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Effect Of Remineralising Agents In The Shear Bond Strength Of Composite And Assessment Of Effects Of Remineralization Agents On White Spot Lesions/ Enamel Demineralization Following Orthodontic Brackets Debonding: A Comparative Study

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Effect Of Remineralising Agents In The Shear Bond Strength Of Composite And Assessment Of Effects Of Remineralization Agents On White Spot Lesions/ Enamel Demineralization Following Orthodontic Brackets Debonding: A Comparative Study

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ABSTRACT

BACKGROUND: Following orthodontic treatment, enamel demineralization and white spot lesions are common aesthetic and structural concerns. This study evaluated and compared the effects of two remineralizing agents, Curodont Repair and GC Tooth Mousse, on orthodontic bracket shear bond strength and post-debonding enamel remineralization, to assess their clinical applicability in managing post-treatment enamel defects without compromising adhesive performance.

METHODS: 106 human premolar teeth were assigned for two experimental objectives.

For Objective 1, 90 teeth were divided into 3 groups Control, GC tooth mousse, Curodont. Teeth were stored for 90 days, and then the shear bond strength of orthodontic brackets was evaluated using a universal testing machine.

For Objective 2, the remaining teeth were divided into 4 groups: Pre-control, Post-control, Curodont, GC Tooth Mousse. After 90 days, they were analyzed using SEM and EDX. Data were analyzed using ANOVA and Tukey's test ($p < 0.05$).

RESULTS: The mean shear bond strength in group I, II and III were 18.84 MPa,20.25 MPa, and 21.01MPa respectively, with no statistically significant difference among the groups ($p > 0.05$). SEM revealed smoothened and well coalesced enamel rods in Curodont group and interprismatic space filling in GC Tooth Mousse group when compared with fine cracks and fissures over the surface in untreated enamel. EDX analysis showed higher calcium and phosphorus recovery in the Curodont group compared with GC Tooth Mousse, with mineral levels approaching baseline enamel values.

CONCLUSION: Both agents displayed remineralizing capability on the tooth surface without affecting the shear bond strength. Curodont exhibited superior remineralization efficacy compared to GC Tooth Mousse, as confirmed by SEM and EDX analyses.

CLINICAL RELEVANCE: Curodont and GC Tooth Mousse effectively treat white spot lesions. Curodont is particularly effective for restoring enamel integrity and aesthetics.

KEYWORDS: Enamel demineralization, Shear bond strength, Orthodontic brackets debonding, GC Tooth Mousse, Curodont Repair

BACKGROUND

Fixed orthodontic therapy corrects malocclusion and enhances facial aesthetics as well as the self-esteem, significantly improving patients' quality of life [1]. However, enamel surface alterations are common sequelae following bracket debonding [2]. The bonding, debonding, and finishing procedures involved during treatment can result in structural defects such as enamel loss due to etching, white spot lesions, microcracks, and surface scratches [3–7]. Studies have reported increased enamel roughness after debonding, regardless of the finishing bur used with surface roughness and demineralization affecting 4.9–84% of teeth [8–10]. These iatrogenic changes compromise aesthetics and enamel integrity, highlighting the need for effective preventive and remineralizing strategies.

Several modalities have been introduced to manage white spot lesions and enamel demineralization, including fluoride varnish, APF gels, amorphous calcium phosphate pastes, ozone therapy, and self-assembling peptides, among which CPP–ACP and peptide-based systems demonstrate superior results [11]. GC Tooth Mousse, a commercially available fluoride-based agent, contains Casein Phosphopeptide–Amorphous Calcium Phosphate (CPP–ACP), a milk-derived complex that stabilizes calcium and phosphate ions, maintains enamel supersaturation, and facilitates apatite crystal formation, while fluoride ions enhance resistance to caries through fluorapatite deposition [12, 13]. Curodont Repair is a biomimetic remineralizing agent that employs a self-assembling peptide to form a supramolecular fibrous matrix within subsurface lesions, attracting calcium and phosphate from saliva to generate new hydroxyapatite crystals, with fluoride exerting a synergistic remineralizing effect [14].

Despite these preventive options, bracket failure remains a recurrent clinical concern during orthodontic treatment [15]. Adequate adhesive bond strength is required to withstand masticatory forces and arch wire stresses while ensuring easy and safe debonding without enamel damage [16]. Bond strengths between 5.9–7.8 MPa are generally considered sufficient for clinical use [17], with resin-modified glass ionomer cements ranging from 5.39–18.9 MPa [18–20] and a minimum of 2.8 MPa deemed acceptable [21]. Within this context, the present study was undertaken with two aims: first, to evaluate and compare the effects of remineralizing agents Curodont Repair and GC Tooth

Mousse on the shear bond strength of composite used for orthodontic bracket bonding, and second, to assess and compare enamel surface characteristics after debonding following the application of these agents.

MATERIALS AND METHODS

The institutional ethical committee approval [Reference number: YEC-1/2021/007] was taken before the study was initiated. The study involved collection of extracted teeth which are otherwise considered as biowaste. There was no direct contact between the researcher and the patients from whom the teeth were extracted. The study was conducted as per the declaration of Helnski. This in-vitro study was conducted on 106 human premolar teeth that were therapeutically extracted from patients undergoing orthodontic treatment. Only teeth with intact buccal enamel were included in the study. Teeth presenting with visible caries, restorations, fractures or developmental defects (like fluorosis or hypoplasia) were excluded from the study. The 90 samples were used for shear bond strength evaluation (Objective 1) and 16 teeth were used to analyze enamel surface (Objective 2).

For the Objective 1, 90 teeth were divided into 3 groups.

- Group I (Control group – C) (n=30),
- Group II (GC tooth mousse – GC) (n=30),
- Group III (Curodont – CU) (n=30).

For Objective 2, the remaining teeth were divided into 4 groups (n=4).

- Pre-control (PRC) group (Debonded teeth with white spot lesions),
- Post-control (PTC) group (Debonded teeth with white spot lesions stored in artificial saliva for 90 days),
- Curodont (CU) group (Debonded teeth with white spot lesions treated with CU stored in artificial saliva for 90 days),
- GC mousse (GC) group (Debonded teeth with white spot lesions treated with GC stored in artificial saliva for 90 days).

Objective 1 - shear bond strength evaluation:

All the samples in group I, II, and III were etched with 37% orthophosphoric acid gel (3M) for 20 seconds followed by thorough washing and air drying for 20 seconds.

GC Tooth Mousse and Curodont Repair was applied on teeth in group II and in group III respectively. The bonding agents were placed on all the teeth and the brackets (pre-adjusted edgewise premolar brackets of 0.022", 3M, M.B.T prescription) were bonded with the adhesive and light-cured for 20 seconds (Fig. 1).

All the samples were placed in artificial saliva for 90 days and were evaluated after 90 days. To best mimic the change in pH of oral environment with the type and time of food intake by Indian population, the samples of each group underwent alterations in pH of artificial saliva medium (5, 5.5, 4.5) during day time every 2 hours and 5.5 overnight. After 90 days, debonding of the bracket on the teeth was done to evaluate the shear bond strength on universal testing machine (UTM Model- Tecsol - TSI-BDS-20Kn/2kN- Sr No. 170710), at a crosshead speed of 1 mm/min. (Fig. 2) Specimens that debonded during mounting or prior to the application of measurable load on the universal testing machine were assigned a value of 0 MPa, and these were retained in the dataset as true bond failure events

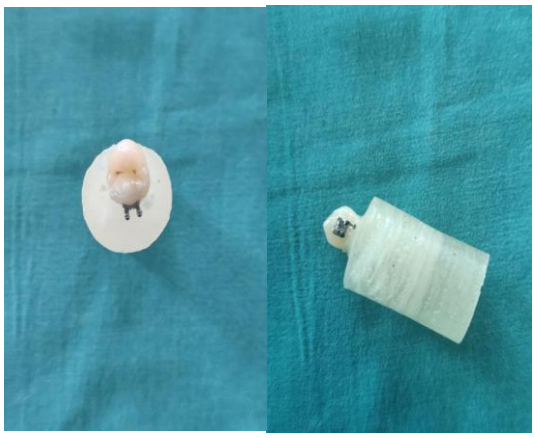


Fig. 1: Bonded sample teeth

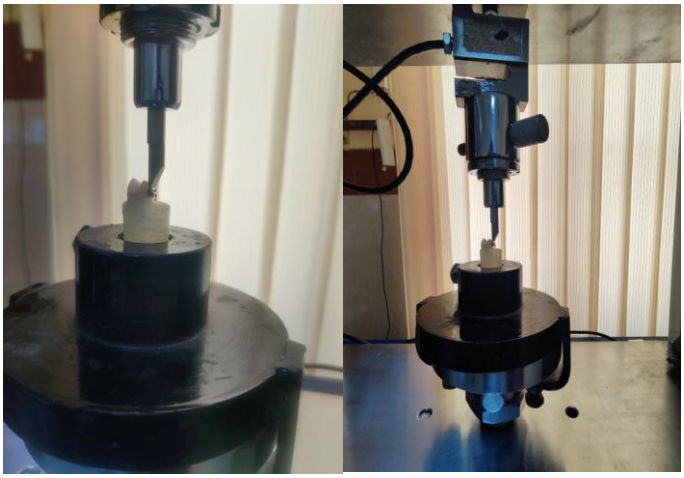


Fig. 2: Evaluation Of shear bond strength using universal testing machine

Objective 2 - enamel surface defects analysis:

Bonding procedure of all the samples in Pre-control (PRC) group, Post-control (PTC) group, Curodont (CU) group, and GC mousse groups were performed as described in Objective 1.The bonding agents were placed on the tooth and the brackets (pre-adjusted edgewise premolar brackets of 0.022", 3M, M.B.T prescription) were bonded with the adhesive and light-cured for 20 seconds. The precontrol teeth were dried and immediately send for SEM & EDX analysis. Postcontrol (PTC) group samples were placed in artificial saliva for 90 days without any intervention. a single coat of Curodont Repair and GC Tooth mousse was applied every day to CU and GC groups respectively and placed in artificial saliva for 90 days. To mimic the oral environment, the samples of each group underwent alterations in pH of artificial saliva medium (5, 5.5, 4.5) during the day every 2 hours and 5.5 overnight. After 90 days the teeth specimens were evaluated for remineralization using SEM (scanning electron microscopy- VEGA3, TESCAN – Czech Republic), and mineralization content was evaluated using EDX (BRUKER Nano, GmbH, D-12489 -Germany; Accelerating voltage: 0 to 30 KeV).

In SEM, each sample was observed with increasing magnifications (500x, 1000x, 2000x, 4000x) to observe the buccal enamel surface. These photomicrographs were scored based on Chandru et al.,2020 [22].

Scoring criteria;

- Score 0: Enamel surface remained perfectly intact with no grooves, pits, and porosity
- Score 1: Presence of surface irregularities on enamel surface, without demineralization of prismatic and/or interprismatic enamel
- Score 2: Presence of wrinkles and demineralization of prismatic/interprismatic enamel
- Score 3: Diffuse demineralization involved the rod core, with decomposition of morphology of prism

Statistical analysis

The data was analysed using GraphPad Prism software version 8.0 (GraphPad Software, San Diego, CA, USA) and SPSS software v 26.0. The level of significance was kept at 5%. The data was assessed for normality using Shapiro Wilk test which showed that the data was following a normal distribution. Therefore, the shear bond strength of three groups was compared using One-way ANOVA test followed by Post hoc Tukey test for pairwise comparisons.

RESULTS

I. **Objective – 1 - Shear bond strength:**

The mean shear bond strength in group I, II and III were 18.84 Mpa, 20.25 Mpa, and 21.01 Mpa respectively. Raw data of individual shear bond strengths of different groups are provided in the supplementary file (S1). The mean shear bond strength in group III was highest followed by group II and the least was noted in the control group, however the difference was not statistically significant (Table 1 and Fig. 3).

Table 2 presents the pairwise comparison of the shear bond strength between the three groups. The mean difference in shear bond strength between control & curodont groups (-1.41) was statistically non-significant (p = 0.854). The mean difference in shear bond strength between control & GC groups (-2.17) was statistically non-significant (p = 0.688). The mean difference in shear bond strength between curodont & GC groups (-0.76) was statistically non-significant (p = 0.955).

Table 1: One way ANOVA test among the three groups

Group	**N**	**Mean**	**SD**	**SEM**	**95% Confidence Interval for Mean**		**p-value**
					Lower	**Upper**	
Control	30	18.84	9.42	1.72	15.33	22.36	0.705
GC	30	20.25	9.78	1.78	16.60	23.90	
Curodont	30	21.01	11.19	2.04	16.83	25.19	

Table 2: Post hoc Tukey test (pairwise comparison)

Pairwise comparisons	**Mean difference**	**p-value**
Control vs Curodont	-1.41	0.854
Control vs GC	-2.17	0.688
Curodont vs GC	-0.76	0.955

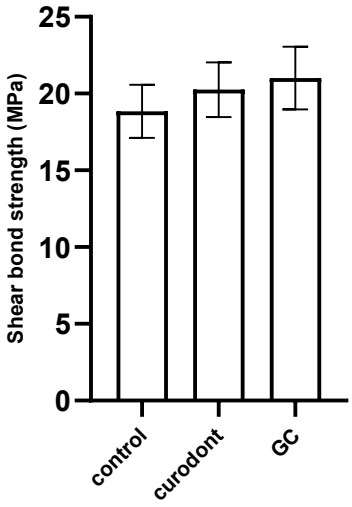
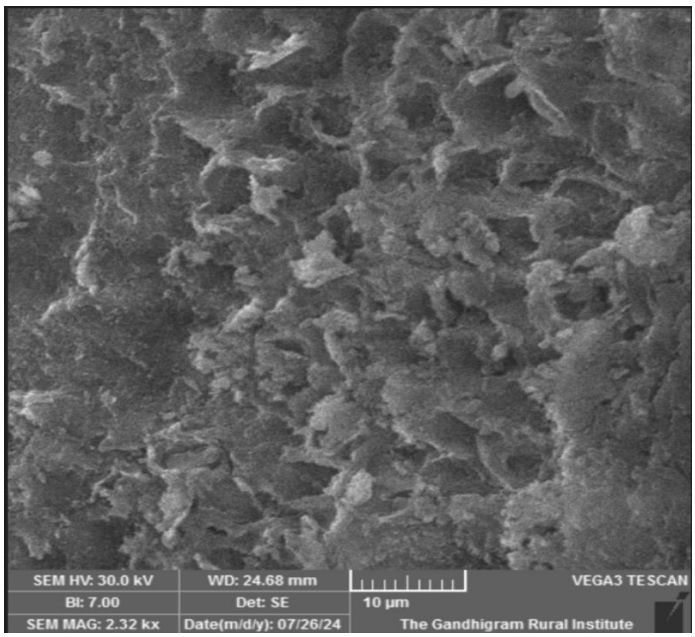


Fig. 3: Mean shear bond strength among the three groups

II. **Objective 2 - Enamel surface defects:**

SEM evaluation of Precontrol (PRC) group revealed coarse scratches, wide grooves, and damage over the enamel surface with a noticeable surface boundary (score 3) (Fig. 4). Whereas, Postcontrol (PTC) group revealed circumferentially arranged enamel rods filled with inter rod material producing a typical keyhole appearance with fine cracks and fissures over the enamel surface with a noticeable clear surface boundary (score 2) (Fig. 5).

SEM images of Curodont (CU) group show smoothened and well coalesced enamel rods corresponding to hydroxyapatite formation by self-assembling peptide. (score 1) (Fig. 6). SEM images of GC mousse (GC) group show filling of the interprismatic spaces with formation of interprismatic substances seen as adherent granules or globules. These correspond to the redeposited minerals subsequent to mobilization of calcium and phosphate from the CCP-ACP (score 1) (Fig. 7).

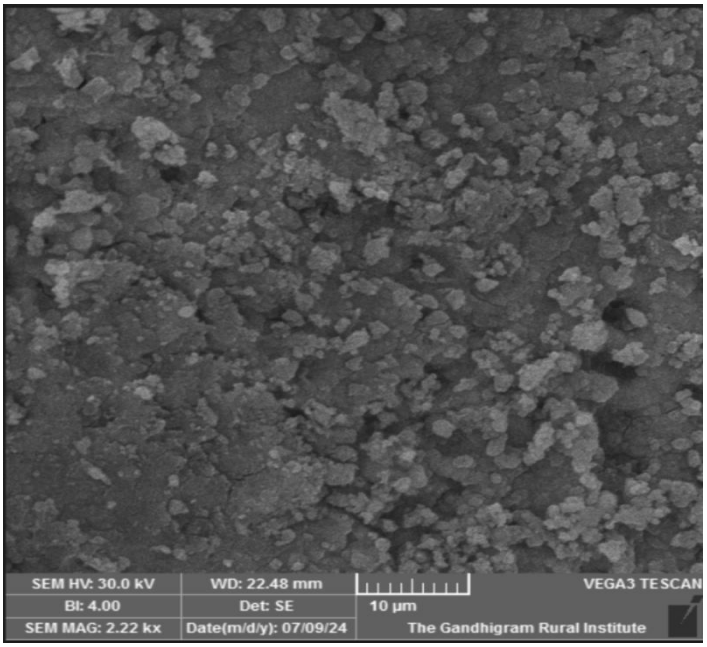


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208 Fig. 4: SEM images (*2000) of Pre control group debonded samples

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211 Fig. 5: SEM images (*2000) of Post control group debonded samples

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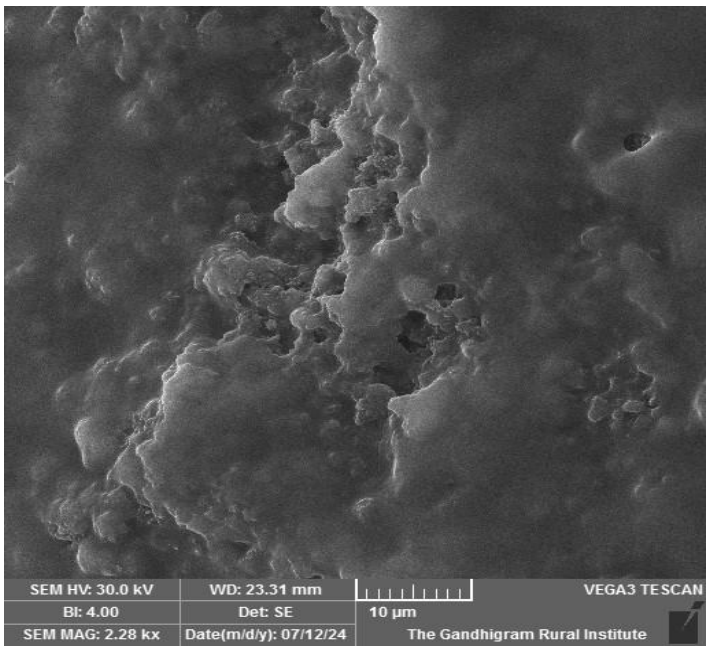


Fig. 6: SEM images (*2000) of Curodont (CU) group debonded samples

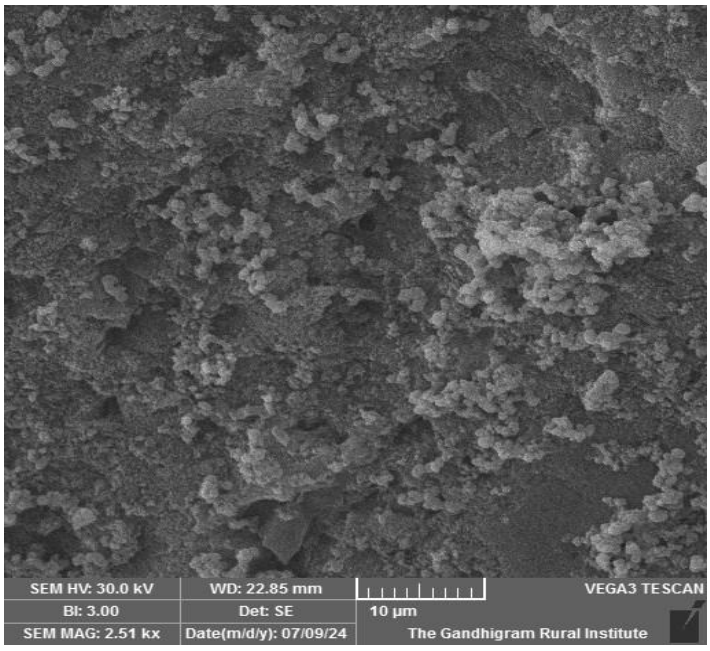


Fig. 7: SEM images (*2000) of GC mousse (GC) group debonded samples

Ca and P element weight percentage of samples was analysed using EDX. Table 3 summarizes the weight percentage of calcium (Ca) and phosphorus (P) across all experimental groups. The pre-control samples demonstrated relatively stable baseline Ca and P values, reflecting the residual mineral content in structurally compromised enamel following debonding. The GC mousse group showed a reduction in both Ca and P weight percentages compared to pre control baseline values, indicating limited mineral deposition under the tested conditions. In contrast, the Curodont group exhibited consistently higher Ca and P values relative to the GC mousse group, with several samples demonstrating Ca and P levels comparable to or approaching baseline mineral content. Post-control samples showed variable Ca and P distribution, suggesting partial mineral recovery following treatment, though with greater inter-sample variability compared to the Curodont group. Mean Ca and P weight percentages (Figure 8) were highest in the Curodont group, while post-control samples demonstrated the lowest mean values, with the GC mousse group showing comparably low values.

All EDX spectra corresponding to Ca and P elemental analysis are provided in the supplementary files (S2–S5). The combined SEM and EDX findings indicate improved remineralization performance in the treated groups, with the Curodont group showing more consistent mineral deposition patterns compared to GC mousse, however none of the treated groups exceeded the pre control baseline Ca and P values.

Table 3. Ca and P element percentage of individual samples in 4 groups.

Groups		1	2	3	4
Pre Control	Ca	40.33	40.59	38.11	41.51
	P	16.98	15.06	16.35	16.10
Post Control	Ca	29.85	26.56	19.18	36.67
	P	13.69	12.02	9.58	15.23
GC mousse	Ca	33.55	24.16	25.05	30.05
	P	14.10	10.61	11.81	14.46
Curodont	Ca	34.60	30.58	38.33	36.73
	P	16.07	13.27	15.77	14.95

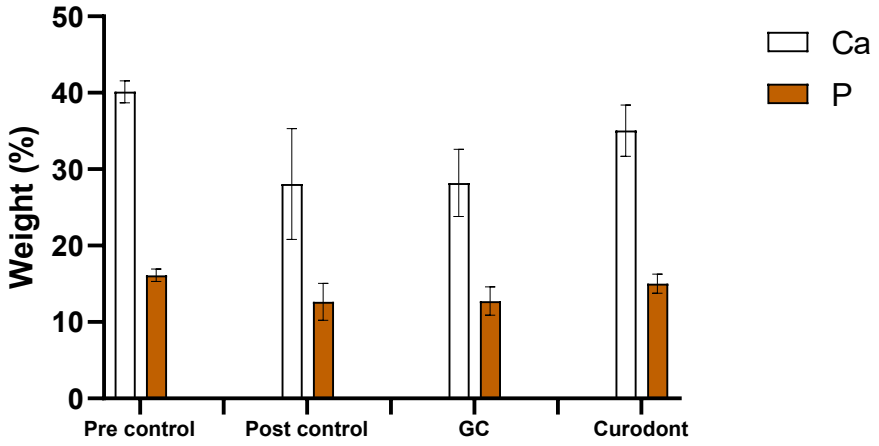


Fig. 8: Mean Ca and P element percentage among 4 groups.

DISCUSSION

Demineralization of enamel after orthodontic therapy and bond failure during treatment frequently concern clinicians. In this study, the mean shear bond strength in the control, Curodont, and GC Tooth Mousse treated groups were 18.84 MPa, 20.25 MPa and 21.01 MPa. In two cases, one in the control group and one in the Curodont group the shear bond strength was recorded to be 0 MPa, which is indicative of pre-test debonding. These values were retained to reflect clinically relevant adhesive failures and did not alter the overall finding of no significant intergroup differences. The bond strength values for all three groups were different from those determined by Sunna and Rock [23] (22.08 MPa), Sfondrini et al. [24] (13.2 MPa), and Ip and Rock [25] (13.6 MPa). Al Shamshi et al. [26] reported a mean shear bond strength of 10.87 ± 2.26 MPa in the APC adhesive brackets group. These variations can be attributed to differences in bonding agents and experimental conditions. No significant differences in the mean shear bond strength were noted among all three groups, indicating that the composite bond strength is not affected by the application of remineralization agents. With the introduction of newer bonding materials, Gia et al. [27] reported that there were no significant differences in shear bond strength between conventional direct and indirect bonding techniques. Similarly, Newman et al. [28] found a mean shear bond strength of 11.03 ± 3.05 MPa in metal brackets bonded with light-cured composite, showing similar properties to precoated resin. Reynold [29] reported that shear bond strengths between 5.9 and 7.8 MPa are adequate to sustain normal oral and orthodontic forces, while Rix et al. [30] indicated that higher

bond strengths might increase the risk of enamel fracture, which was found to occur when bond strength exceeded 13.5 MPa [31].

Although the outermost enamel layer is the hardest and has higher fluoride content, Gorton and Featherstone [32] reported significantly greater demineralization around orthodontic brackets. This occurs due to irregularities created during etching, which enhance plaque accumulation around bonded brackets, intensifying demineralization. Almost 50% of patients exhibit clinically visible white spot lesions (WSL) around bracket sites after debonding, which tend to diminish gradually in the first two years; however, some demineralized regions may persist even up to five years [33]. Over the past decade, several new remineralizing materials have been developed to address such post-orthodontic concerns, although topical fluoride application remains one of the most established methods [34–36]. Despite these advances, literature on enamel surface changes following debonding and the use of commercially available fluoride-based remineralizing agents remains limited. Hence, the present study aimed to evaluate and compare enamel surface defects after debonding with the application of two remineralizing agents Curodont Repair and GC Tooth Mousse.

Remineralization is a biological process involving the deposition of calcium, phosphate, and fluoride ions onto demineralized enamel to restore its crystalline structure [34–36]. EDX analysis demonstrated that Curodont Repair exhibited comparatively higher Ca and P values among the treated groups, whereas GC Tooth Mousse demonstrated lower Ca and P values; the pre-control samples served as a baseline reference condition [37] and reflected residual mineral content in structurally compromised enamel following debonding (Tables 3). GC Tooth Mousse is a fluoride-based remineralizing agent containing Casein Phosphopeptide-Amorphous Calcium Phosphate (CPP–ACP), a milk-derived complex composed of Casein Phosphopeptide (CPP) and Amorphous Calcium Phosphate (ACP). CPP–ACP stabilizes free calcium and phosphate ions, maintaining enamel supersaturation, reducing demineralization, and promoting remineralization. Free ions released from CPP–ACP deposit onto enamel rods to form apatite crystals, while fluoride ions contribute by forming fluorapatite, enhancing enamel resistance to caries [12, 13]. SEM images of the GC Tooth Mousse group revealed filling of interprismatic spaces with thin, adherent granules or globules corresponding to CPP–ACP–mediated surface mineral redeposition, which primarily improves surface morphology rather than bulk mineral content.

Curodont Repair, a biomimetic remineralizing agent, provides a therapeutic approach for enamel regeneration [14]. It operates through a self-assembling peptide that forms a supramolecular fibrous network in the acidic oral environment, filling the intercrystalline enamel spaces and attracting calcium and phosphate ions from saliva to produce de novo hydroxyapatite crystals. The inclusion of fluoride enhances remineralization synergistically [14]. SEM images of the Curodont group showed smoothened and well-coalesced enamel rods, supporting its remineralizing effect. Amin et al. [14] demonstrated that Curodont Repair enabled near-complete healing of incipient lesions, reducing ICDAS scores from 2 to 0. When compared to GC Tooth Mousse, Curodont was reported to be superior as a remineralizing agent, producing greater reductions in the size of white spot lesions. In agreement, samples treated with Curodont and GC Tooth Mousse showed signs of enamel remineralization. Brunton et al. and Bröseler et al. [38, 39] compared Curodont Repair with Duraphat and found significantly greater lesion size reduction with Curodont. They concluded that the aqueous peptide P11-4 is beneficial in managing early carious lesions. Overall, Curodont Repair offers a promising option for enamel regeneration by forming a peptide scaffold that promotes mineral redeposition within lesion bodies [40].

A recent systematic review by Hu et al. (2022) [41] on the prevention of WSLs concluded that acidulated phosphate fluoride (APF) foam showed the best long-term remineralizing efficacy after debonding, followed by difluorosilane varnish and high-concentration fluoride toothpaste. However, current evidence remains inconclusive regarding the complete reversal of WSLs using remineralizing agents. The present study quantitatively and qualitatively analyzed enamel surfaces following debonding and demonstrated that the shear bond strength of composite resin is unaffected by the application of remineralizing agents. Although debonding resulted in surface scratches and grooves indicative of enamel damage, the application of agents such as Curodont Repair and GC Tooth Mousse was associated with surface features consistent with mineral redeposition, with more steady recovery observed in the Curodont group. Further studies with larger sample sizes, varied bonding systems, different remineralizing materials, and clinical validation are warranted to confirm the findings of this preliminary laboratory investigation.

CONCLUSION

The findings of this study indicate that the application of remineralizing agents does not significantly influence the shear bond strength of composite materials. Both Curodont Repair and GC Tooth Mousse exhibited remineralizing

effects on the enamel surface after debonding, with Curodont Repair demonstrating a more consistent remineralization pattern under the conditions of this in-vitro study.

These results underscore the importance of applying remineralizing agents, as enamel damage following debonding may increase the risk of subsequent complications such as dental caries, requiring further clinical intervention. Although an oral environment was simulated, in-vitro bond strength assessments cannot reliably predict clinical outcomes; therefore, the results should be interpreted with caution. This investigation should be considered preliminary, and further studies involving larger sample sizes, a broader range of remineralizing agents, and different bonding systems are warranted to substantiate these findings.

DECLARATIONS

ABBREVIATIONS:

SEM- Scanning Electron Microscope

EDX- Energy-Dispersive X-ray Spectroscopy

APF gels - Acidulated Phosphate Fluoride gel.

CPP–ACP- Casein Phosphopeptide–Amorphous Calcium Phosphate

MPa- Megapascal

ANOVA- Analysis of Variance

ETHICAL APPROVAL AND CONSENT TO PARTICIPATE:

Applicable. The study was ethically approved by the Yenepoya Ethics committee-1 [Reference number: YEC-1/2021/007]. The communication with the ethics committee is attached. No personal data was collected as the samples were delinked.

The ethics committee had waived off the consent from each individual, as there was no direct contact between the researchers and the patients from whom the teeth were extracted. The teeth samples were delinked.

CLINICAL TRIAL NUMBER:

Not Applicable.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

not applicable as all the data generated are either shared in the main manuscript or uploaded as supplementary data.

COMPETING INTERESTS

The authors have no competing interests as defined by Springer, or other interests that might be perceived to influence the results and/or discussion reported in this paper.

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AUTHORS' CONTRIBUTIONS

K C A- Performing the experiments, analyzing data, preparing the figures, drafting, editing, and formatting the manuscript. D U -data analysis and drafting manuscript, S MK and KS-specimen collection, performed the experiments, reviewing manuscript, S F Z- conceptualization, initial proposal drafting, reviewing manuscript, A H-Clinical co-ordination, reviewing manuscript, S G- conceptualization, study plan, primary data evaluation, reviewing and editing manuscript, V A- critical revisions to the proposal, Funding acquisition and reviewing manuscript, S G S-conceived the study, specimen collection, supervision, reviewing the manuscript. All authors reviewed and approved the final version of the manuscript.

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