Original Article

The prognostic value of visually assessing enamel microcracks: *Do debonding and adhesive removal contribute to their increase?*

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ABSTRACT

Objective: To find a correlation between the severity of enamel microcracks (EMCs) and their increase during debonding and residual adhesive removal (RAR).

Materials and Methods: Following their examination with scanning electron microscopy (SEM), 90 extracted human premolars were divided into three groups of 30: group 1, teeth having pronounced EMCs (visible with the naked eye under normal room illumination); group 2, teeth showing weak EMCs (not apparent under normal room illumination but visible by SEM); and group 3, a control group. EMCs have been classified into weak and pronounced, based on their visibility. Metal brackets (MB) and ceramic brackets (CB), 15 of each type, were bonded to all the teeth from groups 1 and 2. Debonding was performed with pliers, followed by RAR. The location, length, and width of the longest EMCs were measured using SEM before and after debonding.

Results: The mean overall width (W_{overall}) was higher for pronounced EMCs before and after debonding CB ($P < .05$), and after the removal of MB. Pronounced EMCs showed greater length values using both types of brackets. After debonding, the increase in W_{overall} of pronounced EMCs was 0.57 μm with MB ($P < .05$) and 0.30 μm with CB; for weak EMCs, $-$ 0.32 μm with MB and 0.30 μm with CB.

Conclusions: Although the teeth having pronounced EMCs showed higher width and length values, this did not predispose to greater EMCs increase after debonding MB and CB followed by RAR. (*Angle Orthod.* 2016;86:437–447.)

KEY WORDS: Bracket; Crack; Damage; Enamel; Orthodontic debonding; Scanning electron microscopy

INTRODUCTION

Careful examination of teeth with an intense light source can often reveal microcracks in the enamel. These enamel microcracks (EMCs) have generally been attributed to the abnormalities in the maturation process, occlusal forces, temperature variations, and restorative processes.[1,2] As previous studies have shown, EMCs can be noticed after debonding at the end of orthodontic treatment.[3–5] While small EMCs may not result in tooth fracture, over prolonged periods their growth can be detrimental as they may serve as sites for demineralization and increase susceptibility to carious lesions.[3,6,7]

Nowadays, patients have high esthetic demands and pay more attention to the possible enamel damage

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Accepted: July 2015. Submitted: February 2015.
Published Online: August 31, 2015

Table 1. Teeth Selection Criteria

Primary Teeth Selection Criteria
· Intact buccal enamel surface with no white spots
· No pretreatment with any chemical agents (such as H_2O_2)
· No previous orthodontic, endodontic, or restorative treatment
Secondary Teeth Selection Criteria
· Enamel microcracks (EMCs, pronounced or weak) on the buccal enamel surface

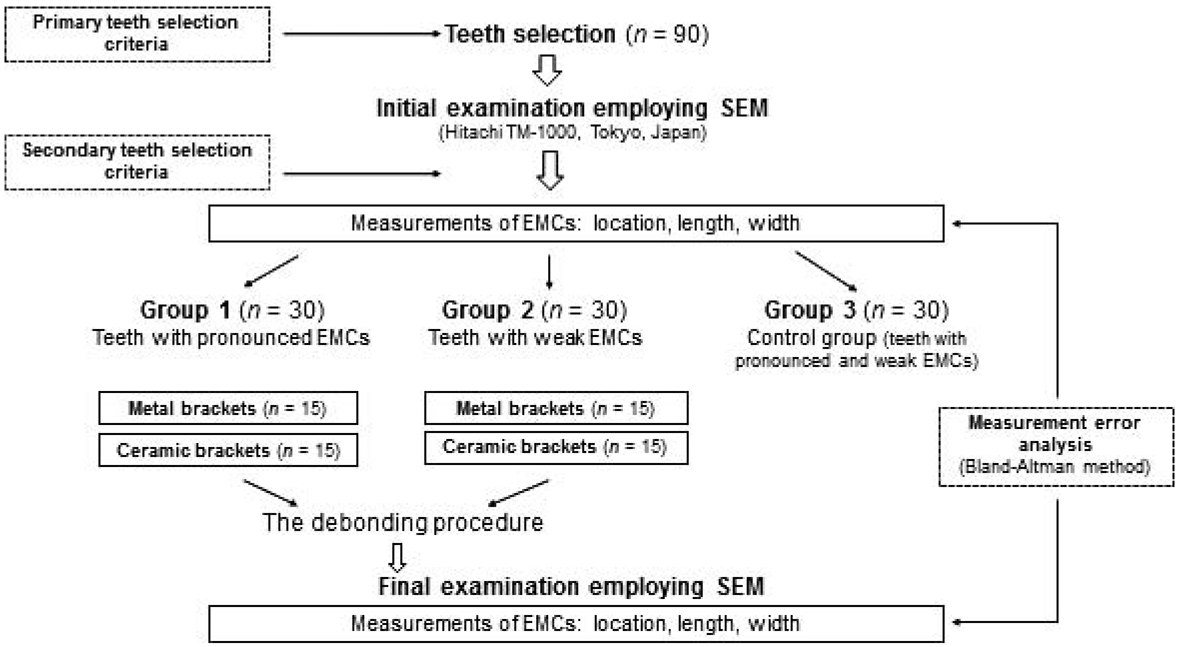

Figure 1. Graphic representation of the study protocol.

that takes the form of EMCs after debonding.[8,9] Enamel irregularities and visible EMCs are often noticed by patients at the beginning of orthodontic treatment and thus arise questions regarding the wisdom of bonding brackets on such teeth. Using ceramic brackets (CB) causes more concern, because the physical properties of ceramics such as hardness, high bond strength, and low fracture toughness or brittleness have led to many reports of irreversible enamel surface damage during the removal procedure.[10–12] Thus, as patient awareness is growing and documentation of EMCs is difficult, it is important

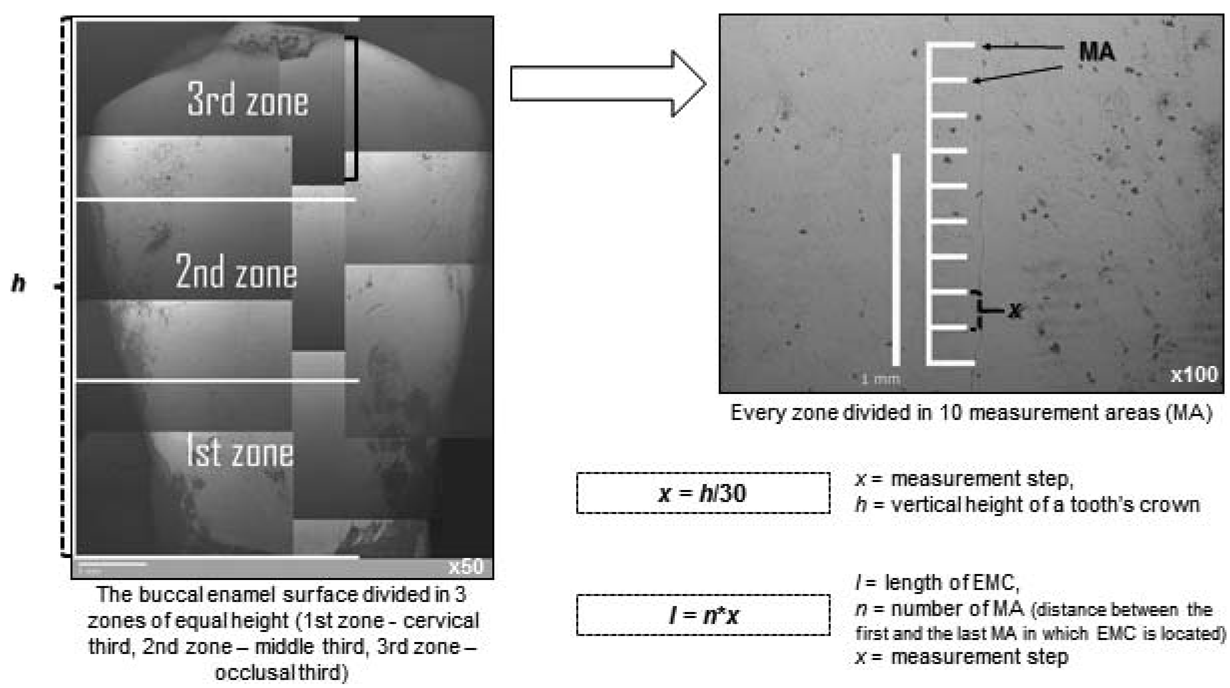

Figure 2. Examination of the buccal enamel surface utilizing SEM. A measurement step (x, the distance between two measurement areas [MAs]) and length (l) of EMC were calculated. For l evaluation, the number (n) of MAs, that is, the distance between the first and last MA in which an EMC was located, was quantified.

Table 2. Bracket Characteristics, Bonding and Debonding Procedures

	Subgroup 1	Subgroup 2
	Metal Brackets (MB, Discovery; Dentaurum, Ispringen, Germany)	Ceramic Brackets (CB, Clarity; 3M Unitek, Monrovia, Calif)
Bracket characteristics		
Slot size (in)	0.022	0.022
Type of bond	Mechanical	Mechanical
Base area (mm²)	11.9	11.83
Bonding procedure	Etching with 34.5% phosphoric acid gel (Vococid; Voco, Cuxhaven, Germany) for 30 s, rinsing with water for 20 s, and drying with air for 10 s	
	Application of a thin uniform coat of primer (Contex Primer; Dentaurum) and curing with light for 10 s	
	Application of resin adhesive on the bonding base of bracket (Transbond XT; 3M Unitek) and firmly positioning it on the enamel surface. Removal of the excess adhesive from the margins of the bracket with a dental probe	
	Polymerization of the light-cure adhesive for 20 s (10 s on each proximal surface) using a halogen light (Mini LED; Satelec, Cambridgeshire, UK)	
Debonding procedure	Conventional utility/Weingart (Dentaurum) pliers	Debonding instrument (3M Unitek)
	Gently squeezing the mesiodistal edges of the bracket wings until the bracket comes free	Positioning pliers against the mesial and distal sides of the bracket and symmetrically against the labial surface to optimize contact surface area
		Gently squeezing the instrument until the bracket collapses, then rocking in the mesiodistal direction until the bracket becomes completely separated from the enamel

to develop an understanding of the effect of debonding metal brackets (MB) and CB on visible EMCs and those EMCs that can be visualized only under scanning electron microscopy (SEM).[3,12]

Many attempts have been made to assess enamel damage after bracket removal.[8,12–16] Several investigations have taken a deeper view to evaluating various EMC characteristics.[5,9,17–19] However, there are no reports on a consistent examination of the effect of debonding teeth having visible EMCs.

Therefore, the purposes of this study were to (1) compare the characteristics (location, length, and width) of EMCs having varying degrees of severity before and after removal of MB and CB, (2) ascertain whether there is a correlation between the original dimensions of EMCs and the likelihood of their increasing during debonding followed by RAR, (3) determine whether EMCs visibility is of any prognostic value, and (4) determine whether invisible EMCs might progress to visible ones.

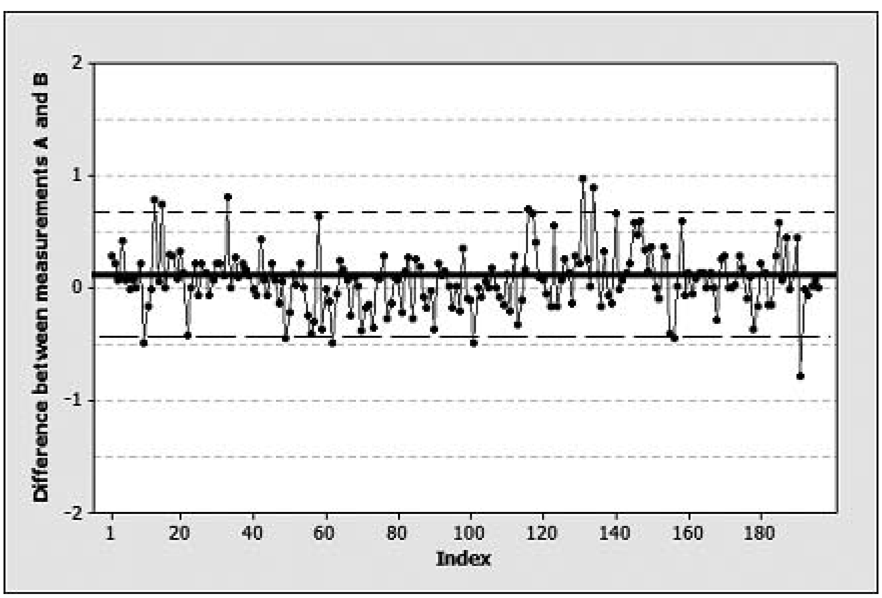

Figure 3. Bland-Altman plot. The solid line shows the mean of the differences between two width measurements; Dashed lines show the upper (mean +1.96 SD) and lower limits (mean −1.96 SD) of the 95% CI of agreement.

Table 3. Width and Length of Pronounced and Weak Enamel Microcracks (EMCs) Before Bonding and After Removal of Metal Brackets (MB)[a]

	Before Bonding (*n* = 15)				After Removal (*n* = 15)					
Width of Pronounced Enamel Microcracks (EMCs, μm)	Mean	SD	Max	Min	Mean	SD	Max	Min	RC (%)	*P*
First zone	1.74	0.96	4.01	0.28	2.46	2.64	13.45	0.31	41.38	NS
Second zone	1.53	0.83	4.60	0.46	2.00	1.08	5.88	0.31	30.72	*
Third zone	1.14	0.71	2.59	0.28	1.72	0.77	3.03	0.58	50.88	*
Overall width	1.53	0.86	4.60	0.28	2.10	1.64	13.45	0.31	37.25	*
Length of Pronounced Enamel Microcracks (EMCs, mm)	Mean	SD	Max	Min	Mean	SD	Max	Min	RC (%)	*P*
Overall length	2.64	1.24	5.72	1.60	2.41	1.02	4.94	1.15	−8.71	NS
Width of Weak Enamel Microcracks (EMCs, μm)	Mean	SD	Max	Min	Mean	SD	Max	Min	RC (%)	*P*
First zone	1.71	0.76	3.21	0.38	2.02	0.76	3.67	0.82	18.13	NS
Second zone	1.58	0.72	3.43	0.37	1.89	0.64	3.12	0.83	19.62	NS
Third zone	–	–	–	–	–	–	–	–	–	–[b]
Overall width	1.65	0.74	3.43	0.37	1.97	0.71	3.67	0.82	19.39	NS
Length of Weak Enamel Microcracks (EMCs, mm)	Mean	SD	Max	Min	Mean	SD	Max	Min	RC (%)	*P*
Overall length	1.79	1.08	3.84	0.56	1.69	1.46	5.28	0.24	−5.59	NS

[a] Max indicates maximum; Min, minimum; SD, standard deviation; RC, relative change.
[b] No statistics could be computed because of absence of EMCs in the third zone before bonding and after bracket removal.
* $P \leq .05$; NS indicates nonsignificant.

Table 4. Width and Length of Pronounced and Weak Enamel Microcracks (EMCs) Before Bonding and After Removal of Ceramic Brackets (CB)[a]

	Before Bonding (*n* = 15)				After Removal (*n* = 15)					
Width of Pronounced Enamel Microcracks (EMCs, μm)	Mean	SD	Max	Min	Mean	SD	Max	Min	RC (%)	*P*
First zone	2.68	1.38	5.92	0.42	2.83	1.49	6.98	0.85	5.60	NS
Second zone	2.41	1.43	5.92	0.28	2.74	1.36	5.92	0.71	13.69	NS
Third zone	1.62	1.11	5.57	0.45	2.19	0.96	3.53	0.56	35.19	*
Overall width	2.36	1.40	5.92	0.28	2.66	1.34	6.98	0.56	12.71	NS
Length of Pronounced Enamel Microcracks (EMCs, mm)	Mean	SD	Max	Min	Mean	SD	Max	Min	RC (%)	*P*
Overall length	3.81	2.05	9.16	0.90	4.05	2.39	9.16	0.90	6.30	NS
Width of Weak Enamel Microcracks (EMCs, μm)	Mean	SD	Max	Min	Mean	SD	Max	Min	RC (%)	*P*
First zone	1.68	0.94	4.02	0.49	2.27	1.03	4.39	0.55	35.12	*
Second zone	1.93	1.10	4.58	0.51	1.52	0.86	3.76	0.55	−21.24	NS
Third zone	0.53	0.14	0.78	0.42	–	–	–	–	–	–[b]
Overall width	1.70	1.02	4.58	0.42	2.00	1.03	4.39	0.55	17.65	NS
Length of Weak Enamel Microcracks (EMCs, mm)	Mean	SD	Max	Min	Mean	SD	Max	Min	RC (%)	*P*
Overall length	2.42	1.77	5.51	0.80	1.80	0.99	3.22	0.80	−25.62	NS

[a] Max indicates maximum; Min, minimum; SD, standard deviation; RC, relative change.
[b] No statistics could be computed because of absence of EMCs in the third zone after bracket removal.
* $P \leq .05$; NS indicates nonsignificant.

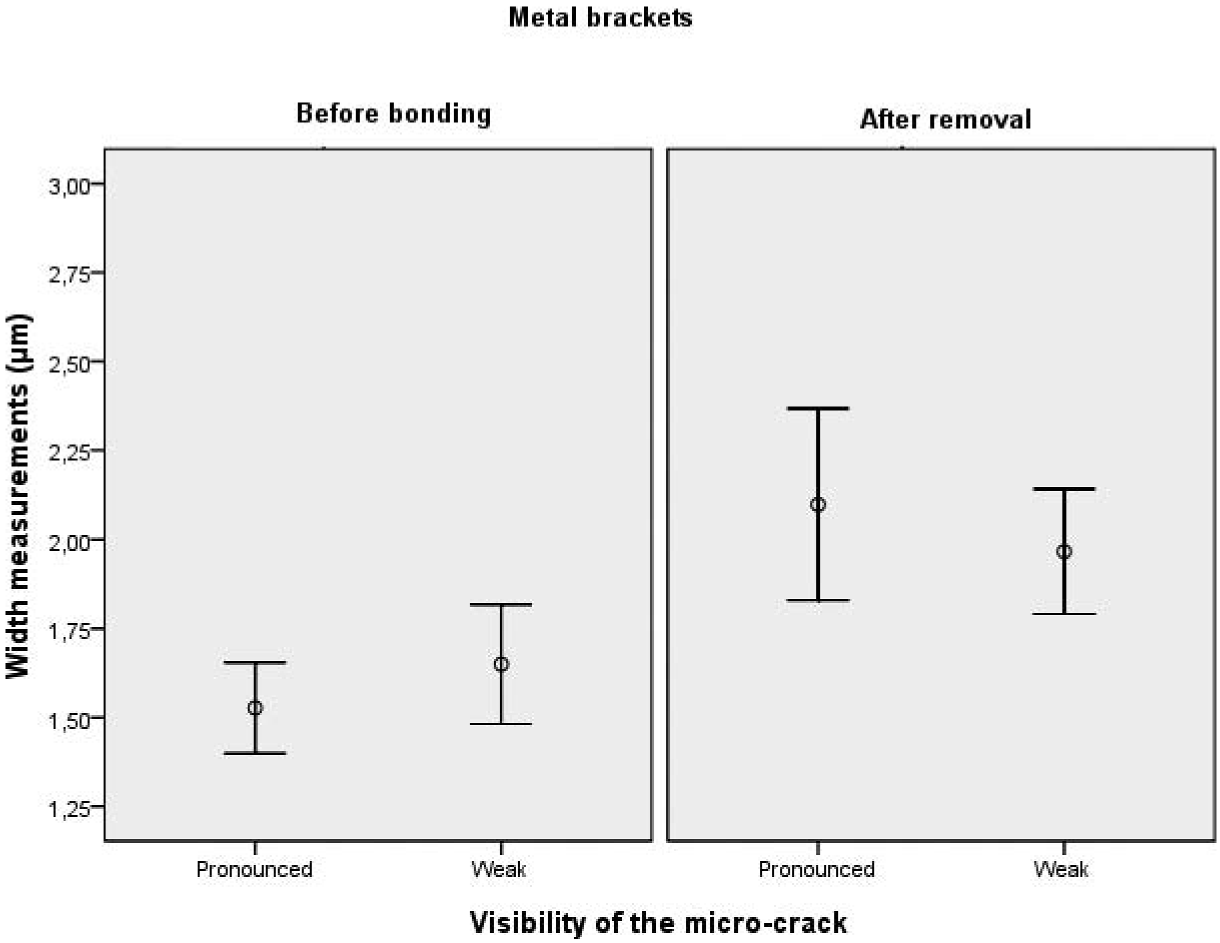

Figure 4. $W_{overall}$ of pronounced and weak EMCs with 95% CI before and after debonding MB followed by RAR.

MATERIALS AND METHODS

Tooth Selection and Enamel Surface Evaluation

The teeth were prepared in accordance with the guidelines of the International Organization for Standardization.[20]

Ninety freshly extracted maxillary premolars were included in the final study. They had been extracted for orthodontic reasons and were used with the patients' informed consent. Selection criteria for the teeth are listed in Table 1. The extracted teeth were decontaminated in 0.5% chloramine-T solution and then stored in distilled water that was changed weekly before preparation and testing.

The sample size was estimated using the sample size calculator,[21] by which a sample size of 90 was required to detect differences with a 5% confidence interval (CI) and 90% confidence level (population size, 133).

The study was performed according to the protocol presented in Figure 1.

The buccal enamel surfaces of all the teeth included in the study were evaluated using SEM (TM-1000, Hitachi, Tokyo, Japan).[19] The SEM was operated at 15 kV, at $\leq 5 \times 10^{-2}$ Pa (electron gun vacuum) and at $\approx$ 30–50 Pa (specimen chamber vacuum). The teeth were not coated with a conductive layer prior to SEM examination. The initial evaluation of EMCs was performed at $\times$50–$\times$100.

Examination of the buccal enamel surface is shown in Figure 2. Montages (stitching together of multiple images) of the SEM micrographs were made to reconstruct images of some larger crowns. From these micrographs the height (h) of each crown was measured. For detailed mapping of the EMCs, the buccal surface was divided into three zones of equal height: first zone—cervical third, second zone—middle third, third zone—occlusal third.[9,12,19] After direct inspection by the naked eye under normal room illumination and initial examination with the SEM, the teeth were divided into three groups of 30: group 1, teeth having pronounced EMCs; group 2, teeth showing weak EMCs; and group 3, a control group (comprised of an equal number of teeth with pronounced and weak EMCs) to study the effect of dehydration on existing EMCs. EMCs were classified

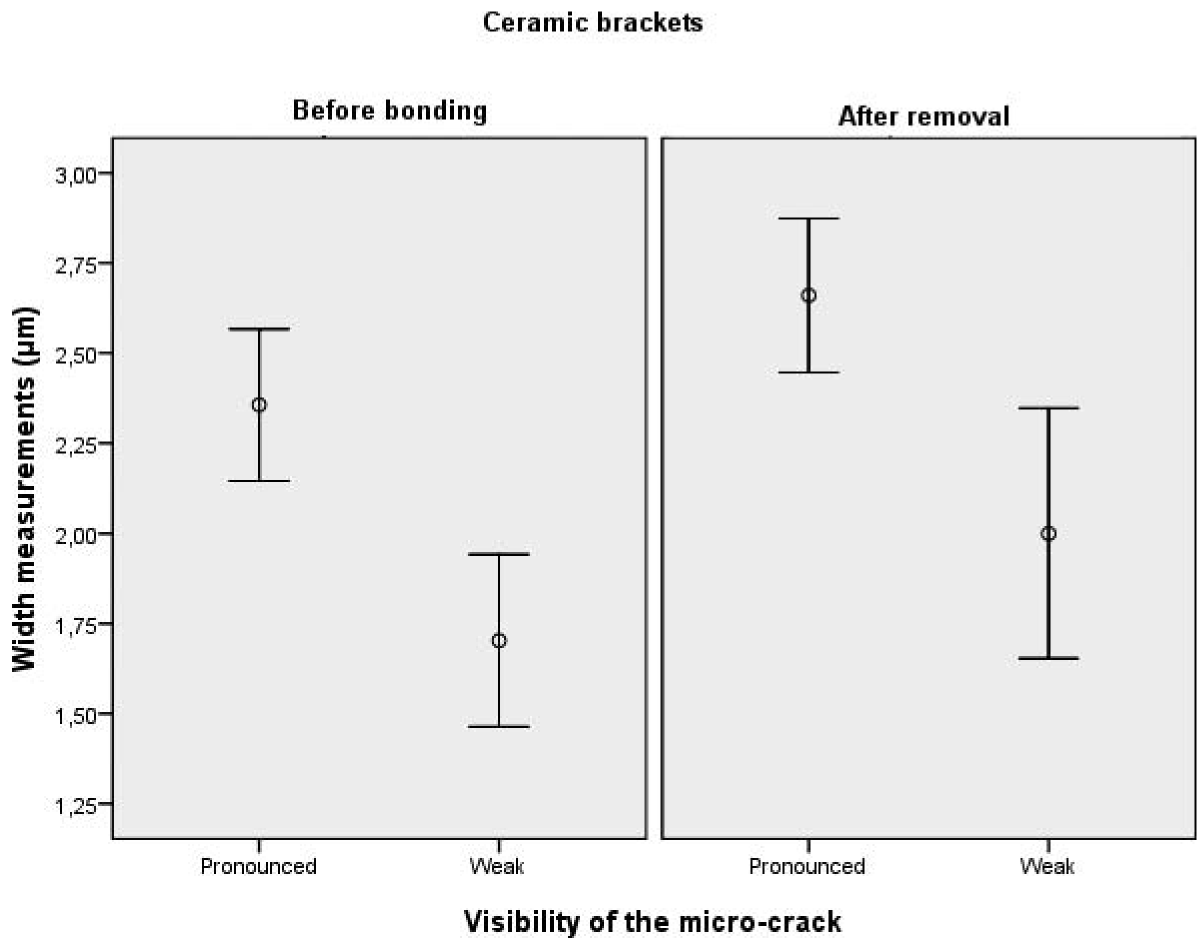

Figure 5. $W_{overall}$ of pronounced and weak EMCs with 95% CI before and after debonding CB followed by RAR.

into pronounced (visible with a naked eye under normal room illumination) and weak (not apparent to the naked eye under normal room illumination but visible under SEM based on their visibility).[3,12]

Using a digitally sketched ruler, each zone was divided into 10 measurement areas (MAs); a total of 30 MAs of every tooth was obtained (Figure 2). Using our derived formula, a measurement step (x, the distance between two MAs) was quantified. Despite the existing number of EMCs, one, the longest, was chosen and analyzed in detail. The width of the longest EMC in each zone was measured (10 MAs of the width could be registered in each zone). The length of the longest EMC was calculated (Figure 2).

The location (cervical, middle, and occlusal third), length, and width of the longest EMC in groups 1 and 2 were determined before and after debonding. The width of the longest EMC was examined in the same segment before and after bracket removal, regardless of changes in its length.

In group 3 (control group), the teeth were subjected to the same analysis but without bonding. All the teeth from group 3 were examined twice by SEM, as were the other specimens after the same time and means of storage. All evaluations were performed by the same examiner.

Bonding Procedure

The teeth from groups 1 and 2 were randomly assigned to one of two subgroups, using the lottery method. Each tooth was assigned a unique number. The numbers were placed in a bowl and thoroughly mixed. Without looking, the researcher selected 15 numbers for subgroup 1, and the rest were assigned to subgroup 2. The teeth that were assigned those numbers were then included in the sample. The procedure was performed twice for groups 1 and 2 separately.

In subgroup 1, 15 teeth from groups 1 and 2 were bonded with maxillary premolar MB (Discovery; Dentaurum, Ispringen, Germany). In subgroup 2, 15 teeth from groups 1 and 2 were bonded with maxillary premolar CB (Clarity; 3M Unitek, Monrovia, Calif). Bracket characteristics and bonding procedures are presented in Table 2. After bonding, the specimens were placed in distilled water at 37°C and stored for 24 hours prior to testing.[20]

Table 5. Width and Length of Pronounced and Weak Enamel Microcracks (EMCs) for Group 3[a]

	Width of Pronounced Enamel Microcracks (EMCs, μm)									
	Initial Measurement (n = 15)				Final Measurement (n = 15)					
	Mean	SD	Max	Min	Mean	SD	Max	Min	RC (%)	P
First zone	3.15	1.87	9.88	0.74	2.96	1.51	6.94	0.93	−6.03	NS
Second zone	3.30	2.03	9.26	0.31	3.29	2.24	9.89	0.33	−0.30	NS
Third zone	2.16	1.64	7.16	0.29	2.26	1.64	8.49	0.31	4.63	NS
Overall width	2.97	1.95	9.88	0.29	2.95	1.98	9.89	0.31	−0.67	NS
	Length of Pronounced Enamel Microcracks (EMCs, mm)									
	Initial Measurement (n = 15)				Final Measurement (n = 15)					
	Mean	SD	Max	Min	Mean	SD	Max	Min	RC (%)	P
Overall length	3.70	1.43	5.94	0.90	3.83	1.40	5.94	0.90	3.51	NS
	Width of Weak Enamel Microcracks (EMCs, μm)									
	Initial Measurement (n = 15)				Final Measurement (n = 15)					
	Mean	SD	Max	Min	Mean	SD	Max	Min	RC (%)	P
First zone	1.83	0.83	3.40	0.46	2.02	0.64	3.40	0.76	10.38	NS
Second zone	1.17	0.47	1.79	0.56	1.36	0.72	2.61	0.51	16.24	NS
Third zone	0.63	0.09	0.72	0.51	0.73	0.17	0.96	0.57	15.87	NS
Overall width	1.55	0.80	3.40	0.46	1.72	0.76	3.40	0.51	10.97	NS
	Length of Weak Enamel Microcracks (EMCs, mm)									
	Initial Measurement (n = 15)				Final Measurement (n = 15)					
	Mean	SD	Max	Min	Mean	SD	Max	Min	RC (%)	P
Overall length	2.22	1.56	5.22	0.96	2.20	1.62	5.22	0.87	−0.9	NS

[a] Max indicates maximum; Min, minimum; SD, standard deviation; RC, relative change.
NS indicates nonsignificant.

Debonding Procedure

The debonding procedure for subgroups 1 and 2 is described in Table 2. All visible residual adhesive was carefully removed with a slow-speed handpiece and a carbide finishing bur under normal clinical conditions. After debonding, the enamel surfaces were reevaluated with SEM.

Statistical Analysis

Statistical analysis was carried out using the Statistical Package SPSS 17.0 (SPSS Inc, Chicago, Ill). Descriptive statistics were calculated for each variable. A paired samples t test was performed to evaluate differences between length and width measurements before and after debonding followed by RAR. An independent samples t test was applied to compare the mean overall width ($W_{overall}$) and length ($L_{overall}$) between two unrelated groups (MB and CB or pronounced and weak EMCs) on the same continuous, dependent variable. The nonparametric Spearman correlation coefficient of the dimensions of EMCs (width, length) and their changes during debonding was calculated. For graphical representation, error bars were used in which 95% CI was shown. In case of overlapping CI, there was no statistical difference between the two comparison groups. In other cases with no overlapping CI, the statistical significance of the differences was evident with 95% probability. Significance for all statistical tests was predetermined to be $P \leq .05$.

RESULTS

Assessing the visibility of the EMCs was performed repeatedly by the same investigator three times every second day. For standardization, the same location, time of day, and tooth position were chosen. Following repeated EMC visibility assessments, no significant discrepancies between results were observed.

Measurement errors were analyzed using a method suggested by Bland and Altman.[22] The enamel surface was reimaged and the measurements repeated for 10 teeth. There was 100% agreement between two length measurements of EMCs. The mean of the differences between two width measurements was 0.073 μm, while the limits of agreement were −0.459 and 0.606, indicating that 95% of the differences between these two measures, excepting the six measures, were within this range (Figure 3).

The mean widths and lengths of pronounced and weak EMCs before and after MB removal are presented in Table 3. Pronounced EMCs showed higher $L_{overall}$ before and after debonding ($P > .05$) compared with weak ones. $W_{overall}$ was greater for pronounced EMCs

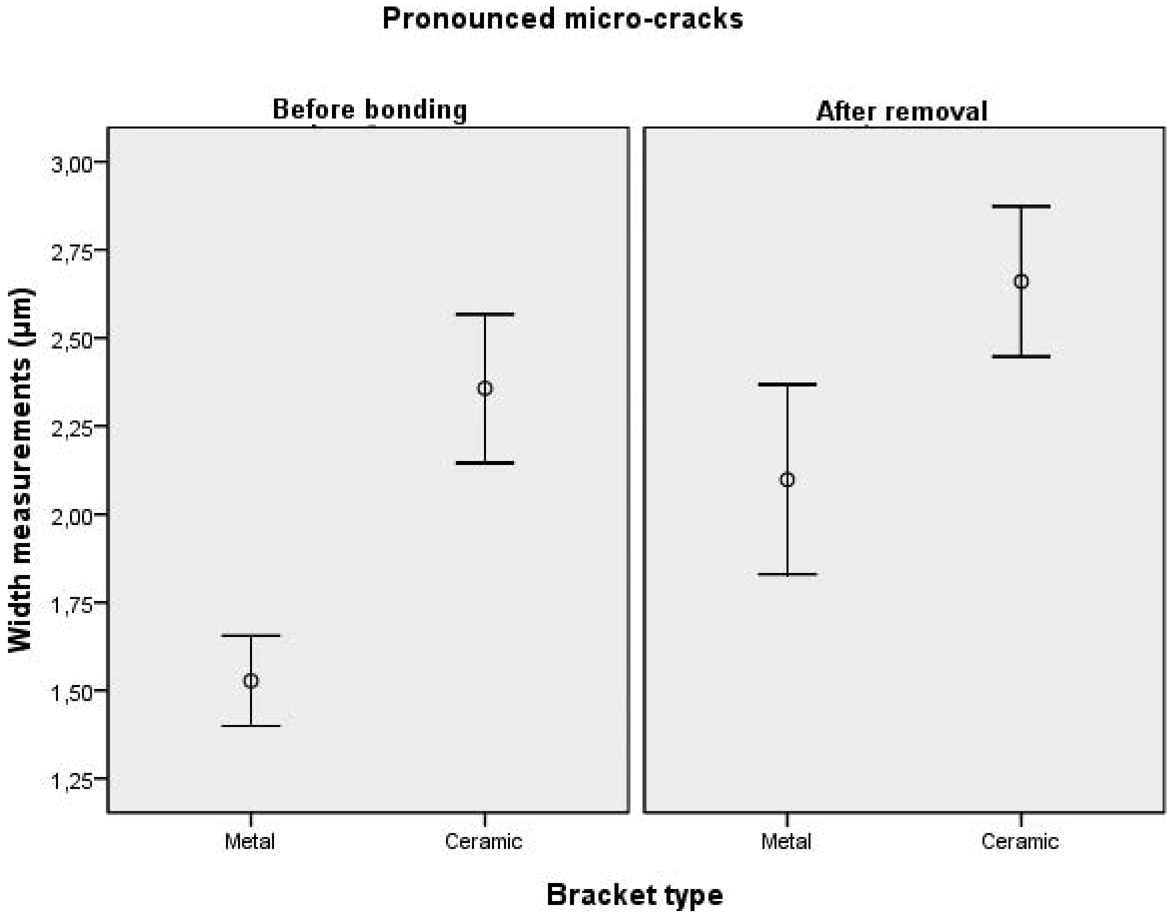

Figure 6. $W_{overall}$ of pronounced EMCs with 95% CI before and after debonding MB and CB followed by RAR.

only after removal ($P > .05$; Figure 4). Width values increased for both types of EMCs following debonding, although a significant result was found only in the pronounced EMCs group (0.57 μm; $P < .05$). The greatest width increase in the pronounced EMCs was observed in the first zone (cervical third; 0.72 μm; $P > .05$), followed by the third zone (occlusal third; 0.58 μm; $P < .05$). In the weak EMCs group, the extent of width increase did not differ between zones. Following MB debonding, none of the weak EMCs progressed to visible ones.

Descriptive statistics of the width and length of pronounced and weak EMCs before and after debonding CB are shown in Table 4. Pronounced EMCs possessed significantly greater $W_{overall}$ and $L_{overall}$ ($P < .05$; Figure 5). However, we recorded the same amount of increase in $W_{overall}$ after removal for both types of EMCs (0.30 μm; $P > .05$). After debonding, the difference in width was greatest in the third zone (occlusal third) for pronounced EMCs (0.57 μm; $P < .05$) and the first zone (cervical third) for weak EMCs (0.59 μm; $P < .05$). Following removal of the CB, four (26.67%) weak EMCs progressed to pronounced ones.

Both types of EMCs showed higher $W_{overall}$ ($P < .05$ for pronounced and $P > .05$ for weak EMCs) and $L_{overall}$ ($P > .05$) before and after debonding CB compared with MB (Figures 6 and 7).

A less-than-moderate negative correlation between EMCs width and their increase during debonding followed by RAR was found (Spearman rho $= -.310$; $P < .05$). No correlation between the length of EMCs and their progress with bracket removal was observed (Spearman rho $= -.053$; $P > .05$).

Changes in width and length measurements of EMCs for group 3 are given in Table 5. Differences in $W_{overall}$ and $L_{overall}$ of pronounced and weak EMCs were quite small and nonsignificant.

DISCUSSION

Since the purpose of this investigation was to evaluate in detail qualitative EMCs characteristics, the model of an in vitro study was chosen. It allowed us to collect the proper sample size, and analyze and make direct precise measurements of the location, length, and width characteristics using SEM.

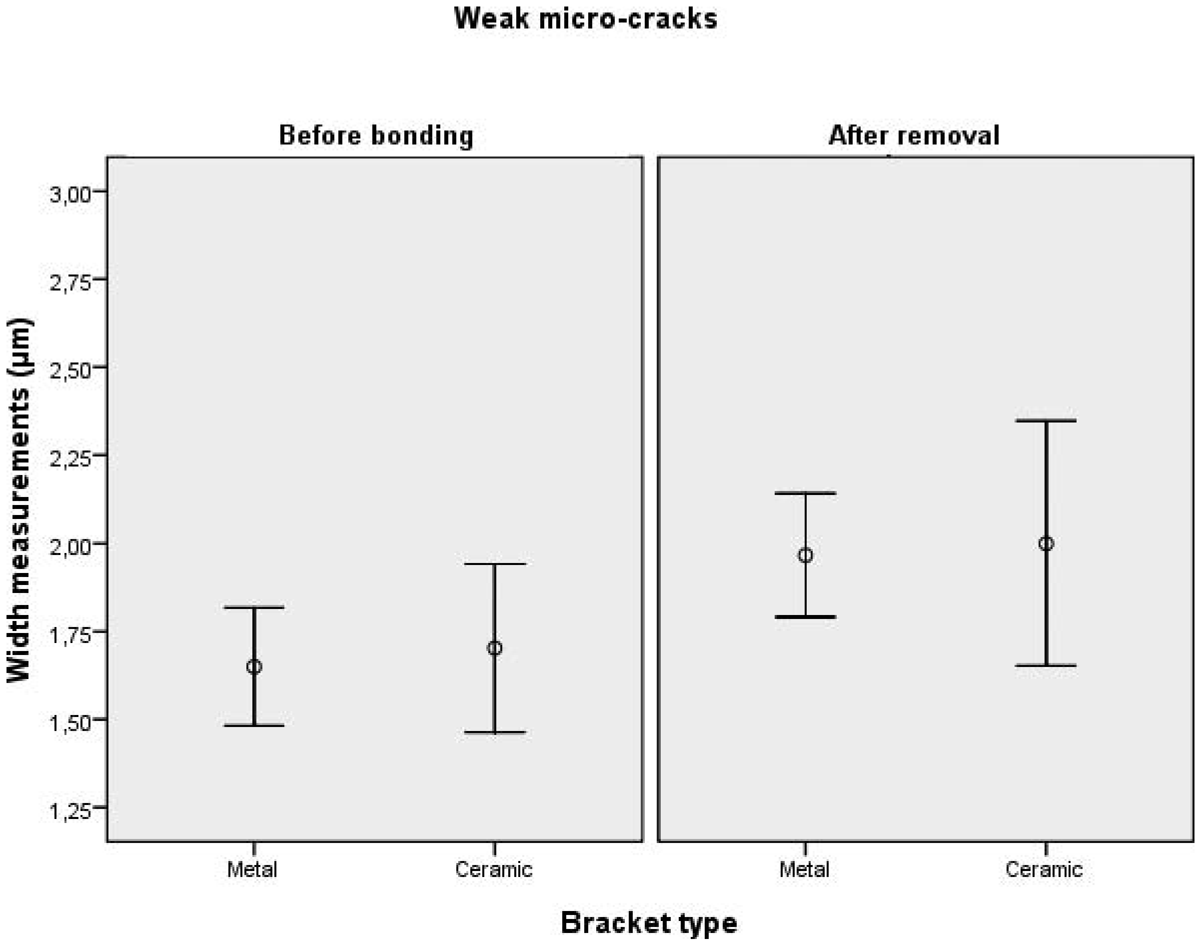

Figure 7. $W_{overall}$ of weak EMCs with 95% CI before and after debonding MB and CB followed by RAR.

The findings of this study showed that visible EMCs possessed higher $W_{overall}$ and $L_{overall}$ compared with weak EMCs (except for the width measurement before bonding MB). Although we found no investigation addressed to this specific subject (pronounced vs weak EMCs), we calculated that the $W_{overall}$ and $L_{overall}$ of both types of EMCs were lower than those found in other studies (evaluating the dimensions of EMCs without considering their visibility).[17–19]

A different amount of EMCs increase was noticed not only comparing pronounced and weak EMCs, but also in analyzing the effect of debonding MB and CB. Both easily visible EMCs and weak ones showed higher $W_{overall}$ and $L_{overall}$ before and after CB removal. The greatest difference was observed in the pronounced EMCs group. However, investigations evaluating the impact on the enamel of debonding MB and CB have not yet come to one common conclusion regarding which bracket type could lead to the greatest tooth structure defects.[5,12]

Following bracket removal, the $W_{overall}$ of all EMCs increased. Changes for pronounced EMCs were 0.57 µm with MB and 0.30 µm with CB; for weak EMCs, $-$ 0.32 µm with MB and 0.30 µm with CB. The apparent tendency of the increase in the width parameter after debonding is consistent with the findings of the previously published study.[19] However, it is important to emphasize that bond strength in vitro is higher than that in vivo (because of the oral humidity, etc), thus the increase in EMCs may be greater than in a clinical situation.[23]

The lack of statistically significant differences in width and length between weak and pronounced EMCs before bonding poses the question, what makes EMCs visible? Experimental evaluation of the depth parameter of these two groups of EMCs using a confocal optical profilometer (COP; Sensofar PLµ 2300, Barcelona, Spain) did not show significant differences, either. Thus, such findings suggest that not the EMC morphology (length, width, or depth) determines its visibility, but the instrument used for evaluation (SEM, COP, or human eye). The latter possesses all the features of the above-listed devices—although having a much lower spatial resolution—plus cognitive averaging. Therefore, solid and unbroken EMCs were visible in contrast to fragmented or branched.

Further examination of the results revealed that the highest increase in the width of pronounced EMCs was observed in the cervical third (0.72 μm) for MB and occlusal third (0.57 μm) for CB. The greatest changes in the width for weak EMCs were found in the cervical third (0.59 μm) with CB but did not differ between the zones using MB (0.31 μm). These results show that forces during debonding are more concentrated on the cervical portion of the buccal tooth surface, followed by the occlusal and middle thirds.[13,15,19] Different enamel quality in these zones might be the reason why the location on the enamel surface has an effect on EMCs. Thus, a greater EMC increase in the cervical area after debonding followed by RAR may be due to a thinner enamel layer.[24]

Analyzing the changes in the length parameter, we noted that the increase in $L_{overall}$ was found only after removal of the CB from the teeth having pronounced EMCs. There are conflicting results in the literature regarding the effect of debonding on the length of EMCs. Whereas some studies reported an increase of this measurement after MB and CB removal,[17,18] others found no significant difference following debonding,[25] or even a decrease in $L_{overall}$ on MB removal.[19]

CONCLUSIONS

- Teeth having pronounced EMCs showed higher $W_{overall}$ and $L_{overall}$ before and after debonding followed by RAR compared with weak EMCs.
- Greater width and length values were noticed using CB for both types of EMCs compared with MB.
- During debonding CB, 26.67% of invisible EMCs progressed to visible ones.
- Following bracket removal, $W_{overall}$ in all cases increased, but the teeth having pronounced EMCs were not predisposed to a greater EMCs increase after debonding followed by RAR.
- Visibility of EMCs before bonding is of low prognostic value for predicting EMCs increase after bracket removal.

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