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Effect of 5.25% Sodium Hypochlorite on Shear Bond Strength of Orthodontic Brackets Bonded with OBA-MCP

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Abstract

Introduction: Bracket debonding is a frequent issue that clinicians encounter, leading to increased chair time, lost revenue, and material usage. In addition to patient compliance with their diet recommendations, the preparation and conditioning of teeth for bonding significantly influence bond strength and consequently impact orthodontic treatment success and efficiency. Because of OBA-MCP's (orthodontic bonding adhesive with modified calcium phosphate) decreased shear bond strength (SBS), the purpose of this study was to evaluate the effects of conditioning with 5.25% sodium hypochlorite (NaOCl) before etching in the bonding protocol. Materials and Methods: 90 extracted teeth were divided into 3 groups to be bonded with orthodontic brackets with different bonding protocols: 1) Transbond XT with regular bonding protocol (etch + prime + adhesive); 2) OBA-MCP with regular bonding protocol; and 3) OBA-MCP with NaOCl prior to acid etching in the regular bonding protocol. SBS (in Newtons) were measured using an MTS universal testing machine with a custom jig to apply a vertical force onto the bracket and ARI (adhesive remnant index) scores were recorded for each sample after de-bond to rate the amount of adhesive remaining. Results: The addition of NaOCl to the bonding protocol statistically significantly increased the SBS of OBA-MCP to comparable levels to Transbond XT. The ARI scores showed that when NaOCl was added, more adhesive remained. Conclusion: The addition of NaOCl to the bonding protocol can increase the SBS of adhesives with historically weaker bond strengths. However, the increased amount of adhesive remaining and the increased time spent during bonding must be considered. Further testing can be done *in vivo* to demonstrate the practicality of this new procedure.

Keywords

Shear Bond Strength, Sodium Hypochlorite, Orthodontic Brackets

1. Introduction

Orthodontists have been constantly looking to improve their clinical efficacy and efficiency, especially during longer and technique-sensitive procedures such as the bonding of orthodontic brackets. The de-bonding of brackets by patients is a very common emergency visit that clinicians face and can lead to increased chair time, lost revenue, and increased use of materials. The typical bonding protocol usually includes removing any plaque and residue off of the surface of teeth with pumice, etching with 37.5% phosphoric acid, applying a primer, and most commonly bonding with a resin composite-based bonding adhesive [1]. If not done correctly with proper isolation and removal of plaque, calculus, and other residue left on the teeth, the bonding of orthodontic brackets can be compromised, leading to bond failure and more emergency visits by patients. In addition to patient compliance with their diet recommendations, the conditioning and preparation of the teeth to be bonded is an important step that affects bond strength and therefore the success and efficiency of the orthodontic treatment.

Another factor that can affect the bond strength of orthodontic brackets is the type of bonding adhesive used during bonding. There is a variety of bonding adhesives available to clinicians, with resin composite-based adhesives being the most common. Other bonding adhesives include resin-modified glass ionomer cement and a novel composite-orthodontic bonding adhesive with modified calcium phosphate. Previous studies have shown that resin-modified glass ionomer types of cement do not perform as effectively as resin composite-based bonding adhesives in terms of SBS [2]. Therefore, even with the favorable properties of sustained fluoride release in resin-modified glass ionomer types of cement, the decreased SBS compared to composite resins may hinder clinicians from using this adhesive in their bonding protocol. Transbond XT is a light-cure composite adhesive that provides strong bonding for ceramic and metal brackets, with extended working time, easy clean-up, and fluoride release to enhance enamel protection during orthodontic treatment (3M Unitek, Monrovia, Calif).

To investigate the possibility of increasing the SBS of orthodontic brackets, especially for bonding adhesives with lower bond strengths compared to those of traditional resin composites, several studies have tested the effects of the addition of sodium hypochlorite conditioning before etching on bond strength [3]-[7]. Sharma *et al.* demonstrated that lightly wetting the tooth with 5.25% sodium hypochlorite for one minute and then rinsing before acid etching significantly increased the SBS of brackets bonded with composite resin compared to the standard bonding protocol without sodium hypochlorite [5].

In the study by Justus *et al.*, it has been shown to increase the SBS of orthodontic brackets bonded with resin-modified glass ionomer, to comparable bond strength to composite resin bonding adhesives [8]. The authors stated that the removal of this outside organic layer allows for the phosphoric acid etch to more consistently reach the enamel surface and allow for greater bonding. Espinosa *et al.* also showed that the addition of 5.25% sodium hypochlorite for 1 minute on the tooth before acid etching improved the etching pattern on the enamel from a type 3 enamel etching pattern to a type 1 pattern [9]. A Type 1 enamel etching pattern compared to a type 3 enamel etching pattern is characterized by having additional enamel rods exposed for bonding [10]. It increases the adhesive tags for the phosphoric acid, primer, and adhesive to reach for better bonding to the tooth. The topography of the outer enamel layer is ultimately improved with conditioning with sodium hypochlorite [11].

In Pellillo's study, it was shown that the organic composition of the enamel essentially remained unchanged with the addition of NaOCl. The carbon content did not differ and the amount of calcium and phosphorous also did not differ between groups treated with and without NaOCl. Thus, neither organic nor inorganic components were significantly altered, but the surface topography changed [12].

A novel adhesive, orthodontic bonding adhesive with modified calcium phosphate, OBA-MCP (PulpDent, Watertown, MA), is also available for clinicians to use in bonding orthodontic brackets. The product claims to release fluoride and provide an anti-caries effect by absorbing fluoride from other fluoride-containing sources, which can make this adhesive particularly beneficial in certain cases. But, in previous studies, it was found that its SBS was statistically significantly weaker than that of a composite resin-based adhesive, like the deficiencies in bond strength of resin-modified glass ionomer cement and amorphous calcium phosphate composite when used to bond orthodontic brackets [13] [14].

Due to the decreased SBS of orthodontic bonding adhesive with modified calcium phosphate, this study aims to evaluate the impact of conditioning with 5.25% sodium hypochlorite before etching. While previous suggestions highlighted the importance of exploring sodium hypochlorite's effects on other bonding adhesives to enhance SBS [15], there is currently no published research specifically addressing the impact of sodium hypochlorite on the bond strength of orthodontic bonding adhesive with modified calcium phosphate.

2. Materials and Methods

To determine the sample sizes for this study, a one-way ANOVA power analysis was done. Sample sizes of 30 for each group are needed to compare the means between groups. The total sample of 90 subjects achieves 99% power to detect differences among the means versus the alternative of equal means using an F test with a 0.05 significance level.

Extracted: Human premolars without any personal identifiers were collected from local oral surgery and general dentistry offices in Northern New Jersey and stored in a jar of 10% formalin. Formalin was chosen to be the medium of choice because it has been shown in previous studies to have very little effect on shear bond strength testing [16]-[20]. Once tooth collection jars reached capacity; they were stored. Subsequently, teeth were cleaned to remove debris and ensured to be free of caries, decalcifications, and residual composite before inclusion in our study.

The 90 extracted premolars were randomly divided into three groups of 30 specimens each. They were preserved in 10% formalin until ready for mounting in custom rings and testing using a custom jig apparatus. Group 1 received Transbond XT, Group 2 received OBA-MCP without NaOCl, and Group 3 received OBA-MCP with NaOCl (**Table 1**). All teeth were prepared, mounted, and bonded with brackets 24 hours before SBS testing to simulate clinical conditions, as bracket debonding often occurs shortly after bonding. This ensured full adhesive polymerization before testing.

Table 1. Description of groups.

Group	Presence of NaOCl	Adhesive	Time of cure
Group1: Transbond XT	No	Transbond XT	20 seconds
Group 2: OBA-MCP (without NaOCl)	No	OBA-MCP	20 seconds
Group 3: OBA-MCP (with NaOCl)	Yes	OBA-MCP	20 seconds

To prepare the teeth for mounting, the extracted premolars were sectioned 5 mm below the CEJ for it to be able to fit comfortably into the mounting ring. The mounting rings were fitted with a layer of pink baseplate wax that formed the floor of the chamber of the mounting ring. Pink denture acrylic (St. George Technology, Wilmington, North Carolina) was then mixed and placed above the baseplate wax and the sectioned tooth was placed 60% of the way into the denture acrylic in a buccolingual dimension. This would allow for enough retention to hold the extracted teeth in place without disengaging from the denture acrylic during testing. Each tooth was centered as close as possible in the mounting rings to allow for the force to de-bond to be as close to the tangent vertical line to the facial axis (FA) point on each tooth. Facial axis or FA point is the point that intersects the mesial and distal and occlusal and gingival aspects of the crown, or the exact center of the tooth. The custom-made Bencor Multi-T testing jig (Danville Engineering, San Ramon, California) was used with the custom mounting rings for SBS testing to minimize non-parallel and non-shear forces onto the brackets to produce more accurate results and measurements for our study.

After mounting the samples in custom rings, brackets were bonded according to different protocols:

For Groups 1 (Transbond XT) and 2 (OBA-MCP without NaOCl):

1) Pumiced tooth surface for 10 seconds

2) Water rinse for 10 seconds

3) Acid etch with 37.5% phosphoric acid for 20 seconds

4) Water rinse for 10 seconds

5) Air dry for 3 seconds until enamel appears frosty

6) Application of Transbond XT primer

7) Air dry for 2 seconds to thin out primer

8) Application of adhesive (Transbond XT or OBA-MCP) onto bracket

9) Bond bracket onto tooth at the facial axis (FA) point

10) Remove excess adhesive after lightly pressing bracket onto tooth

11) Cure for 20 seconds (10 seconds each on mesial and distal sides of bracket)

12) Specimens stored in distilled water for a maximum of 24 hours before testing

The protocol for Group 3 (OBA-MCP with NaOCl) was the same except for the step of lightly scrubbing the buccal surface with a micro-brush dipped in 5.25% NaOCl for 1 minute, followed by rinsing for 10 seconds, and then the application of OBA-MCP as the adhesive for the bracket bonding. In Group 3, the micro-brush was dipped into 5.25% NaOCl and excess was removed. Care was taken to apply only a minimal amount of NaOCl to the buccal surface of the tooth, simulating a clinical environment. It was confirmed visually that the NaOCl NaOCl remained only on the buccal surface to avoid any potential harm to oral soft tissues.

All brackets were bonded at the facial axis (FA) point. An Ortholux LED curing light (3M Unitek, Monrovia, California) was used, ensuring it was fully charged beforehand. The light emitted electromagnetic radiation at 455 nm on the near-blue spectrum, with an intensity of 1000 mW per cm^2. It was positioned within 5 mm of the bracket during bonding for consistent curing. All brackets were cured for 20 seconds (10 seconds each on the mesial and distal sides). Then, specimens were stored in distilled water for a maximum of 24 hours before SBS testing to simulate a clinical environment, considering most bond failures occur shortly after bonding. This duration also allowed for full adhesive polymerization before testing. Each specimen was labeled with the group number and sample number for accurate data collection during SBS testing.

During SBS testing, each mounting ring containing the tooth with the bonded bracket was placed into the Bencor Multi-T testing jig (**Figure 1**). Careful consideration was given to positioning the mounting ring to ensure the piston attached to the testing jig could apply a vertical and stable force onto the bracket. Visual assessment was used to achieve optimal positioning. Additionally, the blade of the jig was carefully positioned to rest passively between the wings and base of the bracket to prevent any sliding that could affect the force measured by the MTS universal testing machine and BasicTest Software. Positioning the tooth and bracket parallel to the direction of force helped eliminate non-vertical forces that could impact data acquisition.

Figure 1. Mounting ring positioned in the custom Bencor Multi T testing jig.

Once the mounting ring was secured into the Bencor Multi-T testing jig and its position was confirmed, it was placed onto the platform of the MTS universal testing machine directly below its piston (Figure 2). The positioning of the jig under the piston was visually confirmed, to ensure stability on the platform and alignment of the piston directly above the blade shank to minimize any rocking or sliding. When a sample was ready for testing, a displacement rate of 0.2 mm/minute was applied downward via the universal testing machine's piston onto the blade of the Multi-T testing jig. The force applied (measured in Newtons) was displayed in real-time on the BasicTest software (Figure 3).

Figure 2. Testing jig mounted under the piston of the MTS universal testing machine.

The force applied and displacement of the piston were monitored on the basic test software until de-bond of the bracket. Bond failure was easily identified in the real-time graph displayed. The force required for debonding was indicated by the lowest point on the force line (highlighted in red in Figure 3). Typically, the force applied gradually increased as the piston displaced downward onto the bracket. At the moment of debonding, both the displacement and force rapidly decreased, indicating bond failure. This point of debonding could also be visually observed and audibly confirmed by a distinct cracking sound. The force at debond was recorded for each sample in every group in a Microsoft Excel spreadsheet, and all samples were retained for determining adhesive remnant index (ARI) scores (**Figure 4**).

Figure 3. Real time data acquisition of displacement and force of the sample. *Y* axis is "displacement" and "force". Redline represents force and blue line represents displacement. *X* axis is "time". Values are negative as the position moves in a downward direction.

Figure 4. Sample after de-bond with remaining adhesive on enamel.

ARI scores, developed by Artun and Bergland to quantify the amount of adhesive remaining on a tooth after bracket removal [21], were assigned to each specimen 24 hours after debonding testing. A score of "0" indicated no composite left on the tooth, "1" indicated less than 50% composite remaining, "2" indicated more than 50% composite remaining, and "3" indicated all or 100% composite remaining (**Table 2**) [22]. Each sample was examined under 3x magnification using loupes, and ARI scores were then recorded.

Statistical analysis involved using IBM SPSS Statistics 28 software to calculate descriptive statistics for both the force required for debonding and the ARI scores across the three groups. A one-way ANOVA was utilized to examine differences in the mean force at debonding among the groups, with Tukey's post hoc test applied for significant findings. Additionally, a chi-squared test was conducted to assess the relationship between group allocation and ARI scores.

Table 2. ARI score classification.

Scores	Adhesive remnant Index
0	No adhesive remained on enamel
1	Less than 50% of the adhesive remained on enamel
2	More than 50% of the adhesive remained on enamel
3	All adhesive remained on enamel

3. Results

The force to debond the bracket for each sample was acquired using the BasicTest software's real-time data acquisition graph. The force applied starts at 0 and as the piston of the Universal Testing machine is displaced in a downward direction onto the custom testing jig and its blade, onto the bracket, the force applied increases. The force is increased until a breakpoint in the graph is noted, indicated by a very sharp drop in the force applied and a rapid decrease in the displacement of the piston (**Figure 3**). The lowest point, or force at debond, of the red line was recorded for all samples and the mean values of debond forces (in Newtons) are shown in **Table 3**. Also included are the descriptive statistics of Groups 1 - 3 for the debond forces.

Table 3. Descriptive statistics of force to debond and comparison of results between the three groups using one way ANOVA.

	n	Mean	Std.Deviation	P-value	Post hoc**
Group 1	30	211.83	51.66		A
Group 2	30	171.50	42.69	0.003*	B
Group 3	30	210.07	54.53		A

* Statistically significant when $p < 0.05$.
** Different letters indicate that there is a significant difference between the groups. A > B.

The one-way ANOVA test revealed a statistically significant difference in the force required to debond among the three groups ($p = 0.003$). Group 1 (Transbond XT) and Group 3 (OBA-MCP with NaOCl) exhibited significantly higher debond forces (211.83 N and 210.07 N, respectively) compared to Group 2 (OBA-MCP without NaOCl) with a force of 171.50 N (**Table 3**). Tukey's post hoc test indicated no significant difference between Group 1 and Group 3.

Additionally, the chi-squared test results for ARI scores are presented in Table 4, showing the number of samples in each ARI score category for each group. The test demonstrated a statistically significant relationship between the groups and ARI scores (p = 0.037). Group 1 (Transbond XT) had the highest percentage of "0" and "1" ARI scores between the 3 groups. This indicates that Group 1 had the least amount of adhesive on the enamel after de-bonding the bracket. Group 3 (OBA-MCP with NaOCl) had the lowest percentage of "0" and "1" ARI scores. Within the ARI scores of "2" and "3", group 3 (OBA-MCP with NaOCl) had the highest percentage. This indicates that Group 3 had the most amount of adhesive remaining on the enamel after de-bonding the bracket.

Table 4. Descriptive statistics of ARI scores and test results of association between the groups and ARI scores using a chi squared test.

		0		1		2		3		
	total	n	%	n	%	n	%	n	%	P-value
Group 1	30	3	75.0	17	42.5	3	12.0	7	33.3	
Group 2	30	1	25.0	14	35.0	10	40.0	5	23.8	0.037*
Group 3	30	0	00	9	22.5	12	48.0	9	42.9	

* Statistically significant when P < 0.05.

4. Discussion

This study aimed to assess the effects of conditioning with 5.25% NaOCl before acid etching on the bond strength of OBA-MCP. It also aimed to compare the bond strengths of OBA-MCP with and without NaOCl to that of Transbond XT, a widely used adhesive known for its reliable bond strength in clinical practice. Additionally, the study evaluated ARI scores between the groups to compare the amount of adhesive residue left on the enamel after debonding.

The findings of our study align with previous research, such as the study by Williams, which demonstrated that OBA-MCP's bond strength was significantly lower than that of Transbond [13]. Our results show that the force required to debond OBA-MCP (Group 2) was only 171.50 N, compared to Transbond XT's force of 211.83 N (Table 3). However, by conditioning the enamel with NaOCl before acid etching, as done in Group 2, the bond strength of OBA-MCP increased to a level comparable to that of Transbond XT. In Group 3, where NaOCl conditioning was applied, the force to debond was 210.07 N, very close to Group 1's force of 211.83 N. Similar results have been observed in studies involving other types of adhesives, such as composite resin-based adhesives and resin-modified glass ionomers. For example, in the study by Justus *et al.*, the addition of NaOCl significantly increased the SBS of Fuji Ortho LC (a resin-modified glass ionomer cement) to 9.74 MPa, compared to 5.71 MPa without NaOCl [8]. The increase in bond strength achieved by the addition of NaOCl brought the adhesive properties of OBA-MCP to levels comparable to Transbond, as observed in their study.

In this study, ARI scores were compared between the groups and it demonstrated that there was a correlation between the groups and the ARI scores. Transbond (Group 1) exhibited the highest proportion of "0" and "1" scores, indicating minimal adhesive residue remaining on the enamel post-debonding. Conversely, OBA-MCP with NaOCl (Group 2) displayed the highest percentage of ARI scores of "2" and "3", suggesting a greater amount of adhesive residue. This observation is likely attributed to the increased enamel roughness following conditioning with NaOCl. These findings are consistent with those reported by Elnafar *et al.* and Mahmoud *et al.* [3] [4].

In our study, scanning electron microscopy was not conducted to assess enamel topography after acid etching and NaOCl conditioning, as done in previous studies [4] [23] [24], due to time and equipment limitations. Consequently, it cannot be definitively concluded that this was the primary reason for the observed increase in bond strength following the addition of NaOCl.

Previous studies have shown that NaOCl can alter enamel topography, transitioning it from a type 3 to a type 1 enamel pattern. This transformation results in a rougher surface with increased exposure of enamel rods, consequently enhancing the surface area for retention. Consequently, the bonding surface for the adhesive is expanded, leading to an increase in bond strength [25]. Therefore, it is reasonable to suggest that in our study, the inclusion of NaOCl led to a more pronounced roughening of the enamel surface compared to acid etching alone.

Christopher *et al.* concluded that deproteinization with 5.25% Sodium hypochlorite before acid etching could enhance the surface area of adhesion of composite material to the primary tooth surface [26]. However, these findings contrast with those of Ahuja B *et al.*, who stated that enamel deproteinization by 5.25% NaOCl did not significantly alter the surface topographic features of enamel before acid etching [27]. Therefore, conducting a future study to investigate the effects of NaOCl on OBA-MCP, utilizing scanning electron microscopy to evaluate topographical changes, could be considered.

Group 3 (OBA-MCP with NaOCl) exhibited the highest amount of adhesive remaining on the enamel, suggesting that the bond failure in this group predominantly occurs between the bracket and adhesive. Conversely, in Group 1 (Transbond), less adhesive remains on the enamel after debonding, indicating that bond failure occurs more frequently between the enamel and adhesive. Though Group 3 may require more chair time during final debonding, this could be balanced by potentially fewer emergency visits due to the stronger adhesive bond.

Factors potentially influencing study results include variations in extracted tooth quality due to differences in patient demographics and collection over a year. Despite efforts to screen and sort teeth, disparities in enamel quality and strength may exist. Operator error, particularly during initial testing with the MTS Universal Testing Machine, could have affected results. Challenges in manipulating the jig's blade for accurate readings were noted, potentially impacting initial sample debond strengths. However, despite lower debond forces in Group 1's initial samples, it still exhibited the highest mean force among groups, suggesting minimal impact on overall comparisons.

This study assessed samples 24 hours post-bonding to simulate clinical conditions. However, considering OBA-MCP's claimed release of fluoride, phosphate, and calcium ions, bond strength may diminish over time due to ion exchange. Therefore, testing OBA-MCP's bond strength at multiple time points post-bonding, such as 24 hours, 7 days, and 1 month, could provide valuable insights.

This research shows NaOCl improves OBA-MCP's bond strength, similar to its effects on other adhesive types observed in prior studies. Clinicians using this composite may benefit from NaOCl conditioning, suggesting the need for in vivo studies for validation in real patients and clinical guidance.

In a subsequent in vivo study conducted by Peloso *et al.*, a split-mouth randomized clinical trial evaluated enamel deproteinization on the bond strength of orthodontic accessories [7]. They found that enamel deproteinization with 5% sodium hypochlorite did not significantly improve the adhesion of orthodontic accessories. However, their study was limited by a short 6-month follow-up, examination restricted to maxillary teeth, and the inability to blind the operator.

Some clinical recommendations that can be practiced and tested in a future study include only applying NaOCl to a few teeth at a time, making sure to remove any excess NaOCl on the microbrush before applying it to the enamel, and placing the high-speed suction close to the tooth throughout the procedure to ensure all excess NaOCl is expelled.

Daou *et al.* investigated the impact of enamel deproteinization on the SBS of Transbond PlusTM (TBP) self-etching primer, using different application times of 5.25% NaOCl [28]. They discovered that varying the deproteinization application times (60, 30, and 15 seconds) did not affect SBS of brackets. Further research should consider conducting a similar study using the traditional etch-and-rinse protocol with OBA-MCP adhesive. The goal would be to determine whether reducing the NaOCl application time can still achieve effective bond strengths. Applying NaOCl to the external surface of teeth is manageable with proper isolation, suction, and chairside assistance. While our study used a standardized 1-minute application, future studies could investigate the potential of shorter application times or alternative techniques to improve practicality. This could not only reduce NaOCl exposure for both the tooth and the patient but also save chair time for the clinician.

5. Conclusions

1) The addition of NaOCl before acid etching statistically significantly increases the SBS of OBA-MCP.

2) Transbond XT left the least amount of adhesive after de-bond and OBA-MCP with NaOCl left the highest amount of adhesive, evident in its higher percentage of "2" and "3" ARI scores.

3) There was a correlation between the groups (Transbond XT, OBA-MCP, and OBA-MCP with NaOCl) and ARI scores.

4) If clinicians wish to improve the SBS of adhesives with lower bond strengths than Transbond, a commonly used adhesive, the addition of NaOCl can be explored.

5) Additional research is needed to investigate this new protocol in vivo and limiting the amount of time that NaOCl is applied to the teeth can also be tested with OBA-MCP.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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