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RESEARCH ARTICLE

Surface Roughness on Cementoenamel Junction After Rubber-Dam Clamp Application

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ABSTRACT

Objective: To investigate the surface roughness on cementoenamel junction after application of various rubber-dam retraction clamps for different durations.

Materials and Methods: Fifty-four extracted human molar teeth were used. Various retraction clamps were placed on the cementoenamel junction. There are three main examination groups in the study. Group 1 ($n=6$) included a polymer clamp (SoftClamp, Kerr Hawe, Switzerland), Group 2 ($n=6$) included a metal clamp with a flat edge (Black Line RDCM7X, Hu-Friedy Group, USA), and Group 3 ($n=6$) included a metal clamp with a serrated edge (Fiesta Color Coded, Coltene, USA). All clamps were applied for 30 min, 1, and 2 h. Surface roughness measurements were performed using a profilometer before and after the clamp application and surface morphology was assessed through the SEM images. One-way ANOVA was used to compare three or more groups. Percentage changes were evaluated using the Kruskal–Wallis test, followed by Dunn's test for post hoc analyses. The deemed significance was set at $p<0.05$.

Results: Between the initial and the final roughness measurements, after 30 min of clamp application, only Group 3 showed significant increases in roughness ($p=0.001$). After 1 and 2 h of clamp application, there were significant increases in roughness for all groups. No significant differences in percentage changes for all groups in 30 min and 2 h of application ($p=0.220$ and $p=0.091$, respectively). However, Group 1 presented significantly lower surface roughness in percentage after the 1 h of application ($p=0.040$). No significant differences in the percentage changes in roughness were observed within the groups for 30 min, 1, and 2 h applications ($p=0.220$, $p=0.884$, and $p=0.755$ for Groups 1, 2, and 3, respectively). In SEM analysis, deep point microstructure defects were seen as the clamp application time increased.

Conclusions: Rubber-dam clamp application may cause damage to the cementoenamel junction area. However, the level of damage is clamp-type-dependent. Slight scratch-type damages were observed on teeth with plastic clamps, while metal clamps generally caused cracks. The increase in the duration of the same rubber-dam clamp application was not considered an effective factor regarding the damage.

Clinical Significance: During rubber-dam isolation, clamp type and duration of the application may cause damage to the tooth surface or progress an existing defect. Examining the teeth before selecting the clamp might be beneficial for minimizing dental tissue damage.

1 | Introduction

Rubber-dam was first introduced in 1864 for operation field isolation in dentistry, and it has remained a standard practice for over a century [1]. The application of rubber-dam is regarded as the gold standard, contributing to the success and optimization of dental treatments [2].

The advantages of rubber-dam in dental procedures are multifaceted as they provide excellent field isolation, ensuring a dry and clean operating area, thereby enhancing visibility and access for dental professionals. Additionally, it may prevent contamination, facilitating optimal adhesion for the restorations. Patients benefit from increased comfort due to the prevention of debris and moisture. Moreover, rubber-dam act as a barrier, reducing the risk of cross-contamination, and postoperative infections. It contributes to procedural efficiency by creating a clear workspace and enhancing patient safety by preventing accidental ingestion or inhalation of materials during treatments [3–5].

Rubber-dam clamps play a crucial role in the proper placement of rubber sheets, providing dentists with better moisture control and operating field view during treatments. These clamps come in various types, sizes, shapes, and colors typically made of durable materials like stainless steel [3, 6, 7]. As an alternative to traditional metal clamps, there are also ones available that are made from soft materials to avoid natural dental tissue damage during the application [8]. They are made of plastic material and appear as radiolucent or radio-opaque on radiography [1, 9]. Some commercially available clamps, such as tiger clamps with serrated jaws, offer enhanced retention on teeth. These differences in the material and design of the clamps may change the forces applied to the tooth [8]. The ideal situation involves achieving a four-point contact in the cervical region of the tooth, irrespective of the type of clamp used [3, 10].

There are also some disadvantages associated with rubber-dam clinical application, including the potential for injury to dental and gingival tissues, intraoperative sensitivity, cost implications, and handling difficulties [2, 11]. The effects on dental hard tissues are not clear, as the clamps are applied at different times depending on the duration of the dental treatment. Furthermore, the effects of different types of clamps available in the market on the cervical area are also remain uncertain. Due to the advocacy of four-point contact in clamp application, the concentration of stress applied at this point of contact in a small area may increase the potential for enamel and/or cement tissue damage [12].

Therefore, this in vitro study aimed to investigate the impact of different rubber-dam clamps on healthy cementoenamel (CE) junction surfaces. The research (h_1) hypotheses were (1) rubber-dam clamp application causes a rougher surface at the CE junction area, (2) the type of rubber-dam clamps affects the surface roughness, and (3) duration of rubber-dam clamp application affects the surface roughness.

2 | Materials and Methods

Ethical approval was obtained from a local ethical committee (protocol number: 2022/594). A power analysis was conducted using the G*Power (G*Power Ver.3.1.9.2, Germany) software to determine the required sample size. It was hypothesized that a minimum difference of 0.1 unit would be considered clinically significant in the pairwise comparisons between final roughness measurements and baseline. The effect size was calculated as $d = 2.20$, and it was determined that a total of 54 samples, with at least six samples in each group, would be required to achieve 80% power at a significance level of $\alpha = 0.05$.

A total of 54 extracted human molar teeth were collected. The teeth were extracted due to periodontal diseases within the last 6 months and included no demineralization or caries lesion, former restoration, fracture, crack, and wear lesion. To precisely examine the defects on the buccal and lingual surfaces of the extracted teeth, they were also observed under a dental operating microscope (OMS2000, Zumax, China) at 31.5× magnification under 5500K illumination. The periodontal tissue residues of the included teeth were gently removed, and the teeth were stored in 0.2% thymol solution at 4°C for 1 week, then stored in distilled water at room temperature until and during the analyses.

Each specimen was fixed in resin acrylic blocks, exposing the dental crown (Figure 1C). After the fixation, they were divided into three main groups using simple random allocation ($n = 18$ for each). Group 1: a plastic clamp (SoftClamp, Kerr Hawe, USA) (Figure 1B-1), Group 2: a metal clamp with smooth surface (Black Line RDCM7X, Hu-Friedy Group, USA) (Figure 1B-2), and Group 3: a metal clamp with a serrated surface (Fiesta Color Coded, Coltene, USA) (Figure 1B-3). All the clamps were applied to the CE junction of the teeth (Figure 1C) for 30 min, 1, and 2 h ($n = 6$ for each application period). A new clamp was placed on each tooth to ensure uniform force and avoid any variation due to repeated use.

A rectangular frame (2 mm × 1 cm) was marked on the buccal or lingual surface of each tooth to enable roughness measurements from the same area before and after the clamp application (Figure 1A). To determine this, the mesiodistal widths of each clamp were measured between the surface-contacting ends, and the distance of the widest clamp was observed to be 1 cm. Regarding the decision on the measurement area and determining the contact area or contact point on the tooth surface, the selected clamp was first placed on the tooth for a very short period and the observed contact points were marked on the surface. Additionally, a macrophotograph was taken for future reference. This process ensured that the correct positioning of the clamps on the marked areas was verified for each sample.

2.1 | Analysis of the Samples

Blinding was implemented in this study to eliminate subjective bias. The researchers responsible for the roughness measurements and SEM analysis were different, ensuring independent assessments.

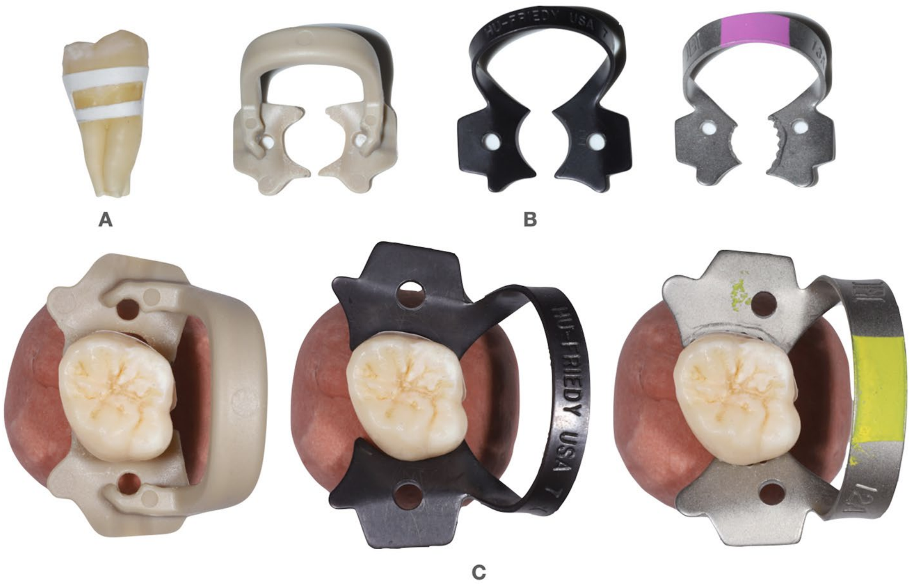

FIGURE 1 | (A) The rectangular observational frame (2 mm × 1 cm) on the buccal or lingual tooth surface. (B) Clamps used (B-1: SoftClamp, B-2: Hu-Friedy Black Line RDCM7X, B-3: Fiesta color coded no. 13A, respectively). (C) Occlusal view of the clamp application (B1: SoftClamp, B2: Hu-Friedy Black Line RDCM7X, B3: Fiesta color coded no. 12A, respectively).

Surface roughness measurements were performed before and after the clamp applications. To measure the average roughness (Ra) values, the teeth were placed individually in a surface roughness profilometer (Surftest 410; Mitutoyo, Kawasaki, Japan) and five measurements were performed for each. The transverse length for each measurement was taken 1.25 mm (mesiodistally), with a cut-off of 0.25 mm. The surface roughness increase ratio was calculated as the percentage changes for each group and was calculated as follows [13]:

$$\%\,\text{change in Ra} = (\text{Ra}_{\text{after clamp application}} - \text{Ra}_{\text{before clamp application}}) / \text{Ra}_{\text{before clamp application}} \times 100$$

Additionally, each tooth's scanning electron microscopy (SEM; EVO LS10, Zeiss Microscopy, Germany) image was analyzed after the clamp application. Before this procedure, the teeth were kept in a desiccator for 24 h. Dried teeth were coated with an average of 1–2 nm of gold using a coating device (SC7620 Sputter Coater, Quorum Technologies Ltd. England) at 15 mA for 120 s. The conductive teeth were analyzed using SEM at 10.00 kV.

Statistical analyses were performed with Statistical Package for Social Sciences software (Version 21.0; IBM). The Shapiro–Wilk test and box plot graphs analyzed the conformity of the obtained data to the normal distribution. When comparing three or more groups with variables showing a normal distribution, the one-way ANOVA test was employed. To evaluate the percentage changes, the Kruskal–Wallis test was used, with post hoc evaluations conducted using the Dunn test. The within-group assessments were performed using the paired samples test. The deemed significance level was set at < 0.05.

3 | Results

The surface roughness scores among the clamp groups were statistically similar before the application at 30 min, 1, and 2 h ($p = 0.250$, $p = 0.182$, and $p = 0.304$, respectively) (Table 1).

Regarding the changes between the initial and the final roughness measurements, after 30 min of clamp application, there were no significant differences for Group 1 and Group 2 ($p \geq 0.05$), but in Group 3 ($p = 0.001$) (Table 1, Figure 2). After 1 h of clamp application, there were significant increases in roughness for Groups 1, 2, and 3 ($p = 0.011$, $p = 0.021$, and $p = 0.009$, respectively) (Table 1, Figure 3). After 2 h of clamp application, there were also significant increases in roughness for Groups 1, 2, and 3 ($p = 0.001$, $p = 0.022$, and $p = 0.007$, respectively) (Table 1, Figure 4).

Regarding the comparison of roughness changes in percentages, there were no significant changes observed within the 30 min and the 2 h for all groups. ($p = 0.220$ and $p = 0.091$, respectively).

However, Group 1 presented significantly lower surface roughness in percentage after the 1 h of application compared to the other two groups ($p = 0.040$) (Table 1).

Regarding the surface roughness changes within the clamp groups, no significant changes were observed after 30 min, 1, and 2 h of application for Groups 1, 2, and 3 ($p = 0.220$, $p = 0.884$, and $p = 0.755$, respectively) (Table 2).

According to the SEM microphotographs, Group 1 exhibited damage in the form of scratching across all time durations, unlike Group 2 and Group 3, which exhibited damage in the form of cracks (Figures 5–7).

TABLE 1 | Comparison of surface roughness before and after rubber-dam clamp application.

Clamp		Group 1	Group 2	Group 3	p[a]
		Application for 30 min			
Initial roughness	Mean ± SD	1.08 ± 0.54	0.98 ± 0.20	1.35 ± 0.32	0.250
Final roughness	Mean ± SD	1.12 ± 0.52	1.11 ± 0.16	1.54 ± 0.37	0.112
	p[c]	0.234	0.069	0.001*	
Change (%)	Mean ± SD	5.99 ± 11.86	16.11 ± 17.83	14.45 ± 5.33	0.220[b]
	Q1–Q3 (Median)	−0.14 to 11.19 (0.83)	0.07–32.8 (13.8)	8.86–18.71 (15.1)	
	95% CI	−6.45 to 18.43	−2.06 to 34.81	8.85–20.04	
		Application for 1 h			
Initial roughness	Mean ± SD	1.18 ± 0.37	1.20 ± 0.36	0.93 ± 0.26	0.182
Final roughness	Mean ± SD	1.23 ± 0.36	1.39 ± 0.39	1.08 ± 0.21	0.203
	p[c]	0.011*	0.021*	0.009*	
Change (%)	Mean ± SD	4.27 ± 2.38	16.18 ± 13.51	19.12 ± 13.27	0.040[b,*]
	Q1–Q3 (Median)	3.8–9.6 (6.0)	6.8–29.42 (12.4)	7.3–35.9 (19.2)	
	95% CI	1.77–6.77	2.00–30.36	5.19–33.04	
		Application for 2 h			
Initial roughness	Mean ± SD	1.55 ± 0.30	1.01 ± 0.28	1.39 ± 0.74	0.304
Final roughness	Mean ± SD	1.64 ± 0.30	1.17 ± 0.3	1.63 ± 0.74	0.303
	p	0.001*	0.022*	0.007*	
Change (%)	MEAN ± SD	6.82 ± 4.97	18.56 ± 16.99	21.91 ± 15.52	0.091[b]
	Q1–Q3 (Median)	1.9–6.6 (3.8)	6.1–25.0 (14.0)	9.5–29.9 (17.7)	
	95% CI	1.60–12.03	0.73–36.39	5.62–38.19	

Abbreviations: 95% CI: 95% confidence interval, Q = quartile.
[a]One-way ANOVA test.
[b]Kruskal–Wallis test and post hoc Dunn test.
[c]Paired samples t-test.
*$p < 0.05$.

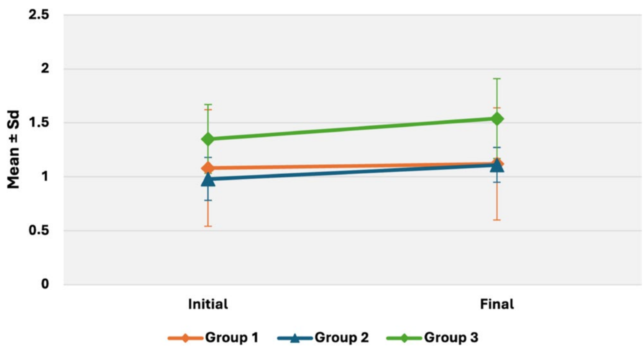

FIGURE 2 | Distribution of roughness scores after 30 min of clamp application.

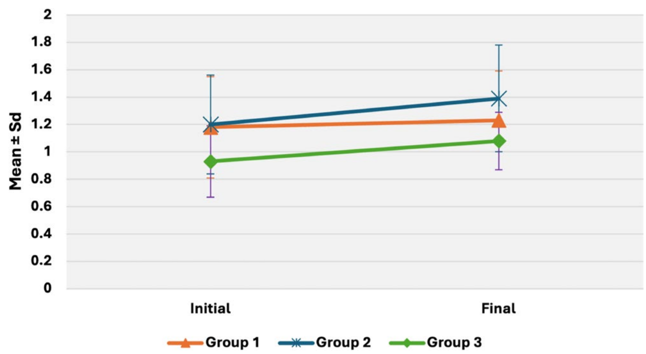

FIGURE 3 | Distribution of roughness scores after 1 h of clamp application.

4 | Discussion

Based on the results of this study, the first hypothesis was accepted due to the observed significant increases in roughness at the final roughness scores for all clamp groups. Although no differences were observed for final roughness among the clamp types, after 1 h of application the Softclamp presented significantly lower roughness in percentage. Therefore, the second hypothesis was partially accepted. Prolonged application of the clamp did not significantly increase the surface roughness and therefore the third hypothesis of the study was rejected.

The literature on this subject features a limited number of studies, mostly focusing on the advantages of clamps, the pain they cause, their hardness, and stress corrosion [1, 5, 14]. One study exploring possible iatrogenic damage caused by metal rubber-dam clamps by SEM analysis, demonstrated that the damage to the tooth might occur [12]. The damage in the form of depressed disruption was mentioned to occur on the surface of cementum or dentin. The researchers concluded that such damage could be exacerbated when a tooth undergoes multiple clamp applications, particularly during extended endodontic treatments. Another study investigated the effect of metal clamps on demineralized cervical enamel and revealed the changes in enamel structure and a loss of mineral content in the areas of clamp application [15]. The results of the present study were consistent with reports mentioning the

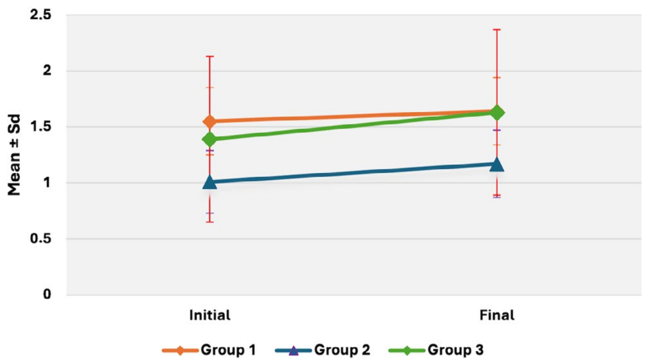

FIGURE 4 | Distribution of roughness scores after 2 h of clamp application.

hard tissue damage due to the clamp application. However, according to our results, the prolonged application of the clamp did not increase the level of the damage. This might be due to the continuous application of the clamp to the same points of the CE area compared to the multiple applications in different points, which was previously reported to cause more damage [15]. While we hypothesize that continuous application might affect damage, we acknowledge that factors like material fatigue or variations in tooth structure could also play a role and warrant further investigation. The SEM images in this study also revealed the enamel damage, in the form of scratches, crushes, compression, and deep point microstructure defects (Figures 5–7). While damage in the form of scratches was especially observed with the SoftClamp, crack formation was noted in teeth where a metal clamp was applied. Although contact-type profilometry is an effective method for measuring surface roughness, it does not provide detailed information about the type of roughness measured or the nature of the damage [16]. This limitation can create difficulties in detecting structural differences, particularly at the microscopic level. Therefore, it may be possible to find no direct correlation between the profilometer and SEM results. Thanks to the high resolution of SEM, more complex and deeper structural damages on the surface, such as cracks, may be detected. The profilometer may not detect such structural changes or they may not be measured accurately.

A previous study compared a metal (Hu-Friedy 14A) and a plastic (SoftClamp) clamp and reported that the stress value created by Hu-Friedy on enamel was 85% higher than that of SoftClamp using the finite element analysis [8]. The results of the present study were consistent with this report. Although we tried to use similar teeth in our study, we preferred to calculate the percentage change to evaluate how much change

TABLE 2 | Comparison of roughness changes within the clamp groups.

Clamp		Group 1	Group 2	Group 3
Application for 30 min % change	Mean ± SD	5.99 ± 11.86	16.11 ± 17.83	14.45 ± 5.33
	Q1–Q3 (Median)	−0.14 to 11.19 (0.83)	0.07–32.8 (13.8)	8.86–18.71 (15.1)
	95% CI	−6.45 to 18.43	−2.06 to 34.81	8.85–20.04
Application for 1 h % change	Mean ± SD	4.27 ± 2.38	16.18 ± 13.51	19.12 ± 13.27
	Q1–Q3 (Median)	3.8–9.6 (6.0)	6.8–29.42 (12.4)	7.3–35.9 (19.2)
	95% CI	1.77–6.77	2.00–30.36	5.19–33.04
Application for 2 h % change	Mean ± SD	6.82 ± 4.97	18.56 ± 16.99	21.91 ± 15.52
	Q1–Q3 (Median)	1.9–6.6 (3.8)	6.1–25.0 (14.0)	9.5–29.9 (17.7)
	95% CI	1.60–12.03	0.73–36.39	5.62–38.19
	p	0.220	0.884	0.755
30 min–1 h		0.180	0.589	0.699
30 min–2 h		0.240	0.937	0.485
1 h–2 h		0.394	1.000	0.937

Note: Kruskal–Wallis test and post hoc Dunn test, $p < 0.05$.
Abbreviations: 95% CI: 95% confidence interval, Q = quartile.

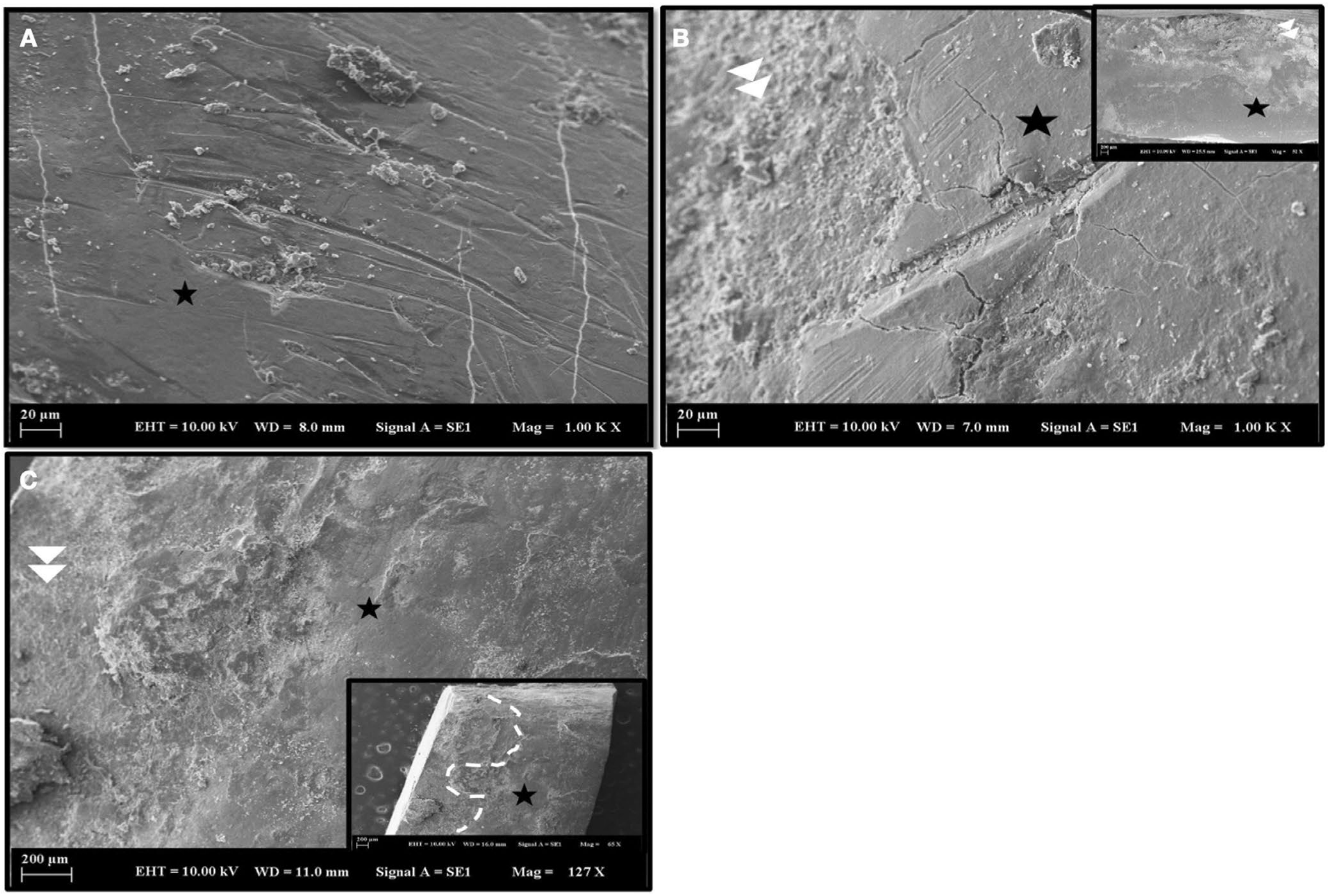

FIGURE 5 | SEM images after 30 min of clamp application: (A) Effect of the Group 1/SoftClamp: slight damage and scratches on the intact enamel surface (★), (B) Effect of the Group 2/Hu-Friedy clamp: slightly superficial damaged (▷▷) and enamel surface (★). INSERT: Small magnification of general appearance, (C) Effect of the Group 3/Fiesta clamp: moderate pressure damage (▷▷) on the intact enamel (★). INSERT: Small magnification of enamel-damaged border (dotted line).

there was in the final roughness compared to the beginning, considering that the surface structure of each tooth is different. This approach aims to minimize the effect of the differences in the natural roughness of each tooth. The percentage change for Softclamp was lower than for the other two clamp types in both the 30 min and 2 h applications, but no statistically significant difference was observed. After 1 h of clamp application, the plastic clamp SoftClamp presented lesser surface roughness, in other words lesser damage to the dental tissue compared to the two metal clamps Hu-Friedy and Fiesta. The SEM analysis also agreed with these findings. SoftClamp is made of polyethylene ketone (PEEK) and was introduced to distribute forces more effectively and minimize iatrogenic damage [7, 8]. This might be why the SoftClamp is considered the safest clamp of all.

The percentage change in roughness did not differ statistically for different durations of time in each group, so the third research hypothesis was rejected. In a study, clamps were applied to demineralized cervical enamel three times for 30 min at 1-week intervals, showing that clamp no. 205 caused more damage to the dental structure than clamp no. 26 from the second application. They attributed this to the fact that clamp no. 26 is less aggressive. This inconsistent result with our study might be due to the demineralized surfaces, clamp removal, and multiple reapplications [15].

According to the findings of our study, clamps may cause defects such as cracks in the enamel, irrespective of the type and duration of application. More severe effects are particularly likely on demineralized surfaces. A crack caused by clamps in teeth undergoing root canal treatment may lead to treatment failure due to microleakage. The use of magnification loops should be made routine, especially for teeth being clamped, and the area of application should be carefully examined. Examining the teeth before selecting the clamp might be beneficial in minimizing dental tissue damage, as it allows for a more informed selection of the clamp type according to the specific surface characteristics of each tooth. In addition, manufacturers have a significant responsibility to ensure that clamps are made from materials that will not damage dental tissues. To further minimize potential damage, the use of protective materials at the clamp-contact areas, limiting the duration of clamp application, and ensuring the clamp is placed in a single attempt without excessive force should also be considered. The accepted Ra value for a healthy tooth surface

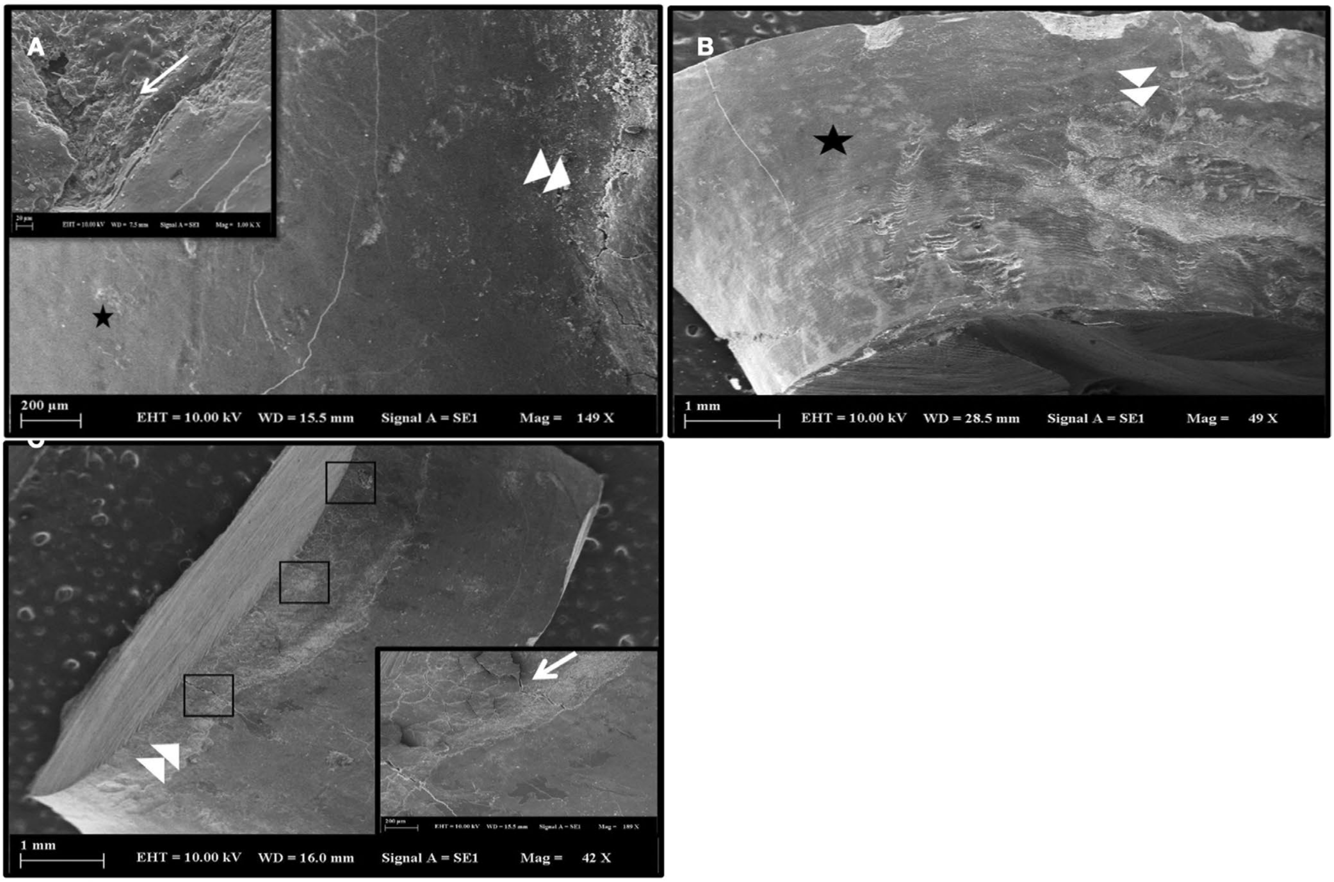

FIGURE 6 | SEM images after 1 h of clamp application: (A) Effect of the Group 1/SoftClamp: slight damage to the clamp on the intact enamel surface (★). Cementoenamel junction line (▷▷) on enamel. INSERT: High magnification of crushed enamel (→), (B) Effect of the Group 2/Hu-Friedy: scratched and crushed areas (▷▷) that disrupt the microstructure of enamel (★) in place, (C) Effect of the Group 3/Fiesta clamp: enamel area compressed by the clamp (▷▷), and deep point microstructure defects (▢). INSERT: Cobblestone appearance of enamel fractures (→).

is 0.2 µm [17], while the irregularities caused by clamp damage in this study were considerably higher than this accepted value. This finding underscores the need for caution, particularly near the CE junction, and suggests that, in such cases, clamps might be applied by spanning over adjacent teeth.

The inability to imitate the intraoral environment, including the lack of saliva, is the most significant limitation of our study. Only extracted molar teeth were used in this study, while the effect on other teeth should also be examined. Additionally, since variables such as age may also affect the surface roughness of teeth, future studies should focus on controlling these variables more precisely. Another limitation is the inability to determine the forces applied by the clamps, though even we selected teeth with similar buccolingual widths. Additionally, although analyses can be performed with superficial scanning instead of using a contact profilometer for planar measurements, the tooth morphology is not fully suitable for this method. Despite these limitations, our findings indicate that clamp application increases surface roughness at the enamel–cement junction, which is an important consideration for the clinical practice. However, the level of damage depends on the type of the selected clamp. Further research is necessary to validate these findings and optimize clamp application to prevent damage to natural dental tissues.

5 | Conclusion

Within the limitations of this study, it may be concluded that:

1. Rubber-dam clamp application may increase the surface roughness of the CE junction area. However, it depends on the type of selected clamp.
2. No significant increase in roughness was considered for Hu-Friedy and SoftClamp clamp types after 30 min of application. However, SoftClamp presented less increase in roughness than Hu-Friedy and Fiesta clamps, after 1 h of application. After 2 h of application, the increase in roughness was significant for all groups, but no statistical difference was observed between the clamp types.
3. The increase in the duration of the same rubber-dam clamp application may not cause a difference in the surface roughness of the CE junction area.

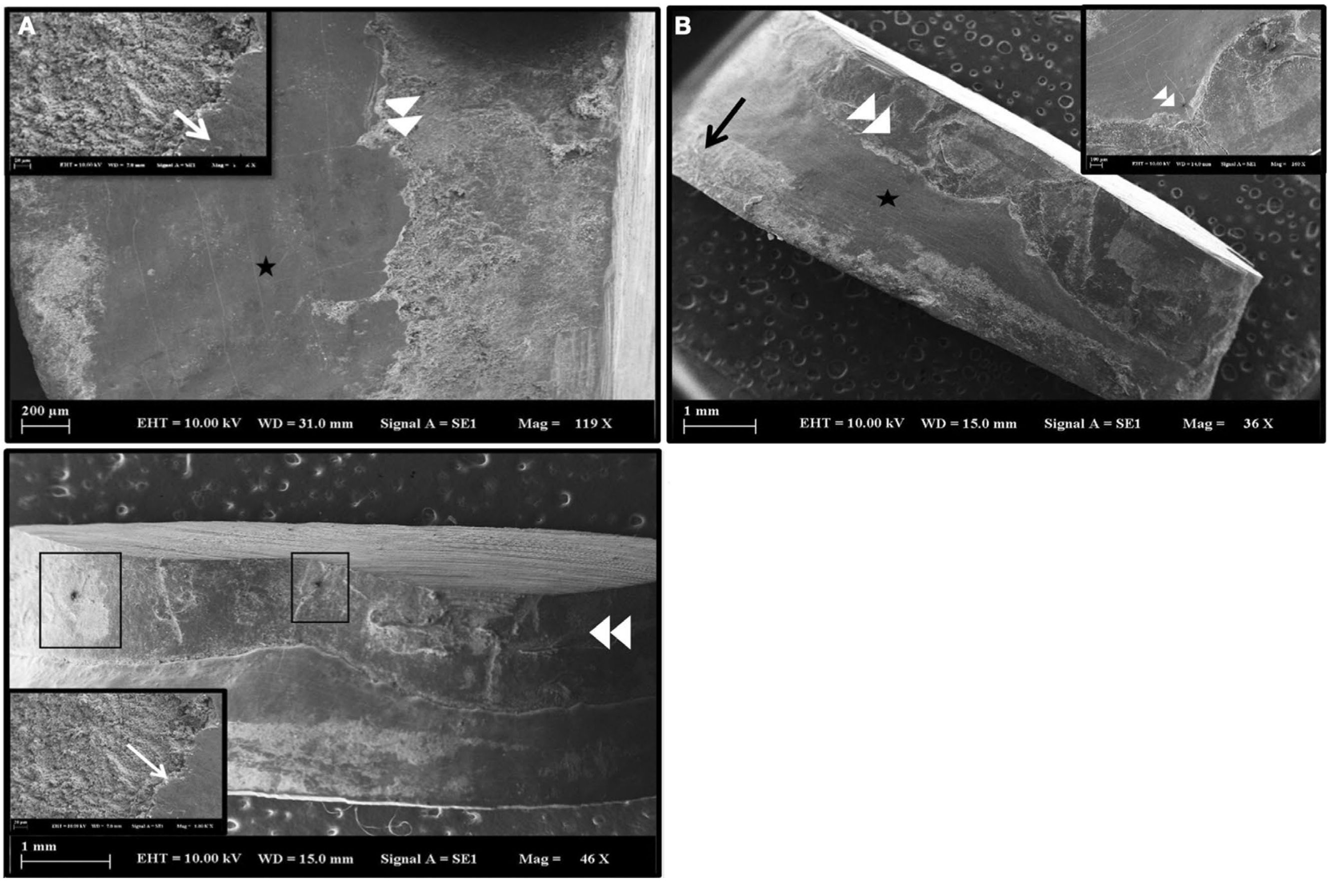

FIGURE 7 | SEM images after 2h of clamp application. (A) Effect of the Group 1/SoftClamp: slight damage to clamp (▷▷) on the intact enamel surface (★). INSERT: Cementoenamel junction line and deep microstructure of enamel (→), (B) Effect of the Group 2/Hu-Friedy clamp: in general view, low-layer crushing in the enamel area (★) compressed by the clamp (▷▷). Straight arrow (→) show cement direction. INSERT: Large magnification of the broken border, (C) Effect of the Group 3/Fiesta clamp: pressure damage of the clamp on the enamel and deep punctate microstructure disorders (▢).

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

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

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