Keywords
Lifestyle diseases, Oral rehabilitation, Prosthodontics, Dental implants, Peri-implantitis, Systemic health

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Effect Of Different Levels Of Ph On The Shear Bond Strength Of Two Different Orthodontic Adhesive System For Bracket Bonding:An In Vitro Study

Abstract

Background: Orthodontic bracket bonding depends on adequate adhesive bond strength for maintaining treatment stability. Salivary pH can fluctuate considerably in the oral environment and may influence the integrity of the enamel–adhesive interface. However, the effects of different pH conditions on commonly used orthodontic adhesive systems remain insufficiently understood.

Objective: To evaluate and compare the effect of acidic, neutral, and alkaline salivary pH conditions on the shear bond strength of two orthodontic adhesive systems, Ormco Enlight and 3M Transbond XT.

Materials and Methods: An in vitro study was conducted using 78 extracted human premolars. The teeth were divided into two groups of 39 specimens according to the adhesive system used: Ormco Enlight and 3M Transbond XT. Each adhesive group was further subdivided into three subgroups ($n = 13$) based on artificial saliva pH: acidic (pH 4.8), neutral (pH 6.8), and alkaline (pH 7.8). After bonding, specimens were immersed in their respective pH-adjusted artificial saliva solutions and incubated for two months. Shear bond strength was evaluated using a universal testing machine. Statistical analysis included Student's unpaired t-test, one-way ANOVA, and Tukey's post hoc test, with statistical significance set at $p < 0.05$.

Results: For Ormco Enlight, the mean shear bond strength was highest at neutral pH (13.75 ± 0.57 MPa), followed by alkaline pH (11.95 ± 0.34 MPa) and acidic pH (10.01 ± 0.39 MPa). For 3M Transbond XT, the corresponding values were 17.74 ± 0.55 MPa, 16.11 ± 0.34 MPa, and 14.90 ± 0.37 MPa, respectively. 3M Transbond XT demonstrated significantly greater shear bond strength than Ormco Enlight under all three pH conditions ($p < 0.001$). Within both adhesive systems, differences among the pH groups were also statistically significant.

Conclusion: Salivary pH significantly influences the shear bond strength of orthodontic adhesives. Neutral conditions provided the highest bond strength, whereas acidic conditions resulted in the greatest reduction. Under all tested pH conditions, 3M Transbond XT demonstrated significantly higher shear bond strength than Ormco Enlight, indicating superior performance under varying environmental pH conditions.

INTRODUCTION

Orthodontics is concerned with the diagnosis, prevention, and correction of malocclusion and dentofacial irregularities, with treatment goals extending beyond tooth alignment to include functional occlusion, facial esthetics, and long-term periodontal stability. Fixed appliance therapy depends on reliable bracket bonding throughout treatment, making adhesive performance a critical determinant of clinical success.

Advances in adhesive dentistry have shifted orthodontic practice from banded appliances to bonded brackets, which offer improved esthetics, patient comfort, and simplified clinical procedures. Brackets may be bonded by direct or indirect techniques, both of which depend on resin-based adhesives and effective moisture control. Although indirect bonding can improve bracket placement accuracy and reduce chair time, both techniques remain vulnerable to contamination during bonding, which may compromise bond strength.

Successful orthodontic bonding is based on acid etching of enamel, which creates microporosities that permit resin penetration and micromechanical retention. Contamination during the etching or priming stages can interfere with resin infiltration and polymerization, increasing the risk of bond failure. Saliva is particularly important in this regard, because it can rapidly form an acquired pellicle over etched enamel and obstruct resin tag formation.

In addition to contamination during bonding, salivary pH may influence adhesive performance. Frequent intake of acidic beverages such as soft drinks, sports drinks, and fruit juices can lower salivary pH, promote enamel demineralization, and alter enamel surface characteristics. These changes may weaken the adhesive-enamel interface, reduce shear bond strength, and increase the likelihood of bracket debonding. Acidic exposure after bonding has also been associated with reduced bond strength and increased microleakage.

Orthodontic brackets function in a dynamic oral environment where they are subjected to masticatory, parafunctional, and orthodontic forces over an extended period. Accordingly, an ideal adhesive must provide not only adequate initial bond strength but also durability under changing intraoral conditions. Although newer materials such as light-cured composites, moisture-insensitive primers, and universal adhesives have improved bonding reliability, the effect of salivary pH on orthodontic adhesive systems remains incompletely understood.

Most previous studies have focused on acidic conditions or evaluated only a single adhesive system. Comparatively less attention has been given to alkaline salivary environments, which may occur with bicarbonate mouth rinses, antacid use, dietary supplements, or variations in buffering capacity. Because intraoral pH fluctuates continuously, evaluating adhesive performance under different salivary pH conditions is clinically relevant.

Therefore, the purpose of this study was to compare the effect of three salivary pH levels on the shear bond strength of two orthodontic adhesive systems used for bracket bonding.

MATERIALS AND METHODS

The present in vitro study was conducted in the Department of Orthodontics and Dentofacial Orthopaedics, Faculty of Dental Sciences, SGT University, Gurugram, after obtaining approval from the Institutional Ethical Committee. A total of 78 human premolars extracted for orthodontic purposes were collected from the Department of Oral and Maxillofacial Surgery.

Sample Size Calculation

The sample size was calculated using G*Power software (Version 3.0.10). Based on an effect size of 0.4602, a significance level of 5%, and 80% power, the required sample size was determined to be 78 teeth.

Inclusion Criteria

- Premolars with intact buccal enamel surfaces.
- Teeth free of enamel fractures or cracks.
- Teeth not previously treated with chemical agents.
- Teeth without hypocalcification.
- Healthy teeth without dental caries.
- Teeth without restorations.

Exclusion Criteria

- Teeth exhibiting fluorosis.
- Teeth with visible fractures or cracks.
- Teeth with hypocalcification.
- Carious teeth.
- Teeth with restorations.
- Root canal-treated teeth.

Materials Used

The materials used in the study included freshly extracted human premolars(Fig1), normal saline for storage, a micromotor handpiece with contra-angle attachment, enamel polishing paste, stainless steel premolar brackets, bracket holding tweezers, a stainless steel bracket positioner, a stainless steel explorer, an LED light-curing unit, glass beakers, pH buffer solutions, artificial saliva, a digital pH meter, an incubator, and a universal testing machine.

Two conventional light-cured orthodontic adhesive systems were evaluated:

- Ormco Enlight light-cure adhesive system (Fig 2)
  - 37% phosphoric acid etching gel
  - Ormco Orthosolo universal bond enhancer
  - Ormco Enlight light-cure adhesive
- ·Transbond XT adhesive system (Fig 3)
  - 37% phosphoric acid etching gel
  - 3M Transbond XT light-cure adhesive primer
  - 3M Transbond XT light-cure adhesive

Fig. 1. Freshly extracted premolars

Fig. 2. Universal bonding primer, 37% phosphoric acid etching gel and Ormco ENLIGHT light-cure orthodontic adhesive

·**Fig. 3. Transbond XT light cure adhesive and curing light**

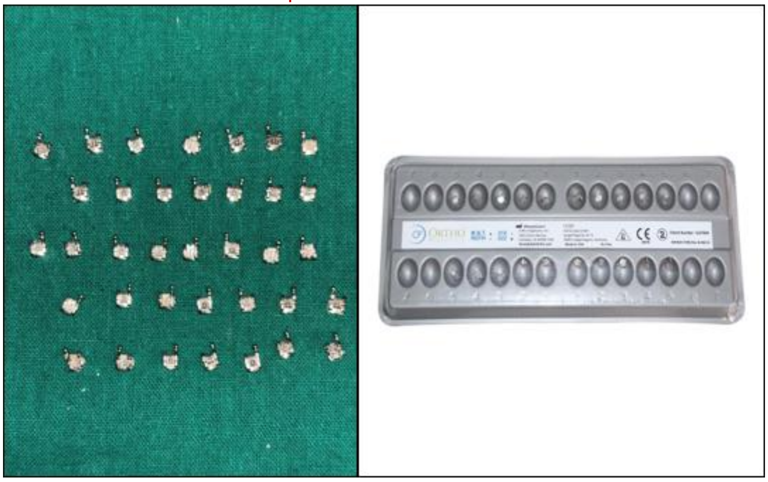

Fig. 4. Stainless steel premolar brackets with MBT prescription

STUDY DESIGN

The study included 78 extracted premolars,(Fig 1) which were divided into two main groups of 39 teeth each according to the adhesive system used. Each main group was further subdivided into three subgroups of 13 teeth each based on the pH of the artificial saliva: acidic (pH 4.8), neutral (pH 6.8), and alkaline (pH 7.8).

METHODOLOGY

Freshly extracted human premolars indicated for orthodontic therapeutic extraction were collected from the Department of Oral and Maxillofacial Surgery. Immediately after extraction, the teeth were rinsed under running water to remove blood and debris and then stored in normal saline at room temperature to prevent dehydration and preserve enamel integrity. The interval between extraction and bonding was minimized for consistency.

PREPARATION OF SAMPLE

Before bonding, the buccal surfaces of all teeth were cleaned using prophylactic paste with a micromotor handpiece and contra-angle attachment. This was done to remove plaque, pellicle, and superficial contaminants. The teeth were then rinsed thoroughly with water for 20-30 seconds and dried with oil-free compressed air. Care was taken to avoid moisture contamination after cleaning.

ETCHING PROCEDURE

The buccal enamel surfaces were etched with 37% phosphoric acid gel for 30 seconds.(Fig 5). The acid was then rinsed off with water for 30 seconds, and the teeth were dried with oil-free compressed air until a uniform frosty white appearance was obtained(Fig 6). Teeth that did not show this appearance were re-etched to ensure standardized enamel conditioning.

Fig. 5. Enamel surface etched with 37% phosphoric acid gel

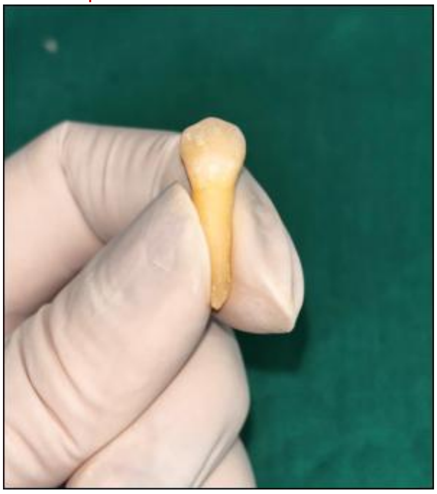

Fig. 6. Premolar after etching with 37% phosphoric acid gel

BONDING PROCEDURE AND GROUP ALLOCATION

Standard stainless steel premolar brackets with MBT prescription and 0.022 x 0.028-in slot size were used in all specimens. Group I (39 teeth) was bonded with Ormco Enlight light-cure orthodontic adhesive, and Group II (39 teeth) was bonded with 3M Transbond XT light-cure adhesive. Each group was further divided into three subgroups of 13 teeth each according to the pH of artificial saliva: 4.8, 6.8, and 7.8.

In Group I, primer was applied to the tooth surface,(Fig 7) and a uniform layer of Ormco Enlight adhesive was placed on the bracket base. The bracket was positioned at the center of the buccal surface along the long axis of the tooth,(Fig 8) and firm pressure was applied to ensure proper seating. Excess adhesive was removed before curing. Polymerization was carried out with an LED curing unit at 850 mW/cm2 for 20 seconds each from the mesial, distal, and gingival aspects, for a total of 60 seconds.

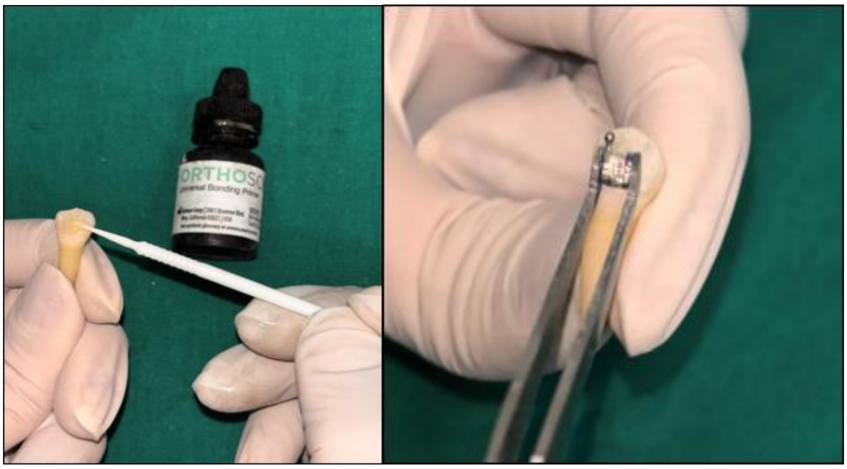

Fig. 7 Universal bonding primer

Fig. 8 Bracket placed on tooth

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In Group II, the same bonding protocol was followed using the Transbond XT adhesive system. All bonding procedures were carried out by a single operator under controlled laboratory conditions to eliminate inter-operator variability.

PREPARATION OF ACIDIC BASIC AND NEUTRAL SOLUTIONS

After bonding, artificial saliva was prepared to simulate the electrolyte balance and buffering capacity of natural saliva. The pH was adjusted to three levels: acidic (4.8), neutral (6.8), and alkaline (7.8) using appropriate buffering agents. The pH of each solution was verified with a calibrated digital pH meter before specimen immersion and monitored periodically throughout the study. (Fig 9 &10)

Fig. 9. Preparation of acidic basic and neutral solutions

Fig. 10. pH tested and divided into three solutions

INCUBATION OF SAMPLE

Each specimen was immersed individually in its designated pH-adjusted artificial saliva solution to avoid cross-contamination.(Fig 11) The samples were incubated at approximately physiologic oral temperature for 2 months to simulate prolonged intraoral exposure. The artificial saliva solutions were refreshed periodically to maintain pH stability and prevent contamination

Fig. 11. Teeth dipped in three different pH solutions

PREPARATION OF ACRYLIC BLOCK

At the end of the incubation period, the specimens were removed, rinsed with distilled water, and air-dried. Each tooth was embedded in self-cure acrylic resin using custom molds. The long axis of each tooth was oriented perpendicular to the base of the acrylic block so that the applied shear force would act parallel to the bracket-enamel interface during testing. (Fig 12)

Fig. 12 Tooth oriented perpendicular to the base of the acrylic block

SHEAR BOND STRENGTH TESTING

Shear bond strength was measured using a Universal Testing Machine.(Fig 13) Each acrylic-mounted specimen was secured in the lower jaw of the machine, and a chisel-shaped blade was positioned at the bracket-enamel interface in an occlusogingival direction.

Fig.13 Unitek Universal Testing Machine

A shear force was applied parallel to the bonding surface at a crosshead speed of 1 mm/min until bond failure occurred.(Fig 14)

Fig. 14. Shear force applied on premolar bracket

The maximum force required to debond the bracket was recorded in Newtons.(Fig 15)

Fig. 15. Debonded premolar bracket

RESULTS

All data were entered into Microsoft Excel 2021 (Microsoft, Redmond, Wash) and analyzed using SPSS version 22.0. A total of 78 extracted human premolars were randomly allocated to 2 adhesive groups: Group I (Ormco Enlight) and Group II (3M Transbond XT), with 39 samples each. Each group was further subdivided into 3 subgroups (n = 13) according to immersion medium: neutral pH 6.8, acidic pH 4.8, and alkaline pH 7.8.

Descriptive statistics were expressed as mean +- standard deviation. Intergroup comparisons were performed with Student's unpaired t-test, and intragroup comparisons were analyzed with one-way ANOVA followed by Tukey's post hoc test. A p value < 0.05 was considered statistically significant.

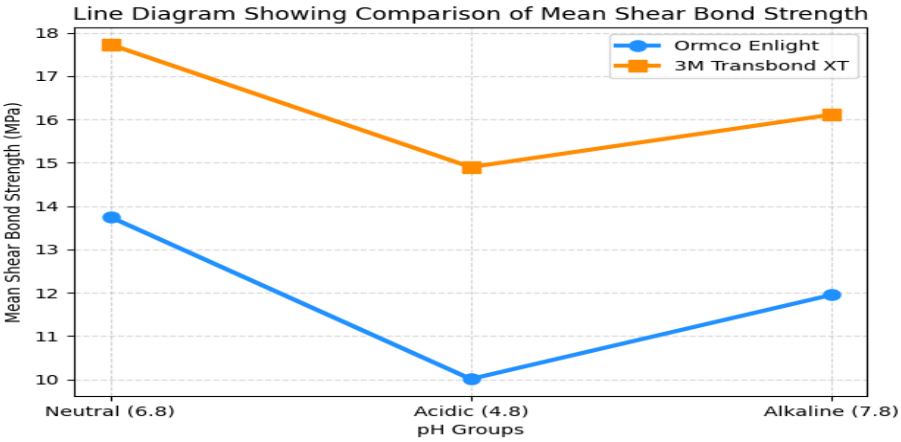
TABLE 1 AND GRAPH 1: DISTRIBUTION OF SAMPLE (N = 78 TEETH) IN TWO ADHESIVE GROUPS

The samples were distributed equally between Group I (Ormco Enlight) and Group II (3M Transbond XT), with further equal subdivision into the three pH subgroups (n = 13 each). This uniform distribution helped standardize the comparison among groups.

Table 1: Distribution of sample (n = 78 Teeth) in two adhesive groups.

Group	Adhesive System	Neutral pH (6.8)	Acidic pH (4.8)	Alkaline pH (7.8)	Total Teeth
Group I	Ormco Enlight	13	13	13	39
Group II	3M Transbond XT	13	13	13	39
Total	—	26	26	26	78

Distribution of sample (n = 78 Teeth) in two adhesive groups



Graph 1: Distribution of sample (n = 78 Teeth) in two adhesives groups.

TABLE 2 AND GRAPH 2: SHEAR BOND STRENGTH OF ORMCO ENLIGHT AND 3M TRANSBOND XT UNDER DIFFERENT IMMERSION MEDIA

For Ormco Enlight, the highest mean shear bond strength was observed at neutral pH (13.75 +- 0.57 MPa), followed by alkaline pH (11.95 +- 0.34 MPa), with the lowest value at acidic pH (10.01 +- 0.39 MPa).

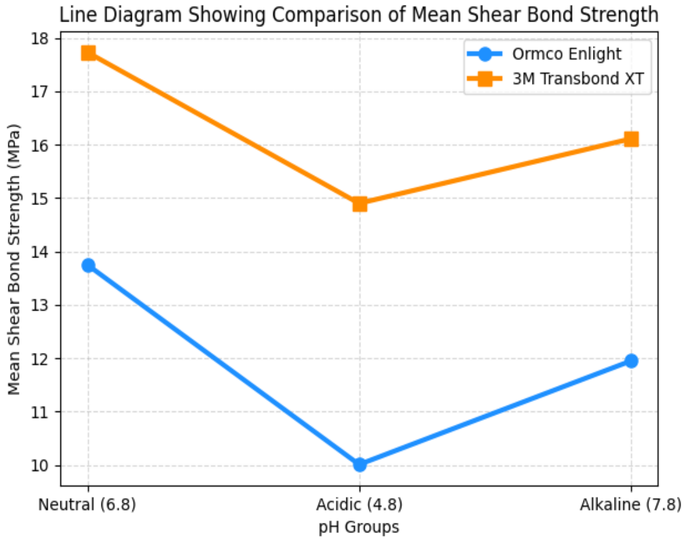
For 3M Transbond XT, the highest mean value was also observed at neutral pH (17.74 +- 0.55 MPa), followed by alkaline pH (16.11 +- 0.34 MPa), and the lowest at acidic pH (14.90 +- 0.37 MPa).

Both adhesive systems showed reduced shear bond strength under acidic conditions. 3M Transbond XT demonstrated higher mean values than Ormco Enlight under all pH conditions.

Table 2: Describes shear bond strength of OrmcoEnlight and 3M Transbond XT under different immersion media.

Sample No. (n)	**Ormco Enlight (MPa)**			**3M Transbond XT (MPa)**		
	Neutral (Saliva)	Acidic pH	Alkaline pH	Neutral (Saliva)	Acidic pH	Alkaline pH
1	13.8	10.4	11.8	17.2	14.3	15.9
2	14.2	9.8	12.2	18.1	15.0	16.4
3	13.5	10.1	11.5	16.8	14.7	16.1
4	14.6	9.5	12.4	17.5	15.4	15.7
5	12.9	10.7	11.9	18.4	14.9	16.5
6	13.7	9.9	12.1	17.9	15.2	16.2
7	14.0	10.2	11.7	16.9	14.5	15.8
8	13.3	9.6	12.5	18.0	15.1	16.6
9	14.4	10.5	11.6	17.4	14.6	16.0
10	13.6	9.7	12.3	18.2	15.3	15.6
11	12.8	10.0	11.4	17.6	14.8	16.3
12	14.1	9.4	12.0	16.7	15.5	15.9

13	13.9	10.3	11.9	17.8	14.4	16.4
Mean ± SD	13.75 ± 0.57	10.01 ± 0.39	11.95 ± 0.34	17.74 ± 0.55	14.90 ± 0.37	16.11 ± 0.34



Graph 2: Describes shear bond strength of adhesive systems under different immersion media.

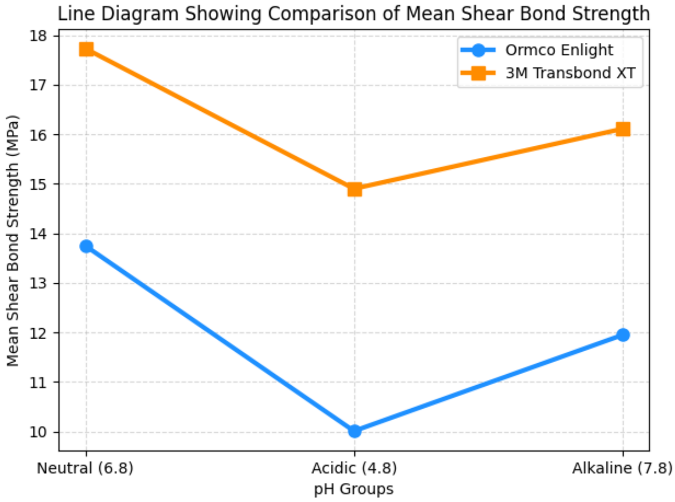
TABLE 3 AND GRAPH 3: INTERGROUP COMPARISON OF SHEAR BOND STRENGTH

Intergroup comparison with Student's unpaired t-test showed that 3M Transbond XT had significantly higher shear bond strength than Ormco Enlight under all pH conditions.

Under neutral pH, the mean difference was 3.98 MPa ($t = 18.12$, $p < 0.001$). Under acidic pH, the mean difference was 4.89 MPa ($t = 31.45$, $p < 0.001$). Under alkaline pH, the mean difference was 4.16 MPa ($t = 28.76$, $p < 0.001$). These findings indicate that 3M Transbond XT showed superior bond strength compared with Ormco Enlight regardless of pH.

Table 3: Intergroup Comparison of Shear Bond Strength.

pH Medium	Ormco Enlight (Mean MPa)	3M Transbond XT (Mean MPa)	Mean Difference (MPa)	t-value	p-value	Interpretation
Neutral (6.8)	13.75	17.73	3.98	18.12	< 0.001	Highly Significant
Acidic (4.8)	10.01	14.90	4.89	31.45	< 0.001	Highly Significant
Alkaline (7.8)	11.95	16.11	4.16	28.76	< 0.001	Highly Significant



Graph 3: Intergroup Comparison of Shear Bond Strength

TABLE 4 AND GRAPH 4: ONE-WAY ANOVA SHOWING INTER-GROUP (BETWEEN PH LEVELS) AND INTRA-GROUP (WITHIN GROUPS) COMPARISON OF SHEAR BOND STRENGTH WITHIN EACH ADHESIVE SYSTEM

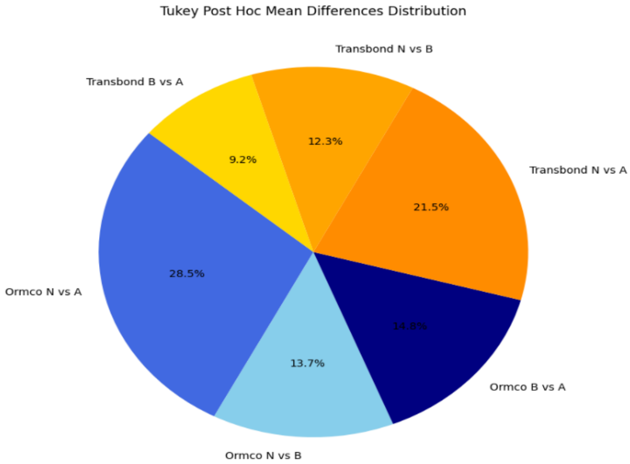
One-way ANOVA showed that pH significantly affected shear bond strength within each adhesive system.

For Ormco Enlight, the difference among pH subgroups was highly significant ($F = 158.64$, $p < 0.001$). For 3M Transbond XT, a similarly highly significant difference was found ($F = 132.85$, $p < 0.001$).

In both adhesive systems, neutral pH produced the highest bond strength, followed by alkaline pH, while acidic pHshowed the lowest values.

Table 4: One-way ANOVA showing inter-group (between pH levels) and intra-group (within groups) comparison of shear bond strength within each adhesive system

Adhesive System	Source of Variation	Sum of Squares (SS)	df	Mean Square (MS)	F-value	p-value	Interpretation
Ormco Enlight	InterGroups (pH)	95.84	2	47.92	158.64	< 0.001	Highly Significant
	IntraGroups (pH)	10.87	36	0.30	—	—	—
3MTransbond XT	InterGroups (pH)	59.42	2	29.71	132.85	< 0.001	Highly Significant
	IntraGroups (pH)	8.05	36	0.22	—	—	—
Total	—	174.18	76	—	—	—	—



Graph 4: One-way ANOVA showing inter-group (between pH levels) and intra-group (within groups) comparison of shear bond strength within each adhesive system

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TABLE 5 AND GRAPH 5: TUKEY'S POST HOC MULTIPLE COMPARISONS WITHIN EACH ADHESIVE SYSTEM

Tukey's post hoc analysis showed significant pairwise differences among the pH subgroups within each adhesive system.

For Ormco Enlight, the mean difference between neutral and acidic pH was 3.74 MPa ($p < 0.001$), between neutral and alkaline pH was 1.80 MPa ($p < 0.01$), and between alkaline and acidic pH was 1.94 MPa ($p < 0.001$).

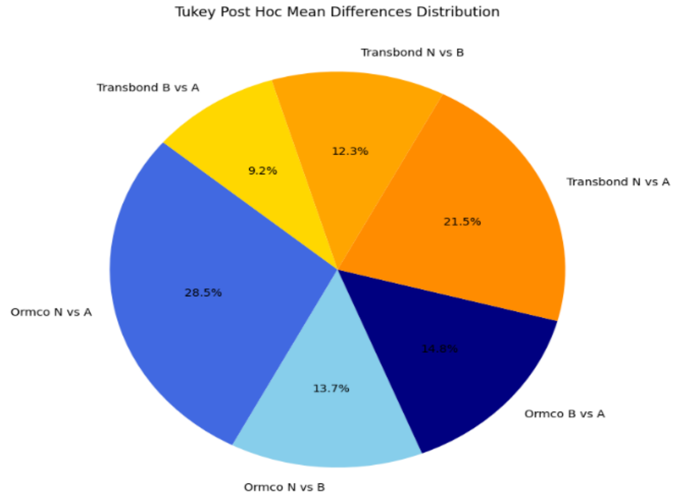
For 3M Transbond XT, the mean difference between neutral and acidic pH was 2.83 MPa ($p < 0.001$), between neutral and alkaline pH was 1.62 MPa ($p < 0.01$), and between alkaline and acidic pH was 1.21 MPa ($p < 0.001$).

These results confirm that acidic pH significantly reduced shear bond strength compared with both neutral and alkaline conditions, while neutral pH provided the most favorable bonding performance.

Table 5: Tukey's Post Hoc Multiple Comparisons Within Each Adhesive System

Adhesive System	**Comparison**	**Mean Difference (MPa)**	**p-value**	**Interpretation**
Ormco Enlight	Neutral vs Acidic	3.74	< 0.001	Highly Significant
	Neutral vs Alkaline	1.80	< 0.01	Significant
	Alkaline vs Acidic	1.94	< 0.001	Highly Significant
3M Transbond XT	Neutral vs Acidic	2.83	< 0.001	Highly Significant
	Neutral vs Alkaline	1.62	< 0.01	Significant
	Alkaline vs Acidic	1.21	<0.001	Highly significant

The value of p value; *p<0.05 and *p < 0.01 were considered as significant, and *p < 0.001 was considered as highly significant.



Graph 5: Tukey's Post Hoc Multiple Comparisons Within Each Adhesive System

OVERALL FINDINGS

Both the adhesive system and the pH of the immersion medium significantly influenced shear bond strength. Acidic conditions adversely affected bonding, whereas neutral conditions produced the highest bond strength. Although both adhesive systems were affected by pH variation, 3M Transbond XT consistently showed significantly higher shear bond strength than Ormco Enlight under all conditions, indicating superior overall performance.

DISCUSSION

Successful orthodontic treatment depends on maintaining a durable bond between the bracket and enamel throughout treatment. Since the introduction of acid-etch bonding, direct bonding of orthodontic attachments has become reliable and clinically efficient. Because brackets are exposed to continuous mechanical and chemical challenges in the oral cavity, factors affecting shear bond strength remain clinically important.

In the present in vitro study, both the type of adhesive and the salivary pH significantly influenced shear bond strength. Although all groups showed bond strengths above the minimum range considered clinically acceptable, clear differences were observed among the test conditions. Neutral pH produced the highest shear bond strength in both adhesive systems, followed by alkaline pH, whereas acidic pH showed the lowest values. In addition, 3M Transbond XT consistently demonstrated higher bond strength than Ormco Enlight under all conditions.

The equal allocation of samples across both adhesive groups and all pH subgroups provided a balanced study design and improved the reliability of intergroup comparisons. Standardization of sample distribution is especially important in in vitro bond strength studies because unequal grouping may affect statistical interpretation.

The findings of the present study indicate that salivary pH has a direct effect on adhesive performance. The reduction in bond strength under acidic conditions may be explained by hydrolytic degradation of the resin matrix, increased water sorption, softening of the composite, and possible alteration of the adhesive-enamel interface. Acidic conditions may also promote partial enamel demineralization around the bonded area, thereby reducing micromechanical retention. In contrast, neutral pH appears to preserve both resin integrity and the enamel-adhesive interface, resulting in more favorable bonding performance. Alkaline conditions showed intermediate values, suggesting less degradation than acidic media but lower stability than neutral conditions.

The superior performance of 3M Transbond XT may be related to differences in resin formulation, filler content, and resistance to environmental degradation. A more stable resin matrix and higher filler loading may improve resistance to water sorption and hydrolytic breakdown, thereby maintaining better bond strength under varying pH conditions. This may explain why Transbond XT consistently outperformed Ormco Enlight in neutral, acidic, and alkaline media.

The intergroup comparison showed that the difference between the two adhesives was statistically significant under all pH conditions, with the greatest difference observed in the acidic subgroup. This suggests that material-related differences become more evident under chemically adverse conditions. Clinically, this is relevant because orthodontic adhesives are routinely exposed to dietary acids, plaque-related pH changes, and other environmental challenges during treatment.

Within each adhesive system, one-way ANOVA and post hoc analysis confirmed significant differences among neutral, acidic, and alkaline environments. The pairwise comparisons showed that each pH level had a distinct effect on shear bond strength. Neutral pH consistently provided optimal bond strength, acidic pH caused the greatest reduction, and alkaline pH produced intermediate values. These results suggest that even routine fluctuations in oral pH may affect the long-term stability of bonded orthodontic attachments.

Overall, the findings suggest that salivary pH is an important determinant of orthodontic adhesive performance. Neutral conditions favor bond stability, whereas acidic conditions significantly compromise bond strength. Although both adhesives were affected by pH variation, 3M Transbond XT demonstrated superior performance and greater resistance to environmental challenge than Ormco Enlight.

LIMITATIONS OF THE STUDY

- The study was conducted in vitro and therefore may not fully reproduce the complexity of the oral environment, including masticatory forces, thermal changes, enzymatic activity, and microbial interactions.
- The immersion period was limited to 2 months, whereas clinical orthodontic treatment usually extends over a much longer duration.
- Only two orthodontic adhesive systems were evaluated.
- Only shear bond strength was assessed; other parameters such as tensile bond strength, adhesive remnant index, and enamel surface changes after debonding were not evaluated.

FUTURE RESEARCH

- Future studies should include long-term aging protocols that better simulate oral conditions, including thermal cycling, mechanical loading, and biofilm exposure.
- A wider range of adhesive materials, including self-etch systems, resin-modified glass ionomer cements, and bioactive orthodontic adhesives, should be evaluated.
- Further investigation should assess additional outcomes such as adhesive remnant index, enamel surface alterations, and durability after prolonged pH cycling.
- Development of bioactive adhesives capable of releasing fluoride or calcium phosphate may help counteract the adverse effects of acidic environments while maintaining adequate bond strength.

CONCLUSION

Salivary pH significantly affected the shear bond strength of both orthodontic adhesive systems. Neutral pH showed the highest bond strength, followed by alkaline pH, whereas acidic pH produced the lowest values. Under all test conditions, 3M Transbond XT demonstrated significantly greater shear bond strength than Ormco Enlight, indicating superior resistance to environmental pH variation.

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