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Shear Bond Strength of Hydrophilic and Conventional Orthodontic Primers Under Dry and Saliva-Contaminated Conditions: An In-Vitro Study

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Abstract

Aim

Moisture contamination during orthodontic bonding can adversely affect bracket adhesion, particularly when conventional hydrophobic primers are used. This in-vitro study aimed to compare the shear bond strength (SBS) and adhesive remnant index (ARI) of a hydrophilic primer (Bracepaste MTP) with those of a conventional primer (Transbond XT) and a moisture-insensitive primer (Transbond MIP) under dry and saliva-contaminated conditions.

Methods

Eighty extracted human premolars obtained from patients undergoing orthodontic treatment were randomly allocated using a computer-generated randomization method into four groups (n = 20): Group A, Transbond XT under dry conditions; Group B, Bracepaste MTP under dry conditions; Group C, Transbond MIP under moist conditions; and Group D, Bracepaste MTP under moist conditions. Following etching with 37% phosphoric acid, primers were applied according to manufacturers' instructions. Artificial saliva contamination was performed in the moist groups before primer application. Stainless steel premolar brackets were bonded using Bracepaste adhesive and light-cured with an LED curing unit. Specimens were stored in artificial saliva for 24 hours before SBS testing using a universal testing machine at a crosshead speed of 1 mm/min. ARI scores were evaluated under a stereomicroscope at ×10 magnification by a blinded examiner. Data were analyzed using one-way ANOVA, Tukey post-hoc test, and Chi-square test ($\alpha = 0.05$).

Results

Significant differences in SBS values were observed among the groups ($P < 0.001$). Group A demonstrated the highest mean SBS (13.93 ± 2.23 MPa), which was significantly greater than Groups B, C, and D ($P < 0.001$). No statistically significant differences were found among Groups B (11.09 ± 0.93 MPa), C (10.96 ± 1.04 MPa), and D (10.71 ± 1.02 MPa) ($P > 0.05$). All groups demonstrated clinically acceptable bond strengths. ARI score distributions showed no statistically significant differences among groups ($P = 0.627$), with score 1 being the most frequent finding.

Conclusion

Conventional Transbond XT primer exhibited superior bond strength under dry conditions. Moisture contamination reduced SBS values in all tested systems; however, Bracepaste MTP maintained clinically acceptable bond strength under both dry and moist conditions, comparable to Transbond MIP. Within the limitations of this in-vitro study, Bracepaste MTP may be considered a suitable alternative for orthodontic bonding in situations where moisture control is difficult. Further in-vivo studies incorporating thermocycling and long-term aging are recommended.

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Keywords: Bonding, Moisture tolerance, Orthodontic primer, Saliva contamination, Shear bond strength.

Background

Bonding orthodontic brackets to enamel is a fundamental step in orthodontic treatment, as it ensures the brackets remain stable throughout the treatment. Achieving reliable adhesion minimizes the need for time-consuming rebonding procedures, enhances overall treatment efficiency, and reduces the risk of bracket detachment (1,2). Several factors influence the bond strength of orthodontic brackets to enamel, including the adhesive type and composition, curing method, etching time, etchant concentration, bracket base design, force application technique, and testing conditions. Adequate bond strength is necessary to withstand orthodontic forces and minimize bracket failure during treatment. However, excessively high bond strength should also be avoided to ensure safe bracket removal at the end of treatment without causing enamel damage (3–5).

Orthodontic bonding is a technique-sensitive procedure, with moisture contamination reported as one of the most common causes of bond failure, significantly reducing shear bond strength (5–7). Conventional Bisphenol A glycidal methacrylate (BISGMA) resins, despite their hydroxyl groups, are hydrophobic in nature and only effective in dry environments (8,9). Moisture exposure during bonding results in plugging of pores due to acid etching and a loss of surface energy, reducing the resin's ability to penetrate and compromising micromechanical retention (9,10). Such difficulty can be encountered in various clinical situations, especially while bonding in difficult-to-reach areas near second molars, particularly in moist conditions during surgical exposure of partially erupted or impacted teeth (10-12). It is suggested that saliva or blood contamination, even for a moment, can inhibit bonding, as these deposits form organic adhesive coatings that do not wash off.

As materials science advances, new materials have emerged, including primers that are moisture-insensitive and designed to perform similarly in wet environments. Primers with hydrophilic properties overcome the disadvantages of reduced adhesion of conventional primers. Hydrophilic primers contain ingredients such as hydroxyethyl methacrylate (HEMA), a low-molecular-weight monomer that enhances the wettability and the diffusion of adhesive monomers into the enamel and dentin microstructure. This property enables primers to better penetrate moist tooth surfaces, improving the bond strength even in the presence of saliva or moisture (13,14).

Conventional primers like Transbond XT maintain superior shear bond strength (SBS) in dry environments but are compromised by moisture. Since the introduction of hydrophilic primers, various studies have evaluated the effect of moisture contamination on shear bond strength (15–19). Hydrophilic primers provided clinically acceptable SBS under moist conditions, with Transbond MIP (Moisture insensitive primer) having the highest mean SBS among the hydrophilic primers (20,21).

Although several studies have evaluated moisture-insensitive primers such as Transbond MIP, limited evidence exists regarding the bonding performance of the recently introduced Bracepaste MTP under saliva contamination (8,22,23).

Bracepaste MTP (Moisture Tolerant Primer) can be easily applied with a brush, and is also a time saver as there is no need to dry after rinsing etch. Bracepaste MTP can be used in place of other primers or sealants and works with any light curable bracket adhesive. So, the present study aimed to compare the shear bond strength of the new hydrophilic primer, Bracepaste MTP, after saliva contamination with that of Transbond MIP.

Methods

Study Design and Sample Preparation

This in-vitro study used a sample of 80 intact extracted premolars collected from the Department of Oral and Maxillofacial Surgery, Mahabubnagar, Telangana, India. Premolars extracted for orthodontic purposes from patients aged 12–25 years were used. Teeth were stored in 0.1% thymol solution for no longer than three months prior to experimentation at room temperature to maintain specimen integrity. The study's protocol was approved by the Institutional Ethical Committee (SVSIDS/ORTHO/4/2019,Mahbubnagar, Telangana, India). Care was taken during sample selection to include only teeth with intact buccal surfaces and to exclude those with caries, fluorosis, restorations, hypoplasia, attrition, abrasion, erosion, fracture, or any chemical pretreatment.

An a priori sample size calculation was performed using G*Power software (version 3.1.9.7; Heinrich-Heine-Universität Düsseldorf, Germany). Based on a significance level of 0.05, a statistical power of 80%, and an effect size derived from previous studies evaluating hydrophilic orthodontic primers under moisture contamination, the minimum required sample size was determined to be 20 specimens per group.

Following sample preparation, 80 extracted human premolars were randomly assigned to four experimental groups (n = 20) using a computer-generated randomization sequence. Allocation was performed by an independent investigator to minimize selection bias and ensure equal distribution of samples among the study groups.

Then the samples were mounted on color-coded acrylic resin blocks, with only the crown portion visible and the roots completely embedded in the blocks. Figure 1 illustrates the flowchart of sample grouping. Before bonding, the teeth were cleaned with an ultrasonic cleaner (CD-4831, Codyson Electrical Co. Ltd., Shenzhen, China) and polished with pumice using a rubber prophylactic cup. Stainless steel MBT 0.022×0.028" premolar brackets (American Orthodontics, Sheboygan, USA) were used in the study with a bracket base surface area of 9.806 mm2 as described by the manufacturers. Transbond XT Primer (3M Unitek, Monrovia, California), Bracepaste MTP (American Orthodontics, Sheboygan, USA), Transbond MIP (3M Unitek, Monrovia, California, USA) primers, and Bracepaste adhesive (American Orthodontics, Sheboygan, USA) were used in this study (Figure 2).

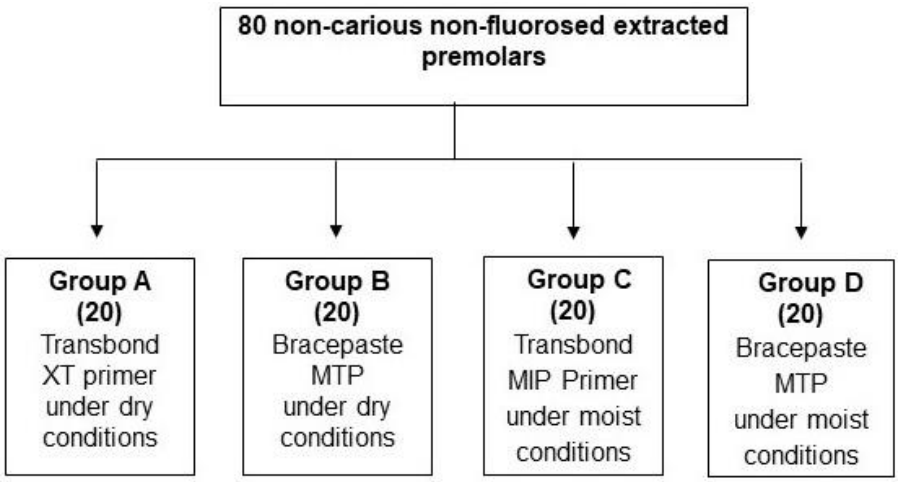

Figure 1: Flowchart of sample grouping. Group A (control, dry condition) Group B (Experimental, dry condition); Group C (control, moist condition); Group D (Experimental, moist condition)



Figure 2: Primers: Transbond XT Primer, Bracepaste MTP, Transbond MIP (left to right) and Bracepaste Adhesive (American Orthodontics, Sheboygan, WI, USA).



Figure 3: Stereomicroscope used in this study (Meiji Techno, Japan)

Bonding Procedure

Bonding procedures of primers were evaluated under two different enamel surface conditions, i.e., dry and moist enamel surfaces. Table 1 summarizes the bonding procedures in each group. In all the four groups, the samples were etched with 37% orthophosphoric acid gel (Neoetch gel, Orikam, India) for 30 seconds, rinsed with water, and air-dried until a frosty-white appearance was attained.

Table 1. Bonding procedures for different groups

Groups	Bonding procedure				
Group A	Etching drying	-	Transbond XT Primer	light-curing	Bonding and curing
Group B	Etching drying	-	Bracepaste MTP	light-curing	Bonding and curing
Group C	Etching drying	Saliva	Transbond MIP	light-curing	Bonding and curing
Group D	Etching drying	Saliva	Bracepaste MTP	light-curing	Bonding and curing

In the dry enamel surface groups (groups A and B), after etching and drying, a thin layer of Transbond XT Primer and Bracepaste MTP was placed on the etched surfaces, respectively, and photopolymerized for 10 seconds using an LEDition (Ivoclar Vivadent 600 mW/cm2). In the moist enamel surface groups (groups C and D) after etching and drying, 0.5 mL of artificial saliva (Wet Mouth, ICPA Health Products Ltd., Mumbai, India) was applied in two coats to the etched surface using an applicator brush, followed by blot drying with sterile gauze to achieve a visible, moist surface. Then a thin layer of Transbond MIP and Bracepaste MTP was applied to the tooth surface, respectively, and polymerized for 10 seconds using an LEDition (Ivoclar Vivadent, Schaan, Liechtenstein). Later, in all the four groups, Bracepaste adhesive was applied to the premolar brackets' base and positioned near the center of the facial tooth surface. An explorer was used to remove excess adhesive around the bracket base, and the bracket was polymerized with an LEDition for 20 seconds (5 seconds from each side). Bonding procedures were performed by a single calibrated operator to reduce operator variability.The samples were preserved in artificial saliva for 24 h after bonding.

Shear Bond Strength and ARI Evaluation

A universal testing machine (DAK System Inc., Series 7200, India) was used to determine shear bond strength at a crosshead speed of 1 mm/min during SBS testing. The maximum load required for bracket debonding or fracture was measured in Newtons. The SBS per unit area was calculated by dividing the force required to debond the bracket by the bracket base surface area. A custom jig was used to align the bracket base parallel to the shearing blade.

Debonding of the brackets was followed by examining the enamel surfaces under a stereomicroscope (Meiji Techno, Japan) at ×10 magnification (Figure 3). The ARI (Adhesive Remnant Index), described by Artun and Bergland, was used to determine the amount of adhesive remaining on the enamel surface (24).

The ARI is a scoring system used in orthodontic research to evaluate how much adhesive remains on the tooth surface after debonding an orthodontic bracket. It helps determine the site of bond failure (whether the failure occurred at the bracket–adhesive interface or the adhesive–enamel interface).

The ARI is usually assessed under a microscope and scored as follows:

- **Score 0:** No adhesive left on the tooth (all adhesive remained on the bracket).
- **Score 1:** Less than 50% of the adhesive left on the tooth surface.
- **Score 2:** More than 50% of the adhesive left on the tooth surface.
- **Score 3:** All adhesive left on the tooth surface, with a clear impression of the bracket mesh.

The operator performing SBS testing and ARI evaluation was blinded to group assignment.

Statistical Analysis

Statistical analysis was performed using SPSS software (version 21.0; IBM Corp., Armonk, NY, USA). Descriptive statistics, including means and standard deviations, were calculated for each group. The normality of data distribution was assessed using the Shapiro–Wilk test, confirming that the data were normally distributed ($P > 0.05$). Therefore, parametric tests were applied. A one-way analysis of variance (ANOVA) was employed to compare the mean shear bond strength values among the experimental groups. In the event of significant differences, Tukey's HSD post-hoc test was applied for pairwise comparisons. Furthermore, the Adhesive Remnant Index (ARI) scores were analyzed using Chi-Squared test. The level of statistical significance for all tests was set at $P < 0.05$.

Results

Table 2 presents shear bond strengths, including means, standard deviations (SD), minimums, maximums and range of all four groups. According to the Table, there were significant differences between four groups (P=0.000). Post hoc multiple comparisons (Table 3) showed that Group A had significantly higher SBS compared with Group B (mean difference = 2.83 MPa, P < 0.001), Group C (mean difference = 2.97 MPa, P < 0.001), and Group D (mean difference = 3.22 MPa, P < 0.001). However, no statistically significant differences were found among Groups B, C, and D (P > 0.05).

Figure 4 shows the mean shear bond strength values of the four groups. Under dry conditions, the Transbond XT primer was associated with significantly higher shear bond strengths compared to other groups.

Table 2. Mean, SD, maximum, minimum and range of shear bond strength of different groups in this study (MPa)

	N	Mean	SD	Maximum	Minimum	Range	p-value
Group A	20	13.93	2.23	17.34	9.69	7.65	<0.000
Group B	20	11.09	0.93	13.05	9.69	3.36	
Group C	20	10.96	1.04	12.54	8.87	3.67	
Group D	20	10.71	1.02	12.03	8.77	3.26	

Table 3. Post hoc tests – multiple comparisons between the groups

GROUPS (I)	GROUPS (J)	Mean Difference (I-J)	Standard Error	P-value	95% Confidence Interval	
					Lower Bound	Upper Bound
A	B	2.83450*	0.44561	0.000	1.6640	4.0050
	C	2.97150*	0.44561	0.000	1.8010	4.1420
	D	3.22100*	0.44561	0.000	2.0505	4.3915
B	A	-2.83450*	0.44561	0.000	-4.0050	-1.6640
	C	0.13700	0.44561	0.990	-1.0335	1.3075
	D	0.38650	0.44561	0.822	-0.7840	1.5570
C	A	-2.97150*	0.44561	0.000	-4.1420	-1.8010
	B	-0.13700	0.44561	0.990	-1.3075	1.0335
	D	0.24950	0.44561	0.944	-0.9210	1.4200
D	A	-3.22100*	0.44561	0.000	-4.3915	-2.0505
	B	-0.38650	0.44561	0.822	-1.5570	0.7840
	C	-0.24950	0.44561	0.944	-1.4200	0.9210

*. The mean difference is significant at the 0.05 level.

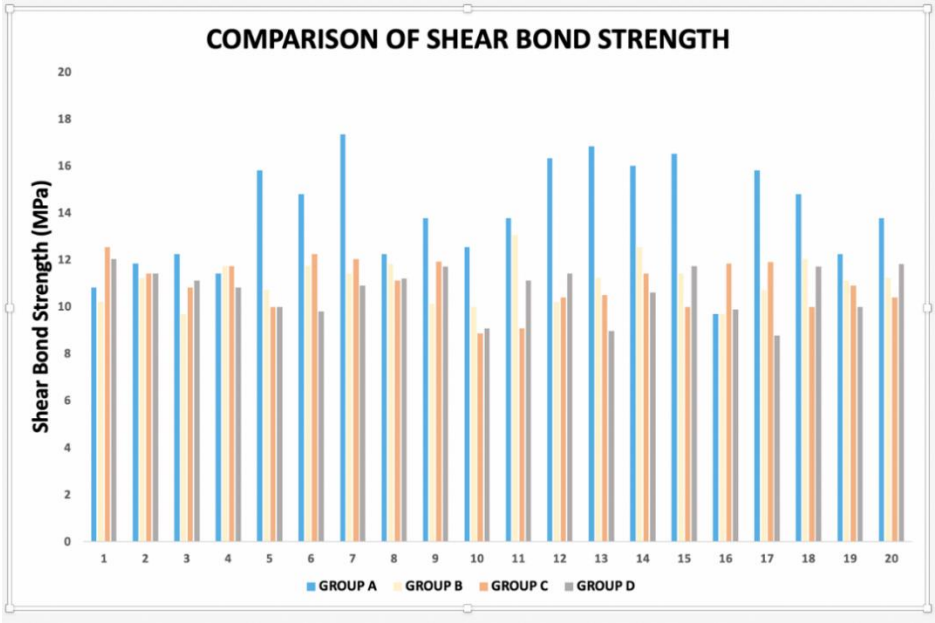

Figure 4: Shear bond strengths for different groups (MPa)

Group A: Transbond XT (dry condition), Group B: Bracepaste MTP (dry condition),Group C: Transbond MIP (moist condition),Group D: Bracepaste MTP (moist condition)

Figure 5 shows the frequency distribution of the ARI scores for all the four groups. According to this Figure, score 1 was the highest in all four groups.

In addition, the Chi-Squared test indicated statistically insignificant differences in the frequency of ARI scores (P=0.627) (Table 4). However, variations were observed between groups: group A (Transbond XT, dry) had a higher frequency of ARI scores of 1 and 2 than the other groups (groups B, C, and D), which had a higher frequency of ARI scores of 0 and 1.

N

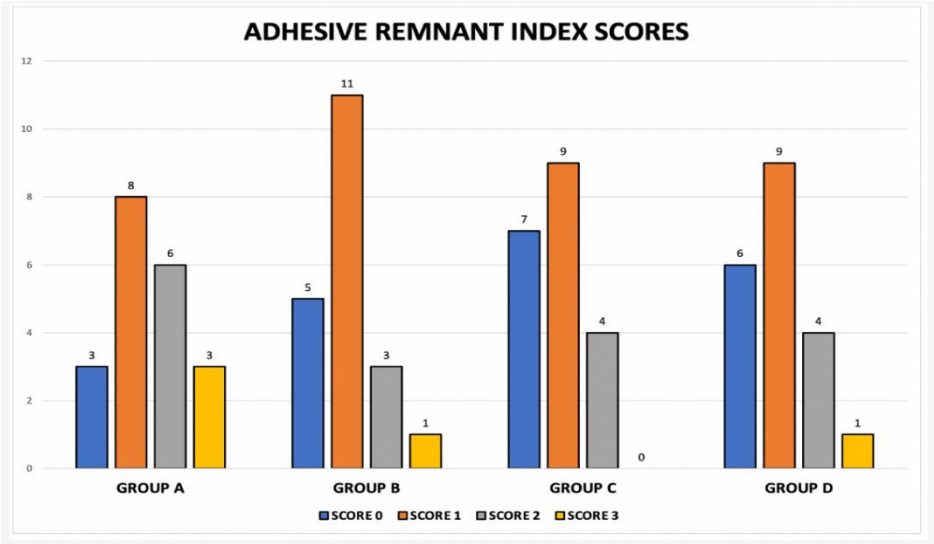

Figure 5: Frequency distribution of adhesive remnant index scores.

Table 4. Frequency distribution of ARI scores among four groups

			Groups				Total	Chi-Square	P-value
			A	B	C	D			
ARI score	0	Count	3	5	7	6	21	7.098	0.627
		% within GROUPS	14.3%	23.8%	33.3%	28.6%	100.0%		
		% within ARI	15.0%	25.0%	35.0%	30.0%	26.3%		
		% of Total	3.8%	6.3%	8.8%	7.5%	26.3%		
	1	Count	8	11	9	9	37		
		% within GROUPS	21.6%	29.7%	24.3%	24.3%	100.0%		
		% within ARI	40.0%	55.0%	45.0%	45.0%	46.3%		
		% of Total	10.0%	13.8%	11.3%	11.3%	46.3%		
	2	Count	6	3	4	4	17		
		% within GROUPS	35.3%	17.6%	23.5%	23.5%	100.0%		
		% within ARI	30.0%	15.0%	20.0%	20.0%	21.3%		
		% of Total	7.5%	3.8%	5.0%	5.0%	21.3%		
	3	Count	3	1	0	1	5		
		% within GROUPS	60.0%	20.0%	0.0%	20.0%	100.0%		
		% within ARI	15.0%	5.0%	0.0%	5.0%	6.3%		
		% of Total	3.8%	1.3%	0.0%	1.3%	6.3%		
Total		Count	20	20	20	20	80		
		% within GROUPS	25.0%	25.0%	25.0%	25.0%	100.0%		
		% within ARI	100.0%	100.0%	100.0%	100.0%	**100.0%**		
		% of Total	25.0%	25.0%	25.0%	25.0%	**100.0%**		

Discussion

Orthodontic bonding is evolving due to advancements in adhesive dentistry. Many bonding agents have been developed to decrease technique sensitivity during adhesion procedures, improving bond strength, reducing enamel loss, and reducing chairside time (14,25–27). One disadvantage of direct bonding is moisture control, which is beneficial for bonding to enamel on moisture-contaminated surfaces, especially in areas with limited access and partially erupted teeth. One possible solution to this problem is the use of hydrophilic primers. Various studies comparing hydrophilic primers with conventional primers have shown conflicting results (23,28-31). The present study aimed to evaluate a new hydrophilic primer, the Bracepaste MTP.

In most clinical orthodontic circumstances, Reynolds recommended a minimum bond strength of 5.9–7.8 MPa, considering that these values are expected to withstand masticatory and orthodontic forces (30). In the present study, all priming systems used under dry and moist enamel surface conditions exceeded the minimum requirement. Non-contaminated enamel surfaces bonded with a conventional primer (Transbond XT) had the highest bond strength, consistent with previous studies (8,9,15,29,31).

Littlewood et al. investigated hydrophilic primers supplied by 3M Unitek for orthodontic bonding and reported superior bond strengths for teeth bonded with conventional primers (9). However, this study was conducted under dry conditions, despite the hydrophilic primer being moisture-insensitive. The moisture-contaminated groups showed decreased bond strength, which is consistent with the studies conducted by Roy et al. (20), Hadrous et al. (32), and Safar Ali et al. (33). Nevertheless, Cacciafesta et al. (22) and Grandhi et al. (8) suggested that saliva contamination before the application of primer did not affect the shear bond strength of brackets. However, Shaik et al. (16) and Singh et al. (34) compared the hydrophilic (Transbond Plus) and hydrophobic (Transbond XT) primers, concluding that hydrophilic primers sustain better bond strength in saliva-contaminated conditions, confirming their clinical utility under moisture contamination.

The mechanism of hydrophilic primers relies on their chemical composition—primarily HEMA and similar monomers—which increase surface wettability and penetration, combined with functional monomers like 10-MDP that provide chemical bonding, leading to improved bond strength and moisture tolerance in orthodontic adhesive procedures (35). Knaup et al. (13) found that rebonding strength can be improved with hydrophilic priming systems; however, the

additional use of a methyl methacrylate-containing primer does not appear to increase shear bond strength. Gonçalves et al. (9) compared the adhesive systems with and without saliva contamination and showed that hydrophilic primers can retain adhesive strength despite moisture contamination. Katyal et al. (36) assessed the propolis-modified orthodontic primer. They demonstrated promising antimicrobial and mechanical properties, including clinically acceptable SBS, suggesting future directions for multifunctional hydrophilic primers with added bioactive benefits.

Anand et al. (37) compared two hydrophilic primers (Transbond MIP and Opal Primo) and concluded that Transbond MIP had a significantly higher SBS than Opal Primo. Bommanna Logesh et al. (21) compared three hydrophilic primers (Transbond MIP, OrthoSolo, Stedman) under salivary contamination and concluded that Transbond MIP showed the highest mean SBS among the hydrophilic primers. However, Gurrala et al. (17) found that Transbond MIP had the lowest bond strength compared with Assure Plus. The present study showed no significant difference between the hydrophilic primers (Transbond MIP and Bracepaste MTP) under moist conditions, confirming that Bracepaste MTP is equally capable as Transbond MIP. Bracepaste MTP showed clinically acceptable bond strength on both dry and moisture-contaminated enamel surfaces.

Fox et al. (38) cautioned that one should not rely solely on SBS to determine the material's ability, since factors such as enamel surface curvature could affect the results. The ARI is one of the most commonly used metrics as a measure of adhesion between bonding agents, bracket bases, and teeth. The ARI serves as a tool for identifying bond failure sites by ranking the amount of resin remaining on the tooth after debonding. The present study showed no significant differences in ARI scores between hydrophilic and conventional primers, findings similar to the previous studies suggesting similar debonding characteristics and clinical cleanup times (29,32,38). However, in contrast to the present study, few studies showed a statistically significant distribution of ARI scores (22,30,39).

Eren et al. (40) investigated the effects of different primers and coloring solutions on enamel and found that bond strength remained clinically sufficient (>6–8 MPa) across all primer groups; however, some primers were more susceptible to color change, an important consideration in esthetic orthodontics. A color-changing adhesive was used in this study, which provides enhanced adhesive cleanup on the tooth surface after debonding. Clinically, it is advantageous to have a lower score after bonding because the tooth surface retains little to no adhesive, resulting in minimal cleanup time.

Limitations

The present in vitro study design excluded the clinical and intraoral factors such as pH variation, cyclic loading, and long-term aging. In vivo clinical trials are necessary with a large number of samples, shear bond strength of new and recycled brackets using Bracepaste primer, and a combination of metal and ceramic brackets bonded with the hydrophilic Bracepaste primer to provide valuable clinical insights.

Conclusion

All evaluated primers—Transbond XT, Bracepaste MTP, and Transbond MIP—demonstrated shear bond strength values within clinically acceptable ranges. Transbond XT showed the highest mean shear bond strength among the tested groups. Although moisture contamination reduced SBS values, Bracepaste MTP and Transbond MIP maintained bond strengths within acceptable limits under wet conditions. Within the limitations of this in-vitro study, Bracepaste MTP showed performance comparable to Transbond MIP under saliva contamination; however, further in-vivo and clinical studies are necessary to validate these findings.

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Conflicts of interests

The authors declared that there are no conflicts of interest.

Data availability statements

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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