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Research Article

Assessment of Fluoridated Orthodontic Adhesive: Exploring Fluoride Release, Rechargeability, and Their Influence on Shear Bond Strength in Intact Tooth Surfaces

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ABSTRACT: The current study aimed to investigate the fluoride release from light-cured orthodontic adhesive resin over various time intervals, examine the rechargeability potential of the resin, and evaluate its influence on shear bond strength in intact tooth surfaces. **Materials and Methods:** This study utilized 30 recently extracted upper premolar teeth for orthodontic treatment. The teeth were divided into three main groups to investigate fluoride release at specific time intervals: one day, one week, and one month. Within each time interval, subgroups were established, with one subgroup receiving a fluoride recharge through the application of a fluoride varnish. Subsequently, fluoride release and shear bond strength measurements were conducted on these samples. The samples were stored in 5 ml of deionized water, and for the recharging groups, fluoride varnish was applied and stored in an additional 5 ml of deionized water. The quantification of total solubilized fluoride was performed using a fluoride-selective electrode, while shear bond strength was evaluated using a Universal testing machine. Statistical analysis of the collected data was carried out using SPSS software version 22. **Results:** The month after group exhibited the highest mean values for both fluoride release and shear bond strength. Moreover, the study identified significant variations in fluoride release and shear bond strength across the different groups investigated. **Conclusions:** The utilization of fluoride varnish in the vicinity of the orthodontic bracket exhibits a favorable impact on the bracket's shear bond strength.

Keywords: Fluoride release; Orthodontic adhesive; Rechargeability; Shear bond strength.

INTRODUCTION

In light of the growing inclination towards optimal oral well-being and the pursuit of aesthetic perfection, the prominence of orthodontic intervention has increased significantly, garnering the attention and consideration of an expanding patient cohort. Currently, fixed orthodontic treatment has become a prevailing orthodontic modality, firmly entrenched within the established protocols of contemporary dental practice.

The placement of fixed orthodontic appliances on teeth poses challenges in maintaining oral hygiene. Residual adhesive and rough surfaces on brackets, archwires, or ligatures can lead to increased bacterial colonization and potential tooth demineralization. This demineralization manifests as white spot lesions (WSLs), which may become clinically visible around 4 weeks after the initiation of orthodontic treatment. Patients with poor oral hygiene are particularly susceptible to this issue. Reported frequencies of WSL occurrence range widely among orthodontic patients (2% to 96%) and are lower in non-orthodontic patients (25%) [2].

White spot lesions emerge as a consequence of subsurface demineralization occurring beneath a resilient outer layer of intact enamel. The nomenclature "white spot lesion" is derived from the distinct alteration in light reflection observed on demineralized enamel surfaces in contrast to adjacent areas of unaffected enamel, thereby imparting a characteristic chalky white aspect [3].

During the initial six months of orthodontic intervention, there was a notable rise in the occurrence of WSLs, which persisted at a decelerated rate until the twelfth month. Hence, heightened attention to oral hygiene practices is particularly crucial during the initial stages of treatment [4]. Their findings suggest that approximately one-third of WSLs could be arrested before caries manifestation. Consequently, the application of agents aimed at preventing tooth decay or halting the progression of primary lesions is recommended for orthodontic patients [5].

The principal approach to mitigating the development of WSLs involves patient education and promoting motivation for proper oral hygiene practices. Several other interventions have demonstrated effectiveness in this regard, such as the application of fluoride gels, varnishes, toothpaste, and mouth rinses. Furthermore, incorporating fluoride into orthodontic adhesives has emerged as a widely accepted approach in the fight against WSLs [6].

Numerous efficacious approaches have been researched and devised to counter enamel demineralization in the context of fixed orthodontic treatment. Primarily, enhancing patient oral hygiene stands as a promising strategy to minimize plaque accumulation. Additionally, topical fluoride application offers a means of reinforcing the enamel's resistance against microbial acidic byproducts [7].

Fluoride-releasing materials demonstrate the capability to uptake fluoride ions from the oral environment, leading to the replenishment of depleted fluoride levels. Termed fluoride recharge, this phenomenon significantly contributes to the extended duration of inhibitory action exhibited by these materials on the enamel demineralization process[8].

In addition to WSLs, bracket detachment stands as another substantial concern encountered in the context of orthodontic treatment involving multiple brackets. The occurrence of bracket detachment holds critical implications in certain clinical scenarios, as it can significantly impact the overall treatment success and duration. The literature has documented notable incidence rates of bracket detachment, warranting thorough consideration due to its potential effect on treatment outcomes [9].

The impact of fluoride application on bonding strength is currently under investigation. Recent studies suggest that the timing of fluoride application, whether applied before or after bracket placement, plays a crucial role in determining its effect on bonding strength [2,10].

The primary objectives of this study are to investigate the fluoride release from light-cured orthodontic adhesive resin over various time intervals, examine the rechargeability potential of the resin, and evaluate its influence on shear bond strength in intact tooth surfaces.

MATERIALS AND METHODS

Collection of Samples and Inclusion Criteria

This study employed recently extracted upper premolar teeth procured from private clinics and dental centers in Mosul City. The selection of teeth adhered to rigorous inclusion criteria, encompassing characteristics such as normal size, intact buccal surfaces without any evidence of cracks or fractures resulting from extraction, and a healthy dental structure devoid of caries or dental fillings, as well as no history of prior orthodontic treatment. To ensure preservation and to inhibit bacterial growth, the samples were thoroughly cleansed and stored in deionized water, which was replaced daily, at ambient room temperature.

Categorization of the Samples

A total of thirty samples were allocated into three primary groups to investigate fluoride release at distinct time intervals:

One day, 10 samples, 5 of them for fluoride release and shear bond strength, other 5 samples for recharge through fluoride varnish application.
One week, 10 samples, 5 of them for fluoride release and shear bond strength, other 5 samples for recharge through fluoride varnish application.
One month, 10 samples, 5 of them for fluoride release and shear bond strength, other 5 samples for recharge through fluoride varnish application.
Subsequently, fluoride release and shear bond strength measurements were conducted for all samples by their respective groupings.

Preparation of the Samples

The samples were affixed to plastic Poly Vinyl Chloride (PVC) rings with specific dimensions (20 mm outside diameter, 18 mm inside diameter, and 30 mm height). Precise positioning was ensured through a systematic mounting process. Initially, the PVC rings were partially filled with dental stone until reaching approximately half of their height. Subsequently, the tooth samples were securely fixed onto the stone surface using soft sticky wax, aligning them centrally within the plastic ring and perpendicular to the base. To maintain uniformity and alignment, the assembled samples were placed on a glass slab connected to a dental surveyor. The long axis of each tooth was oriented parallel to the analyzing rod of the surveyor, thereby replicating the direction of force application during the shear bond strength test [11]. As the final stage, the PVC rings were filled with auto-polymerizing cold-cure acrylic resin, attaining the level of the cementoenamel junction (CEJ)as seen in Figure 1. This step aimed to stabilize and securely immobilize the tooth samples, thereby enabling accurate analysis and testing procedures.

Bonding Procedure

The mounted samples were subjected to a systematic polishing procedure utilizing fluoride-free pumice and a rubber prophylactic cup. Subsequently, the buccal surface of each tooth underwent etching with a 37% phosphoric acid gel for a duration of 30 seconds, followed by thorough rinsing and drying. The complete sample assembly was then positioned on an articulator, incorporating a prefabricated base to ensure stability and alignment. Thereafter, Stainless-Steel Metallic Brackets of the Standard Edgewise type sourced from Dentaurum, Germany, were securely held in place using clamping tweezers. To ensure uniformity, Vega ortho UV light-cured orthodontic adhesive resin from Brazil was uniformly applied to the bracket's base. Attentive bracket placement at the center of the premolar tooth's buccal surface, maintaining a consistent four mm distance from the occlusal surface, was ensured by employing the boons gauge as a guide for precise positioning.

To achieve a uniform resin thickness devoid of air voids, a standardized load of 200g. was applied perpendicularly to the bracket slot on the articulator arm[12], as depicted in Figure 2. The excess resin was subsequently removed, and the curing process was conducted using an LED light curing device (B-Cure, Guilin Woodpecker Medical Instrument Co., Ltd.), which operated within a wavelength range of 385nm-515nm and offered an illumination intensity of 1200-1500 mW/cm^2. For calibration purposes, the curing light was calibrated for every 5 samples using a radiometer. During the curing process, the light exposure persisted for 20 seconds on both the mesial and distal sides of the bracket, with the tip positioned 2mm away from each edge [13]. Eventually, the specimens were carefully immersed in a container containing 5 ml of deionized water.

Fluoride Recharging

In the recharging groups, each sample underwent a meticulous drying process followed by a singular topical application of fluoride varnish (FluoroDose, USA) using a brush applicator surrounding the bracket. After a three-minute interval, the samples were lightly moistened with a gentle air/water spray and subsequently stored individually in 5 ml of deionized water until further analysis [14].

Fluoride Analysis

The fluoride release was done on all samples before and after recharge; the analysis was conducted at the central laboratory located within the College of Agriculture and Forestry, University of Mosul. The quantification of total solubilized fluoride was performed using a fluoride-selective electrode, with readings recorded once stabilization was achieved, as illustrated in Figure 3. To ensure accuracy, the electrode underwent pre-calibration employing a range of fluoride calibration solutions, leading to the generation of a calibration curve. This curve enabled the conversion of millivolt readings to fluoride concentrations expressed in parts per million (ppm). Through this systematic process, precise quantification of fluoride levels in the samples was achieved, enabling meaningful inferences regarding their fluoride content.

Assessment of Shear Bond Strength

The shear bond strength (SBS) test was conducted at the Operative Department laboratories within the College of Dentistry, University of Mosul. The Universal testing machine (Gester, China) was utilized with a crosshead speed set at 0.5mm/min.

To exert force on the tooth-bracket interface in an occlusal-gingival direction, a knife-edge blade was employed. The load required to commence bracket failure or debonding was recorded in Newton units and subsequently converted to Megapascals (MPa). This conversion was achieved by dividing the failure load in Newton units by the standardized base surface area of the brackets, which measured 10.03 mm^2, in accordance with the specifications provided by the manufacturing company.

Figure (1): Samples before bracketing.

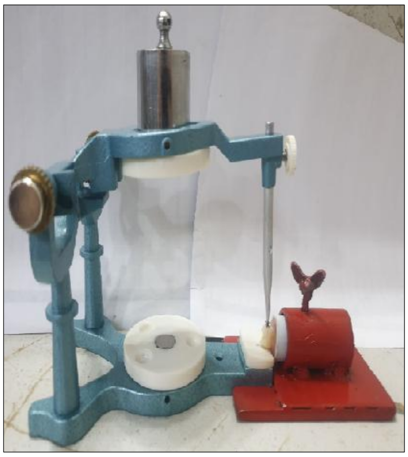

Figure (2): The entire sample was situated on the articulator utilizing a prefabricated base.

Figure (3): Fluoride analysis.

Statistical Analysis

The data were subjected to statistical analysis using IBM SPSS Statistics 22 software. To verify the normal distribution of variables, the Kolmogorov-Smirnov test was employed, where the values were greater than 0.05. Descriptive analysis for each variable, including measures such as mean, standard deviation, range, minimum, and maximum values, was computed. One-way analysis of Variance (ANOVA) was utilized to ascertain significant differences among the groups. Duncan's Multiple Range test was conducted to determine significant differences in fluoride release and SBS among the groups. Significance was established at $p \leq 0.05$.

Results

Fluoride Release Analysis

The analysis of the study's findings revealed that the month after group exhibited the highest mean value, whereas the week before group displayed the lowest mean value among all the groups. The month before the group had the minimum record, while the month after the group had the maximum record, as seen in Table 1.

The results of the analysis of variance (ANOVA) statistical test are presented in Table 2, indicating a significant difference ($p \leq 0.05$) among the mean values of the fluoride release within the present study.

The results of Duncan's multiple range test are depicted in Table 3. It indicates that all groups exhibit significant differences when compared to each other, except for the week before and month before groups, which do not significantly differ from each other.

Shear Bond Strength Analysis

The analysis of the study findings revealed that the month after group had the highest mean value, while the week before group displayed the lowest mean value among all the sound groups. The day before, the group had the minimum record, whereas the month after, the group had the maximum record Table 4.

The results of the analysis of variance (ANOVA) statistical test are presented in Table 5, indicating a significant difference ($p \leq 0.05$) among the mean values of the SBS within the present study.

The results of Duncan's multiple range test are depicted in Table 6. It reveals that the day and week groups (before and after) do not significantly differ from each other. However, the month groups (before and after) exhibit a significant difference when compared to the other groups.

Table (1): Descriptive statistics of the fluoride release

Time	Variables	Mean	Std. Deviat	Minimum	Maximum
Day	Before	0.356	.0383	0.30	0.43
	After	0.865	.0106	0.86	0.88
Week	Before	0.127	.0258	0.09	0.16
	After	0.658	.0334	0.62	0.71
Month	Before	0.184	.0779	0.07	0.29
	After	1.047	.1223	0.87	1.16

The measurements in ppm

Table (2): ANOVA for the mean values of fluoride release

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.687	5	.937	263.434	.000**
Within Groups	.139	39	.004		
Total	4.826	44			

df: degree of freedom; F: F test; Sig: is a highly significant level at ($P \leq 0.01$).

Table (3): Duncan's multiple range test for fluoride release

Time	Variables	Mean	Std. Deviation	Duncan
Day	Before	0.356	.0383	B
	After	0.865	.0106	D
Week	Before	0.127	.0258	A
	After	0.658	.0334	C
Month	Before	0.184	.0779	A
	After	1.047	.1223	E

Different letters mean a significant difference at ($P \leq 0.05$).

Table (4): Descriptive Statistics for the shear bond strength

Time	Variables	Mean	Std. Deviation	Minimum	Maximum
Day	Before	8.063	1.796	6.21	10.88
	After	9.675	2.057	7.11	11.71
Week	Before	8.048	0.711	7.16	8.87
	After	8.218	0.656	7.61	9.26
Month	Before	10.595	0.924	9.39	11.66
	After	10.817	0.944	9.44	11.80

The measurements in MPa

Table (5): ANOVA for the mean values of Shear bond strength.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	41.811	5	8.362	4.945	.003*
Within Groups	40.581	24	1.691		
Total	82.393	29			

df: degree of freedom; F: F test; Sig: is a highly significant level at (P≤0.01).

Table (6): Duncan's multiple range test of shear bond strength

Time	Variables	Mean	Std. Deviation	Duncan
Day	Before	8.063	1.796	A
	After	9.675	2.057	AB
Week	Before	8.048	0.711	A
	After	8.218	0.656	A
Month	Before	10.595	0.924	B
	After	10.817	0.944	B

Different letters mean a significant difference at (P≤0.05).

DISCUSSION

The exploration of preventive strategies concerning the occurrence of WSLs before and during fixed orthodontic treatment constitutes a significant domain of scholarly investigation. This relevance is underscored by the substantial incidence rates of WSLs, ranging between 30% to 70%, that have been documented in association with fixed orthodontic interventions[5]. Among these strategies, the utilization of fluoride-releasing orthodontic adhesives emerges as a promising approach in potentially mitigating the occurrence of WSLs [15].

The incorporation of fluoride into orthodontic adhesives poses a pragmatic challenge in terms of fluoride replenishment. It is imperative to maintain a continuous and sustained supply of fluoride to the enamel surface even after the composite has fully released its fluoride content. As a result, the recharging of the adhesive with sodium fluoride (NaF) becomes a necessary measure to enhance the presence of fluoride ions within the medium over a specified duration.

The principal aim of this study was to assess the fluoride release behavior of Vega ortho UV light-cured orthodontic adhesive at distinct time intervals while investigating its rechargeability through the utilization of Fluoride Varnish. Furthermore, the study aimed to address the existing ambiguity regarding the potential influence of these procedures on the shear bond strength (SBS) of brackets.

To attain these objectives, the investigation involved evaluating the SBS at multiple time points, both before and after the recharge process.

The observed fluoride release pattern in the groups before recharge demonstrated a significant initial surge in fluoride ion release on the first day, which can be attributed to the presence of fluoride ions in the adhesive that had not yet been absorbed by the tooth surface. Subsequently, there was a gradual decline in fluoride ion release after one week, with a slight increment observed after one month. These findings are consistent with the results reported in previous studies[8,16].

Another phase of this study was directed towards evaluating the uptake of fluoride ions and their subsequent release from orthodontic adhesives after the application of topical fluoride varnish. The investigation demonstrated that orthodontic adhesives are capable of absorbing and subsequently re-releasing fluoride ions after exposure to topical fluoride applications. Among the groups subjected to recharge, the one-month group exhibited the highest mean value, possibly attributed to the adhesive's substantial fluoride release during the recharge process, leading to greater reuptake and subsequent larger release. The remaining groups displayed intermediate values, showcasing statistically significant differences when compared to each other according to the Duncan test.

The initial increase in fluoride ion release following the topical application of fluoride can be explained by the expulsion of fluoride ions that were initially retained on the surface or within the material's pores during the refluoridation process. These findings suggest that the adhesive being studied has the capacity to recharge with fluoride ions introduced through fluoride application methods.[8]

Nevertheless, previous research endeavors have generated divergent and contradictory findings concerning the influence of fluoride application on shear bond strength (SBS). In general, fluoride pretreatment has been linked to reduced SBS values, leading to a compromised bonding efficacy of orthodontic brackets. The application of topical fluoride has been observed to potentially disrupt the etching process of phosphoric acid on enamel surfaces, which, in turn, may lead to a decline in the bond strength associated with the adhesion of orthodontic brackets. [10,17-19].

The present study has elucidated a positive association between fluoride release and shear bond strength (SBS), as indicated in Table 4. Notably, the SBS values observed in the month after groups exhibited the highest mean value. These findings deviate from earlier research, where fluoride-treated groups demonstrated lower SBS values. This discrepancy can be attributed to fluoride's propensity to interact with the enamel surface, resulting in the formation of calcium fluoride and fluorapatite, consequently rendering the surface more resistant to demineralization. Importantly, in those studies, fluoride application occurred before bracketing, potentially compromising the etching effect of phosphoric acid on enamel surfaces and thus reducing the bond strength of dental resin [20]. Conversely, our investigation applied fluoride varnish after the bracketing procedure to tooth surfaces, resulting in a significant improvement in the shear bond strength of the orthodontic attachments.

CONCLUSIONS

Within the limitations of the current study, it is possible to conclude that:
the application of fluoride varnish in proximity to the orthodontic bracket exerts a beneficial influence on the shear bond strength of the bracket. This observation provides valuable insights into the dynamics of fluoride release and its impact on the bonding strength of orthodontic adhesives, offering potential avenues for enhancing orthodontic treatment outcomes.

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Authors' Contribution

Conceptualization: Agha NF. Data curation: Yaseen MS, Formal analysis: Yaseen MS, Agha NF. Funding acquisition: Yaseen MS Investigation: Yaseen MS, Agha NF Methodology: Agha NF, Al-Naimi RJ Project administration: Agha NF, Yaseen MS Resources: Yaseen MS Software: Yaseen MS, Agha NF Supervision: Agha NF Validation: Agha NF, Al-Naimi RJ Visualization: Yaseen MS, Agha NF Writing–original draft: Yaseen MS Writing–review editing: Agha NF, Al-Naimi RJ.All authors have read and approved the final manuscript.

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Ethical statement: The protocol of this study was approved by the Research Ethical Committee at the University of Mosul (UoM.Dent.23/3).

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Availability of data and materials: Data is available at the request of the corresponding author.

Declaration of Generative AI and AI-assisted technologies

No generative AI or AI-assisted technologies were used in the preparation of this work. The authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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تقييم لاصق تقويم الأسنان المفلور: استكشاف إطلاق الفلورايد وقابلية إعادة الشحن وتأثيرهما على قوة الارتباط القصي في أسطح الأسنان السليمة

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الملخص

الأهداف: هدفت الدراسة الحالية إلى التحقق من إطلاق الفلوريد من الراتنج اللاصق لتقويم الأسنان المعالج بالضوء على فترات زمنية مختلفة ، وفحص إمكانية إعادة الشحن للراتنج ، وتقييم تأثيره على قوة رابطة القص في أسطح الأسنان السليمة. **المواد وطرائق العمل**: في هذه الدراسة ، تم استخدام ثلاثين ضاحكًا علويًا تم خلعها مؤخرًا لعلاج تقويم الأسنان. تم تقسيم الأسنان إلى ثلاث مجموعات رئيسية للتحقق من إطلاق الفلوراید في فترات زمنية محددة: يوم واحد ، وأسبوع ، وشهر واحد. في غضون كل فترة زمنية ، تم إنشاء مجموعات فرعية ، مع مجموعة فرعية واحدة تتلقى إعادة شحن الفلوراید من خلال تطبيق ورنيش الفلوراید. بعد ذلك ، أجريت قياسات إطلاق الفلوريد وقياسات قوة رابطة القص على هذه العينات, تم تخزين العينات في خمسة مل من الماء منزوع الأيونات ، وبالنسبة لمجموعات إعادة الشحن ، تم تطبيق ورنيش الفلوراید وتخزينه في خمسة مل إضافية من الماء منزوع الأيونات. تم إجراء القياس الكمي للفلوريد المذاب الكلي باستخدام قطب فلوريد انتقائي ، بينما تم تقييم قوة رابطة القص باستخدام آلة اختبار عالمية. **النتائج**: أظهر البحث أن مجموعة الشهر بعد إعادة الشحن أظهرت أعلى متوسط قيم لكل من إطلاق الفلوراید وقوة رابطة القص. علاوة على ذلك ، حددت الدراسة اختلافات كبيرة في إطلاق الفلوريد وقوة رابطة القص عبر المجموعات المختلفة التي تم فحصها. **الاستنتاجات**: استخدام ورنيش الفلوريد بالقرب من قوس تقويم الأسنان يظهر تأثير إيجابي على قوة رابطة القص للقوس.

الكلمات المفتاحية: إطلاق الفلوراید؛ لاصق تقويم الأسنان؛ قابلية إعادة الشحن؛ قوة ربط القص.