

# Evaluation of Er: YAG Laser Enameloplasty and Fissurotomy of Pits and Fissures for Effective Sealant Sealing: An In-Vitro Comparative Study

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## ABSTRACT

**Objective:** This study aimed to compare how well pit-and-fissure sealants perform—looking at both microleakage and shear bond strength (SBS)—after six different enamel surface preparation methods that combined either rotary bur or Er:YAG laser treatment with acid etching and/or adhesive bonding.

**Materials and Methods:** Sixty healthy extracted posterior teeth were split randomly into two groups (n = 30 each): Group1 (Bur mechanical preparation) and Group2 (laser mechanical preparation). Group1 was further subdivided into three subgroups: subgroup A (bur alone + sealant), subgroup B (bur + etch + sealant), subgroup C (bur + etch + bonding + sealant). Similarly, Group 2 was subdivided into three sub groups: subgroup D (laser alone + sealant), subgroup E (laser + etch + sealant), and subgroup F (laser + etch + bonding + sealant). Clinpro sealant was used for all specimens. The teeth went through 500 thermal cycles (5–55°C). Microleakage was checked by looking at methylene blue dye penetration under a stereomicroscope (×40) using a standard 4-point scale. SBS was measured with a universal testing machine. Statistical analysis used Kruskal-Wallis and Mann-Whitney U tests (with Bonferroni correction) for microleakage, and one-way ANOVA with Tukey's post-hoc test for SBS ( $P \leq 0.05$ ).

**Results:** subgroup E gave the lowest microleakage ( $0.53 \pm 0.73$ ) and the highest SBS ( $9.32 \pm 1.83$  MPa). subgroup A showed the most microleakage ( $1.13 \pm 0.97$ ) and the weakest bond strength ( $5.34 \pm 0.49$  MPa). Both differences were statistically significant ( $P = 0.004$ ;  $P < 0.001$ ).

**Conclusion:** Using Er: YAG laser followed by acid etching—without a bonding agent—created the best sealant-tooth interface. Acid etching remains essential no matter how the enamel is prepared, and adding a bonding agent did not bring extra benefit.

**Keywords:** Enameloplasty; Fissurotomy; Er:YAG Laser; Acid Etching; Microleakage; Shear Bond Strength; Pit and Fissure Sealant

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**Conflict of interest:** None

## INTRODUCTION

The shape of our back teeth—deep, narrow pits and grooves—makes them a prime spot for cavities to start. These tiny anatomical traps keep saliva from cleaning them out, resist toothbrush bristles, and create a low-oxygen home where cavity-causing bacteria can thrive.<sup>1</sup> Studies show that roughly 80–90% of cavities in permanent molars happen on these chewing surfaces, and they also account for a good chunk of decay in baby teeth.<sup>4</sup> That is why sealing at-risk grooves has become one of the most trusted prevention tools we have, especially for kids with newly erupted molars, deep fissures, or high cavity risk.<sup>2–3</sup>

How long a sealant lasts and how well it protects depends almost entirely on how well it sticks to the enamel underneath. If the sealant leaks at the edges, bacteria, food bits, and acids can sneak in and cause decay right under what looks like a perfectly fine sealant.<sup>8–9</sup> At the same time,

the sealant needs enough strength to hold up to chewing forces without popping off or cracking at the edges.<sup>13</sup>

That is why how we prep the enamel matters so much. The classic method—using 35–37% phosphoric acid to etch the tooth—has been around for ages because it creates a rough, porous surface that lets the sealant flow in and lock on.<sup>10</sup> But using a dental bur leaves behind a messy "smear layer" that can clog up those pores and make etching less effective.<sup>24</sup> Some dentists add an adhesive bonding layer to try and improve retention, but the evidence for that extra step is not solid.<sup>2–11</sup>

The Er:YAG laser (2940 nm wavelength) has been getting a lot of attention as a possible alternative for prepping enamel. This wavelength matches the absorption peaks of both water and the minerals in enamel, so it can etch the tooth very precisely without overheating the surrounding tissue.<sup>12</sup> The surface left by the laser has a unique cratered look, free of any smear layer, which might make it easier

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for the sealant to soak in.<sup>29–30</sup> Patients also seem to prefer laser work over the drill—a big plus for nervous kids and adults alike.<sup>10</sup>

Even with all these potential upsides, researchers still do not agree on whether laser prep alone gives good enough sealant retention, or if you still need to etch and bond afterward. There is no standard method yet.<sup>31–34</sup>

Our starting assumption—the null hypothesis—was that none of the six preparation methods would show any real difference in microleakage or bond strength. Our main goal was to test all six head-to-head and figure out which one works best for placing pit-and-fissure sealants.

## MATERIALS AND METHODS

### Ethical Approval

The ethics board at the National Institute of Laser Enhanced Sciences (NILES), Cairo University, Egypt, gave the green light for this study. Everyone who donated teeth signed a

consent form before extraction, and we followed all institutional rules for working with human tissue.

### Study Design

This was a prospective, single-blinded, in-vitro lab study done at NILES, Cairo University.

### Sample Size Calculation

We used G\*Power 3.1 (Heinrich-Heine-Universität Düsseldorf, Germany) to figure out how many teeth we would need. Based on average SBS numbers from a similar earlier study,<sup>17</sup> we calculated that at least 8 teeth per group would give us 80% power with  $\alpha = 0.05$  (effect size  $f = 0.55$ , one-way ANOVA). To be safe in case we lost any samples during prep, we went with 10 teeth per group, for a total of 60.

### Materials

All the materials we used are listed in Table 1.

**Table 1.** Materials used in the study.

| Brand Name                     | Manufacturer                | Nature                              | Key Composition                                                                                      |
|--------------------------------|-----------------------------|-------------------------------------|------------------------------------------------------------------------------------------------------|
| Scotch Bond Universal Etchant  | 3M ESPE, USA                | Phosphoric acid gel                 | 35% phosphoric acid                                                                                  |
| Single Bond Universal Adhesive | 3M ESPE, USA                | Universal self-etching adhesive     | 10-MDP, HEMA, dimethacrylate resins, Vitrebond copolymer, filler, ethanol, water, initiators, silane |
| Clinpro Sealant                | 3M, St. Paul, MN, USA       | Resin-based pit-and-fissure sealant | TEGDMA, Bis-GMA, silane-treated silica, fluoride-releasing agents                                    |
| Er:YAG Laser (Twinlight)       | Fotona, Ljubljana, Slovenia | Solid-state laser device            | Wavelength: 2940 nm                                                                                  |
| I-LED Plus Curing Light        | Woodpecker, China           | LED light-curing unit               | Output intensity: up to 2300 mW/cm <sup>2</sup> ; cure time 1 s per 2 mm resin                       |

### Tooth Selection and Storage

We gathered 60 intact, cavity-free human permanent back teeth (both premolars and molars) from people aged 18–45 who had teeth pulled for orthodontic or gum-related reasons. We did not use any teeth that had cracks (visible with a light), defects like fluorosis or hypomineralization, old fillings, or any history of decay. Right after extraction, each tooth got an ultrasonic bath to clean off any leftover tissue or tartar, then went into 0.1% thymol solution at 4°C. We used all teeth within three months of extraction, following ISO/TS 11405:2015 guidelines for adhesion testing.

### Specimen Grouping and Randomization

We used a computer (Random.org) to randomly assign teeth to one of six subgroups ( $n = 10$  each). A separate researcher who was not involved in prepping or measuring outcomes handled the allocation. The Sub groups were:

- **Subgroup A:** Bur prep → sealant
- **Subgroup B:** Bur prep → acid etch → sealant
- **Subgroup C:** Bur prep → acid etch → bonding → sealant
- **Subgroup D:** Laser prep → sealant
- **Subgroup E:** Laser prep → acid etch → sealant
- **Subgroup F:** Laser prep → acid etch → bonding → sealant

## MICROLEAKAGE TESTING

### Specimen Preparation

Before any treatment, we cleaned each tooth with an ultrasonic scaler and then polished it with fluoride-free pumice mixed with water, using a rubber cup on low speed. We left the roots intact throughout the microleakage prep.

### Surface Treatment Protocols

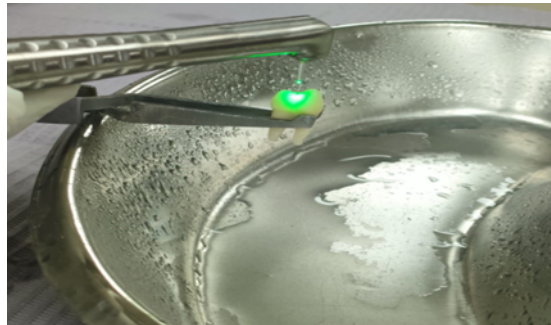
**Subgroup A – Rotary Bur Only:** We used a 330 tapered fissure carbide bur (SS White, Lakewood, NJ, USA) at high speed with lots of water spray. We lightly ran the bur along the fissure without going into dentin or making a real cavity—just enough to standardize the roughness without removing too much healthy enamel.<sup>10</sup>

**Subgroup B – Bur + Acid Etch:** After the same bur prep as subgroup A, we put 35% phosphoric acid gel on the fissure for 15 seconds, rinsed it off for 15 seconds, and gently air-dried for 10 seconds until the enamel turned that familiar chalky white.

**Subgroup C – Bur + Etch + Bonding:** After etching like in subgroup B, we put a drop of Single Bond Universal Adhesive on the enamel, spread it with a brush in a scrubbing motion for 15 seconds, gently blew air to thin it out, and cured it with light for 20 seconds as the instructions said.

**Subgroup D – Er:YAG Laser Only:** We used a Fotona Twinlight Er:YAG laser (2940 nm) with settings based on earlier studies that showed good enamel removal without hurting the pulp:<sup>14</sup> 4 W power, 200 mJ per pulse, 20 Hz,

pulse width 230  $\mu$ s, water coolant at 5 mL/min, for 30 seconds total, moving the handpiece in a sweeping motion perpendicular to the fissure. The tip stayed 10 mm away from the enamel the whole time (Figure 1).



**Figure 1:** The specimen exposed to the laser beam during Er:YAG laser treatment (subgroup D).

**Subgroup E – Laser + Acid Etch:** After the same laser prep as subgroup D, we etched with phosphoric acid exactly as we did for subgroup B.

**Subgroup F – Laser + Etch + Bonding:** We did the laser and etching steps from subgroup E, then added the bonding agent just like in subgroup C.

#### Sealant Application

We squeezed Clinpro sealant into the main fissure using the manufacturer's syringe tip, spread it evenly with a small brush, and cured it for 20 seconds with the I-LED Plus light, holding it perpendicular to the tooth and about 2 mm away.

#### Thermocycling

To mimic the hot and cold stress sealants deal with in the mouth, we put all samples through 500 cycles between 5°C and 55°C water baths. Each cycle meant 30 seconds in one bath, then 30 seconds in the other, with a 10-second switch in between. This followed ISO/TS 11405 recommendations for lab aging.

#### Dye Penetration and Microleakage Scoring

After thermocycling, we sealed the root tip openings with glass ionomer cement (HI flex, Prevost Direct, India) so dye could not sneak in from the bottom. We painted the whole outside of each tooth with two coats of nail polish, leaving a 1-mm ring around the sealant edge open for dye to enter. Then we soaked the teeth in 2% methylene blue (SD Fine-Chem Ltd., Mumbai, India) for 24 hours at room temperature. After rinsing, we embedded each tooth in self-curing acrylic resin (UNIFAST Trad, GC America, Alsip, IL, USA) and cut it into three equal slices (buccal to lingual) with a water-cooled diamond saw.

A single trained examiner who did not know which group was which looked at the slices under a stereomicroscope (BX60, Olympus, Japan) at  $\times 40$  magnification. We picked the middle slice as the representative one for each tooth. Leakage was scored using this standard scale:<sup>21</sup>

- **Score 0:** No dye got in
- **Score 1:** Dye went only up to the first third of the sealant depth

- **Score 2:** Dye reached between one-third and two-thirds deep
- **Score 3:** Dye went past two-thirds of the sealant depth

To check consistency, the same examiner re-scored a random 20% of the slices two weeks later. Cohen's kappa was calculated to see how well the scores matched.

#### SHEAR BOND STRENGTH TESTING

##### Specimen Preparation

We cut off the roots 2 mm below the cemento-enamel junction with a low-speed diamond disc and water cooling. Then we split each crown in half lengthwise (front to back). We embedded each half flat in self-curing acrylic (Acroston, Egypt) inside standard PVC rings (2 cm wide, 1 cm tall). After the acrylic set, we took off the rings and polished the exposed enamel with 120- and then 400-grit sandpaper under running water until we had a flat bonding surface at least 3 mm across. The person doing the polishing did not know the group assignments. We checked to make sure no dentin was showing.

##### Surface Treatment

We prepped the SBS samples exactly the same way as described in Section 3.2 for each subgroup (A through F).

##### Sealant Application

We put a clear gelatin tube (3 mm inner diameter, 4 mm tall) on each treated enamel surface to make sure the sealant was always the same shape and size. We squeezed extra Clinpro sealant into the tube with a syringe and cured it for 20 seconds with the Woodpecker I-LED Plus light (1000–1200 mW/cm<sup>2</sup>), shining it from both the top and the sides.

##### Shear Bond Strength Measurement

We clamped each sample into a Universal Testing Machine (LLOYD Instruments, Ametek, UK). A chisel-shaped blade was placed flush against the enamel right at the sealant-tooth edge. We pushed down at a constant speed of 1 mm/min until the sealant broke off. The machine recorded the peak force in Newtons, and we converted it to MPa using:

$$\text{SBS (MPa)} = \text{Force (N)} / \text{Bonded area (mm}^2\text{)}$$

The bonded area came from the tube's inner radius:  $\pi \times r^2 = 7.07 \text{ mm}^2$ .

### STATISTICAL ANALYSIS

We used SPSS version 26.0 (IBM Corp., Armonk, NY, USA) for all analyses, with  $P \leq 0.05$  as the cutoff for significance.

For microleakage (ordinal data), we first ran the Shapiro-Wilk test to check for normality. Since the data were not normal, we used the Kruskal-Wallis H-test to look for overall differences among the six groups, then did pairwise comparisons with the Mann-Whitney U test. We applied Bonferroni correction to keep the error rate in check. Effect sizes were given as rank-biserial correlation coefficients ( $r$ ). For SBS (continuous and normally distributed—confirmed by Shapiro-Wilk and Levene's test for equal variance), we used one-way ANOVA for the overall comparison, then Tukey's HSD post-hoc test for pairwise differences. Effect size was reported as eta-squared ( $\eta^2$ ). All results are shown as mean  $\pm$  standard deviation (SD) with 95% confidence intervals when relevant.

## RESULTS

### Intra-Examiner Reliability

The repeat scoring of 20% of the microleakage slices gave a Cohen's kappa of 0.88 (95% CI: 0.79–0.97), which means the examiner was very consistent.

### Microleakage Results

Table 2 shows the score distributions and basic stats for each group. The Kruskal-Wallis test confirmed a real overall difference across the six subgroups ( $P = 0.004$ ).

Subgroup E (laser + etch) did the best, with the lowest average leakage score ( $0.53 \pm 0.73$ ) and the lowest mean rank (71.17), meaning dye had the hardest time getting in. Subgroup A (bur alone) did the worst, with the highest leakage score ( $1.13 \pm 0.97$ ) and highest mean rank (103.17), showing the most leakage.

After Bonferroni correction, the Mann-Whitney tests showed significant differences between A and B, A and E, B and D, and D and E. No big differences were seen among A, C, D, and F as a subgroups, nor among B, C, E, and F.

Ranked from most to least leakage:  $A > D > C > F > B > E$ .

**Table 2.** Microleakage score distribution, mean  $\pm$  SD, mean ranks, and inter-subgroup comparisons.

| Subgroup | Score 0    | Score 1    | Score 2   | Score 3   | Mean $\pm$ SD        | Mean Rank           |
|----------|------------|------------|-----------|-----------|----------------------|---------------------|
| A        | 26.7% (8)  | 46.7% (14) | 13.3% (4) | 13.3% (4) | $1.13 \pm 0.97^a$    | 103.17 <sup>a</sup> |
| B        | 43.3% (13) | 50.0% (15) | 6.7% (2)  | 0% (0)    | $0.63 \pm 0.61^b$    | 79.92 <sup>b</sup>  |
| C        | 43.3% (13) | 26.7% (8)  | 13.3% (4) | 16.7% (5) | $1.03 \pm 1.13^{ab}$ | 93.55 <sup>ab</sup> |
| D        | 33.3% (10) | 33.3% (10) | 16.7% (5) | 16.7% (5) | $1.17 \pm 1.09^a$    | 102.08 <sup>a</sup> |
| E        | 56.7% (17) | 36.7% (11) | 3.3% (1)  | 3.3% (1)  | $0.53 \pm 0.73^b$    | 71.17 <sup>b</sup>  |
| F        | 40.0% (12) | 33.3% (10) | 16.7% (5) | 10.0% (3) | $0.97 \pm 1.00^{ab}$ | 93.12 <sup>ab</sup> |
| P-value  |            |            |           |           | <b>0.004 (S)</b>     | <b>0.004 (S)</b>    |

Different superscript letters mean statistically significant differences (Mann-Whitney U with Bonferroni,  $P \leq 0.05$ ). S = significant. Scoring: 0 = no dye; 1 = up to 1/3 depth; 2 = 1/3 to 2/3 depth; 3 = beyond 2/3 depth.

### Shear Bond Strength Results

Table 3 shows the SBS results. All subgroups passed normality (Shapiro-Wilk  $P > 0.05$ ), and variances were equal (Levene's  $P = 0.09$ ). One-way ANOVA found a strong subgroup effect ( $F(5,54) = 38.7$ ,  $P < 0.001$ ,  $\eta^2 = 0.78$ ).

**Table 3.** Mean shear bond strength (MPa)  $\pm$  SD with 95% CI and inter-subgroup comparisons.

| Subgroup | Mean (MPa)             | SD   | 95% CI     |
|----------|------------------------|------|------------|
| A        | 5.34 <sup>c</sup>      | 0.49 | 4.99–5.69  |
| B        | 8.93 <sup>a</sup>      | 0.88 | 8.30–9.56  |
| C        | 6.33 <sup>bc</sup>     | 0.82 | 5.74–6.92  |
| D        | 5.84 <sup>c</sup>      | 0.66 | 5.37–6.31  |
| E        | 9.32 <sup>a</sup>      | 1.83 | 8.01–10.63 |
| F        | 7.11 <sup>b</sup>      | 1.05 | 6.36–7.86  |
| P-value  | <b>&lt; 0.001 (HS)</b> |      |            |

Different superscript letters mean significant pairwise differences (Tukey HSD,  $P \leq 0.05$ ). HS = highly significant.  $\eta^2 = 0.78$ .

Subgroup E had the highest average SBS ( $9.32 \pm 1.83$  MPa; 95% CI: 8.01–10.63 MPa), while Subgroup A had the lowest ( $5.34 \pm 0.49$  MPa; 95% CI: 4.99–5.69 MPa).

Tukey HSD post-hoc tests showed significant differences between A–B, A–E, A–F, B–C, B–D, B–F, C–E, C–F, D–F, and E–F. No significant difference was seen between A, C, and D as a Subgroup, nor between B and E.

Ranked from highest to lowest SBS:  $E > B > F > C > D > A$ .

## DISCUSSION

We tested six ways of prepping enamel for sealants, looking at both leakage and bond strength. Our starting assumption—that all methods would be the same—turned out to be wrong, since we found clear differences in both measures.

### Bur Prep Without Acid Etching (Subgroup A)

Just using a bur without any etching (Subgroup A) gave the worst sealant bond, with the most leakage and lowest strength. The problem is the smear layer—the fine dust and debris that the bur leaves behind. It clogs up the enamel

pores, so the sealant cannot soak in. Instead, it sticks to a loose, weak layer that is prone to leaking and breaking.<sup>10–24</sup>

#### **Adding Acid Etch to Bur Prep (Subgroup B)**

When we added acid etching after the bur (Subgroup B), both leakage and bond strength got significantly better. The acid dissolves the smear layer and opens up the enamel, creating a rough, porous surface that lets the sealant flow in and lock tight.<sup>25</sup> This confirms that etching is a must, no matter how you prep the tooth, matching what other studies have found.<sup>25</sup>

#### **Adding Bonding Agent to Bur + Etch (Subgroup C)**

Even though it sounds logical to use a bonding agent as an extra layer, Subgroup C (bur + etch + bond) did not do any better than Subgroup B in either outcome. One reason might be that bonding agents are thicker than sealants. When you put them on an etched surface, they fill up the tiny pores first, so the sealant cannot get in as deep.<sup>26–27</sup> Subgroup C also had a fair number of Score 3 leakages (16.7%), suggesting that bonding might actually create tiny voids or stress points. Overall, this challenges the idea that bonding always helps.

#### **Laser Alone (subgroup D) vs. Bur Alone (subgroup A)**

We were surprised that subgroup D (laser only) did about the same—or even slightly worse—than subgroup A (bur only). The laser should leave a clean, smear-free surface, but without etching, it did not help. One explanation is that even though the laser creates a rough, cratered surface, the heat might partially melt the enamel surface, lowering its energy and making it harder for the sealant to spread and seep in.<sup>14–29–30</sup> Other researchers have also found that laser alone does not beat bur alone, and sometimes makes things worse.<sup>29–30</sup> So laser prep is not a stand-alone solution; it needs acid etching to really shine.

#### **Laser + Acid Etch (subgroup E) — The Best Approach**

Subgroup E was the clear winner on both leakage and bond strength. The laser creates big, rough features—craters and exposed crystal ends—that give the acid even more surface area to work on. Then the acid removes any heat-melted residue and deepens the porous layer, so the sealant can form long, strong tags that hold tight.<sup>32–34</sup> This fits with what several research teams have recommended: laser first, then etch, for the best sealant bond.<sup>32–34</sup>

#### **Adding Bonding to Laser + Etch (subgroup F)**

Subgroup F (laser + etch + bond) did significantly worse than subgroup E, just like we saw when comparing subgroups C and B. Again, the bonding agent seems to clog up the very pores and craters that the laser and acid created, keeping the sealant from getting in where it needs to go.<sup>35–36</sup> It also adds another interface where failure can start. So unless there is a special reason, adding bonding to a laser + etch protocol is not recommended.

### **LIMITATIONS**

We have to be honest about the limits of this study. First, lab conditions cannot fully capture what happens in a real mouth—saliva, chewing forces, bacteria, and temperature changes over years. Second, 10 teeth per group gave us enough power for SBS, but we might have missed small differences in the ordinal leakage data. Third, only one examiner scored the leakage; having several would have

been better. Fourth, we used just one sealant and one bonding system; other products might give different results. Fifth, 500 thermal cycles is a shortcut for aging, not the same as years of use. We really need long-term clinical trials to see if these results hold up in people.

### **CONCLUSIONS**

Within the limits of this lab study, here is what we found:

1. **Laser prep followed by acid etching (subgroup E)** gave the lowest leakage and the strongest bond of all six methods, making it the best approach in this experiment.
2. **Acid etching is non-negotiable.** Whether you use a bur or a laser, you have to etch afterward. Neither method alone is enough.
3. **Adding a bonding agent** before the sealant—whether after bur or laser prep—did not help and may actually hurt by blocking the pores that the sealant needs to fill.
4. **Laser by itself** did not beat the bur by itself. The laser's real benefit only shows up when you add acid etching.
5. **We need clinical trials** before telling dentists to switch to the laser + etch protocol for everyday sealant placement.

### **Ethics Approval**

The ethics board at the National Institute of Laser Enhanced Sciences (NILES), Cairo University, Egypt, approved this study. All participants who donated teeth signed a consent form before extraction, and we followed all institutional rules for working with human tissue.

### **Competing Interest**

The authors have no conflicts to declare.

### **Data Availability**

The full dataset is available from the corresponding author upon reasonable request.

### **Funding**

No outside money supported this study.

### **Author Contributions**

All authors helped design the study, ran the experiments, analyzed the data, wrote the paper, and approved the final version.

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