Journal of
Composites Science

Article

Orthodontic Bracket Rebonding with and without Fluoride: A Pilot Study

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Abstract: Adhesion between orthodontic brackets and conditioned enamel surfaces is essential for treatment success with fixed appliances. During treatment, enamel demineralization lesions commonly appear although remineralization is possible through fluoride application. Aim: Evaluation of the surface rugosity in bracket rebonding, specifically the influence of fluoride application before the bonding protocol. In total, 30 human premolars extracted for orthodontic reasons were used and divided into three groups. The control group was not submitted to any experimental manipulation; group 1 and 2 were placed in a demineralization solution and group 2 was additionally subjected to a subsequent fluoride application. The surface rugosity was measured at different timings: T0—before bracket bonding; T1—first bracket debonding after composite removal; and T2—second bracket debonding after composite removal. For the statistical analysis, the Kruskal–Wallis test, Mann-Whitney test, and Student's *t*-test were used. Regarding the comparison between groups, at T0 and T1, no statistically significant differences were observed. However, at T2, statistically significant differences were verified between the control group and group 1 for the parameters: Ra ($p = 0.0043$), Rq ($p = 0.0043$), Rqmax ($p = 0.0043$), Rp ($p = 0.0087$), and Rv ($p = 0.026$). Regarding the evaluation between time points, in the control group, no statistically significant differences were observed. In group 1, statistically significant results were found between T0 and T1 for the parameters: Rq ($p = 0.0451$), Rqmax ($p = 0.0451$), Rp ($p = 0.0091$), and Rvk ($p = 0.0433$) and between T1 and T2 for the parameters: Ra ($p = 0.0465$), Rq ($p = 0.0433$), Rqmax ($p = 0.0433$), and Rp ($p = 0.0155$). In group 2, statistically significant differences were found between T0 and T1 for the parameter Rvk ($p = 0.0405$). A decrease In surface rugosity was observed during multiple bracket rebonding procedures. Therefore, this study suggests that rebonding procedures alter the enamel surface rugosity. The need for rebonding should be avoided, opting for a more effective and correct first bonding. In the case of multiple rebonding, enamel remineralization maneuvers must be applied to recover the surface, since the results of this study suggest that the application of fluoride prior to bracket adhesion promotes lower surface roughness.

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Citation: Vale, F.; Travassos, R.; Pinto, M.D.; Ribeiro, M.P.; Marques, F.; Ramalho, A.; Antunes, P.; Marto, C.M.; Paula, A.B.; Nunes, C.; et al. Orthodontic Bracket Rebonding with and without Fluoride: A Pilot Study. *J. Compos. Sci.* **2024**, *8*, 10. https://doi.org/10.3390/jcs8010010

Academic Editors: Francesco Tornabene and Vincenzo Fiore

Received: 23 October 2023
Revised: 10 December 2023
Accepted: 25 December 2023
Published: 27 December 2023

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Keywords: rebond; surface roughness; demineralization; orthodontic treatment; enamel and fluoride

1. Introduction

Enamel etching with orthophosphoric acid was introduced by Buonocore in 1955, enabling the development of new bonding techniques for use in orthodontics [1]. The application of this agent causes selective decalcification of the enamel [2], creating a rough surface, increasing the contact area and surface energy that provides the substrate for infiltration of the bonding agent, making micromechanical bonding possible between adhesive materials and the enamel surface. Three types of adhesive systems are currently available: etch&rinse, self-etch, and the universal system [3,4]. The etch&rinse adhesive system is characterized by conditioning the enamel with orthophosphoric acid and involves two or three steps, as the primer and bonding agents can be separate or combined in a single bottle. The self-etch adhesive system contains an acidic primer with hydrophilic acid monomers, reducing the number of steps to two (acidic primer and bond). This reduces appointment time and the possibility of contamination with saliva during bracket bonding. The universal system combines both, being applied to the tooth surface with or without prior application of orthophosphoric acid. These universal systems contain acidic primers and resin monomers, always mixed in a single bottle [5,6].

Adhesion between the bracket and the conditioned enamel surface is essential in order to achieve an effective orthodontic treatment [7]. The need to replace brackets during treatment slows down its progress and implies costs for the patient and clinician (appointment time, cost of materials, and time lost in educating) [8]. Bracket adhesion depends on the preparation of the tooth surface, the bracket base, and the bonding material. The factors that can influence the percentage of bracket detachment are: the bracket material, the type of adhesive system, the location of the brackets (anterior or posterior sector; maxilla or mandible), occlusion, and the patient's age [9–11].

Regarding the type of material, ceramic brackets have greater shear strength than metallic brackets [12]. The clinician should consider that the ideal orthodontic adhesive should have the following characteristics: (1) sufficient bond strength to keep the brackets bonded to the teeth throughout treatment. The ideal bond strength should not be too strong in order to avoid damaging the tooth surface when the appliance is removed. Adhesive forces higher than 13.5 MPa can cause enamel fracture [13]. It is preferable for a failure to occur between the adhesive and the bracket rather than a failure between the adhesive and the enamel, as this can cause the enamel to fracture or develop cracks [14]; (2) easy to use; (3) protects against dental caries lesions; (4) available at a reasonable cost. Currently available composites include resin-modified glass ionomer cements or compomers [8].

In addition, the type of malocclusion can also influence bracket debonding. According to the literature, the highest prevalence of bracket debonding occurs in patients with Class II division 2 or patients with a deep bite [9], given that the upper incisor brackets interfere with the lower brackets [15]. The location of the brackets also plays a role in the debonding rate, with the mandibular first molar being the most commonly affected tooth [16]. Many factors can influence the bonding process, such as saliva contamination and improper handling of the products. For a proper bonding protocol, the orthodontist needs an isolated working field (with cotton rolls, suction, and cheek retraction), good bonding technique, and the right materials [17–19].

Finally, if it is impossible to bond the bracket in the correct position due to the type of malocclusion, position deviations, or tooth rotations, the brackets must be reattached in order to avoid incorrect positioning of the teeth and reduce the need for bends in the arch [17,20,21].

Brackets should be reattached in cases of bracket detachment or in cases of incorrect initial bonding by adhering a new bracket or reattaching it [20]. There are several options for removing excess adhesive and resin: tungsten drills, aluminum oxide blasting, finishing drills, bracket heating, and Softlex discs [22]. In the heating technique, the bracket can reach temperatures of between 600 °C and 800 °C, making it more susceptible to deformation and changes in structure [22]. Among the methods available, several studies have shown that the method that achieves the greatest adhesion strength is aluminum oxide blasting. This technique is carried out with a high-speed jet of oxide particles through compressed air [23], increasing adhesive strength through micro-etching on the surface of the bracket [24,25].

The enamel surface must also be considered in the bracket repositioning protocol. During detachment, enamel damage inevitably occurs due to the mechanical bond between the adhesive and the conditioned enamel surface [26,27]. However, enamel demineralization can often occur during fixed orthodontic treatment due to the combination of insufficient oral hygiene and a sugar-rich diet, which lowers the oral pH, enhancing the action of bacteria present in the oral cavity with consequent enamel demineralization. According to the literature, the prevalence of white spot lesions in patients with fixed braces varies between 11.7 and 25.6% [28,29]. Considering that detaching brackets inevitably leads to damage to the enamel, preventive methods should be considered to protect it, such as fluoride. This decrease in adhesion strength can occur if fluoride is applied before [30,31] or after acid etching [32,33]. On the other hand, other studies refute this decrease in adhesion promoted by the application of fluoride [29,34,35]. Due to the existing controversies, more studies on bracket reattachment protocols and the interference of fluoride application on bracket bonding should be carried out in order to improve clinical procedures. This study has the following objectives: to evaluate the roughness of the tooth surface when brackets are replaced and to assess whether the application of fluoride before the bonding protocol affects the roughness of the tooth surface.

The null hypothesis is that there are no significant differences in tooth surface roughness between the different procedures.

2. Materials and Methods

2.1. Study Design

This ex vivo study received a favorable opinion from the Ethics Committee of the Faculty of Medicine of the University of Coimbra, with the procedural identification number CE-065/2023. Informed consent was signed by the patients or legal representatives regarding the teeth used in this study.

2.2. Selection Criteria

Human molar or premolar teeth extracted for orthodontic reasons in patients aged between 14 and 20 years were stored in 0.9% normal saline at 5 °C for no more than 4 months after extraction. The selection of teeth took into account the following inclusion criteria: intact buccal surface, absence of fractures and/or fissures, absence of caries lesions, absence of restorations, and absence of exposure to chemical agents such as hydrogen peroxide. In order to assess the eligibility of the teeth, these were evaluated using a microscope with a magnification of ×8 (Omano CX3-3360-TL 6.7X-45X Zoom Stereo Microscope Inspection System, Roanoke, VA, USA).

2.3. Sample Preparation

2.3.1. Mounting the Acrylic Samples

The teeth were placed in 3 cm long and 10 cm high self-curing acrylic molds, with only the buccal surface of the tooth exposed.

2.3.2. Cleaning the Samples

The tooth surface was cleaned using a nylon prophylaxis brush attached to a low rotation instrument and fluoride-free paste for 5 s on the buccal surface. The tooth was then rinsed with water for 10 s and dried with an air/water tip.

2.4. Sample Distribution

After selecting the teeth, the final sample was divided into 3 groups, each comprising 10 teeth. Table 1 describes the protocol applied to each group.

Table 1. Experimental protocol applied to each group.

	Control Group	Group 1	Group 2
Sample Size	**10**	**10**	**10**
Step 1	Evaluation of tooth surface roughness	Evaluation of tooth surface roughness	Evaluation of tooth surface roughness
Step 2	Bracket bonding according to manufacturer's instructions	Bracket bonding according to manufacturer's instructions	Pre-treatment of enamel surfaces with 3M Vanish (3M, St. Paul, USA) for 3 min, leave to stand for 30 min in distilled water
Step 3	Bracket debonding using the shear test	Placement in demineralization solution	Bracket bonding according to manufacturer's instructions
Step 4	Assessment of tooth surface roughness after composite removal	Bracket debonding using the shear test	Placing in demineralization solution
Step 5	Bracket re-bonding according to manufacturer's instructions, up to 24 h after bracket removal	Assessment of tooth surface roughness after composite removal	Removal of bracket using the shear test
Step 6	Bracket detachment again by shear test	Bracket re-bonding according to the manufacturer's instructions, up to 24 h after bracket removal	Assessment of tooth surface roughness after composite removal
Step 7	Roughness assessment after composite removal	Bracket detachment again by shear test	
Step 8		Roughness assessment after composite removal	

Three evaluation times were defined: T0—before bracket bonding; T1—first bracket detachment after composite removal; T2—second bracket detachment after composite removal.

2.5. Bracket Bonding

For this study, 30 stainless steel premolar brackets were used (Orthos, Roth prescription, 0.018-inch box, Ormco Corporation, Orange, CA, USA). New brackets were used in each bonding sequence. Six brackets were selected at random from the same batch in order to determine the average size of the bracket base. It was determined that the average area of the base of the brackets is 10.22 mm^2.

After prophylaxis of the samples, acid etching was carried out using 37% liquid phosphoric acid (Ormco, CA, USA) for 30 s and then the teeth were rinsed for the same length of time. The tooth surface was dried using an air/water syringe until the surface of interest appeared white and dull. Next, Ortho Solo™ primer (Ormco, CA, USA) was applied to the buccal surface of the tooth in order to attain a uniform layer. Finally, the tooth was dried for 5 s with an air/water syringe directed perpendicularly to the buccal surface.

Regarding bracket preparation, Greengloo™ adhesive paste (Ormco, CA, USA) was applied to the base and then the bracket was positioned on the tooth using a universal positioner at a standardized height of 4 mm from the top of the buccal cusp. Excess adhesive was removed with an exploratory probe without altering the bracket. Light curing was then carried out using the Ortholux™ LED Curing Light (App. 1000 mW/cm^2) (LED), placed in a fixed position 2–3 mm away from the bracket (10 s mesially and 10 s distally). After the bonding protocol, each tooth was stored for 24 h in distilled water at room temperature.

2.6. Placement in Demineralization Solution

After bonding the bracket, the teeth in group 1 were placed in a demineralization solution for 96 h consisting of 2.2 mM calcium chloride, 2.2 mM monosodium phosphate and 0.05 M acetic acid in order to adjust the pH to 4.4. The demineralization solution was changed every 3 h [36].

2.7. Removing the Adhesive after Take-Off

After detaching the bracket, the adhesive was removed using a tungsten drill (Ormco, CA, USA) with high rotation and water cooling. Removal of the adhesive on the enamel surface was considered complete when a polished surface appeared [37,38] and the enamel surface recovered smoothness. Each drill was used only 10 times.

2.8. Roughness Assessment

The teeth were submitted to an evaluation of the roughness of the tooth surface, using the Mitutoyo Surftest 402 Surface Tester (Mitutoy Co., Kawasaki, Japan), in accordance with ISO 4288 standards. The area of adhesion was delimited on the tooth surface to ensure that surface roughness measurements were always taken in the same area. The parameters assessed were arithmetic mean surface roughness (Ra), mean square root roughness (Rq), square root maximum roughness (Rqmx), maximum roughness height (Rp), maximum valley depth (Rv), and reduced valley depth (Rvk).

The arithmetic mean of the evaluation profile (Ra) corresponds to the arithmetic mean of the absolute values of the profile coordinates, where c is the base length. This value is given by the equipment through Equation (1):

$$Ra = \frac{1}{c}\int_0^c |Z(x)|dx \tag{1}$$

The maximum profile height (Rz) corresponds to the sum of the maximum height of the profile peaks, Zp, with the maximum depth of the profile values, Zv, included in the sample length, Ir. This value is given through Equation (2). Rmax corresponds to the highest roughness value of the profile during the measurement path; in other words, it is the highest value of Rz:

$$Rz = Zp + Zv \tag{2}$$

The average squared deviation of the evaluated profile (Rq) corresponds to the square root of the arithmetic mean of the squared values of the profile coordinates, where c is the base length. This value is given through Equation (3):

$$Rq = \sqrt{\frac{1}{c}\int_0^c z^2\,(x)dx} \tag{3}$$

The maximum height of the roughness profile (Rt) is defined as the sum of the greatest of the profile peak heights, Zp, and the greatest of the profile valley depths, Zv, within the evaluation length, In. This value is given through Equation (4), where the maximum height of the profile peaks (Rp) corresponds to the distance from the maximum peak to the midline:

$$Rt = Zp_{max} + Zv_{max} \tag{4}$$

Five measurements were taken on each specimen, uniformly and at constant speed, along the surface. The specimens were positioned on a metal support, with the same orientation as their length. The extension for measuring the surface was from 0.8 to 4 mm for a Ra between 0.1 and 2 µm.

2.9. Statistical Analysis

The data were analyzed using the Statistical Package for the Social Sciences software, version 24.0 for Windows (SPSS Inc., Chicago, IL, USA). The significance level adopted for all analyses was 0.05. Normality/non-normality was checked using the Shapiro–Wilk test for the different groups of assessment times. In the comparison between groups, times T0 and T1 were analyzed using the Kruskal–Wallis test, while T2 was analyzed using the Mann–Whitney test. Regarding the comparison between the different assessment times, the control group and group 1 were analyzed using the mixed effect analysis test, while group 2 was analyzed using the paired *t*-test.

3. Results

3.1. Sample Characterization

The final sample comprised 20 human premolar teeth divided into 3 groups: control group—6 teeth; group 1—8 teeth; and group 2—6 teeth (Table 1). Surface roughness was assessed at times T0, T1, and T2 in the control groups and group 1, while group 2 was assessed only at times T0 and T1.

3.2. Comparative Assessment between Groups

3.2.1. At Time T0

Figure 1 shows the variation in surface roughness in the experimental groups at T0. No statically significant differences were observed between the surface roughness of the different experimental groups. In addition, a greater dispersion of results was observed in group 1.

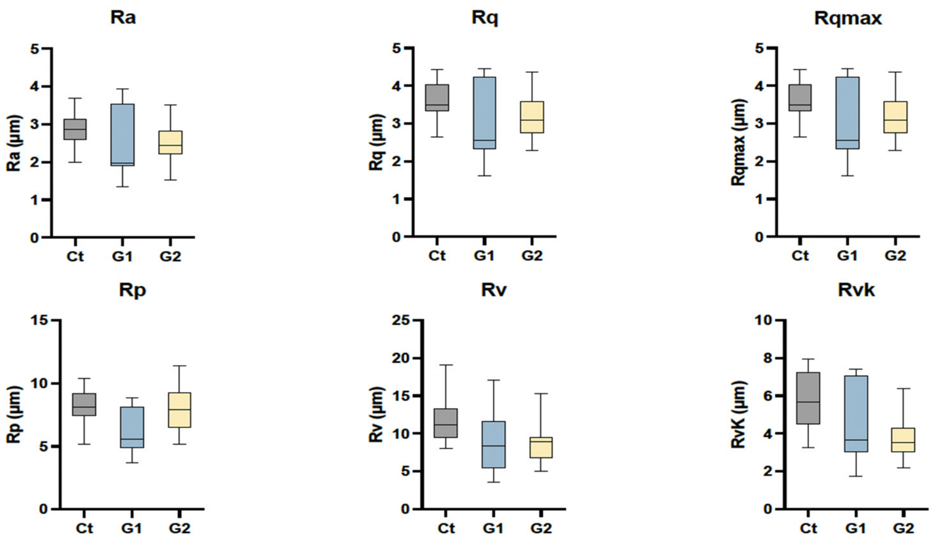

Figure 1. Surface roughness variation in the experimental groups at T0 (Ct—Control Group, G1—Group 1; G2—Group 2).

3.2.2. At Time T1

Figure 2 shows the variation in surface roughness in the experimental groups at T1. Group 2 was found to have lower roughness values in all the parameters assessed. However, the differences are not statically significant.

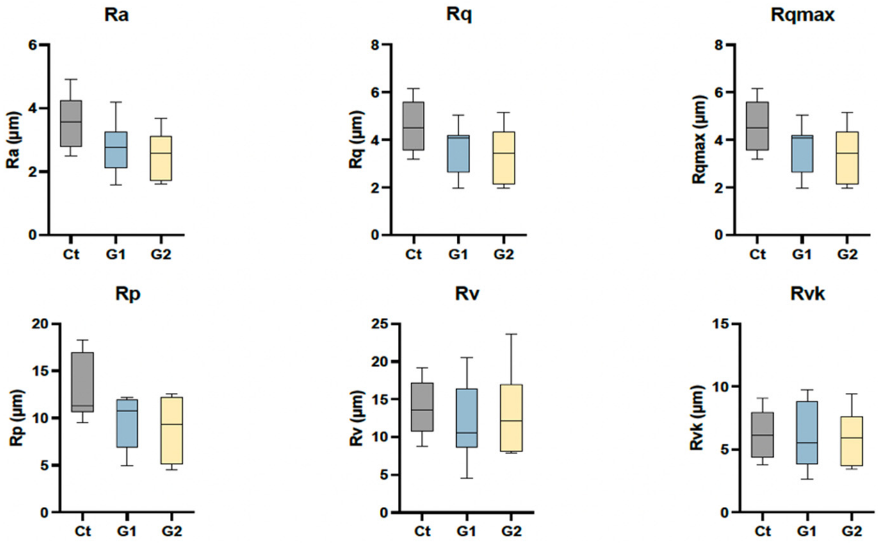

Figure 2. Surface roughness variation in the experimental groups at T1 (Ct—Control Group, G1—Group 1; G2—Group 2).

3.2.3. At Time T2

Figure 3 shows the variation in surface roughness in the experimental groups at T2. There were statistically significant differences between the control group and group 1 for the parameters: Ra (p = 0.0043), Rq (p = 0.0043), Rqmax (p = 0.0043), Rp (p = 0.0087), and Rv (p = 0.026). There were no statistically significant differences for the Rvk parameter (p > 0.05).

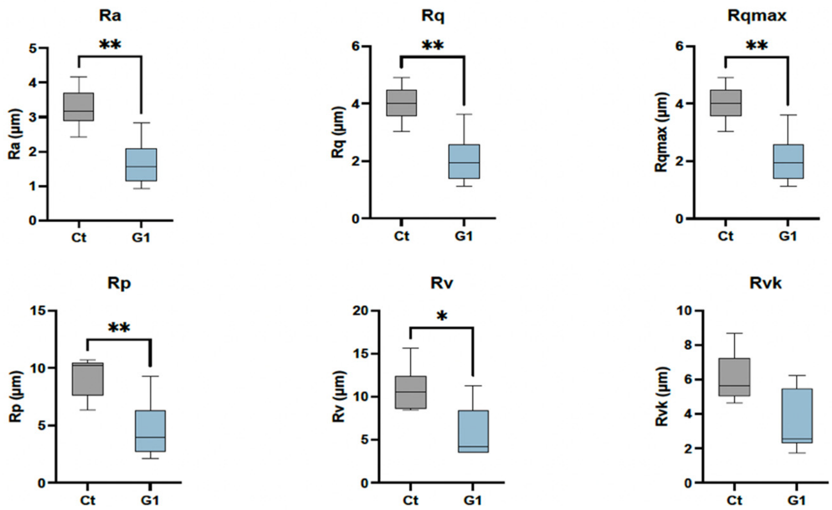

Figure 3. Surface roughness variation in the experimental groups at T2 (Ct—Control Group, G1—group 1). * means $p < 0.05$; ** means $p < 0.01$.

3.3. Comparative Assessment between Times

3.3.1. In the Control Group

In all the parameters evaluated, there was an increase in roughness between T0 and T1 followed by a decrease between T1 and T2, but without statistical significance (Figure 4). The greatest difference was recorded at T1 in the Rp parameter and the difference between T1 and T2 in this same parameter proved to be statistically significant (p = 0.0366).

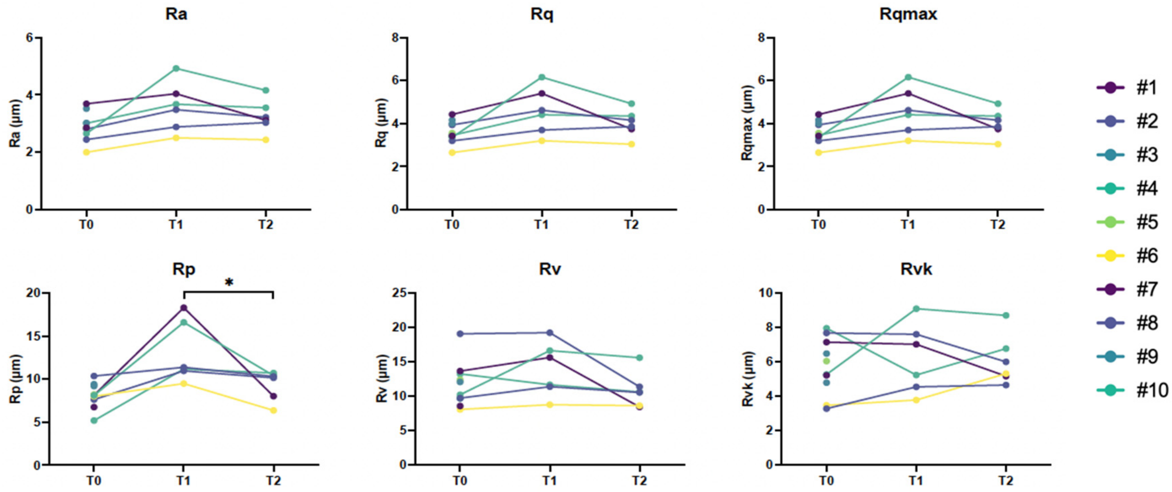

Figure 4. Variation in surface roughness throughout the experimental protocol in the control group over time (T0 to T1). #1 to #10—number of teeth (some samples fractured and were removed from the study). * means $p < 0.05$.

3.3.2. Group 1

An increase in surface roughness was observed between T0 and T1 for most of the parameters evaluated, followed by a decrease at T2 (Figure 5). In group 1, statically significant results were observed between times T0 and T1 for the parameters: Rq ($p = 0.0451$), Rqmax ($p = 0.0451$), Rp ($p = 0.0091$), and Rvk ($p = 0.0433$) and between times T1 and T2 for the parameters: Ra ($p = 0.0465$), Rq ($p = 0.0433$), Rqmax ($p = 0.0433$), and Rp ($p = 0.0155$). There were no statically significant differences between T0 and T2 for the Rv parameter and between T1 and T2 for Rvk ($p > 0.05$).

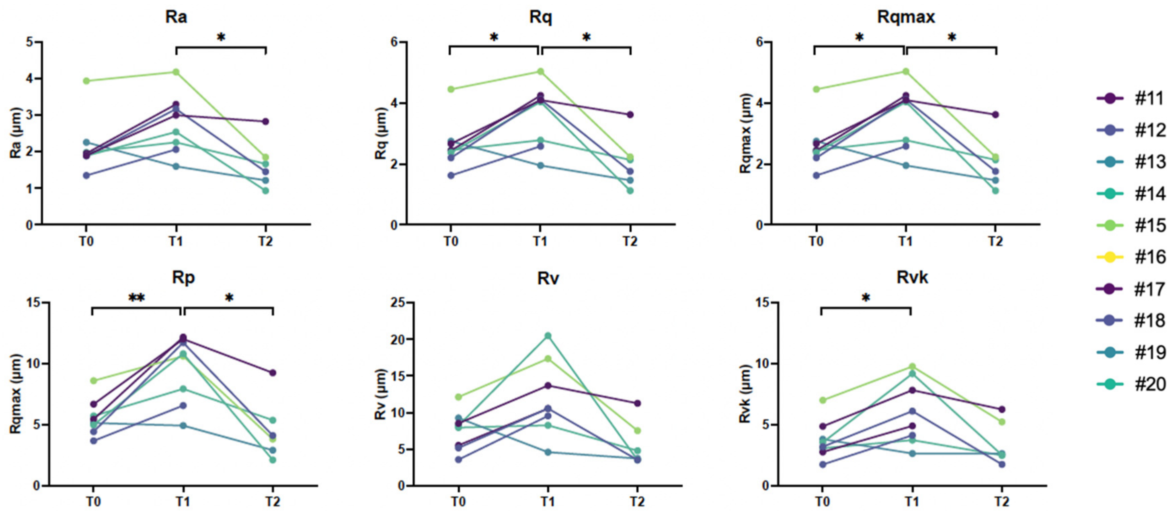

Figure 5. Surface roughness variation in group 1 throughout the experimental protocol over time (T0 to T1). #1 to #10—number of teeth (some samples fractured and were removed from the study). * means $p < 0.05$; ** means $p < 0.01$.

3.3.3. Group 2

There were statically significant differences between times T0 and T1 for the Rvk parameter ($p = 0.0405$) (Figure 6).

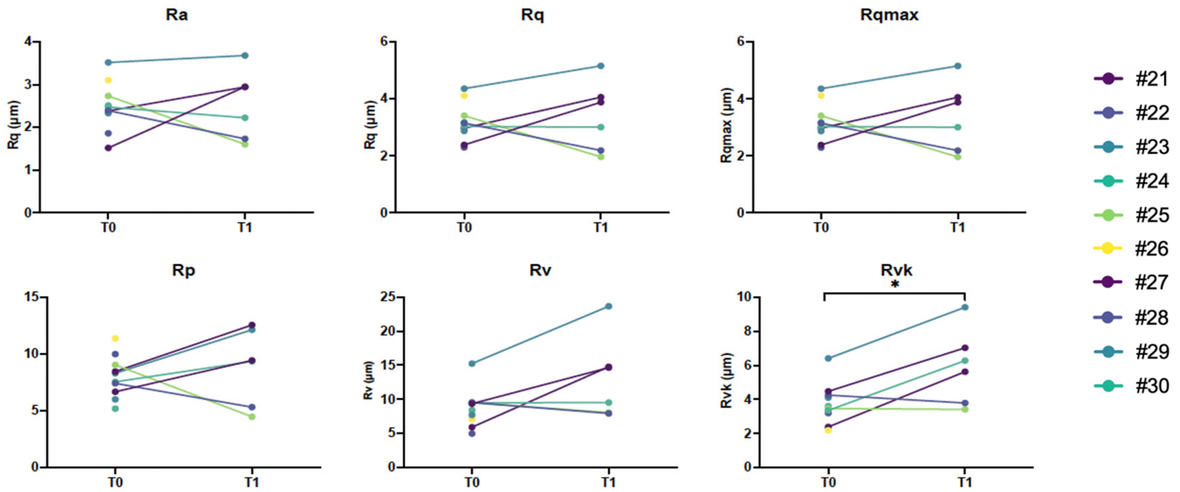

Figure 6. Surface roughness variation in group 2 throughout the experimental protocol over time (T0 to T1). #1 to #10—number of teeth (some samples fractured and were removed from the study). * means $p < 0.05$.

4. Discussion

One of the primary objectives of orthodontic treatment is to preserve the enamel surface with the same degree of roughness or smoothness as it was originally prior to any treatment. However, during the treatment, various bonding, debonding, and enamel cleaning procedures can result in minimal enamel surface loss. Enamel demineralization is a common problem in fixed orthodontic treatment, with a prevalence between 11.7% and 22.6% [28,29]. In order to counteract enamel demineralization, one of the therapeutic strategies mentioned in the literature is fluoride application [39]. However, the influence of fluoride on adhesive strength is controversial and the use of this substance can lead to a significant decrease in adhesive strength. The possibility of reduced adhesion forces can be explained by the interaction between fluoride and the enamel layer, which is resistant to acid etching. This is due to the bond that is established between the fluoride ions and the calcium ions present in the enamel, favoring the formation of hydroxyapatite and, subsequently, fluorapatite [40–42]. Thus, the increased resistance of enamel to orthophosphoric acid can lead to less infiltration of the adhesive system due to less formation of resin tags [40,41] and, subsequently, a greater accumulation of adhesive on the tooth surface, which, consequently, would lead to an increase in the roughness of the tooth surface [42]. However, some studies indicate that the application of fluoride does not promote changes in adhesive strength [43].

Nevertheless, accidental detachment of brackets can occur due to adhesion failure between the interface: adhesive–enamel (adhesive failure); adhesive–bracket (adhesive failure); or within the adhesive (cohesive failure). Often, bracket adhesion failure results from a combination of adhesive and cohesive failures (cohesive–adhesive failure), resulting in the retention of material on the enamel and bracket surface [27,44].

Regarding the assessment of the different groups in this study, it was found that in the control group there was an increase in roughness after the first enamel manipulation, T1, and a decrease in roughness in T2. Thus, the null hypothesis was rejected. These results can be expected, since there is a greater adhesion force between the resin and the enamel at the first take-off, T1, which leads to a greater presence of resin on the enamel surface compared to the base of the bracket (mostly adhesive take-off pattern). In the second take-off, T2, the residual resin is mostly localized on the bracket surface compared to the enamel surface. In this way, the tooth surface is more polished, promoting a reduction in roughness (mostly cohesive take-off pattern). These results are not compatible with the study by Bishara et al. [45], which showed a correlation between adhesion forces when reattaching brackets and surface roughness: the lower the adhesion, the higher the surface roughness.

The roughness assessment of group 1 showed the same debonding pattern as the control group, with statistically significant differences in the variables Ra, Rq, Rqmax, and Rvk. However, this group had more peaks, which could be explained by the addition of the demineralization solution. Baka et al. [46] showed that teeth with demineralization have a lower bond strength. This is correlated by microscopy with greater surface roughness. Lastly, when analyzing group 2, there were no statistically significant differences in roughness at T0 and T1. Furthermore, there was an inconsistency in the results of the different species included in this group, i.e., there was no homogeneous pattern of increase/decrease in roughness. This result may be related to the fact that the application of fluoride obliterates the enamel prisms, which in turn promotes an adhesive–cohesive peeling pattern. In addition, the method of fluoride application was not uniform, and consequently, its application may not have been homogeneous, which may have led to alterations in the different tooth surfaces of the different species analyzed [42].

When comparing the groups at the different assessment times, there were no statistically significant differences at T0. These results were to be expected since the tooth surface had not been subjected to any manipulation at this stage of the study. The individual variations recorded may be due to the anatomical differences of the tooth microsurface and the different origins of the sample. In fact, the teeth evaluated were from different oral cavities, and therefore, subject to different factors that can lead to surface changes, such as more acidic diets [47].

Regarding the evaluation of the different groups in this study, it was found that in the control group, there was an increase in roughness after the first enamel manipulation, T1, and a decrease in roughness in T2. Thus, the null hypothesis was rejected. These results are to be expected since there is a greater adhesion force between the resin and the enamel at the first debonding, T1, which leads to a greater amount of resin on the enamel surface when compared to the base of the bracket (mostly adhesive debonding pattern).

Lastly, it is important to emphasize that this study presents some limitations such as: (1) it being an ex vivo study that may not represent all the conditions present in the oral cavity, since that in the oral cavity the brackets are subject to a multiplicity of shear, traction and torsion forces; (2) the teeth used were premolars, which makes it impossible for the resin layer between the enamel surface and the bracket to be uniform due to the concavity of the tooth surface; (3) the sample is small. Concerning the aforementioned limitation, the present study was conducted as a pilot study to facilitate data collection for the planning of a subsequent study, particularly in terms of power analysis. Initially, this study was initiated with 10 samples per group. Some samples were lost due to fractures, resulting in a smaller sample size at T2 compared to the initial sample. The experimental procedures led to sample loss and alterations in the evaluated parameters. However, these data will enable the authors to calculate the appropriate sample size for future studies with increased reproducibility, mitigating the risk of undersampling or excessive sampling. The refinement of experimental protocols during this phase contributes to the replicability and validity of the results, while feasibility tests assess the practical implementation of the experiment. Therefore, this type of study represents a strategic investment, conserving resources and optimizing the quality of scientific research.

Conversely, some strong points stand out, such as: (1) detaching and cleaning the tooth surface are operator-dependent procedures, so in order to minimize this error, only one operator carried out all the clinical procedures in this study; (2) the results can vary with the type of adhesive and resin. Therefore, the materials used were standardized for all groups. Future studies focusing on surface changes, the architecture of the bracket base, and the type of resin should be carried out. Further studies should also be carried out to increase knowledge of other variables that may alter bracket adhesion, such as brushing techniques, bad oral habits, the type of food and drink consumed, and the type of saliva.

5. Conclusions

In this ex vivo study, there was a decrease in enamel surface roughness during multiple bracket detachments suggesting that reattachment procedures alter enamel surface roughness. The need for rebonding should be avoided, opting for a more effective and correct first bonding. In the case of multiple rebonding, enamel remineralization maneuvers must be applied to recover the surface, since the results of this study suggest that the application of fluoride prior to bracket adhesion promotes lower surface roughness.

Author Contributions: Conceptualization, F.V.; methodology, A.B.P., C.M.M. and I.F.; formal analysis, C.M.M.; Investigation, P.A., A.R., M.D.P., C.N. and R.T.; resources, A.R. and F.V.; data curation, P.A., F.M. and M.P.R.; writing—original draft preparation, R.T., M.D.P. and C.N.; writing—review and editing, R.T., I.F. and A.B.P.; visualization, F.M. and M.P.R.; supervision, F.V. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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