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Original Article

Shear Bond Strength of Reused Orthodontic Brackets after Multiple Bonding Cycles: An in Vitro Study

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ABSTRACT

Repeated bonding of orthodontic brackets is a common clinical necessity, yet its impact on shear bond strength (SBS) and enamel integrity remains inadequately characterized. This study evaluated the effect of multiple bonding cycles using the same bracket on SBS and enamel surface characteristics. Twenty human premolars extracted for orthodontic purposes were randomly allocated to two groups (n=10 per group): Group A (Enlight® adhesive, Ormco) and Group B (Transbond XT® adhesive, 3M Unitek). Specimens underwent five consecutive bonding-debonding cycles using stainless steel mesh-based brackets. After each debonding, brackets were cleaned using a flaming technique (5 seconds), and enamel surfaces were polished with a tungsten carbide bur. SBS was measured using a universal testing machine (crosshead speed: 6 mm/min). Data were analyzed using repeated measures MANOVA with Bonferroni post hoc tests (α=0.05). Initial SBS values differed significantly between groups (Group B: 22.38±17.41 MPa vs. Group A: 9.92±4.36 MPa; $p<0.05$). Group B demonstrated a progressive decline in SBS, reaching 4.73±3.82 MPa by the fifth cycle—below the clinically acceptable threshold of 5.9 MPa. Group A maintained more stable SBS values across all cycles (range: 8.31–14.86 MPa). Statistical analysis revealed significant effects of bonding cycle ($p<0.001$) and adhesive type ($p<0.05$), with a significant interaction effect ($p<0.05$). Repeated bonding significantly compromises SBS, with high-filler adhesives showing greater degradation despite superior initial performance. Adhesives with simpler formulations demonstrate better stability across multiple cycles. Clinical protocols should prioritize optimal cleaning techniques and consider bracket replacement after multiple failures to ensure treatment efficacy and enamel preservation.

Keywords: Adhesive systems, Enamel integrity, Orthodontic brackets, Re-bonding, Shear bond strength

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Introduction

Successful orthodontic treatment relies fundamentally on the reliable attachment of fixed appliances to dental enamel. The transition from banding to direct bonding using acid-etch techniques has substantially improved patient comfort, reduced plaque accumulation, and decreased chairside time [1-3]. Contemporary bonding systems employ micromechanical retention mechanisms, wherein phosphoric acid etching creates resin tags penetrating approximately 50 µm into enamel prisms, establishing the foundation for adhesive attachment [4, 5].

The mechanical properties of orthodontic adhesives are determined by their composition, specifically the organic matrix (typically Bis-GMA and TEGDMA) and inorganic filler content, which collectively influence polymerization characteristics and bond durability [6-8]. Shear bond strength (SBS) serves as a critical parameter for evaluating adhesive performance, with clinically recommended values ranging from 5.9–7.8 MPa for routine orthodontic applications, though

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some literature suggests optimal values between 11–25 MPa [9, 10].

Clinical practice frequently necessitates bracket rebonding due to adhesive failure, patient trauma, or treatment modifications. This process may involve either new brackets or recycled brackets that have undergone cleaning and reconditioning [11, 12]. Repeated bonding cycles present clinical concerns regarding both bond strength maintenance and enamel surface integrity, as successive acid-etching and mechanical cleaning procedures may compromise enamel structure [4, 13].

Previous investigations have documented variable outcomes regarding SBS after bracket recycling, with outcomes dependent upon cleaning methodologies, adhesive systems, and enamel conditioning protocols [14-16]. However, limited evidence exists regarding the progressive degradation of bond strength across multiple bonding cycles using identical brackets, particularly concerning the interaction between adhesive formulation and repeated thermal-mechanical stress.

The present study was designed to address this evidence gap by systematically evaluating SBS across five consecutive bonding cycles using two commercially available adhesive systems with distinct compositional profiles. The primary objective was to determine whether repeated bonding with identical brackets significantly compromises SBS and to characterize the differential performance of high-filler versus simplified adhesive formulations under cyclic loading conditions.

Materials and Methods

Experimental design and sample selection

This in vitro experimental study was conducted at the Faculty of Dentistry, Universitas Trisakti, following approval by the Institutional Ethics Committee Review Board (Protocol No: 870/S2/KEPK/FKG/9/2024). Twenty human maxillary premolars extracted for orthodontic therapeutic purposes were collected and stored in distilled water at 4°C with monthly solution changes to maintain hydration and prevent bacterial degradation. Inclusion criteria comprised intact buccal enamel surfaces without restorations, caries, fluorosis, or structural defects. Teeth with visible cracks, hypoplastic lesions, or previous orthodontic treatment were excluded.

Sample size calculation was performed using G Power software (version 3.1.9.7), assuming an effect size of 0.5, α=0.05, and power=0.80, indicating a minimum requirement of 18 specimens. Twenty specimens were enrolled to account for potential attrition.

Group allocation and specimen preparation

Samples were randomly allocated to two experimental groups (n=10) using computer-generated randomization:

Group A: Enlight® light-cured orthodontic adhesive (Ormco Corporation, Glendora, CA, USA)

Group B: Transbond XT® light-cured orthodontic adhesive (3M Unitek, Monrovia, CA, USA)

Each tooth was embedded in cylindrical acrylic resin blocks (diameter: 25 mm; height: 20 mm) using a standardized orientation jig to ensure perpendicular exposure of the buccal enamel surface. The embedded specimens were stored in artificial saliva (pH 7.0) at 37°C for 24 hours prior to initial bonding.

Bonding and debonding protocol

A single operator performed standardized bonding procedures to minimize technique variability:

Surface preparation: Enamel surfaces were polished using a rubber cup with non-fluoridated pumice slurry for 10 seconds, rinsed with distilled water for 20 seconds, and air-dried until desiccated.

Acid etching: Thirty-seven percent phosphoric acid gel (3M ESPE, St. Paul, MN, USA) was applied to enamel surfaces for 20 seconds, followed by thorough water rinsing (30 seconds) and gentle air drying until a frosted, chalky appearance was achieved.

Adhesive application: Adhesives and associated primers were applied according to manufacturer specifications:

Group A: Enlight® primer followed by adhesive

Group B: Transbond XT® primer followed by adhesive

Bracket placement: Stainless steel premolar brackets with 80-gauge mesh bases (American Orthodontics®, Sheboygan, WI, USA; Slot dimension: 0.022 × 0.028 inches) were positioned on the buccal surface at the center of the clinical crown with standardized pressure using a bracket placement instrument (ORMCO, Glendora, CA, USA). Excess adhesive was removed from the peripheries using a dental explorer.

Light curing: Polymerization was performed using an LED light-curing unit (Valo, Ultradent Products, South Jordan, UT, USA; intensity: 1000 mW/cm²) for 40 seconds total: 10 seconds at each of four bracket aspects (mesial, distal, occlusal, gingival).

Storage: Bonded specimens were incubated in artificial saliva at 37°C for 24 hours before mechanical testing.

Shear bond strength testing

SBS was measured using a universal testing machine (Instron 5967, Norwood, MA, USA) equipped with a 1 kN load cell. A chisel-edge fixture was positioned to apply shear force at the bracket-enamel interface with a crosshead speed of 6 mm/minute. Force application continued until bracket debonding, with peak force (Newtons) recorded. SBS values were calculated using the formula: SBS (MPa) = Force (N) / Bracket base area (mm^2). The bracket base area was measured using digital calipers and confirmed as 10.12 mm^2 for all specimens.

Recycling protocol

Following debonding, brackets and enamel surfaces underwent standardized recycling procedures:

Bracket cleaning: Residual adhesive was removed from the bracket mesh using a flaming technique—heating with a butane torch (Bernzomatic, Worthington Industries, Columbus, OH, USA) for 5 seconds until a red glow appeared, followed by immediate quenching in distilled water at room temperature and air drying.

Enamel cleaning: Residual adhesive on enamel surfaces was removed using a slow-speed handpiece (NSK, Kanuma, Japan) with a tungsten carbide bur (Hager & Meisinger GmbH, Neuss, Germany) at 10,000 RPM for 60 seconds under water irrigation, followed by pumice polishing and rinsing.

This bonding-debonding-cleaning cycle was repeated five times for each specimen, with SBS measured after each cycle.

Statistical analysis

Normality was assessed using Shapiro-Wilk tests, and homogeneity of variances using Levene's test. Repeated measures multivariate analysis of variance (MANOVA) evaluated the effects of bonding cycle (within-subjects factor) and adhesive type (between-subjects factor) on SBS, with Bonferroni correction for multiple comparisons. Statistical significance was set at $p<0.05$. All analyses were performed using SPSS Statistics (version 26.0, IBM Corp., Armonk, NY, USA).

Results and Discussion

Descriptive statistics for SBS across five bonding cycles are presented in **Table 1**. Group B (Transbond XT®) demonstrated significantly higher initial SBS (22.38±17.41 MPa) compared to Group A (9.92±4.36 MPa). However, Group B exhibited substantial degradation across cycles, with SBS declining to 4.73±3.82 MPa by the fifth cycle—a value below the clinically acceptable minimum of 5.9 MPa. Conversely, Group A maintained relatively stable SBS values ranging from 8.31±5.19 MPa to 14.86±10.32 MPa across all cycles **(Table 1)**.

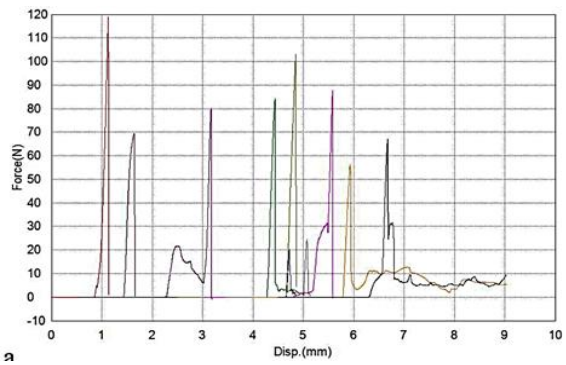
Table 1. Average Results of Shear Bond Strength (MPa)

Bonding Cycle	Group A (Enlight®) (Mean ± SD)	Group B (Transbond XT®) (Mean ± SD)
1st	9.92 ± 4,36	22.38 ± 17,41
2nd	14.86 ± 10,32	14.23 ± 11,39
3rd	8.31 ± 5,19	8.19 ± 4,39
4th	9.84 ± 4,51	19.73 ± 16,12
5th	10,00 ± 8,62	4.73 ± 3,82
Overall	10.58 ± 7,10	13.85 ± 13,38

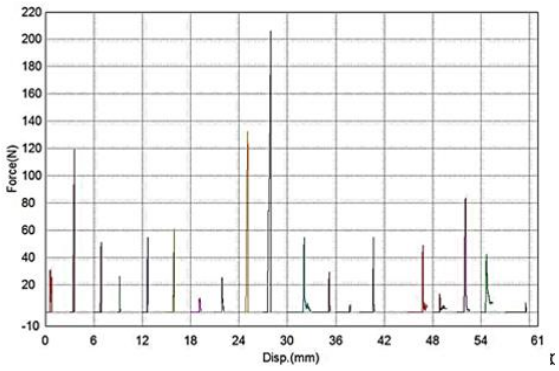
SD: standard deviation; n=10 per group per cycle

Repeated measures MANOVA revealed significant main effects for bonding cycle (Wilks' $\lambda=0.342$, $F(4,15)=7.21$, $p<0.001$, partial $\eta^2=0.658$) and adhesive type ($F(1,18)=5.47$, $p=0.031$, partial $\eta^2=0.233$), with a significant interaction effect (Wilks' $\lambda=0.456$, $F(4,15)=4.48$, $p=0.012$, partial $\eta^2=0.544$). Bonferroni post hoc analysis indicated that Group B showed significant reductions in SBS between cycles 1→3 ($p=0.008$), 1→5 ($p<0.001$), and 2→5 ($p=0.004$). Group A demonstrated no statistically significant differences between consecutive cycles (all $p>0.05$).

Debonding failure patterns were categorized using adhesive remnant index (ARI) scoring [17]. In Group B, initial cycles predominantly demonstrated cohesive failure within the adhesive (ARI 3), transitioning to adhesive failure at the enamel-adhesive interface (ARI 1-2) by the fifth cycle. Group A consistently showed mixed failure modes across all cycles.



a)



b)

Figure 1. Graph of average shear bond strength. a) 1st Repetition, b) 5th Repetition.

Representative load-displacement curves **(Figure 1)** illustrate distinct mechanical behaviors between groups. First-cycle Group B specimens exhibited sharp, high-magnitude peaks (>100 N) characteristic of brittle failure, consistent with high initial SBS values. Fifth-cycle Group B specimens demonstrated reduced peak forces with irregular load distributions, indicating compromised interfacial integrity. Group A specimens showed consistent, lower-magnitude curves across all cycles, suggesting more ductile failure patterns.

The present findings demonstrate that repeated bonding with identical orthodontic brackets significantly compromises shear bond strength, with the magnitude of degradation dependent upon adhesive formulation. These results have important clinical implications for orthodontic practice, particularly regarding bracket recycling protocols and treatment efficiency.

The significantly higher initial SBS observed with Transbond XT® (Group B) aligns with established literature regarding filled adhesive systems. This adhesive incorporates bisphenol A diglycidyl methacrylate (Bis-GMA) and triethylene glycol dimethacrylate (TEGDMA) monomers with optimized silica filler loading, facilitating enhanced micromechanical retention through improved resin tag formation and reduced polymerization shrinkage [13, 14, 18-21]. The superior penetration of low-viscosity monomers into acid-etched enamel creates robust mechanical interlocking, explaining the elevated initial bond values.

Conversely, the lower initial SBS of Enlight® (Group A) likely reflects its formulation characteristics, which prioritize handling properties and fluoride release over maximum bond strength. Nevertheless, the observed mean value of 9.92 MPa exceeds the minimum clinically acceptable threshold of 5.9–7.8 MPa recommended for orthodontic applications, indicating adequate clinical performance [22-26].

The divergent degradation patterns between adhesive systems represent a novel finding with significant clinical relevance. The precipitous decline in Group B SBS—particularly the 78.9% reduction from initial to fifth cycle—suggests cumulative damage to the bracket-enamel interface that compromises the high-performance characteristics of filled adhesives.

Several mechanisms likely contribute to this degradation: Enamel Surface Alteration: Repeated acid-etching (five cycles × 20 seconds = 100 seconds total exposure) progressively removes enamel perikymata and alters prism morphology, reducing available surface area for micromechanical retention [4, 27-32]. Previous studies indicate that multiple etching cycles can extend resin tag depth but compromise tag integrity, creating weaker interfacial zones [33-35]. Bracket Mesh Degradation: The flaming technique, while effective for adhesive removal, induces thermal stress on stainless steel mesh structures. Repeated thermal cycling (5× heating/quenching) may alter mesh geometry, reduce undercut retention features, and potentially induce surface oxidation that compromises chemical adhesion [36-39]. Adhesive Residue Accumulation: Despite cleaning protocols, microscopic adhesive remnants within mesh interstices may accumulate across cycles, creating a "hybrid" interface with compromised mechanical properties. Additionally, repeated light-curing exposure may cause residual monomer degradation or filler particle dislodgement, reducing bond homogeneity [40-42].

The relative stability of Group A SBS across cycles suggests that simplified adhesive formulations may be more tolerant of interfacial imperfections. The lower filler content and modified monomer ratios in Enlight® may facilitate better adaptation to minimally compromised enamel and bracket surfaces, though at the cost of reduced peak bond strength.

These findings challenge the conventional clinical practice of repeated bracket recycling, particularly when using high-performance filled adhesives. The drop in Group B SBS below 5.9 MPa by the fifth cycle indicates a high risk of clinical failure, potentially necessitating additional rebonding appointments, extended treatment duration, and increased costs [43-46].

The results suggest that when multiple rebonding events are anticipated—particularly in patients with high bracket failure rates—adhesives with stable, moderate bond strength (such as Group A) may offer superior long-term performance compared to high-peak adhesives that degrade rapidly. However, this

must be balanced against the risk of enamel fracture with higher bond strengths, as cohesive enamel failure represents a more serious clinical complication than adhesive failure [47, 48].

From a clinical protocol perspective, these data support:

1. Limiting bracket recycling to fewer cycles when using high-filler adhesives
2. Implementing alternative cleaning methods (e.g., ultrasonic, sandblasting) that may preserve mesh integrity better than thermal techniques
3. Considering bracket replacement rather than recycling after the third bonding failure, particularly with filled adhesive systems
4. Prioritizing enamel-preserving cleaning protocols, including air-polishing with sodium bicarbonate rather than rotary instrumentation where feasible [49]

The present results corroborate findings by Sadhiya *et al*. [40] and Eslamian *et al*. [50], who documented significant SBS reductions after multiple debonding cycles. However, our study extends these observations by characterizing the differential performance of distinct adhesive classes under identical recycling conditions, suggesting that adhesive selection should be tailored to anticipated rebonding frequency.

Conversely, our findings diverge from reports by Quick *et al*. [51] and Khanal *et al*. [52], who observed maintained bond strength after optimized recycling protocols. This discrepancy likely reflects methodological differences in cleaning techniques, bracket types, or adhesive systems, underscoring the critical importance of protocol standardization in clinical recycling procedures.

This in vitro study presents inherent limitations. The use of extracted teeth stored in distilled water may not fully replicate the dynamic oral environment, including thermal fluctuations, humidity changes, and functional loading. Additionally, the standardized debonding procedure (shear force only) does not simulate complex intraoral force vectors.

The flaming technique, while clinically relevant, may not represent the optimal recycling method. Future investigations should compare multiple cleaning modalities (sandblasting, ultrasonic bath, chemical solvents) across repeated cycles to identify protocols that best preserve both bracket and enamel integrity. Additionally, microscopic analysis (SEM, AFM) of enamel and bracket mesh surfaces after multiple cycles would elucidate the structural mechanisms underlying SBS degradation.

Conclusion

Within the constraints of this in vitro investigation, several key findings emerge. Repeated bonding using the same orthodontic brackets markedly diminishes shear bond strength, with the extent of this decline varying by adhesive type. Adhesives with high filler content, such as Transbond XT®, deliver robust initial bond strength but undergo steady deterioration over successive cycles, dropping below clinically viable levels by the fifth rebonding. In contrast, simpler adhesive systems like Enlight® yield modestly lower yet consistently stable bond strengths through multiple cycles, staying within acceptable clinical limits. Therefore, clinicians should tailor adhesive choices to expected rebonding needs, favoring bracket replacement over reuse—especially with premium adhesives when repeated failures arise.

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Conflict of Interest: None

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