RESEARCH PAPER

Evaluation of Shear Bond Strength of Conventional versus Moisture-Insensitive Orthodontic Adhesives Following Acute Thermocycling: An In Vitro Study

Dr. Soumya Mishra[1*], Dr Krishna S[2], Dr P.V.S. Ankita[3], Dr. Saibalini Pani[4], Dr. Abhishek Dubey[5], Dr. Shubhra Chandan Saha[6]

[1]PGT, Dept of Orthodontics and Dentofacial Orthopaedics, Institute of Dental Sciences, Siksha O Anusandhan (Deemed to be University).Email ID: soumyamishra32@gmail.com, ORCID - 0009-0001-4938-4098
[2]PGT, Dept of Orthodontics and Dentofacial Orthopaedics, Institute of Dental Sciences, Siksha O Anusandhan (Deemed to be University). Email ID: krishnasmith99@gmail.com ORCID : 0009-0002-0950-5022
[3]PGT Dept of Orthodontics and Dentofacial Orthopaedics, Institute of Dental Sciences, Siksha O Anusandhan (Deemed to be University). Email ID: pvsankita125@gmail.com ORCID ID: 0009-0004-3495-1629
[4]Associate Professor, Department of Orthodontics and Dentofacial Orthopaedics, Institute of Dental Sciences, Siksha O Anusandhan (Deemed to be University). Vaisakhi.pani@gmail.com , ORCID ID :0009-0000-9008-0013
[5]PGT Dept of Orthodontics and dentofacial orthopedics, Institute of Dental Sciences, Siksha O Anusandhan (Deemed to be University). abhidubey9820@gmail.com, ORCID - 0009-0005-1284-6657
[6]PGT Dept of Public Health Dentistry, Institute of Dental Sciences, Siksha O Anusandhan (Deemed to be University). drsubhrasaha@gmail.com. ORCID - 0009-0007-5540-6461

Corresponding author
Dr. Soumya Mishra
Email ID: soumyamishra32@gmail.com

ABSTRACT

Objective: To evaluate and compare the shear bond strength (SBS) and adhesive remnant index (ARI) of conventional and moisture-insensitive orthodontic adhesives after acute thermocycling simulation. **Materials and Methods:** Sixty extracted human premolars were randomly divided into two groups (n=30 each): Group 1 bonded with conventional adhesive (Transbond XT); Group 2 bonded with moisture-insensitive adhesive (Transbond MIP). All samples underwent 500 thermocycles (5°C-55°C, 30-second dwell time). SBS was measured using a Universal Testing Machine, and ARI scores were assessed under stereomicroscope at 10× magnification. Statistical analysis included independent t-test and Chi-square test (α=0.05). **Results:** Mean SBS fo r Transbond XT was 12.34±2.67 MPa versus 13.89±2.41 MPa for Transbond MIP (p=0.021). Both groups showed predominantly cohesive failures with no significant difference in ARI distribution (p=0.312). **Conclusions:** Moisture-insensitive adhesive exhibited significantly higher shear bond strength following acute thermocycling while maintaining clinically acceptable bond strengths (>6 MPa). Both adhesives demonstrated favorable failure patterns, suggesting moisture-insensitive systems may provide superior performance during the critical initial bonding period.

Keywords: Shear bond strength; Thermocycling; Orthodontic adhesive; Moisture-insensitive primer; Bracket bonding

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INTRODUCTION

Orthodontic bracket bond failure remains a significant clinical challenge, contributing to extended treatment duration, increased chair time, and patient dissatisfaction.[1,2] The oral environment presents unique challenges for adhesive stability, including thermal fluctuations from hot and cold beverages that create repetitive expansion and contraction at the adhesive-enamel interface.[3,4]

Conventional orthodontic adhesives like Transbond XT (3M Unitek) employ hydrophobic bonding systems requiring meticulous moisture control during application.[5] These systems demonstrate excellent bond strength under ideal conditions but remain vulnerable to contamination—common in clinical scenarios, particularly during molar bonding or with pediatric patients.[6]

Moisture-insensitive adhesive systems such as Transbond MIP (Moisture Insensitive Primer, 3M Unitek) incorporate hydrophilic primers that tolerate moisture contamination while maintaining adequate bond strength.[7,8] The primer's unique chemistry allows

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**Author for Correspondence:* soumyamishra32@gmail.com penetration through surface moisture, establishing chemical bonding with underlying enamel structure.

Thermocycling represents an established methodology for simulating thermal stress experienced by dental materials.[9] While extensive thermocycling (10,000+ cycles) has been investigated for long-term degradation,[10] limited research addresses acute thermal stress effects on newly bonded brackets—a clinically relevant scenario as patients often resume normal dietary habits shortly after placement. The 500-cycle protocol represents approximately 6 months of clinical exposure,[11] providing insight into early bond performance during the critical stabilization period.

Despite numerous investigations comparing these adhesives under various contamination scenarios,[12,13] limited research examines their comparative performance specifically following acute thermocycling stress. This study aimed to evaluate and compare the shear bond strength and failure modes of conventional versus moisture-insensitive orthodontic adhesives following 500 thermocycles.

Null Hypothesis: There is no statistically significant difference in shear bond strength between conventional and moisture-insensitive orthodontic adhesives following acute thermocycling.

2. MATERIALS AND METHODS

2.1 Sample Collection and Preparation

Sixty freshly extracted human premolars were collected. Teeth were extracted for therapeutic orthodontic purposes from patients aged 12-35 years with informed consent obtained.

Inclusion criteria: Intact buccal enamel without cracks, caries, or restorations; no prior orthodontic treatment; complete root formation; extraction within 1 month of study.

Exclusion criteria: Enamel fractures or structural anomalies; fluorosis or demineralization; previous bonding; buccal surface restorations.

Teeth were cleaned, stored in 0.1% thymol solution at room temperature for maximum 1 month,[14] then embedded in self-cure acrylic resin using cylindrical molds (20mm diameter × 25mm height) with buccal surfaces positioned perpendicular to the mold base.

2.2 Sample Size and Randomization

Sample size calculation (G*Power 3.1.9.7) with effect size $d=0.75$, $\alpha=0.05$, power=0.80 indicated minimum 24 teeth per group. To account for potential losses, 30 teeth per group were included (total n=60). Computer-generated random numbers allocated teeth to:

- **Group 1:** Conventional adhesive (Transbond XT, 3M Unitek) (n=30)
- **Group 2:** Moisture-insensitive adhesive (Transbond MIP, 3M Unitek) (n=30)

2.3 Bonding Procedure

All bonding was performed by a single experienced orthodontist under standardized conditions.

Surface Preparation (Both Groups):

1. Cleaning with fluoride-free pumice for 10 seconds
2. Water rinsing for 10 seconds
3. Air-drying for 10 seconds
4. Etching with 37% phosphoric acid gel for 30 seconds
5. Water rinsing for 15 seconds
6. Air-drying for 15 seconds until chalky white appearance

Group 1 (Transbond XT):

- Transbond XT Primer applied and light-cured for 10 seconds (LED, 1200 mW/cm²)
- Transbond XT adhesive applied to bracket base
- Bracket positioned (stainless steel premolar, 0.022" slot, MBT, 3M Unitek)
- Excess adhesive removed
- Light-curing: 10 seconds each from mesial, distal, occlusal, gingival (total 40 seconds)

Group 2 (Transbond MIP):

- Transbond MIP Primer applied with scrubbing motion for 3 seconds
- Gentle air-thinning for 2 seconds (no primer curing)

- Identical bracket bonding and curing as Group 1

Bracket base area: 3.2mm × 2.8mm = 8.96mm²

2.4 Thermocycling Protocol

Twenty-four hours post-bonding, specimens underwent thermocycling (SD Mechatronik THE-1100) with:

- 500 cycles between 5±2°C and 55±2°C
- 30-second dwell time per bath
- 10-second transfer time
- Distilled water medium

2.5 Shear Bond Strength Testing

Following thermocycling, specimens were stored in distilled water at 37°C for 24 hours. SBS was measured using Universal Testing Machine (Instron 3345) with:

- Crosshead speed: 0.5 mm/min
- Chisel edge positioned at bracket-adhesive interface
- Force applied occluso-gingivally

SBS Calculation: SBS (MPa) = Force (N) / Bracket Base Area (mm²)

2.6 Adhesive Remnant Index (ARI)

Debonded surfaces were examined under stereomicroscope (Olympus SZ61, 10×) and scored according to Årtun and Bergland: [15]

- **Score 0:** No adhesive on enamel
- **Score 1:** <50% adhesive on enamel
- **Score 2:** >50% adhesive on enamel
- **Score 3:** All adhesive on enamel

Two calibrated examiners independently scored specimens, with inter-examiner reliability assessed using Cohen's kappa.

2.7 Statistical Analysis

SPSS 26.0 was used with α=0.05. Shapiro-Wilk test assessed normality. Independent t-test compared SBS between groups. Chi-square test analyzed ARI distribution. Cohen's d calculated effect size.

3. RESULTS

3.1 Shear Bond Strength

All 60 specimens completed the protocol without premature failures. Shapiro-Wilk test confirmed normal distribution for both groups (p>0.05).

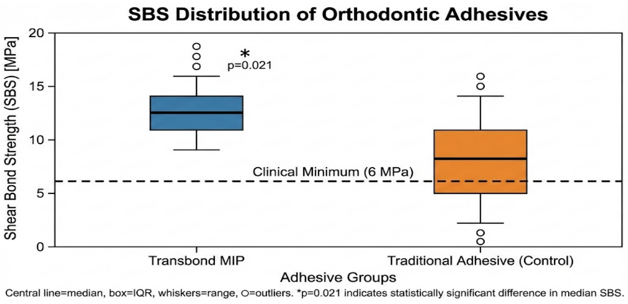
Table 1: Descriptive Statistics for Shear Bond Strength (MPa)

Group	Adhesive	n	Mean	SD	Median	Min	Max	95% CI
1	Transbond XT	30	12.34	2.67	12.15	7.82	17.56	11.34-13.34
2	Transbond MIP	30	13.89	2.41	13.72	9.14	18.92	13.00-14.78

Independent t-test results:

- Mean difference: 1.55 MPa
- t(58) = 2.365, p = 0.021
- 95% CI: 0.24-2.86 MPa
- Cohen's d = 0.612 (medium effect)

Transbond MIP demonstrated significantly higher SBS (12.6% increase) compared to Transbond XT (p=0.021). Both systems exceeded the clinical minimum of 6-8 MPa.[2]



Central line=median, box=IQR, whiskers=range, ○=outliers. *p=0.021 indicates statistically significant difference in median SBS.

Figure 1 : Box plot showing SBS distribution. Central line=median, box=IQR, whiskers=range, ○=outliers. Dashed line at 6 MPa indicates clinical minimum.

Transbond MIP shows higher median and narrower distribution (*p=0.021).

3.2 Adhesive Remnant Index

Cohen's kappa = 0.847 (excellent inter-examiner agreement). Only 4 specimens (6.7%) required third examiner adjudication.

Table 2: ARI Score Distribution

ARI Score	Description	Transbond XT n(%)	Transbond MIP n(%)	Total n(%)
0	No adhesive	3 (10.0)	2 (6.7)	5 (8.3)
1	<50% adhesive	11 (36.7)	8 (26.7)	19 (31.7)
2	>50% adhesive	13 (43.3)	16 (53.3)	29 (48.3)
3	All adhesive	3 (10.0)	4 (13.3)	7 (11.7)

Chi-square results: $\chi^2=1.165$, df=3, p=0.762

No significant difference in failure mode distribution. Both groups showed predominantly cohesive failures (ARI 1-2: 80% for both).

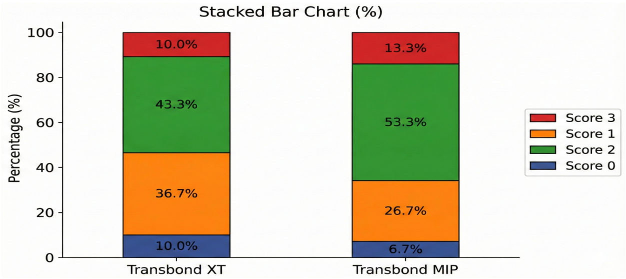


Figure 2: Percentage distribution of ARI scores showing similar failure patterns between groups. Both demonstrate predominantly cohesive failures (Scores 1-2 combined: 80% each), $\chi^2=1.165$, p=0.762.

3.3 Performance Categories

Table 3: SBS Category Distribution

Category	Range (MPa)	Transbond XT	Transbond MIP
Below optimal	<8.0	2 (6.7%)	0 (0%)
Optimal	8.0-14.0	20 (66.7%)	18 (60.0%)
High	>14.0	8 (26.7%)	12 (40.0%)

All Transbond MIP specimens achieved SBS >8 MPa, while 2 Transbond XT specimens (6.7%) fell below this threshold.

4. DISCUSSION

This study demonstrates that moisture-insensitive adhesive (Transbond MIP) exhibits significantly higher shear bond strength compared to conventional adhesive (Transbond XT) following acute thermocycling (p=0.021). The 12.6% difference in mean SBS, while statistically significant, must be interpreted within clinical context.

4.1 Clinical Implications

Both adhesives substantially exceeded Reynolds' recommended minimum of 6-8 MPa,(2) indicating adequate clinical performance. However, Transbond MIP's higher bond strength and reduced variability (CV: 17.3% vs 21.6%) may provide advantages in:

- Early dietary habits with temperature-extreme beverages
- High-risk bonding sites (molars with challenging moisture control)
- Pediatric patients with reduced cooperation
- Patients with suboptimal enamel conditions

The 500-cycle protocol approximates 6 months of thermal exposure,(11) representing the critical initial stabilization period when bracket failures most commonly occur.(16)

4.2 Mechanistic Interpretation

The superior performance of moisture-insensitive adhesive following thermocycling relates to several mechanisms:

Hydrophilic Primer Chemistry: Transbond MIP's hydrophilic primer containing phosphoric acid methacrylate and HEMA(7) enables deeper enamel penetration, creating extensive resin tag formation and increased bonding surface area.(17) The hydrophilic nature facilitates hydrogen bonding with residual water molecules and hydroxyapatite, potentially creating more stable transitions during thermal cycling.

Thermal Stress Resistance: Thermocycling induces repetitive stress through differential thermal expansion coefficients among enamel (11.4×10^{-6}/°C), resin composite ($25\text{-}50\times10^{-6}$/°C), and stainless steel (10.4×10^{-6}/°C).(3)The hydrophilic primer's moisture tolerance may mitigate water-induced plasticization and hydrolytic degradation that compromise conventional hydrophobic primers during thermal cycling.(18)

4.3 Comparison with Literature

Our findings align with Vicente et al. (2009)(12) who reported superior MIP performance under contamination, extending this to demonstrate advantages persist under thermal stress even in ideally bonded specimens. This suggests the performance benefit derives from enhanced interfacial stability beyond just contamination resistance.

Uysal et al. (2010)(13) reported comparable or slightly higher SBS for hydrophilic primers with 1000 thermocycles. Our shorter 500-cycle protocol specifically targets acute effects during the critical early bonding period, revealing differential thermal stress resistance.

In contrast to Ekizer et al. (2012)(19)who found no difference after combined thermocycling and mechanical loading, our isolated thermal stress protocol reveals specific thermal resistance advantages that may be obscured when multiple stress factors interact.

4.4 ARI Interpretation

The similar ARI distribution (p=0.762) with predominantly cohesive failures (80% for both groups) is clinically favorable:

- Indicates bond strength exceeded adhesive cohesive strength
- Minimizes enamel damage risk during debonding
- Facilitates efficient adhesive cleanup

The low frequency of ARI Score 3 (10-13%) suggests minimal enamel fracture risk, representing ideal balance between adequate retention and safe debonding. Since both adhesives use identical Transbond XT paste with only primer differences, the SBS advantage of MIP reflects enhanced interfacial bonding rather than altered adhesive properties.

4.5 Study Limitations

In Vitro Constraints: While thermocycling simulates thermal stress, the oral environment presents additional challenges not replicated: enzymatic degradation, pH fluctuations, combined thermal-mechanical stress, continuous moisture exposure, and biofilm formation.

Extracted Tooth Model: Teeth stored in thymol solution,(14) while validated short-term, may differ subtly from in vivo enamel regarding permeability, dentinal fluid pressure, and pellicle presence.

Single Stress Modality: The study isolated thermocycling without combined mechanical loading. Clinical failures often result from combined thermal-mechanical fatigue, which may produce different relative performance.

Standardized Conditions: Laboratory bonding occurred under ideal conditions (perfect moisture control, optimal lighting). Clinical bonding involves greater variability that may influence relative performance differently.

4.6 Future Directions

Extended thermocycling studies (5,000-10,000 cycles) should assess whether the acute advantage persists during long-term thermal aging. Combined thermo-mechanical cycling with pH cycling would better simulate complex oral conditions. Prospective clinical trials using split-mouth design could validate laboratory findings with actual patient outcomes and dietary habit documentation.

Material characterization studies including water sorption analysis, thermal expansion coefficient measurement via DMA, and confocal microscopy of resin tag formation would elucidate the physical basis for differential thermocycling resistance.

5. CONCLUSIONS

Within this study's limitations:

1. Moisture-insensitive adhesive (Transbond MIP) demonstrated significantly higher shear bond strength (13.89±2.41 MPa) compared to conventional adhesive (12.34±2.67 MPa) following 500 thermocycles (p=0.021).

2. Both adhesive systems maintained bond strengths substantially exceeding clinical minimum thresholds (6-8 MPa), indicating adequate performance despite thermal stress.

3. No significant difference in failure mode distribution (p=0.762), with both showing predominantly cohesive failures (80%) suggesting favorable patterns minimizing enamel damage risk.

4. Moisture-insensitive adhesive exhibited reduced variability (17.3% vs 21.6%), indicating more predictable performance.

5. The null hypothesis is rejected based on statistically significant SBS difference with clinically meaningful effect size (Cohen's d=0.612).

Clinical Recommendations:

- Consider moisture-insensitive adhesives for challenging bonding scenarios (molars, pediatric patients, suboptimal moisture control)

- Provide dietary guidance emphasizing moderation of temperature-extreme beverages during initial post-bonding period

- Maintain meticulous bonding protocols regardless of adhesive system

- Evaluate individual patient risk factors when selecting adhesive systems

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