

An in Vitro Comparison of Shear Bond Strength and Adhesive Remnant Index Among Conventional Acid Etching, Self-Etching Primer, And Er,Cr:YSGG Laser

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Abstract: Background: Optimal orthodontic bonding requires enamel pretreatment to achieve sufficient shear bond strength (SBS) while minimizing enamel damage. Conventional acid etching, self-etch primers, and laser etching are widely used, each with distinct benefits and drawbacks. **Objective:** To compare SBS and Adhesive Remnant Index (ARI) values of orthodontic brackets bonded using conventional acid etching, self-etch primer, and Er,Cr:YSGG laser at two power settings (1 W and 1.5 W). **Materials and Methods:** Eighty extracted maxillary premolars were randomly assigned to four groups (n=20): Group 1 – 37% phosphoric acid etching; Group 2 – Er,Cr:YSGG laser at 1 W; Group 3 – Er,Cr:YSGG laser at 1.5 W; Group 4 – self-etch primer. Brackets were bonded with Transbond XT and tested for SBS using an Instron testing machine. ARI was scored under $\times 10$ stereomicroscopy. Data were analyzed using ANOVA and Tukey's post hoc test at a significance level of 0.05. **Results:** Mean SBS values were: acid etch – 12.77 ± 1.93 MPa; self-etch primer – 13.00 ± 1.97 MPa; laser 1.5 W – 10.52 ± 2.01 MPa; laser 1 W – 7.82 ± 1.46 MPa. ANOVA showed significant differences ($p < 0.001$). Post hoc tests confirmed that both acid etch and self-etch primer groups had significantly higher SBS than laser groups. ARI scores revealed more adhesive remaining on enamel in acid etch and self-etch groups, whereas laser groups had lower ARI scores, indicating reduced adhesive remnants. **Conclusion:** Conventional acid etching and self-etch primer achieved significantly higher SBS than Er,Cr:YSGG laser etching. Laser-treated enamel showed reduced adhesive remnants, suggesting a potential advantage in minimizing enamel damage during debonding.

Keywords: Shear bond strength, Adhesive remnant index, Orthodontic bonding, Laser etching, Self-etch primer

INTRODUCTION

The introduction of acid etching revolutionized orthodontic bonding, making direct bonding of brackets to enamel a predictable and effective technique. Buonocore¹ first demonstrated in 1955 that phosphoric acid could create a roughened enamel surface to improve adhesion of acrylic resin. This principle was refined with the use of 37% phosphoric acid, which remains the gold standard for enamel preparation. Conventional acid etching selectively dissolves enamel prism cores and interprismatic substance, producing microporosities that allow resin infiltration and formation of resin tags for micromechanical retention^{2,3}. The technique is inexpensive, reliable, and typically yields SBS well above Reynolds'⁴ suggested clinically acceptable threshold of 5.9–7.8 MPa. However, it removes 5–50 μm of enamel, increasing susceptibility to demineralization⁵.

Self-etch primers (SEPs) emerged to reduce procedural steps and technique sensitivity⁶. Containing acidic monomers, SEPs simultaneously demineralize and infiltrate enamel, forming a hybrid layer with shallower resin tags than phosphoric acid^{7,8}. This may reduce enamel damage on debonding but raises concerns about consistently achieving high SBS⁹.

Laser etching, especially with Er,Cr:YSGG, offers a non-chemical alternative^{10,11}. Working via photoablation, the laser's 2780 nm wavelength is absorbed by water in enamel, causing micro-explosive removal of mineral¹². This creates an irregular surface that can retain adhesive. Laser irradiation can also

reduce carbonate content, potentially improving acid resistance¹³.

The Er,Cr:YSGG hydrokinetic laser uses water spray to limit thermal damage¹⁴. Higher power settings increase etching depth and may enhance SBS¹⁵. However, reports vary: some show comparable SBS to acid etching¹⁶, others lower¹⁷.

While SBS measures bond effectiveness, excessively high values may increase enamel fracture risk⁸. The ARI helps identify failure location – higher scores mean more adhesive remains on enamel, while lower scores mean cleaner enamel but potentially more enamel fracture risk¹⁹.

This study compares SBS and ARI among acid etching, SEP, and Er,Cr:YSGG laser etching at two power settings, hypothesizing that acid etch and SEP yield higher SBS, but laser yields lower ARI scores.

MATERIALS AND METHODS

Eighty extracted human maxillary premolars, free from cracks, restorations, hypoplasia, and prior bonding, were stored in 0.1% thymol until use. Teeth were embedded in acrylic resin blocks, buccal surfaces perpendicular to force direction.

Teeth were randomly assigned (n=20/group):

1 **Acid etch:** 37% phosphoric acid gel for 30 s, rinsed, dried to frosty appearance.

2 **Laser 1 W:** Er,Cr:YSGG laser, non-contact, with water spray.

3 **Laser 1.5 W:** Same as above, higher power.

4 **SEP:** Transbond™ Plus SEP per manufacturer instructions.

All but SEP group received Transbond XT primer. Gemini stainless steel brackets were bonded with Transbond XT adhesive, excess removed, and light cured (LED, 10 s occlusal + 10 s gingival). Samples were stored in distilled water at 37°C for 24 h. SBS testing used an Instron universal testing machine at 1 mm/min. Force was converted to MPa. ARI scores (0–3) were recorded at ×10 magnification. ANOVA with Tukey's test was used for SBS; chi-square for ARI ($\alpha=0.05$).

Results

Table 1. Shear Bond Strength (MPa)

Group	Mean ± SD	Min	Max
Acid etch	12.77 ± 1.93	9.48	15.80
Laser 1 W	7.82 ± 1.46	5.12	10.42
Laser 1.5 W	10.52 ± 2.01	6.70	13.78

SEP	13.00 ± 1.97	9.20	16.80
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Acid etch and SEP had highest SBS, laser 1 W the lowest (Table 1).

Table 2. ANOVA for SBS

Source	df	F	p
Between groups	3	46.25	<0.001
Within groups	76	—	—

SBS differences between groups were significant (Table 2).

Table 3. Tukey's Post Hoc p-values

Comparison	p-value
Acid vs Laser 1 W	<0.001
Acid vs Laser 1.5 W	0.002
Acid vs SEP	0.982
SEP vs Laser 1 W	<0.001
SEP vs Laser 1.5 W	0.001
Laser 1 W vs Laser 1.5 W	0.006

Acid etch and SEP performed similarly, both outperforming laser (Table 3).

Table 4. ARI Score Distribution

ARI Score	Acid etch	Laser 1 W	Laser 1.5 W	SEP
0	1	8	5	2
1	3	6	8	4
2	6	5	5	7
3	10	1	2	7

Laser groups left less adhesive on enamel than acid etch and SEP (Table 4).

DISCUSSION

This study found that acid etching and SEP yielded significantly higher SBS than Er,Cr:YSGG laser etching at either 1 W or 1.5 W. The similarity in SBS between acid etching (12.77 MPa) and SEP (13.00 MPa) confirms earlier findings that modern SEPs can match conventional etching performance^{7,8}. Both exceeded Reynolds⁴ clinical threshold, ensuring adequate retention.

Laser etching at 1 W yielded the lowest SBS (7.82 MPa), barely above the clinical minimum, while 1.5 W improved SBS to 10.52 MPa, suggesting a dose-response effect^{5,15}. Still, neither matched acid or SEP, aligning with reports that erbium laser parameters require optimization for reliable bonding^{16,17}.

ARI analysis showed that laser groups had lower scores, meaning cleaner enamel after debonding. Acid etching and SEP often failed at the bracket-adhesive interface, leaving adhesive on enamel (higher ARI), which protects enamel but prolongs clean-up^{18,19}. Laser failures occurred closer to the enamel-adhesive interface, reducing clean-up but potentially risking enamel fracture if SBS is high.

Clinically, laser etching may suit patients at higher caries risk or when minimizing adhesive removal is prioritized, but lower SBS could limit its use in high-stress situations (deep bite, heavy mastication)²⁰.

Strengths include controlled in vitro conditions and use of the same bracket/adhesive system across groups. Limitations include lack of thermocycling or aging, and only two laser power settings. Future studies should explore more laser parameters and in vivo performance.

CONCLUSION

Acid etching and SEP achieved the highest SBS, suitable for most orthodontic bonding needs. Er,Cr:YSGG laser etching, while producing lower SBS, left less adhesive on enamel, potentially reducing post-debonding enamel damage. Choice of method should balance bond strength requirements with enamel preservation goals.

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