçacı et al. 2017) [28].

A study by Mirzaie et al. [29] explored the effect of lasers on enamel surface morphology and found that laser etching created a rougher and more uniform surface compared to conventional acid etching. This roughened surface improves adhesive penetration and bonding. Our study supports this by demonstrating that laser etching yields bond strengths comparable to or greater than those achieved with conventional etching, particularly when combined with bleaching procedures. This suggests that laser etching may offer enhanced enamel preparation, particularly in challenging clinical situations like post-bleaching bonding.

The research by Azarbayjani et al. [30] also provides important insights into the efficacy of laser etching in contemporary orthodontics. Their findings demonstrated that laser etching is particularly advantageous when treating bleached enamel, as it maintains bond strength without the need for extensive enamel preparation or waiting periods after bleaching. This is in agreement with our study, which showed that laser etching allowed for immediate bonding after bleaching, with significantly better SBS results than acid etching.

Yadav et al. and Rahul et al. [31,32] utilized metal and ceramic brackets bonded with Transbond XT under an enamel remineralization (ER) protocol as control groups to assess the effects of enamel bleaching on shear bond strength (SBS). Their results indicated a significant reduction in SBS following bleaching, with a notable difference between the SBS of ceramic brackets and metal brackets in the control group. In a separate study, Bilen et al. [33] observed that Clarity Advanced brackets exhibited higher SBS, regardless of whether self-etching (SE) or ER methods were employed. A critical finding from their research was the increased microleakage associated with metal brackets, which could lead to lower SBS due to inadequate polymerization of the orthodontic adhesive. The metal brackets' opaque structure restricts light penetration from the curing lamp, in contrast to the more translucent ceramic brackets. Moreover, the SBS values in the current study were in accordance with Bilen et al. results, but, was different from SBS results in study done by Oladzad et al. [34], which might bhee a result of t thermocycling procedure in their study.

One of the studies found no statistically significant difference in shear bond strength (SBS) between ceramic brackets (14.62 MPa) and metal brackets (13.71 MPa) [35]. Conversely, the other study demonstrated that metal brackets had a significantly higher SBS (24.92 MPa) compared to ceramic brackets (10.74 MPa). The perceived inferiority of ceramic brackets is not corroborated by the findings of the present study and may be attributed to the absence of micromechanical retention on the base of the AO brackets [36].

In addressing the limitations observed in prior studies, our research emphasizes the importance of sample integrity and consistency in enamel preparation. Previous studies often utilized varied methodologies and sample conditions, leading to inconsistent results regarding shear bond strength (SBS) after bleaching. By employing a standardized protocol for tooth selection, including the exclusion of teeth with visible cracks or decalcification, we ensured that our sample was homogenous. This careful selection process not only enhances the reliability of our findings but also facilitates direct comparisons between the different etching techniques employed.

Our study utilized robust statistical methods, including ANOVA and t-tests, to analyze the data, which provided a more thorough understanding of the differences in SBS across treatment groups. By setting a significance level at $p < 0.05$, we confidently identified that laser etching significantly improved bond strength compared to conventional methods after bleaching. This rigorous approach to data analysis strengthens our claims and provides a solid foundation for future research in orthodontic bonding techniques.

Our study not only focused on immediate bond strength but also assessed ARI scores, offering insights into adhesive retention and potential enamel damage during debonding. By correlating these two critical factors, we provide a more comprehensive evaluation of the clinical performance of laser etching in orthodontics. This holistic approach enables us to advocate for laser etching as a viable alternative to traditional methods, particularly in scenarios following bleaching, thereby addressing a significant gap in the existing literature.

Conclusion:

The present study demonstrates that Er:YAG laser etching significantly enhances the shear bond strength (SBS) of orthodontic brackets applied to bleached enamel compared to conventional phosphoric acid etching. The results indicate that laser etching not only mitigates the reduction in bond strength typically associated with enamel bleaching but also offers comparable bond strength to traditional acid etching methods. This suggests that clinicians can effectively utilize laser etching as a reliable approach for bonding orthodontic brackets immediately after bleaching, thereby improving overall treatment outcomes and patient satisfaction.

Recommendations

Future research should focus on the long-term stability of bonds achieved through laser etching, particularly in clinical settings with varying patient behaviors and dietary habits. Additionally, studies could explore the optimal parameters for laser etching to maximize bond strength while minimizing enamel damage. Investigating the effects of different laser wavelengths and pulse durations on SBS and enamel morphology would also be beneficial. Furthermore, clinical trials assessing patient comfort, sensitivity, and aesthetic outcomes following laser etching in conjunction with bleaching treatments would provide valuable insights into the practical applications of this technique in orthodontics. Finally, exploring the cost-effectiveness and time efficiency of laser etching compared to traditional methods would help in evaluating its feasibility for widespread clinical use.

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