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Research on Treating Demineralized Enamel with Different Remineralizing Agents before Bonding Orthodontic Brackets

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Abstract: Many orthodontic clinics have problems with patients who have dental demineralization. This study aimed to evaluate "the shear bond strength (SBS)" of braces after being bonded to demineralized teeth treated with herbal materials. Our study samples were divided into five groups. The first group was left with no treatment. The surfaces of the second, third, and fourth groups were first treated with a demineralizing solution. The second group was left after being demineralized without any subsequent treatment; the third group was treated with rosemary oil; the fourth was treated with ginger–honey. Casein phosphopeptide–amorphous calcium phosphate with fluoride paste (CPP–ACPF) was applied to the fifth group. A universal testing machine evaluated the SBS. A stereomicroscope was used to determine the adhesive remnant index (ARI). The enamel surface changes were observed using surface microhardness (SMH) testing, scanning electron microscopy (SEM), and energy dispersive spectrometry (EDS) to determine the element percentages. Our data revealed that the values of both SBS and SMH were significantly ($p < 0.05$) increased after remineralization. Rosemary and ginger–honey significantly enhanced the SBS and SMH of the demineralized teeth.

Keywords: remineralization; demineralization; shear bond strength; orthodontic brackets; herbal treatment.

1. Introduction

Regardless of the positive outcomes of orthodontic treatment, periodontal tissues and tooth surfaces may experience adverse effects, especially in patients who are unable to practice good oral hygiene throughout treatment. The use of archwires, brackets, and bands compromises patients' oral hygiene routines and increases the incidence of white spot lesions [1]. When an orthodontist begins treatment on a patient with demineralized enamel, the problem of white spots is worse.

White spot lesions (WSLs) are described as subsurface enamel porosities. The optical characteristics of demineralized enamel differ from those of neighboring sound enamel because enamel translucency is directly related to its mineral percentages. Because of the different ways that porous enamel scatters light, one clinical outcome is that the enamel surfaces appear frosty white [2, 3].

Orthodontic appliances act as a mechanical trap for food accumulation and interfere with the salivary and oral musculature's natural self-cleaning processes [4]. Banded and bonded orthodontic appliances have been linked to increased plaque buildup, as well as increased bacteria and carbohydrate concentrations in plaque [5]. Streptococcus mutans bacteria in particular have been demonstrated to have a crucial function at the beginning of enamel decalcification by producing acids [2, 6].

A broad range of percentages for individuals who developed WSLs following fixed orthodontic treatment has been described in the literature. According to most research, the rates of orthodontic patients with WSLs range from 23% to 73%, depending on how long their treatments last [7-11].

Clinical professionals and the orthodontic community have been concerned about demineralization. Many attempts have been made to reduce the amount of demineralization during orthodontic therapy and to identify a novel treatment for demineralized enamel before starting treatment [12].

Numerous strategies have been proposed to lower the occurrence of white spot lesions. Among these strategies are patient education to maintain good oral hygiene, adding fluoride to dentifrices [13, 14], the use of adhesives containing remineralizing materials [15], and enamel varnishes [16]. In addition to these preventive methods, there is a benefit to using remineralizing agents before the orthodontic bonding procedure, especially for patients who have demineralized enamel before treatment.

Many studies have found that topical fluoride application might diminish or prevent demineralization during fixed orthodontic treatment [17]. The fluoride ions chemically link with hydroxyapatite and convert it to fluorapatite, which may affect the bond strength between the bonded interfaces [18]. Casein phosphopeptide–amorphous calcium phosphate (CPP–ACP)—and the fluoride-containing version (CPP–ACPF)—pastes have benefits for caries prevention and elimination of enamel decalcification during orthodontic treatment [19, 20].

The philosophy of decreasing the decalcification of enamel with remineralizing agents consists of increasing the resistance of the enamel against acids [21].

Some studies reported a severe drop in bond strength when fluoride or calcium phosphate derivatives were used before enamel etching [22-25]. However, other studies found that topical fluoride or calcium phosphate materials did not affect the SBS of brackets [26-29].

Numerous studies have been carried out on the use of herbal materials for dental prophylaxis and remineralization. In addition, they have been used to treat demineralized enamel [30-32].

Gulcin et al. found that increased remineralization was seen with herbal therapy methods, including with rosemary and ginger. By measuring the microhardness of enamel and using fluorescence tests, significant variations between treatments were found. The honey–ginger treatment regimen significantly increased the amount of remineralization [32].

In their study, Sara M. Hassan et al. concluded that fluoride brushing and using a gel made from ginger or rosemary can help to reduce the appearance of white spot lesions after orthodontic treatment [33]. As more people prefer alternatives herbals treatments to artificially derived chemical products today, ginger and rosemary may be better for preventing enamel defects during the first stage of remineralization.

Honey’s ingredients are very effective antibiotic agents and do not harm cells [34]. The effectiveness of honey against oral pathogenic microorganisms has been proven in numerous studies [34-36]. However, no studies have been carried out to determine the interaction between herbal remineralizing agents and the SBS of orthodontic brackets.

Bond bracket failure is a prevalent issue in orthodontic workplaces. Decreasing the shear bond strength causes brackets’ debonding, which may need a lot of time from the doctor and the patient for rebonding, increasing the cost and duration of the therapy [37]. Understanding how these remineralizing substances affect the bond strength of brackets is crucial.

It is important to find remineralizing agents that can treat demineralized enamel as well as not affect SBS. The chosen materials should not reduce the SBS to below the minimum values suggested by Reynolds and Whitlock et al. for bracing since these values represent the threshold for ensuring sufficient bond strength [38].

In this study, we used rosemary oil, ginger–honey, and CPP–ACPF as remineralizing agents, and we investigated the shear bond strengths (SBSs) and the adhesive remnant indexes (ARIs) of brackets attached to premolars. This study also used surface microhardness (SMH), energy dispersive spectrometry (EDS), and scanning electronic microscopy (SEM) images to assess the enamel surfaces after applying these materials.

2. Materials and Methods

2.1. Ethical Approval

The study was done in accordance with the principles outlined in the Declaration of Helsinki. The research proposal was submitted to the head of Kut University College's Research Ethics Committee. KUC/1619/2022-025 was issued as formal ethical certification. Our study subjects received and signed consent forms.

2.2. Study Samples

2.2.1. Premolar Specimens for SBS and ARI

Seventy-five extracted human maxillary first premolars were used in this study. The teeth were extracted for orthodontic evaluation and management. The teeth were required to have a normal buccal surface morphology, no trauma during extraction, and no restoration or caries.

All teeth samples were cleaned from remnants. Then, all the samples were retained in sterile water in the refrigerator at 4 °C to avoid stagnation for approximately 1 month. The water was changed every 24 h [39]. In this study, we formed 5 groups according to the type of surface remineralization, and each group had 15 premolars (n = 15). These study groups are shown in Table 1.

Table 1. *Study groups.*

Group No.	Group Name	Intervention
G1	Control	Sound enamel without any treatment
G2	Demineralized	Demineralized enamel without remineralizing agents
G3	Rosemary group	Demineralized enamel treated with rosemary oil
G4	Ginger–honey group	Demineralized enamel treated with ginger–honey
G5	CPP–ACPF group	Demineralized enamel treated with a casein phosphopeptide–amorphous calcium phosphate with fluoride paste (CPP–ACPF)

2.2.1.1. Demineralization Process

We performed the demineralization step to produce a white spot lesion like that in a patient's mouth. The roots of the premolars were painted with a thick layer of nail varnish. All the groups, except group 1 (which was used as a positive control to compare with the demineralized groups), were immersed in a demineralization solution, containing 2.9 g of $CaCl_2$, 0.12 g of $NaCl_2$, 0.13 g of NaH_2PO_4, and 1.5 g of acetic acid (with the pH adjusted to 4.5) and were incubated at 37 °C for 5 days [40, 41]. An amount of 15 mL of demineralization solution was used for each sample, with daily changes. The positive control group (group 1) was stored in distilled water until the end of the demineralization and remineralization processes of the other groups.

2.2.1.2. Remineralization Process

After completing demineralization, the premolars were randomly classified into 4 groups. Each tooth was treated with its assigned remineralizing agent according to the selected instructions:

- The demineralized group (group 2) was left without applying any remineralizing agent;
- The rosemary oil was purchased from Silverline Chemicals. The rosemary oil was applied to the enamel surface (group 3) using a brush for 3 min. The thickness of the oil was approximately 2 mm. The application was repeated once per day for 7 days [32];
- For the ginger–honey group (group 4), ginger powder was obtained from the local spice market under the label of Ceylon providore. The honey was directly acquired from a farm in Tataouine south of Tunisia and sealed as an original pure honey product. We manually mixed the chosen ratio (8 mg/1 mL) of ginger powder to honey until we obtained a homogeneous paste [32, 42]. The mixture was brushed onto the enamel at a thickness of 2 mm for 3 min and then rinsed. The paste was prepared fresh daily, and the application was repeated once per day for 7 days;
- In the CPP–ACPF group (group 5), the demineralized enamel was covered with CPP–ACPF paste for 3 minutes and then rinsed and dried according to the manufacturer's instructions [26]. The application was repeated once per day for 7 days.

The teeth were kept in glass jars filled with artificial saliva for 7 days, with daily changes during the remineralization procedures while incubated in an incubator at 37 °C [41, 43]. The artificial saliva was composed of 2.91 g of $NaCl$, 0.12 g of $CaCl_2$, 0.13 g of NaH_2PO_4, 5 mL of NaF, and 5 mL of NaN_3, with the pH adjusted to 7.0. At the end of this period, the teeth were rinsed and stored in distilled water.

2.2.1.3. Bonding of Orthodontic Brackets

Premolar stainless-steel brackets (advanced, orthometric, Brazil) were bonded. The bonding materials were applied according to the manufacturer's instructions and guidelines [19, 44].

Finally, the teeth were kept in deionized water for 24 h to complete the polymerization. Then, to simulate a typical oral situation before the shear bond strength test, thermal cycling was performed in deionized water at 5 ± 2 °C to 55 ± 2 °C for 1000 cycles. The total period of exposure to both 5 ± 2 °C and 55 ± 2 °C was 10 s, with a dwell time of 5 s in each bath and 5 s intervals between baths, similar to the procedure in previous studies [45].

Shear Bond Strength (SBS) Test

The roots of each tooth were placed in an acrylic cube mold to align the buccal surface of the crown. The cubic mold was fixed into the bottom jaw of a universal testing device for shear bond testing. The brackets were forced in an occlusal–gingival direction with a speed of 1 mm/min [26, 46]. The minimum force required to dislodge the brackets was recorded as the SBS value.

2.2.1.4. Assessment of Adhesive Remnant Index (ARI)

After removing all brackets, the teeth were examined with a stereomicroscope with 10× zoom to evaluate the adhesive remaining. The modified adhesive remnant index scores ranged from 1 to 5. The scores are detailed in Table 2.

Table 2. *ARI criteria of scores.*

Score	Criteria
1	All the adhesive, with an impression of the bracket base shape, remained on the teeth
2	More than 75% of the adhesive remained on the teeth
3	Less than 75% but more than 25% of the adhesive remained on the teeth
4	Less than 25% of the adhesive remained on the teeth
5	No adhesive remained on the teeth

2.2.2. Molar Study Specimens for SMH, EDS, and SEM

The crowns of 15 molars were sectioned from the roots at the cement–enamel junctions, and each crown was cut longitudinally in an occlusal–gingival direction using a water-cooled saw, taking equal buccal parts of the molars with an appropriate thickness. The molars were used because they had more flat surfaces than premolars, which we needed in these tests.

The enamel samples were fixed in a custom-made wax mold to obtain slightly flat enamel surfaces and facilitate conducting the tests [43]. The enamel cuts were randomly divided into 3 remineralization groups (rem groups), according to the remineralization materials used, with 5 enamel pieces for each rem group listed below:

1. Rosemary rem group;
2. Ginger–honey rem group;
3. CPP–ACPF rem group.

Then, all the samples were numbered (each sample had a specific number), and the enamel surfaces were demineralized and remineralized according to their groups.

The procedures of demineralization and remineralization were performed according to the steps described previously. The measurement tests were performed before demineralization, after demineralization, and, finally, after remineralization, separately for each sample.

2.2.2.1. Surface Microhardness (SMH)

All enamel pieces were measured for surface microhardness using a Vickers digital microhardness analyzer. Enamel SMH was measured at baseline for the sound enamel, after surface demineralization, and after remineralization, with a rate of 10 s and a load of 100 g at a distance of 500 μm from the edge [41]. For each sample, three indentations were made (see Figure 1), and their average was calculated by the examiner and recorded as the sample's hardness value with the sample number, the process step, and the rem group name. The data were used to compare each step and compare between the different remineralizing agents.

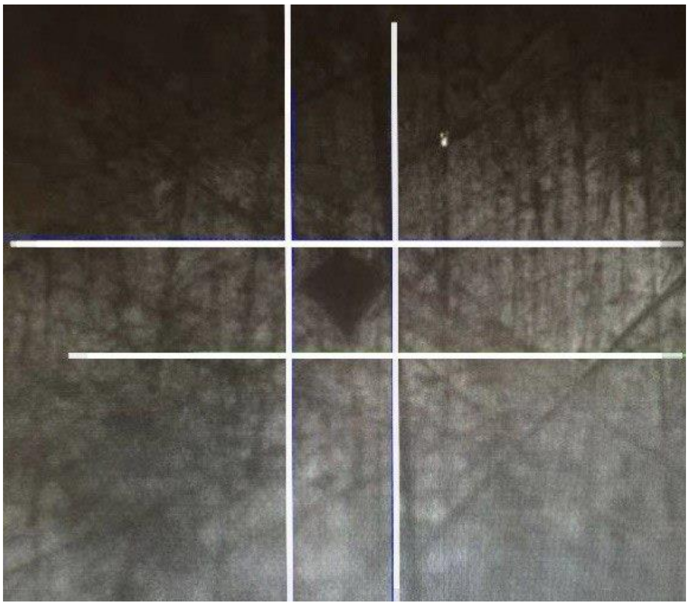

Figure 1. *Indentation of SMH test on enamel surface. white lines indicate the borders of the indentation.*

2.2.2.2. Energy Dispersive Spectrometry (EDS) with Scanning Electron Microscopy (SEM)

To evaluate the morphology, the chemical composition of the enamel surface, the effect of the demineralization and remineralization protocols, and the Ca/P ratio, a scanning electron microscope (SEM) coupled with EDS was used.

EDS is a technique to identify the elemental composition of materials. EDS applies the X-ray spectrum emitted from a sample after bombardment by electrons [47].

The atomic and weight percentages were obtained for the following elements in each step and for all rem groups: phosphorus, calcium, sodium, silicon, fluorine, carbon, and oxygen. The test quantified the calcium, phosphorus, and fluoride uptake by the enamel after remineralization [43].

One enamel piece from each rem group was prepared to observe the enamel surfaces under a scanning electron microscope and compare them with sound, demineralized enamel surfaces. For SEM, the enamel was cleaned with acetone, dehydrated using alcohol, and left to dry for 24 h at 25 °C [48].

2.3. Statistical Analysis

We utilized SAS (Statistical Analysis System—version 9.1) to conduct the statistical analysis of the data. Significant differences between means were evaluated using one-way ANOVA and the least significant differences (LSD) post hoc test. $p < 0.05$ was considered statistically significant, consistent with the guidelines in [19].

3. Results

3.1. Shear Bond Strength (SBS) Test

Our data show that the SBS values of the demineralized group (group 2, the group without a remineralization agent) were significantly lower than those in all other groups.

On the other hand, there was a significant increase in the SBS values in group 3, group 4, and group 5 (the groups in which we used the remineralization agents of rosemary, ginger–honey, and CPP–ACPF, respectively). Furthermore, group 4 (ginger–honey study agent) was as effective as group 5 (CPP–ACPF, a well-known remineralizing agent), and there was no significant difference ($p > 0.05$) between these two groups. However, group 3 (rosemary study agent) was significantly ($p < 0.05$) less effective than group 4 and group 5. The results in MPa are shown in Table 3 and Figure 2.

Table 3. *SBS results.*

Group	Strength
(Group 1) Sound teeth	34.06 ± 1.51 a
(Group 2) Demineralized	11.46 ± 1.10 b
(Group 3) Rosemary oil	21.93 ± 1.18 c
(Group 4) Ginger–honey	30.40 ± 1.23 a
(Group 5) CPP–ACPF	33.57 ± 1.45 a
LSD	3.67

Means with different letters are significantly different ($p < 0.05$).

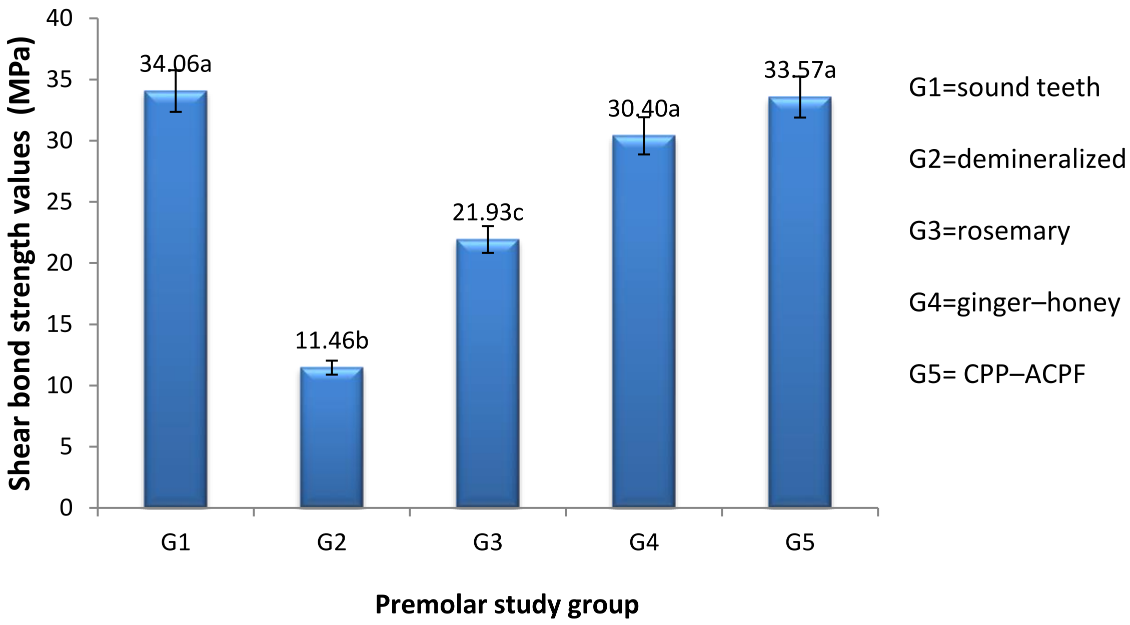

Figure 2. *Shear bond strength means ± standard deviation (S.D.). Means with different letters are significantly different ($p < 0.05$).*

3.2. Adhesive Remnant Test (ARI)

Table 4 presents the findings of the assessment of the adhesive remnants on the tooth surfaces. Generally, more composite remnants on teeth surfaces were found when our remineralizing agents were applied. This was characterized by a shift in ARI scores from four and five to two and three after applying the remineralizing agents.

Table 4. *ARI results.*

Group \ Score	1	2	3	4	5	No. of Teeth
Control	0	6	5	4	0	15
Demineralized	0	1	2	7	5	15
Rosemary	0	3	5	4	3	15
Ginger–honey	0	3	7	5	0	15
CPP–ACPF	0	4	7	4	0	15
Total	**0**	**17**	**26**	**24**	**8**	**75**

3.3. SMH Results

The results of the microhardness test revealed that there were no significant differences between the samples before applying any agent. This was carried out to standardize our study samples (the sound teeth step). Our data also show a significant decrease in the SMH values after applying the demineralization solution (the demineralization step).

On the other hand, there was a significant increase in the SMH values after applying the three remineralization agents (the remineralization step). Additionally, our data reveal no significant difference between ginger–honey and CPP–ACPF, both showing similar potencies, while rosemary was significantly less effective than CPP–ACPF. The results are shown in Table 5.

Table 5. *SMH results.*

Group	Sound	Demineralization Step	Remineralization Step
Rosemary oil	402.80 ± 9.09 a	92.80 ± 9.28 a	179.00 ± 17.92 b
Ginger–honey	429.80 ± 11.39 a	93.00 ± 5.16 a	208.80 ± 7.95 ab
CPP–ACPF	438.20 ± 24.11 a	95.20 ± 6.23 a	230.40 ± 9.66 a
LSD	50.13NS	21.91NS	38.89

Means with different letters are significantly different ($p < 0.05$).

3.4. SEM/EDS Results

The enamel surface morphologies are displayed in Figure 3. The chemical element spectra and the atomic percentages for carbon, oxygen, chloride, phosphorus, calcium, sodium, silicon, and fluorine are shown in Figure 4. Furthermore, the Ca/P ratio, which is important to determine the chemical composition of the hydroxyapatite on the enamel surface, was calculated in each step and for all groups.

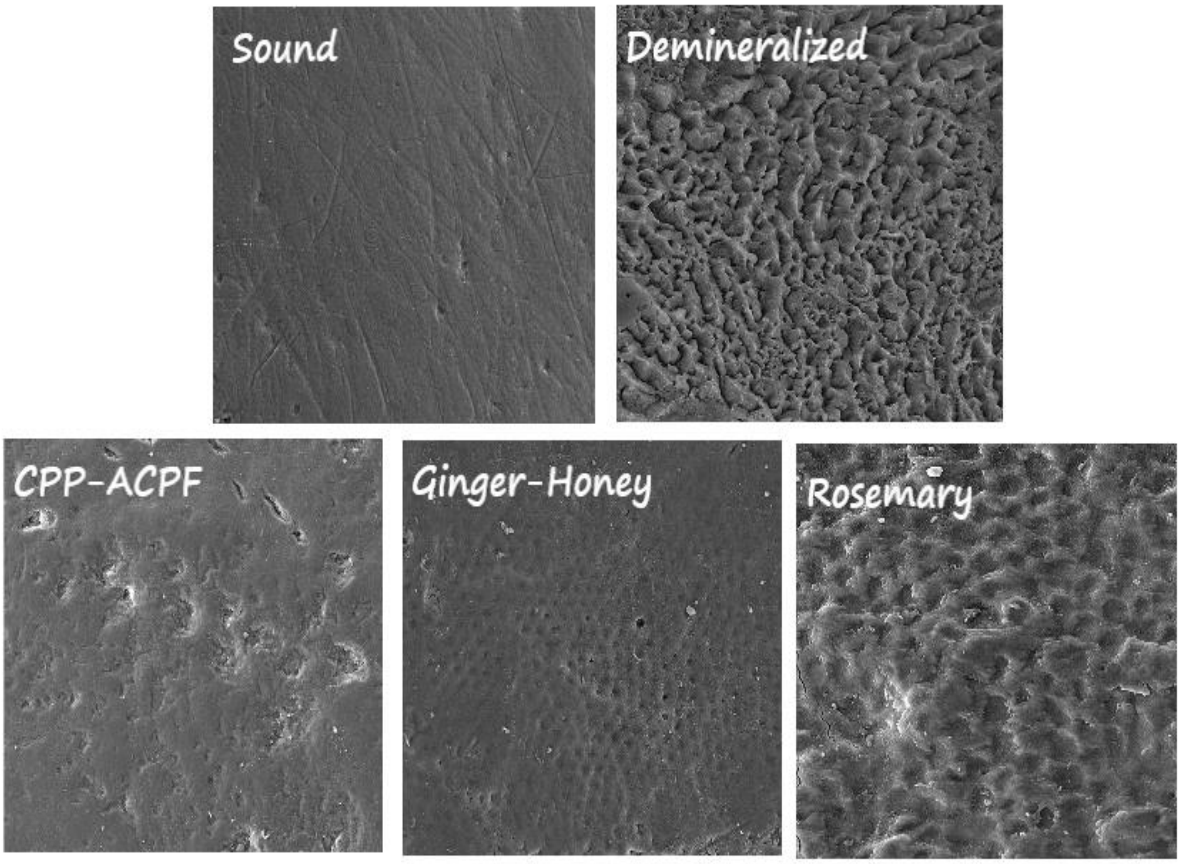

Figure 3. *Scanning electron microscopy images.*

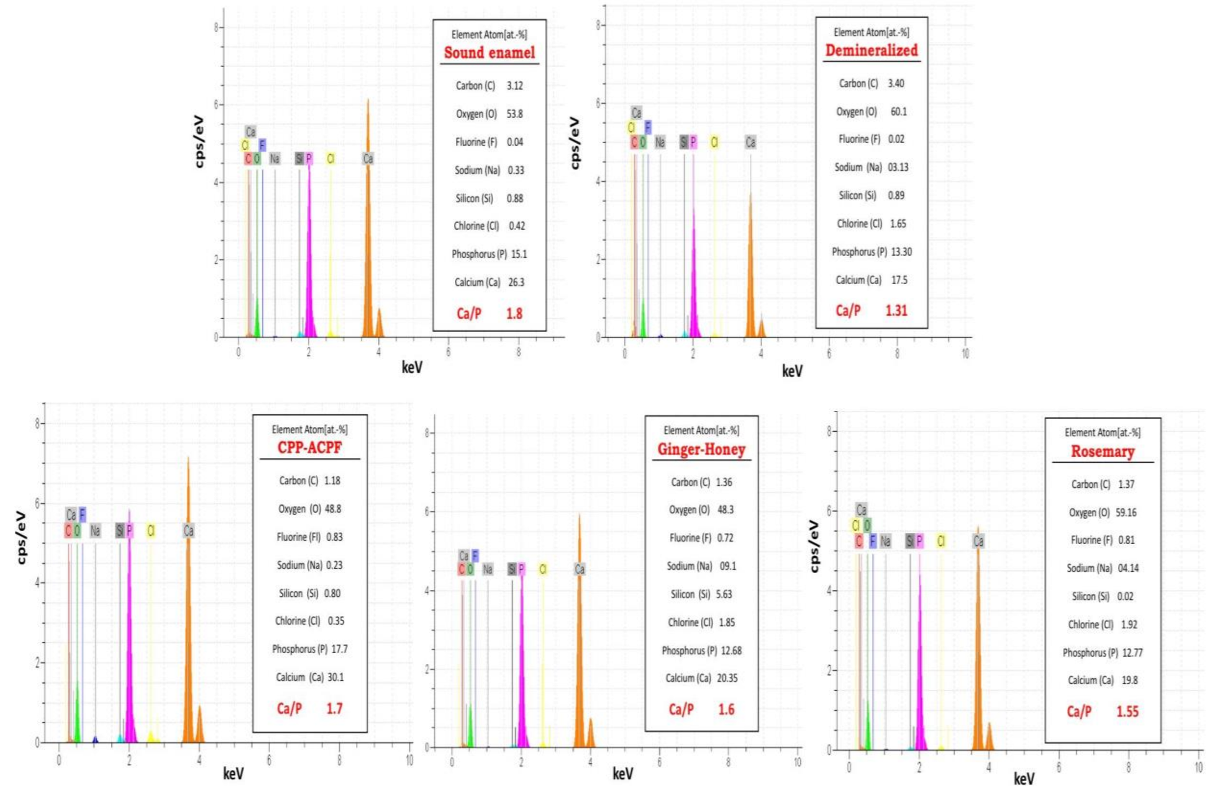

Figure 4. *EDS results showing elemental percentages on enamel surfaces and spectrum of elements. keV: kilo-electron-volt. cps/eV: counts per second per electron-volt.*

4. Discussion

With the increasing demand for orthodontic treatment among the population, many patients with already demineralized teeth visit orthodontic clinics to correct their malocclusion.

There are two treatments for this condition. First, their dentist sends them to a restorative clinic for filling treatment, which is an aggressive treatment approach for white spot lesions without dentine caries. Second, a remineralizing agent is used continuously to solve this problem before or during orthodontic treatment.

Many recognized preventive strategies for dealing with this problem have been discovered, such as using fluoridated adhesives and utilizing chemical remineralization materials on enamel surfaces before bracket bonding [24, 49].

The acid-etching procedure produces micro-pores on the enamel surface, which allow the adhesive materials to attach to the tooth surface. Fluoride- and calcium-phosphate-containing derivative materials change the hydroxyapatites into stronger crystals, which help to prevent demineralization and enhance demineralized enamel strength [19, 50]. This mechanism may conflict with the acid-etching procedure, prevent the production of enamel tags, and reduce the attachment of orthodontic braces [20, 51].

Moreover, a high debonding rate is unacceptable for fixed orthodontic treatments because it makes them inefficient, time-consuming, and costly.

The treatment of demineralized enamel, without affecting the bracket attachment method, is a primary concern in orthodontics research.

It is important to mention that herbal materials are highly biocompatible materials, and they can safely be used for long-term treatment. Many studies prefer herbal material use [52]. Calcium phosphate is an old material used in the dental field and the whole human body for bone repair as well as for white spot treatment and the re-enhancement of tissue structure [24].

Calcium phosphate salt technology is used to keep the calcium and phosphorus components from reacting with each other before use. When the salts are mixed, they rapidly form amorphous calcium phosphate (ACP) that precipitates on the tooth surface. The precipitated ACP readily dissolves into the saliva to be available for tooth remineralization. ACP is readily converted to stable crystalline phases such as octacalcium phosphate or hydroxyapatite in aqueous media [53].

There are many studies on the treatment of demineralized enamel with ginger–honey and rosemary derivatives, but there are no reports of measuring the shear bond strength of braces after applying these remineralization agents [32, 42].

Therefore, this study evaluated the effect of using herbal materials and fluoride with calcium phosphate to repair demineralized enamel and measure the effect on the shear bond strength of braces. The current study also tested sound enamel without any pretreatment and demineralized enamel to facilitate the comparison among study groups.

The remineralizing agents were applied to demineralized human enamel according to the same procedures used for these materials in previous studies [32, 42, 54]. Artificial saliva was employed to provide an idea of what would happen in patients' mouths and to resemble the clinical conditions of patients who will take these herbal materials.

Remineralization mainly depends on changes in the mineral percentages in the dental hard tissue, comprising mainly calcium, phosphate, and fluoride [55].

The demineralization led to a significant decrease in the microhardness (SMH) values, as indicated by our results. The decrease in the SMH values corresponded with the loss of elements from the enamel, as indicated by the EDS results of demineralized enamel. This decrease in the hardness of demineralized enamel has been mentioned in previous studies [56, 57]. The statistically significant increase in the SMH that appeared after remineralization explained the relationship between the increase in the Ca/P ratio of EDS and the increase in the hardness of remineralized enamel. This matter confirmed our remineralization procedure and the uptake of minerals from the enamel.

The ginger–honey and CPP–ACPF groups had higher microhardness values than the rosemary group. These differences may be related to the increase in the important materials in the composition of hydroxyapatite, which was confirmed via EDS. Moreover, it is important to mention that the rosemary group had higher microhardness than the demineralized group. The results showed no statistically significant difference between the ginger–honey and CPP–ACPF remineralization groups.

Energy-dispersive X-ray spectrometry (EDS) is a powerful technique that has been used to perform quantitative analysis of the enamel elements by measuring the characteristics of re-emitted X-rays from atoms [58].

The chemical compositions of enamel surfaces were analyzed to determine the presence of specific elements. The specific elements were carbon (C), phosphorus (P), calcium (Ca), and oxygen (O). These are the fundamental parts of hydroxyapatite (HAP) in enamel [41, 43, 59].

The normal Ca/P ratio in human enamel typically ranges from approximately 1.5 to 2.0. This ratio can vary slightly between individuals and even within different parts of the same tooth. The specific Ca/P ratio in hydroxyapatite's structure can influence the enamel's strength and resistance to decay [60].

Maintaining a healthy Ca/P ratio in enamel is crucial for dental health, as deviations from this range can lead to enamel demineralization, tooth decay, and other oral health issues.

In comparison with the demineralized enamel and the other study groups, this study discovered that sound enamel had a high atomic percentage of calcium ions (26.3%) and phosphorus ions (15.1%).

Furthermore, we found the enamel of the control group had a higher Ca/P ratio than the demineralized enamel. In the control sound group, the Ca/P ratio of the enamel was close to 1.8. This ratio dropped to 1.31 in the demineralized enamel, with decreases in the atomic percentages of calcium and phosphate. This discrepancy may refer to the amount of phosphate and calcium ions that were removed from teeth surfaces during demineralization. Similar results were observed in previous studies [41].

The ratio of calcium to phosphate (Ca/P) was increased for group 3 (rosemary—1.55), group 4 (ginger–honey—1.6), and group 5 (CPP–ACPF—1.7) after treatment with the assigned remineralizing agents. The new crystals had a calcium-to-phosphorus ratio (Ca/P) approximately near that of the intact enamel. These results could indicate that the type and layout of the crystals produced were similar to those found in the sound enamel.

There was a lot of calcium and phosphate in the newly created layer in the ginger–honey group. This group also had the highest quantities of sodium and silica compared with all other groups. This means the ginger–honey application increased the ability of the enamel to uptake these ions that would combine with enamel prisms and make the enamel harder.

The chemical analysis of the CPP–ACPF group showed the highest atomic percentages of calcium and phosphate compared with all other groups (Ca = 30.1% and P = 17.7%). The composition of the CPP–ACPF remineralizing agent might be the cause of these high percentages.

A scanning electron microscope (SEM) produces high-resolution pictures that reveal much information about the surface of a material [61].

The images from the SEM showed that the morphology of the sound enamel surfaces was homogenous and smooth, with fewer abnormalities. The demineralized sample displayed a rough enamel surface with degraded enamel rods.

The surface of the ginger–honey-treated enamel was almost entirely covered with mineral deposition, although the underlying design was still visible in some sites. This might indicate that the demineralized enamel amassed new minerals and that a new layer was made.

The rosemary group exhibited the complete disappearance of the underlying pattern and coalescence in the enamel prisms. On the surface of the enamel, multiple granular particles and amorphous crystals were formed. The CPP–ACPF samples showed that approximately 80% of the enamel surface was covered with crystalline structures. It was densely packed as a result of the combined effect of calcium phosphate and fluoride ions on the enamel surface. This group had a relatively smooth, more homogeneous surface compared with the other treatment groups.

This study found that shear bond strength significantly decreased when braces were attached to demineralized enamel. The low SBS results explained the weakness of demineralized enamel, which was confirmed via SMH, EDS, and SEM assessments. The decrease in the SBS of demineralized enamel in this study matched with previous studies [62].

Furthermore, there was a statistically significant enhancement in the SBS withing groups 3, 4, and 5 after treating them with the assigned remineralizing agents. In addition, there was a statistical difference between the rosemary group and the other two remineralizing groups after treatment.

This study found that high shear bond strengths were recorded in group 1 (sound enamel), followed by groups 5 (CPP–ACPF) and 3 (ginger–honey).

In the current study, there was a clear difference in the ARI scores of the demineralized group compared with the other study groups. Most of the composite was seen on the brackets of this group. Detachment occurred between the composite and enamel, and 60% of samples obtained scores of 4 or 5. This means that the enamel was weakened, so the orthodontic bracket could not bond to it. After remineralization, the deboned method showed that the demineralized enamel became stronger and attached to the composite in the same manner as the intact enamel.

According to our results, we conclude that ginger–honey alone and rosemary alone can change the demineralized enamel surface and make it similar to intact enamel without decreasing the shear bond strength to unacceptable levels.

5. Conclusions

Our data showed that using Ginger-Honey or Rosemary significantly (p <0.05) enhanced the shear bond strength of demineralized teeth, and they did not interfere with the bond strength of the braces. Furthermore, there was no significant difference ($p > 0.05$) between Ginger-Honey and CPP-ACPF in the efficacy of remineralizing the teeth. The limitations of our study are that the samples were collected at one institution, and there was no follow-up after a different period of time (e.g., 3 months, 6 months, and one year). Further clinical studies involving orthodontic patients is necessary in order to expand our current understanding of the impact of remineralizing agents on the efficacy of orthodontic appliances.

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Institutional Review Board Statement: The study was done in accordance with the principles outlined in the Declaration of Helsinki. The research proposal was submitted to the head of Kut University College's Research Ethics Committee. KUC/1619/2022-025 was issued as formal ethical certification. Our study subjects received and signed consent forms.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data supporting the reported results are available on request from the corresponding author, including links to publicly archived data sets analyzed or generated in this study.

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