Iran J Orthod. 2024 December; 19(2):e1177. doi:10.32592/ijorth.19.2.1177.
Published online 2024 December 1 Research Article
Original Article **Open Access**

Effect of Different Surface Pretreatment Methods on Shear Bond Strength of Orthodontic Brackets Bonded with a Self-Adhesive Composite

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Received: 2024 October 20; **Revised:** 2024 November 13; **Accepted:** 2024 November 24

Abstract

Aim: Patients undergoing fixed orthodontic treatments face a higher risk of white spot lesions (WSLs) due to difficulties in effective plaque control. Several preventive measures provide remineralization and antibacterial benefits that reduce WSLs. These measures, while protective, may adversely affect the shear bond strength (SBS) of orthodontic brackets, potentially leading to bracket debonding and impacting overall treatment effectiveness. This study comparatively evaluated the effects of pretreatments with fluoride varnish, chlorhexidine fluoride mouthwash (CHXF), and fluoridated casein phosphopeptide-amorphous calcium phosphate (CPP-ACPF) on the shear bond strength (SBS) of orthodontic brackets bonded with GC Ortho Connect composite resin.
Methods: Sixty extracted premolar teeth were randomly divided into four groups. The first group was the control without pretreatment, and the second to fourth groups were pretreated with 5% fluoride varnish for 4 minutes, with a CHXF for 7 days, and with CPP-ACPF for 3 minutes, respectively. Specimens were subsequently tested for the SBS in a universal testing machine. Each tooth was visually examined and magnified (×10) using a Stereomicroscope to evaluate the adhesive remnant index (ARI).One-way ANOVA, followed by post hoc Tukey tests used for statistical analysis. The significance level was set at $P<0.05$.
Results: Evaluation of SBS showed no significant differences between the control, chlorhexidine fluoride mouthwash, and CPP-ACPF groups ($P>0.05$). However, the SBS of the fluoride varnish group was significantly lower than in other groups ($P<0.05$). Adhesive remnant index (ARI) scores did not show significant differences between the four groups ($P=0.057$).
Conclusion: The results showed that the SBS of the brackets in the CPP-ACPF paste, CHXF, and fluoride varnish groups were within acceptable range for orthodontic purposes.

Keywords: Adhesive Remnant Index, Orthodontic Bracket, Shear Bond Strength, Surface Pretreatment.

Background

The formation of white spot lesions (WSLs) is a side effect of fixed orthodontic treatment (1,2). Bacteria that cause dental caries (Streptococcus mutans and Lactobacillus) are often involved in the progression of WSLs during the fixed orthodontic treatment period (3). Poor oral hygiene can increase the colonization of these bacteria, followed by a decrease in pH below the critical level of 5.5, and accelerate the demineralization process and formation of WSLs (4). Brushing may be difficult or ineffective with braces due to the presence of bands, brackets, elastics, hooks, and springs, which can prevent access to the teeth (5). In addition, the acid-etching process leads to the loss of the tooth surface enamel (approximately 5–10 µm), followed by permanent demineralization of the surface enamel around or under orthodontic brackets. Excess adhesive around the bracket also facilitates plaque accumulation (6). All the mentioned factors increase the risk of developing WSLs. White spot lesions often form on the buccal surfaces and in the gingival area (7). Therefore, WSLs also pose a beauty challenge and negatively affect patient satisfaction (8).

Different treatments have been suggested for orthodontic patients to improve dental mineralization. One of the best treatments is the topical use of fluoride in its various forms. The fluoride varnish is the most common form of it. Fluoride ions combine with hydroxyapatite to form fluorohydroxyapatite, mineralizing the tooth surface. The fluoride binding to tooth enamel causes the enamel to dissolve less in acidic environments, increasing the tooth's resistance to decay (9).

Another new substance for preventing the formation of WSLs in orthodontic patients is casein phosphopeptide-amorphous calcium phosphate (CPP-ACP), a bioactive substance based on dairy products (10). The CPP-ACP nano-complex releases free calcium and phosphate ions, which help buffer the enamel environment. This mechanism creates a supersaturated state of these ions, actively preventing demineralization and promoting remineralization of tooth enamel, thereby supporting dental health. In an acidic environment, ACP is isolated from CPP. Thus, the level of calcium and phosphate in saliva increases. In addition, CPP can stabilize ACP levels in saliva by preventing the deposition of calcium and phosphate (11). Adding fluoride to CPP-ACP improves the remineralization effect compared to CPP-ACP. CPP-ACPF can provide calcium, phosphate, and fluoride ions to form a highly acid-resistant fluorapatite layer on tooth surfaces (12).

Another preventive treatment is the use of chlorhexidine (CHX), which is known as an effective antimicrobial agent in the control of primary carious lesions. Studies reported chlorhexidine's plaque control efficiency in the normal oral flora (13). Fluoride can be added to oral health products in various formulations. Since CHX and fluoride have antibacterial activities and are effective agents against dental caries and gingivitis, it has been argued that their combination can have a synergistic effect (14). In the presence of fluoride, lower concentrations of CHX are required, and their combination may have long-term effects compared to each of these mouthwashes individually (15).

It is also important to note that these preventive treatments do not interfere with the bracket bonding process and its shear bond strength (SBS), as this leads to debonding, necessitating a rebonding procedure, which can increase the risk of tooth enamel damage (16). The optimum shear bond strength of the orthodontic bracket should be at a level that, in addition to withstanding the forces during the treatment period, will break and be debonded at the end of the treatment without damaging the enamel (17).

Since debonding is not desirable for both the patient and the clinician, a proper bond should hold the brackets in place throughout the orthodontic treatment.

Several composite resins have been introduced to improve the bond strength, speed up the clinical process, and reduce contamination during work. It is used directly to bond the teeth and attach brackets to the surface of tooth enamel. GC composite resin reduces the procedural steps to two stages by removing the primer stage (bonding solution), which reduces the procedural steps, saving time for the clinician and providing adequate adhesion to the tooth structure where moisture is difficult to control and separate (18).

Since surface preparation is useful for controlling orthodontic white spot lesions, it is essential to note that these materials can affect the SBS of orthodontic brackets (17,19,20).

This study innovates by critically evaluating and comparing the effects of different surface pretreatment protocols on the shear bond strength of orthodontic brackets using a self-adhesive composite resin. The aim was to provide valuable insights for material selection in orthodontics and optimize clinical practices for improved treatment outcomes.

Methods

The present study used sixty human premolars extracted for orthodontic purposes, with healthy enamel without cracks, caries, or abnormalities. After disinfecting the samples, the teeth were kept in distilled water at room temperature until the test was performed. For the experiment, all the sample surfaces were cleaned and polished with a brush using fluoride-free pumice paste for 10 seconds. Finally, the samples were randomly divided into four groups (n=15).

Group 1 was a control group in which no surface preparation was performed. At first, the buccal surface of the samples was etched with 37% phosphoric acid (Denfil, South Korea) for 30 seconds, washed for 30 seconds, and dried with oil-free air until a frosty white appearance was achieved. The GC Ortho Connect (Japan) composite resin was placed on a standard metal bracket (American Orthodontics, USA); then, the brackets were placed at the center of the buccal surface of teeth with uniform pressure of the hand. After completely removing excess composite resin from around the base bracket, the composite resin was cured by a light-curing device (Woodpecker, China) with an output beam bandwidth of 420–480 nm for 20 seconds (10 seconds from the mesial and distal aspects).

In group 2, a 5% sodium fluoride varnish (Aria Dent Company, Iran) was applied to the tooth surface for 4 minutes. It was then left for 30 minutes and washed with air/water spray for 1 minute. Subsequently, the brackets were placed on the enamel surface in a manner similar to that of the control group.

In group 3, the teeth were first soaked in CHXF (Iran Avandfar Company, Iran) for one week. After that, the brackets were placed on the enamel surface in a manner similar to that of the control group.

In group 4, GC MI Paste Plus (USA) containing casein phosphopeptide-amorphous calcium phosphate fluoride (CPP-ACPF) was applied to the tooth surface for 3 minutes. It was then left for 30 minutes and washed with air/water spray for 1 minute. After that, the brackets were placed on the enamel surface in the same manner as the control group.

The mounting steps were performed using self-cured acrylic resin until the tooth crown was entirely outside the acrylic resin, and each tooth was placed at the center of a cylinder. The tooth's longitudinal axis was perpendicular to the horizontal surface, and the maximum convexity of the tooth was in contact with the blade of the Survivor device. Before the SBS test, the samples were immersed in distilled water at 37°C for 24 hours. The SBS of the specimens was measured by a universal testing machine (UTM) (Zwick Roell, Germany). After fixing each specimen in UTM, a shear force was applied parallel with the bracket base at a crosshead speed of 1 mm/minute with 0.5-mm blades in the occlusogingival direction. The force was applied to the bracket base–tooth interface in all the samples. The shearing force and the SBS were determined in N and MPa, respectively. The adhesive remnant index (ARI) was observed on the tooth under a stereomicroscope (Nikon SMZ800, Japan) at ×10 magnification. Figure 1 shows an image of the SBS testing by the UTM that applies the shearing force parallel to the upper base of the brackets.

The ARI score was defined as below (20,21):

Score 0: No adhesive on the enamel tooth surface

Score 1: Less than 50% adhesive remaining on the enamel surface

Score 2: More than 50% adhesive remaining on the enamel surface

Score 3: All the adhesive remaining on the enamel surface

An observer determined the ARI index.

Data were statistically analyzed using SPSS 24. The shear bond strengths were compared between the different surface pretreatment groups using one-way ANOVA, followed by post hoc Tukey tests to identify specific differences between groups. Descriptive statistics, including means and standard deviations, were calculated for all the groups. The significance level was set at $P<0.05$.

Results

Figure 2 and Table 1 show the box plot and the descriptive statistics of the SBS of orthodontic brackets in the four studied groups, respectively. The average shear bond strengths in the control, fluoride varnish, CHXF, and CPP-ACPF paste groups were 21.54±7.50, 12.19±8.58, 22.93±8.78, and 20.81±8.09 MPa, respectively.

The results showed that the highest and lowest shear bond strengths were related to the CHXF (mean: 22.93 MPa) and fluoride varnish (Mean: 12.19 MPa) groups, respectively.

The shear bond strength of the CHXF, CPP-ACPF paste, fluoride varnish, and control groups were compared by one-way ANOVA; the results showed a significant difference between the groups ($P=0.003$). Tukey test results showed no significant difference between the shear bond strength of the control, CHXF, and CPP-ACPF paste groups ($P>0.05$). However, the shear bond strength of the fluoride varnish group was significantly lower ($P<0.05$).

Figure 1. Applying the shear force parallel to the upper base of the brackets at UTM

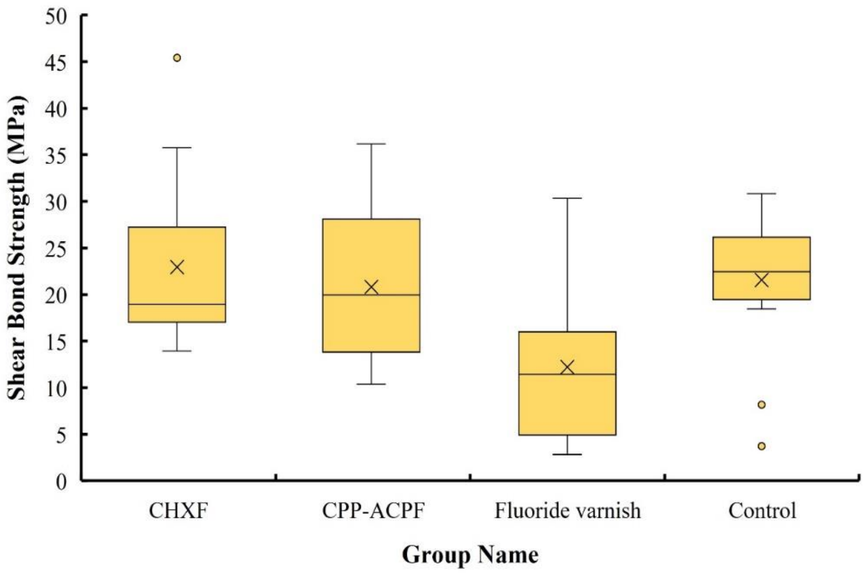

Figure 2. Box plot description of SBS of the studied groups

Table 1. Comparison of mean and standard deviation of shear bond strengths in four study groups based on one-way ANOVA

Group No.	Surface preparation	N	Shear Bond Strength (MPa)			
			Mean±SD	**Min.**	**Max.**	**P-value**
1	Control[a]	15	21.54±7.50	3.71	30.81	
2	Fluoride varnish[b]	15	12.19±8.58	2.83	30.33	0.003
3	CHXF[a]	15	22.93±8.78	13.94	45.38	
4	CPP-ACPF[a]	15	20.81±8.09	10.38	36.17	
Total		60	19.36±9.09	2.83	45.38	

Different letters (a, b) show significant statistical difference within groups at $p < 0.05$.

After bracket removal, the tooth surface was examined under a stereomicroscope at ×10 magnification to determine the amount of adhesive remaining. An observer assessed the (ARI) based on the tooth surface. Figure 3 displays a stereomicroscopic image of the tooth surface with various ARI scores.

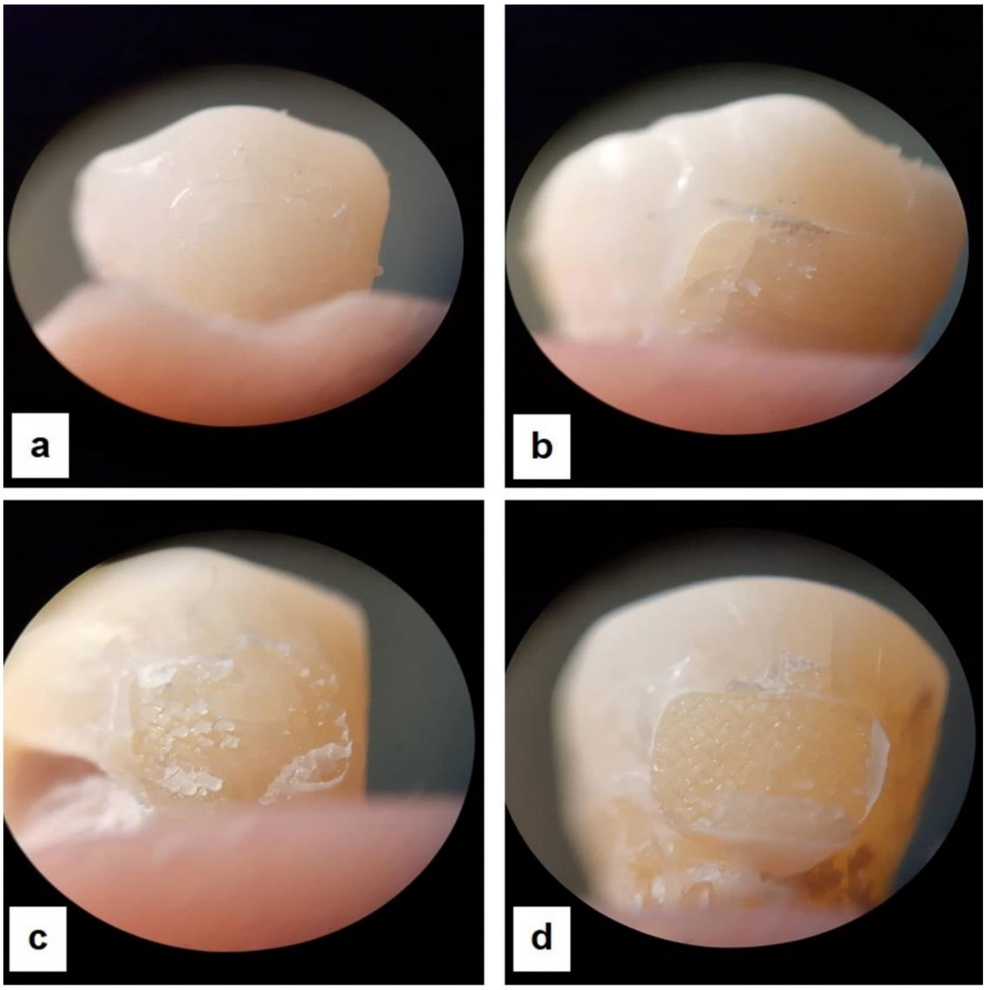

Figure 3. The stereomicroscopic image of the tooth surface with various ARI scores: a) ARI with a score of 0; b) ARI with a score of 1; c) ARI with a score of 2; and d) ARI with a score of 3.

Table 2 shows the distribution of ARI in the four study groups. As shown in Table 2, the highest prevalence in the fluoride varnish group was an ARI score of 0. ARI scores of 2 and 3 for CHXF, 2 for the CPP-ACPF paste, and 3 for the control groups were the most common.

The chi-squared test was used analyze the ARI data in this study. The P-value obtained by a Monte Carlo simulation was 0.057. Although this P-value showed no significant difference between the groups, its value was very close to 0.05.

Table 2. The amount of residual adhesive (ARI) on the teeth in each of the studied groups

Surface preparation	Adhesive Remnant Index (ARI)				Total	P-value
	0	1	2	3		
Control	2 (13.3%)	3 (20.0%)	3 (20.0%)	7 (46.7%)	15 (100%)	0.057
Fluoride varnish	7 (46.7%)	4 (26.7%)	4 (26.7%)	0 (0.0%)	15 (100%)	
CHXF	2 (13.3%)	1 (6.7%)	6 (40.0%)	6 (40.0%)	15 (100%)	
CPP-ACPF	3 (20.0%)	2 (13.3%)	7 (46.7%)	3 (20.0%)	15 (100%)	
Total	14 (23.3%)	10 (16.7%)	20 (33.3%)	16 (26.7%)	60 (100%)	

Discussion

In the present study, three prophylactic materials containing fluoride, including fluoride varnish, CHXF, and CPP-ACPF paste, were applied to the enamel tooth surface before placing the bracket on the tooth with GC Ortho Connect adhesive, which is a light-cured adhesive for orthodontic bracket bond and does not need a primer.

Using the topical sodium fluoride before acid etching of tooth enamel reduces the dissolution and demineralization of enamel in acidic conditions, increases remineralization in surface crystals, and inhibits bacterial enzymes (20). The results showed that sodium fluoride varnish reduces the shear bond strength compared to the control group, consistent with studies by Tabrizi and Cakirer (19) and Al-Kawari et al. (22). Biria et al. (23) reported that fluoride therapy with NaF gels reduced micro-shear bond strength before tooth-colored restorations. However, the difference was not significant, indicating no negative impact on the bond strength. Some studies have suggested that using sodium fluoride varnish can decrease the shear bond strength of orthodontic brackets because fluoride may interfere with phosphoric acid during enamel acid etching, which reduces the SBS. Orthodontists have suggested that this decrease is caused by interference from the formation of enamel tags. However, teeth with higher fluoride concentrations are more resistant to acid etching (24). Additionally, fluoride can produce reactive products such as $Ca_5(PO_4)_3F$ and CaF_2, which are formed after surface preparation with sodium fluoride, and $Sn_3PO_4F_3$ and CaF_2, which are formed after the use of stannous fluoride. These salts deposit on the tooth surface and partially fill the space between the tubules, resulting in a smaller surface area for the bracket bond (25). Naseh et al. showed that fluoride (0.005% fluoride mouthwash) did not affect shear bond strength (17). However, Keçik et al. showed an increase in the shear bond strength of the bracket (26).

In conclusion, the differences in the results can be attributed to the use of various fluoride products with different concentrations. Higher fluoride concentrations provide greater resistance to acid etching, making them more effective in this regard, where higher fluoride concentrations are more resistant to acid-etching. As a result, the shear bond strength decreases, similar to the case of fluorosis teeth (19).

Several studies have suggested that the fluoride applied after enamel acid-etching does not affect the shear bond strength (27,28). However, Tavakolinejad et al. (20) reported no significant difference between shear bond strength in the groups that used fluoride before and after acid-etching, contrary to our study where fluoride varnish before acid-etching reduced the shear bond strength. One reason for this difference is that they used fluoride gel with a concentration of 1.23%, while the fluoride concentration in the present study was 5%. In addition, they performed an SBS test after 72 hours of bracket bonding, while the SBS test was performed after 24 hours in our study.

In addition, the present study investigated the effect of using CPP-ACPF paste during surface preparation on the shear bond strength of orthodontic brackets. The results showed that the preparation of tooth enamel with CPP-ACP paste containing fluoride did not result in significant differences from the control group and had no effect on the SBS of brackets. The findings were consistent with the outcomes of various previously published studies (2,19,29,30). There are two reasons for these findings: first, the sodium fluoride in CPP-ACPF paste can interfere with the ACP component of the casein complex and inactivate both mineral components. However, the present study was performed in vitro, so this hypothesis requires further research on clinical applications. Second, the fluoride in the CPP-ACPF compound may precipitate as a nano-complex on the surface of the enamel. However, any surface preparation with fluoride on intact tooth enamel may not affect the shear bond strength or have a minor negative effect (30). Heravi et al. (29) found that CPP-ACPF can decrease the shear bond strength (SBS) of brackets, which contradicts our findings. The difference in results may be attributed to different bonding materials, material concentrations, and application times used in various studies. In the present study, CPP-ACPF was used before applying enamel demineralizing agents. The results showed that the SBS of orthodontic brackets for the sodium fluoride varnish group was 5% lower than the CPP-ACPF. Al-Kawari et al. showed that the sodium fluoride varnish group had more reduction in the shear bond strength of the orthodontic bracket than the CPP-ACPF paste group (22). Khosravanifard et al. reported that a high percentage of fluoride negatively affects the shear bond strength of orthodontic brackets (31). Lata et al. reported that enamel remineralized with sodium fluoride varnish was harder than enamel remineralized with CPP-ACPF paste, which may be due to their different reactions with surface enamel and remineralizing activity (32). In addition, differences in physical properties between sodium fluoride varnish and CPP-ACPF paste may have effects. Sodium fluoride varnish forms a protective layer on the enamel surface, while CPP-ACPF paste tends to enhance the clarity of the enamel surface following rinsing.

The present study showed that pre-preparation of tooth enamel with CHXF was not significantly different from the control group and did not affect the shear bond strength of the bracket, consistent with the findings reported by Tavakolinejad et al. (20). However, their study used the combination of chlorhexidine and fluoride gel separately in the preparation of surface enamel. Tavakoinejad et al. (20) reported a decrease in the shear bond strength of orthodontic brackets when using 0.2% chlorhexidine (without fluoride). This difference could be attributed to the absence of fluoride, as chlorhexidine without fluoride is quickly absorbed by the enamel surface, which interferes with the tooth enamel surface and can compromise the bonding process. Discrepancies in various study results may be attributed to differences in concentration, method, duration of use, and even its compounds (with or without fluoride). Since the shear bond strength of the orthodontic brackets in pre-preparation with CHXF was not significantly different from the control group, its use is recommended due to fluoride's anti-caries and chlorhexidine's antimicrobial properties. Little information about CHXF is available, so clinical studies are needed to explore its effects.

In addition, the present study showed no significant difference in the SBS of orthodontic brackets between the CHXF, CPP-ACPF paste, and control groups, indicating that these materials do not negatively affect the SBS of orthodontic brackets. One possible reason for differences in the bracket SBS observed in other studies that used prophylactic materials could be the use of GC Ortho Connect, which does not require a primer for bracket bonding. However, Dadgar et al. (33) found that the SBS of orthodontic brackets using GC Ortho Connect was within an appropriate range. One of the main points in orthodontic brackets' bond is that the SBS should be strong enough so that it will not be debonded during orthodontic treatment; on the other hand, it should be low enough so that after orthodontic treatment and bracket debonding, there will be no or minimal damage to the enamel (16). Esmaily et al. (34) reported that the universal bond significantly reduced the shear bond strength in the GC Ortho Connect composite resin but had little effect on the OrthoCem composite resin. This indicates that the effectiveness of universal bonds may vary with the composite type, highlighting the need for further research to optimize bonding methods for various orthodontic materials. Several studies have indicated that an SBS of 6–8 MPa is adequate for orthodontic purposes (17,20,35). In the present study, all three groups obtained shear bond strength values higher than the minimum requirement of orthodontic brackets.

The results concerning ARI showed that a score of 0 was the most common in the sodium fluoride varnish group. Kimura et al. (36) reported that fluoride varnish increased the bond failure at the enamel–adhesive interface, probably because the adhesive could not penetrate the tooth enamel surface due to fluoride varnish. Since the fluoride varnish group had the highest score of 0, this substance, used as a prophylaxis material before the bracket bonding procedure, increases the probability of damage to tooth enamel (38). The most common ARI scores in the CHXF group were 2 and 3. The most prevalent ARI score in the CPP-ACPF paste group was 2, while in the control group, it was 3. The lowest prevalence of ARI score of 0 was found in both groups.

Conclusion

The results demonstrated that the shear bond strength (SBS) of orthodontic brackets treated with all three surface preparation materials, CPP-ACPF paste, CHXF, and sodium fluoride varnish, fell within the clinically acceptable range for orthodontic applications. Therefore, these pretreatment techniques did not negatively impact the bond strength of metal orthodontic brackets. Given their efficacy in preventing caries, these methods are recommended for routine use in orthodontic practice.

Conflicts of interest

The authors have no relevant financial or non-financial interests to disclose

Data Availability

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

Acknowledgments

The authors wish to appreciate the Clinical Research Development Unit of Dental School, Alborz University of Medical Sciences, for funding and technical support.

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