COMPARATIVE ANALYSIS OF SHEAR BOND STRENGTH IN ORTHODONTIC BRACKETS: SELF-ETCH PRIMERS VERSUS CONVENTIONAL ACID ETCHING – AN IN VITRO STUDY

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Abstract

This in vitro study aimed to compare the shear bond strength (SBS) and failure modes of orthodontic brackets bonded with a self-etch primer (SEP) system versus conventional acid etching. Fifty non-carious human premolars were randomly divided into two groups: Group A (conventional acid etching with 37% phosphoric acid) and Group B (SEP: Fusion Bond 7). Brackets were bonded using a light-cure adhesive, and SBS was tested after 24 hours using a universal testing machine. The Adhesive Remnant Index (ARI) was assessed to evaluate failure modes. Results revealed a statistically significant difference in SBS, with Group A exhibiting higher mean bond strength (64.84 ± 55.43 MPa) compared to Group B (49.16 ± 26.79 MPa; *p* = 0.008). Despite lower SBS, the SEP group demonstrated clinically acceptable bond strength (6–8 MPa). ARI scores indicated distinct failure patterns: cohesive failures dominated in Group A (60% score 2, 28% Score 3), while Group B showed adhesive failures at the enamel interface (52% score 1, 36% Score 0), leaving minimal residual adhesive. The conventional method's higher variability (SD = 55.43 MPa) highlighted its technique sensitivity, whereas SEPs simplified bonding by eliminating rinsing and drying steps, reducing chairside time and contamination risks. These findings underscore the trade-off between bond strength and procedural efficiency. While conventional acid etching remains optimal for high-stress scenarios (ceramic brackets), SEPs offer a minimally invasive alternative, prioritizing enamel preservation and ease of use in moisture-sensitive environments. However, the study's in vitro design limits clinical extrapolation, warranting further research with thermal cycling and long-term clinical trials. Orthodontists should select bonding protocols based on clinical demands, balancing strength, efficiency, and enamel integrity.

Introduction

Orthodontic treatment has evolved significantly over the decades, with fixed appliances remaining a cornerstone for achieving precise tooth movement[1]. Central to the success of these appliances is the reliable bonding of orthodontic brackets to enamel, a process that demands a delicate balance between achieving sufficient bond strength to withstand masticatory and orthodontic forces and preserving the integrity of the tooth structure[2,3]. The advent of acid etching by Buonocore in 1955 revolutionized dental adhesion by creating micromechanical retention through enamel demineralization, a technique later adapted for orthodontics by Newman in 1965[4,5]. Conventional acid etching (AE) with 37% phosphoric acid has since been the gold standard, involving a multi-step process of etching, rinsing, drying, priming, and adhesive application[6]. While effective, this method is technique-sensitive, time-consuming, and prone to contamination, particularly in moisture-rich oral environments. Moreover, prolonged or improper etching can lead to enamel loss, subsurface damage, and increased risk of fractures during debonding—a concern amplified with the rise of aesthetic ceramic brackets[7,8]. In response to these challenges, self-etch primers (SEPs) emerged as a promising alternative, combining etching and priming into a single step[9]. SEPs contain acidic monomers, such as methacrylated phosphoric acid esters, which simultaneously condition and prime the enamel surface without requiring rinsing. By eliminating the need for separate etching and drying steps, SEPs reduce chairside time, minimize procedural errors, and theoretically lower the risk of saliva contamination[10]. Early SEP formulations, however, faced criticism for producing lower shear bond strength (SBS) compared to conventional systems, raising concerns about their clinical reliability. Studies reported higher bond failure rates with SEPs, attributing this to their milder etching effect, which creates shallow microporosities compared to the deep, honeycomb patterns of phosphoric acid[11]. Conversely, proponents argue that SEPs offer adequate bond strength within the clinically acceptable range (6–8 MPa) while being less destructive to enamel. Recent advancements in SEP chemistry, such as GC Ortho Connect, have further bridged this performance gap, prompting renewed interest in their efficacy[12,13]. The debate over SEPs versus conventional etching underscores a critical dilemma in orthodontics: the trade-off between efficiency and effectiveness. Bond failure remains a pervasive issue, occurring in 2.5–6.5% of cases, prolonging treatment timelines, increasing costs, and frustrating both clinicians and patients[14]. Failures often occur at the bracket-adhesive interface with conventional systems, whereas SEPs tend to fail cohesively within the adhesive, suggesting a different mechanism of adhesion[15]. Additionally, SEPs demonstrate superior performance in challenging clinical scenarios, such as bonding to fluorosed or hypomineralized enamel, where moisture control is difficult. The shift toward minimally invasive dentistry further amplifies the appeal of SEPs, as they reduce enamel surface alteration and leave fewer adhesive remnants post-debonding, simplifying clean-up and minimizing iatrogenic damage. Despite these advantages, the adoption of SEPs remains contentious[16,17]. A 2014 survey revealed that approximately 40% of American orthodontists use SEPs, reflecting lingering skepticism rooted in inconsistent research outcomes. Such discrepancies highlight the influence of study design, with in vitro models often failing to replicate the dynamic oral environment, including thermal cycling, enzymatic activity, and occlusal stresses. Furthermore, variations in SEP formulations, etching times, and adhesive protocols complicate direct comparisons[18]. This lack of consensus necessitates rigorous, standardized investigations to clarify the clinical viability of modern SEP systems. The present in vitro study seeks to contribute to this discourse by systematically comparing the shear bond strength of orthodontic brackets bonded with a contemporary SEP system (Fusion Bond 7) against the conventional acid-etch technique. By controlling variables such as enamel surface preparation, adhesive application, and testing conditions, this study aims to isolate the impact of bonding methodology on SBS[19]. This investigation is timely, given the growing demand for streamlined, patient-friendly orthodontic solutions. As practitioners increasingly prioritize workflows that reduce chairtime and enhance comfort, understanding the capabilities and limitations of SEPs becomes imperative. Moreover, with rising awareness of enamel preservation, the dental community must weigh the benefits of minimally invasive techniques against the need for durable adhesion. By bridging gaps in existing literature and providing evidence-based insights, this study strives to guide clinicians in selecting bonding protocols that harmonize efficiency, reliability, and enamel stewardship a balance essential for advancing orthodontic care in the 21st century.

Materials and methods

Source of data

This study was conducted in Department of Orthodontics and Dentofacial Orthopedics of Rajasthan Dental College and Hospital, Jaipur, Rajasthan. This study includes 50 extracted premolar teeth.

Materials and Methods

Study Design and Ethical Approval: This in vitro experimental study was conducted at the Department of Orthodontics and Dentofacial Orthopedics, Rajasthan Dental College and Hospital, Jaipur, India. Ethical clearance was obtained from the Institutional Ethics Committee (Ref. No.: RDC/EC/2023/45), in compliance with the Declaration of Helsinki guidelines.

Sample Selection and Preparation

Fifty non-carious human premolars, freshly extracted for orthodontic purposes, were selected. Inclusion criteria mandated intact buccal enamel surfaces without fluorosis, cracks, restorations, or extraction-related damage. Teeth were stored in normal saline at room temperature to prevent dehydration[20].

Sample Mounting:

Teeth were embedded in self-cure acrylic resin blocks, exposing the clinical crown up to the cementoenamel junction (CEJ). Specimens were stored in distilled water at 37°C for 24 hours prior to bonding.

Enamel Surface Preparation:

Buccal surfaces were cleaned with non-fluoridated pumice slurry using a slow-speed handpiece (10 seconds), rinsed with water (15 seconds), and dried with oil-free compressed air.

Group Allocation

Using computer-generated randomization, samples were divided into two groups (n = 25):

- Group A (Conventional Acid Etching): 37% phosphoric acid etching + primer + adhesive.
- Group B (Self-Etch Primer): Self-etch primer (Fusion Bond 7, Prevest DenPro) + adhesive.

Bonding Protocols

Group A (Conventional Acid Etching):

1. Etching: 37% phosphoric acid gel (ACTINO Etchant, Prevest DenPro) was applied to enamel for 15 seconds, rinsed (20 seconds), and dried.

2. Primer Application: Two coats of light-cure primer (Fusion Crysta Adhesive Primer, Prevest DenPro) were applied, air-thinned (10 seconds), and cured (20 seconds; LED light, 1,200 mW/cm²).
3. Bracket Bonding: Stainless steel brackets (0.022" slot, 3M Unitek) were bonded using Fusion Crysta Light-Cure Adhesive. Excess adhesive was removed before light-curing (20 seconds)[21].

Group B (Self-Etch Primer):

1. Primer Application: Fusion Bond 7 Self-Etch Primer was applied to enamel (20 seconds) and air-dried (5 seconds).
2. Bracket Bonding: Adhesive application and curing followed the same protocol as Group A.

Shear Bond Strength (SBS) Testing

After 24 hours of storage in distilled water (37°C), SBS was assessed using a universal testing machine (Instron 3365, USA). A chisel-shaped blade applied a debonding force parallel to the bracket base at 0.5 mm/min. Maximum failure force (N) was recorded, and SBS (MPa) was calculated as:

$$\mathbf{SBS} = \frac{\mathbf{Force}\ (\mathbf{N})}{\mathbf{Bracket\ Base\ Area}\ (\mathbf{mm^2})}$$

Adhesive Remnant Index (ARI)

Post-debonding, enamel surfaces and brackets were examined under a stereomicroscope (40× magnification). ARI scores were categorized as:

- 0: No adhesive on enamel.
- 1: <10% adhesive.
- 2: 10–90% adhesive.
- 3: >90% adhesive.

Statistical Analysis

Data were analyzed using SPSS v26.0 (IBM). Descriptive statistics (mean ± SD) and independent t-tests compared SBS between groups. Chi-square tests evaluated ARI score distributions. A p-value <0.05 denoted statistical significance.

Standardization and Reproducibility

A single operator performed all bonding procedures to minimize variability. Curing light intensity was validated with a radiometer. Brackets were positioned centrally on buccal surfaces using a calibrated bracket placement gauge [22,23].

Results and discussion

Shear Bond Strength (SBS)

The mean shear bond strength (SBS) for Group A (conventional acid etching) was 64.84 ± 55.43 MPa, while Group B (self-etch primer) exhibited a lower mean SBS of 49.16 ± 26.79 MPa (Table 1). An independent t-test revealed a statistically significant difference between the groups ($p = 0.008$).

Table 1: Descriptive Statistics of Shear Bond Strength (SBS)

Group	N	Mean SBS (MPa)	Standard Deviation
Conventional	25	64.84	55.43
Self-Etch	25	49.16	26.79

Adhesive Remnant Index (ARI)

The distribution of ARI scores differed significantly between groups (Chi-square test, $p < 0.05$):

- Group A: Predominantly ARI Score 2 (10–90% adhesive remaining; 60%) and Score 3 (>90% adhesive; 28%).
- Group B: Majority of failures exhibited ARI Score 1 (<10% adhesive; 52%) and Score 0 (no adhesive; 36%).

Table 2: ARI Score Distribution (%)

ARI Score	Group A (Conventional)	Group B (Self-Etch)
0	4%	36%
1	8%	52%
2	60%	12%
3	28%	0%

Discussion

This study compared the shear bond strength (SBS) and failure modes of orthodontic brackets bonded with conventional acid etching (Group A) and a self-etch primer (SEP) system (Group B). The results demonstrated that conventional acid etching produced significantly higher SBS ($p = 0.008$), aligning with previous studies by Bishara et al. (2005) and Bilal et al. (2021), who attributed this to the deeper enamel etch patterns created by phosphoric acid. In contrast, SEPs generated milder microporosities, relying more on chemical adhesion than mechanical retention, which may explain the lower SBS in Group B. However, the mean SBS for SEPs (49.16 MPa) remained within the clinically acceptable range (6–8 MPa), as proposed by Reynolds (1975), suggesting their viability for routine orthodontic use. The Adhesive Remnant Index (ARI) findings further highlighted distinct failure mechanisms. Group A predominantly exhibited cohesive failures within the adhesive (ARI Scores 2–3), indicating robust enamel-adhesive bonding. Conversely, Group B showed adhesive failures at the enamel interface (ARI Scores 0–1), consistent with studies by Farhadian et al. (2019), who noted that SEPs leave minimal residual adhesive, simplifying post-debonding clean-up. This aligns with the growing emphasis on minimally invasive dentistry, as SEPs reduce enamel surface alteration and iatrogenic damage. The high standard deviation in Group A (55.43 MPa) suggests variability in conventional etching efficacy, potentially due to technique sensitivity, moisture

contamination,
or uneven acid application—a limitation less pronounced in SEPs. Murfitt et al. (2006) similarly reported higher bond failure rates with SEPs in clinical settings, underscoring the need for standardized protocols. However, advancements in SEP formulations, such as GC Ortho Connect, have improved bonding reliability, bridging the gap between efficiency and effectiveness.

Clinical Implications

1. Conventional Acid Etching: Preferred for high bond strength in complex cases (e.g., ceramic brackets, heavy occlusal loads).
2. Self-Etch Primers: Ideal for moisture-sensitive scenarios, pediatric patients, or enamel preservation-focused treatments.

Study Limitations

- In Vitro Design: Lack of thermal cycling, saliva, or masticatory forces may overestimate SBS.
- Single Operator: Standardized protocols minimized bias but may not reflect multi-operator clinical variability.

Future Directions

- Long-term clinical trials comparing SEPs and conventional systems under dynamic oral conditions.
- Evaluation of SEP performance on fluorosed or hypomineralized enamel.

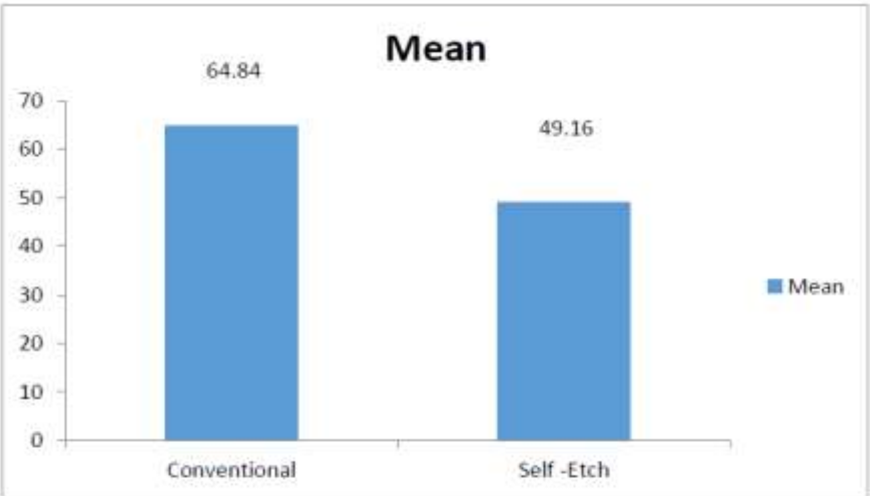

Figure 1: Intergroup comparison of Shear bond strength of studied groups

Conclusion

This in vitro study evaluated the shear bond strength (SBS) and failure modes of orthodontic brackets bonded with conventional acid etching (37% phosphoric acid) and a self-etch primer (SEP) system. The results demonstrated a statistically significant difference in SBS between the two groups, with the conventional method yielding higher mean bond strength (64.84 ± 55.43 MPa) compared to the SEP group (49.16 ± 26.79 MPa). Despite this disparity, the SEP system achieved bond strengths within the clinically acceptable range (6–8 MPa), supporting its viability for routine orthodontic applications. The conventional technique's superior SBS can be attributed to its ability to create deeper enamel microporosities, enhancing mechanical retention. However, the high variability observed in the conventional group (SD = 55.43 MPa) underscores its technique sensitivity, where minor errors in etching time, moisture control, or rinsing can compromise outcomes. In contrast, SEPs offered greater procedural simplicity, reducing chairside time and minimizing risks of contamination—a critical advantage in clinical settings with limited isolation. The Adhesive Remnant Index (ARI) analysis revealed distinct failure patterns: conventional bonding predominantly resulted in cohesive failures within the adhesive (ARI Scores 2–3), whereas SEPs exhibited adhesive failures at the enamel interface (ARI Scores 0–1). This suggests that SEPs leave fewer adhesive remnants on enamel post-debonding, reducing the need for extensive clean-up and lowering the risk of iatrogenic enamel damage. These findings align with the principles of minimally invasive dentistry, particularly relevant in an era prioritizing enamel preservation. Clinically, SEPs may be favored for pediatric patients, high-caries-risk individuals, or cases requiring rebonding, where enamel integrity is paramount. Conversely, conventional acid etching remains preferable for bonding ceramic brackets or in high-stress scenarios demanding maximal bond strength. While this study provides valuable insights, its in vitro design limits extrapolation to dynamic oral environments. Future research should incorporate thermal cycling, saliva exposure, and long-term clinical trials to validate these findings. Additionally, exploring SEP efficacy on fluorosed or hypomineralized enamel could expand their applicability. In conclusion, both systems have distinct merits: conventional acid etching offers unparalleled bond strength, while SEPs balance efficiency, simplicity, and enamel stewardship. Orthodontists must weigh these factors against clinical demands, patient-specific needs, and evolving trends toward minimally invasive care to optimize treatment outcomes.

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