Loss of surface enamel after bracket debonding: An in-vivo and ex-vivo evaluation

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Introduction: The objective of this study was to evaluate the surface enamel after bracket debonding and residual resin removal. **Methods:** Thirty patients (female, 20; male, 10; mean age, 18.4 years) who completed orthodontic treatment with fixed appliances (Twin Brackets, 3M Unitek, Monrovia, Calif) (n = 525) were included. The amounts of adhesive left on the tooth surfaces and the bracket bases were evaluated with the adhesive remnant index (ARI). ARI_{tooth} (n = 498) was assessed on digital photographs by 2 operators. After resin removal and polishing, epoxy replicas were made from the maxillary anterior teeth (n = 62), and enamel surfaces were scored again with the enamel surface index. Elemental analysis was performed on the debonded bracket bases by using energy dispersive x-ray spectrometry mean area scanning analysis. The percentages of calcium and silicon were summed up to 100%. Tooth damage was estimated based on the incidence of calcium from enamel in relation to silicon from adhesive (Ca%) and the correlation between the $ARI_{bracket}$ and Ca%. **Results and Conclusions:** While ARI_{tooth} results showed score 3 as the most frequent (41%) (P <0.05), followed by scores 0, 1, and 2 (28.7%, 17.9%, and 12.4%, respectively), $ARI_{bracket}$ results showed score 0 more often (40.6%) than the other scores (P <0.05). Maxillary anterior teeth had significantly more scores of 3 (49%) than the other groups of teeth (10%-25%) (chi-square; P <0.001). There were no enamel surface index scores of 0, 3, or 4. No correlation between the enamel surface index and ARI_{tooth} scores was found (Spearman rho = 0.014, P = 0.91). The incidence of Ca% from the scanned brackets showed significant differences between the maxillary and mandibular teeth (14% ± 8.7% and 11.2% ± 6.5%, respectively; P <0.05), especially for the canines and second premolars (Kruskal-Wallis test, P <0.01). With more remnants on the bracket base, the Ca% was higher (Jonckheere Terpstra test, P <0.05). Iatrogenic damage to the enamel surface after bracket debonding was inevitable. Whether elemental loss from enamel has clinical significance is yet to be determined in a long-term clinical follow-up of the studied patient population. (Am J Orthod Dentofacial Orthop 2010;138:387.e1-387.e9)

After orthodontic therapy with fixed appliances, from the clinical standpoint, a major concern is to avoid cohesive failures in the enamel during debonding brackets and at the same time to obtain tooth surfaces without adhesive.[1] Bonding onto and removal of brackets from the enamel surfaces are potential risks for topographic changes in the form of cracks, scarring, scratches, or loss of enamel.[2-7] The dilemma in adhesion of brackets in orthodontics is that it should be strong enough to prevent failure during all treatment but also low enough so that enamel damage would be none or minimal during bracket removal after treatment.

Debonding forces can be influenced by many factors: type of enamel conditioning agents (phosphoric acid, self-etching primers, polyacrylic acid),[8] adhesive resin, cement, polymerization methods, bracket type, or bracket base architecture.[9,10] Usually, an increase in debonding force causes an increased risk of enamel damage.[11] Even though the dental literature contains many studies looking at these possible factors on bracket adhesion, their clinical significance remains scarce, since, in in-vitro studies, data are usually obtained without considering major intraoral factors—eg, saliva, masticatory forces, temperature, and pH changes.[12] Furthermore, clinical debonding with pliers creates a combination of shear, tensile, and torque forces. Therefore, 1 test method (shear or tensile) in vitro might not represent in-vivo debracketing techniques and, consequently, in-vivo bond strengths and failure types.[12]

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Several debonding techniques were introduced,[13-18] but there were insufficient data regarding diverse susceptibility to debonding damage in the maxillary or mandibular dental arches or in specific tooth groups.[19,20] Bracket debonding strength for incisors in vitro requires significantly higher shear strength compared with molars.[20] However, the effect of enamel damage relative to the tooth type is unknown.[20] Because of variations in enamel thickness or enamel prism orientation, different failure types could be expected depending on the tooth type.[21,22] Since etched anterior teeth have greater mean areas than do posterior teeth, it can be expected that anterior teeth have greater potential for enamel damage than do posterior teeth.[22]

Possible failure types after bracket debonding are either adhesive between the enamel and the adhesive resin, partially adhesive and cohesive in the adhesive resin (mixed), or adhesive between the bracket base and the adhesive resin, where the latter 2 require removal of the remnants. Unfortunately, remnant removal can eventually cause further unwanted damage in the enamel because it is often done with rotating instruments. Various methods are available to remove adhesive remnants: pliers, scalers, abrasive disks, diamond or tungsten carbide burs, stones, or ultrasonic instruments.[23] Although consensus is lacking in the dental literature, the most common and efficient way of removing adhesive remnants in daily practice is with tungsten carbide burs in a low-speed rotating hand piece.[15,23] Potential detrimental effects of bracket debonding from enamel or elemental loss from surface enamel either during bracket debonding or removal of the remnants is an iatrogenic problem.[5,7,24] Calcium loss from the enamel surface particularly can result in dental erosion, which is a localized loss of dental hard tissues.[25]

Although enamel surface morphology after bracket debonding has been the topic of some in-vitro studies,[13,15,18,23] quantitative information relevant to enamel damage after bracket debonding in vivo is limited.[24] Therefore, the objective of this study was to evaluate the surface morphology and the elemental loss from surface enamel by using a semidirect method in an in-vivo and ex-vivo study.

MATERIAL AND METHODS

Thirty consecutive patients (20 female, 10 male; mean age, 18.4 years) who completed orthodontic treatment with fixed appliances (Twin Brackets, 3M Unitek, Monrovia, Calif) were included in this study. The surface areas of the brackets provided by the manufacturer were as follows: maxillary central incisor, 10.52 mm^2; maxillary lateral incisor, 8.97 mm^2; maxillary canine, 10.19 mm^2; maxillary premolar, 9.61 mm^2; maxillary molar, 10.21 mm^2; mandibular incisor, 9.81 mm^2; mandibular canine, 10.129 mm^2; mandibular premolar, 9.61 mm^2; and mandibular molar, 10.21 mm^2. During the orthodontic treatment, the patients received the corresponding stainless steel brackets on all teeth in the mandible and the maxilla except on the second molars. Direct bracket bonding was done by 5 operators. A standardized protocol was followed for adhering the brackets to the tooth surfaces. Enamel surfaces were cleaned with water and fluoride-free pumice (Zircate Prophy Paste, Dentsply Caulk, Milford, Del) with a prophylaxis brush (Hawe Prophy-Cup Latch-Type, KerrHawe SA, Bioggio, Switzerland), rinsed with water, and dried with an air syringe. Each tooth surface was etched with 37% H_3PO_4 (Total etch, Ivoclar Vivadent, Schaan, Liechtenstein) for 30 seconds, rinsed thoroughly with an oil-free air-water spray for 20 seconds, and air dried until they appeared frosty. The bonding adhesive (Heliobond, Ivoclar Vivadent) was applied with a microbrush, air thinned, and photo-polymerized for 10 seconds (Ortholux, 3M Unitek, St Paul, Minn). Then the brackets were bonded by using adhesive cement (Transbond XT, 3M Unitek). After removal of the excess around the bracket margins with the tip of a probe, they were photo-polymerized from 5 directions: above the bracket, cervico-incisal, inciso-cervical, mesial, and distal for 20 seconds each (Ortholux, 3M Unitek) (light output, 430-480 nm).

At the end of treatment, all brackets were debonded by placing the debonding pliers (Dentronix E231, Konstanz, Germany) at the outer wings of the bracket.[7] One clinician carried out all debonding procedures. After debonding, the gross adhesive remnants were removed with a tungsten carbide bur (Komet H22 AGK 016, Lemgo, Germany) in a slow-speed hand piece under water cooling. Subsequently, the remaining resin was removed with a fine tungsten carbide bur (Komet H46 204 012) in a slow-speed handpiece. After removing the resin, the tooth surfaces were polished with a polish cup (Hawe Prophy-Cup, white 967) and polishing paste (Zircate Prophy Paste, Dentsply, Konstanz, Germany). Final polishing was achieved with rubber points (Ceramiste Midipoint, Shofu, Ratingen, Germany).

The amounts of adhesive remnants were scored by using the adhesive remnant index (ARI) on all debonded bracket bases (n = 525).[26] The $ARI_{bracket}$ scoring system consists of a 4-point scale from 0 to 3: 0, no adhesive left on the bracket base; 1, less than half of the adhesive remained on the bracket; 2, more than half of the adhesive remained on the bracket; and 3, all adhesive was left on the bracket.[10]

To evaluate the adhesive remnants on the tooth surfaces, after debonding the brackets, before removing the remaining resin, the enamel surfaces were subjected to the disclosing medium (GUM Red-cote, Chicago, Ill). This allowed better contrast between the tooth-colored adhesive remnant and the enamel for the failure-site evaluation. Then standardized digital photographs (DX1 with a micro 60-mm lens, Nikon, Tokyo, Japan) were taken of the dyed tooth surfaces (n = 498). These photographs were examined by 2 calibrated observers who were blinded to the objectives of the study. The sites of the failure types were recorded by using the ARI (ARI_{tooth}) scoring system. In cases of conflict, consensus was reached. ARI_{tooth} scores ranged from 0 to 3: 0, no adhesive left on the tooth; 1, less than half of the adhesive remained on the tooth; 2, more than half of the adhesive remained on the tooth; and 3, all adhesive was left on the tooth, with a distinct impression of the bracket mesh.

Possible damage to the enamel was evaluated in the maxillary anterior teeth (n = 62) only, according to the enamel surface index (ESI) described by Zachrisson and Årtun.[5] The ESI consists of a 5-point scale from 0 to 4: 0, perfect surface with no scratches and distinct intact perikymata; 1, satisfactory surface with fine scratches and some perikymata; 2, acceptable surface with several marked and some deeper scratches with no perikymata; 3, imperfect surface with several distinct deep and coarse scratches but no perikymata; and 4, unacceptable surface with coarse scratches and deeply marked appearance. For ESI scoring, immediately after the residual adhesive removal and polishing, impressions (President, Colténe/Whaledent, Altstätten, Switzerland) were made from the entire labial surface and thereafter epoxy resin (Epofix Resin, Struers, Ballerup, Denmark) replicas were obtained. Secondary mode images were made with cold field emission scanning electron microscope (FE-SEM 6301F, Jeol, Tokyo, Japan) (magnification, 10 times) at 25 kV from epoxy replicas that were sputter-coated with 200 A° Au (BAL-TEC sputter coater; type 07 120B, Balzers, Liechtenstein) and fixed to the specimen holder with a photo-polymerized dental composite (Kulzer TransLUX EC, Wehrheim, Germany).

Enamel damage was also quantified ex vivo from the debonded brackets that received $ARI_{bracket}$ scores 1, 2, or 3 (n = 306). Energy dispersive x-ray spectrometry (EDX) mean area scan analysis (JSM-6400, Jeol) (accelerating voltage, 20 kV; beam current, 6.1 nA; type of detector, Si(Li)-liquid N_2 cooled, secondary mode, ThermoNoran System Six, SelectScience Ltd, Bath, UK); spectra acquisition time, 100 seconds; detector dead time, 25%; resolution, 143 eV; magnification, between 25 and 30 times; scan mode, area; type of correction, ZAF; type of analysis, standardless) was performed on the entire surface of the bracket base. The percentages of calcium (from enamel) and silcon (from adhesive) were summed up to 100%, and calcium incidence was calculated in relation to silicon in percentages (Ca%). In addition, the correlation between $ARI_{bracket}$ and Ca% was determined. No materials used contained calcium (Table I). Therefore, the calcium found on the resin was assigned to enamel loss.

Statistical analysis

The statistical analysis was performed with the SPSS software package (version 11.5, SPSS, Chicago, Ill). Descriptive results for ARI, ESI, and Ca% were calculated and expressed as frequencies, percentages, means, and standard deviations. The frequencies of ARI_{tooth} and $ARI_{bracket}$ scores were compared by using the chi-square test. Mann-Whitney U and Kruskal-Wallis tests were applied to analyze the differences in Ca% between the maxillary and mandibular teeth, and the tooth types. Ca% in relation to $ARI_{bracket}$ scores was analyzed by using the Jonckheere Terpstra test. Furthermore, the nonparametric Spearman correlation test was used to examine the correlation between ESI scores and ARI_{tooth} scores. Statistical significance was defined as $P < 0.05$ in all tests.

RESULTS

Overall, while ARI_{tooth} results showed that score 3 (204 of 498) was the most frequent (41%) ($P < 0.05$), followed by 0, 1, and 2 (28.7%, 17.9%, and 12.4%, respectively). $ARI_{bracket}$ results showed score 0 (213 of 525) most often (40.6%) ($P < 0.05$), followed by 3, 2, and 1 (29.1%, 18.1%, and 12.2%, respectively) (Table II). The highest incidence of ARI_{tooth} score 3 (29%) was observed in the central incisors, and the lowest percentage of score 0 in the first molars (3%).

The maxillary anterior teeth had significantly more scores of 3 (49%) than other groups of teeth (16%-25%) (chi-square, $P < 0.001$) (Table III). Typical failure types after bracket debonding are shown in Figure 1.

In the 62 teeth of the maxilla (28 central incisors, 28 lateral incisors, 6 canines), there were no ESI scores of 0, 3, or 4. Both scores 1 (8%) and 2 (14%) were observed the least in the canines (Table IV). In general, all cleaned teeth had acceptable to satisfactory enamel surfaces after debonding, with ESI scores of either 1 or 2 (Fig 2). No correlation between ESI and ARI_{tooth} scores was found (Spearman rho = 0.014, $P = 0.91$).

All evaluated brackets with $ARI_{bracket}$ scores of 1, 2, and 3 had calcium incidence at varying degrees. Ca%

Table I. Brands, compositions, manufacturers, and batch numbers of the materials used in this study

Brand name	*Composition*	*Manufacturer*	*Batch number*
Twin Brackets	17-4 stainless steel alloy	3M Unitek, Monrovia, Calif	3017-916 3017-917 3017-918 3017-9200
Heliobond	Monomer matrix: dimethacrylate <60% Bis-GMA <40% triethyleneglycol	Ivoclar Vivadent, Schaan, Liechtenstein	H29583 154518
Transbond XT	Silane-treated quartz (70-80 wt%) silane-treated silica <2% BisDMA 10-20wt% BisGMA 5-10wt%	3M Unitek, Monrovia, Calif	147

Table II. Frequencies (%) of ARI scores for tooth/bracket surfaces ($ARI_{tooth/bracket}$) in the maxilla and mandible obtained from the teeth and their corresponding brackets

$ARI_{tooth/bracket}$ n = 498/525	*Score 0 (n = 143/213)* $\%_{tooth}/\%_{bracket}$	*Score 1 (n = 89/64)* $\%_{tooth}/\%_{bracket}$	*Score 2 (n = 62/95)* $\%_{tooth}/\%_{bracket}$	*Score 3 (n = 204/153)* $\%_{tooth}/\%_{bracket}$
Central incisor	16/28	12/22	19/11	29/14
Lateral incisor	18/22	16/28	32/17	23/16
Canine	21/22	20/22	26/22	22/18
First premolar	20/14	33/14	13/27	16/18
Second premolar	22/10	18/6	10/17	9/23
First molar	3/4	1/8	0/6	1/11

ARI_{tooth} score 0, no adhesive was left on the tooth; score 1, less than half of the adhesive remained on the tooth; score 2, more than half of the adhesive remained on the tooth; score 3, all adhesive was left on the tooth with a distinct impression of the bracket mesh. $ARI_{bracket}$ score 0: no adhesive left on the bracket base; score 1, less than half of the adhesive remained on the bracket; score 2, more than half of the adhesive remained on the bracket; score 3, all adhesive was left on the bracket.

from scanned bracket bases showed a total mean incidence of 12.6% (± 7.8%), with significant differences between the maxillary and mandibular teeth (14% ± 8.7% and 11.2% ± 6.5%, respectively; $P < 0.01$). Ca% especially for the canines and the second premolars showed significant differences between the maxilla and the mandible ($P < 0.05$) (Kruskal-Wallis test, $P < 0.01$) (Fig 3). The mean Ca% differed significantly in relation to the $ARI_{bracket}$ scores: the more ARI remnants on the bracket base, the higher the Ca% (Jonckheere Terpstra test, $P < 0.05$).

DISCUSSION

It was previously emphasized that the outermost layer of enamel should be left as intact as possible, since it has greater microhardness and contains more minerals and fluoride than the deeper zones.[27] Consequently, the loss of surface enamel and associated exposure of the enamel prism endings to the oral environment might cause a decrease in the resistance of enamel to the organic acids in plaque. This eventually makes enamel more prone to demineralization.[27]

Since adhesion has 2 aspects—one to the tooth surface and the other to the bracket base—evaluation of the ARI scores provides information on the site of bond failure as either adhesive at the bracket-adhesive resin interface or the adhesive at the enamel-adhesive resin interface. Macroscopic evaluation could also show cohesive failures in the enamel or in the adhesive resin. In this study, no macroscopically cohesive failures in the enamel were observed. ARI_{tooth} and $ARI_{bracket}$ scores agreed; ie, the ARI_{tooth} scores of 3, 2, 1, and 0 had similar frequencies to the $ARI_{bracket}$ scores of 0, 1, 2, and 3.

However, ARI_{tooth} and $ARI_{bracket}$ percentages did not indicate that the failure type on the bracket base was a mirror image of the adhesive remnants on the tooth surface. This means that some failures were experienced solely in the adhesive resin. Although flexural behavior is different compared with metal brackets, similar observations were noted in previous studies with ceramic and polycarbonate brackets after debonding.[10,28]

Overall, ARI_{tooth} results showed that score 3 was the most frequent (41%), indicating adhesive failure between the bracket base and the adhesive resin with a distinct impression of the bracket mesh on the tooth

Table III. Frequencies (%) of ARI scores for tooth surfaces (ARI_{tooth}) depending on location (anterior vs posterior) per jaw (maxilla vs mandible)

ARI_{tooth}	Score 0 (n = 143) $\%_{tooth}$	Score 1 (n = 89) $\%_{tooth}$	Score 2 (n = 62) $\%_{tooth}$	Score 3 (n = 204) $\%_{tooth}$
Maxillary anterior	20	25	45	49
Mandibular anterior	36	23	33	25
Maxillary posterior	31	26	6	10
Mandibular posterior	13	26	16	16

ARI_{tooth} score 0, no adhesive was left on the tooth; score 1, less than half of the adhesive remained on the tooth; score 2, more than half of the adhesive remained on the tooth; score 3, all adhesive was left on the tooth with a distinct impression of the bracket mesh.

surface. No attempt was made to condition the bracket base surfaces for practical reasons because it prolongs chair-side time. This approach, however, could have affected the results and decreased the incidence of $ARI_{bracket}$ score 0.[10,28] The second most common failure type was adhesive failure between the enamel and the adhesive resin (score 0). Score 0 implies weak adhesion between the adhesive and the enamel, and score 3 means weak adhesion between the bracket and the adhesive resin. Since no brackets spontaneously debonded during orthodontic treatment, sufficient adhesion, at least for the duration of the treatment, was achieved with the bonding materials and the protocol used. Therefore, although an ARI_{tooth} score of 0 or 3 indicates weak bond strength of the brackets in in-vitro orthodontic studies, it should not necessarily lead to early clinical failure.[13,15,18,25]

Adhesion between the tooth-adhesive-bracket assemblies is primarily influenced by fatigue and the cyclic forces on the bonded interfaces during chewing, resulting in higher debonding failures at the adhesive-enamel interface.[29,30] Temperature change, humidity, and acidity (pH) might all additionally affect adhesive strength, and it is almost impossible to simulate these factors ex vivo.[29,30] Considering these factors, it is conceivable that clinical debonding values could be lower than those reported in in-vitro studies.[31] In this context, when failure types per tooth and site were evaluated, maxillary anterior teeth had significantly more frequent ARI_{tooth} scores of 3 (adhesive failure between cement and bracket base) than did the other groups of teeth. This could be attributed to the absence of direct occlusal forces applying shearing forces between the enamel and the adhesive resin on the maxillary anterior teeth compared with the mandibular anterior or posterior teeth. However, depending on the severity of the case (eg, crossbite or reverse deepbite in Class III malocclusion situations), maxillary teeth might also be exposed to fatigue loads from chewing forces. The incidence of other failure types indicates this possibility.

The high incidences of ARI_{tooth} score 0 on the first molars and score 3 on the central incisors could be explained based on the etching pattern variations. The difference in etched enamel morphology of different tooth types could affect composite resin bond strengths.[22] In an in-vitro study, prismless enamel with a greater depth on the posterior teeth was found to be more common,[21] thus producing an inferior etch pattern.[32] Other factors relevant to low bond strength of brackets to posterior teeth were also attributed to the mismatch (poor adaptation) between the bracket base architecture and the buccal surface convexity of the posterior teeth.[33] This results in an uneven composite layer with inferior mechanical properties. Moreover, moisture control in the posterior region of the mouth was found to be less favorable during bonding procedures.[34,35] Although it cannot be proved that one of these factors is the only cause for ARI_{tooth} score 0 in molars, when the failures were evaluated based on the quadrant and the ARI_{tooth} scores of 0 and 3 incidences were summed, the mandibular posterior teeth had the lowest percentages of these scores (29%). Therefore, it cannot be generalized that the mandibular teeth or the molars are more prone to bracket debonding or that adhesion is lower to those teeth.[35] Interestingly, however, mandibular (61%) and maxillary (69%) anterior teeth had more frequent sums of ARI_{tooth} scores of 0 and 3. Most probably, the debonding forces varied individually, depending on crowding and severity of the malocclusion. Therefore, in-vitro bracket bonding studies and the failure characteristics should be evaluated with caution. Future studies are warranted to study the bracket debonding phenomena correlated with the clinical severity before orthodontic treatment. Currently, the methodologic quality of clinical trials evaluating debonding and bracket failure is generally poor to make comparisons with other clinical trials.[36]

When failure type findings are coupled with the Ca%, more explanations can be made. Information relevant to calcium loss was derived from brackets with $ARI_{bracket}$ scores of 1, 2, or 3 or from ARI_{tooth} scores of 0, 1, or 2. Ca% was significantly higher in the maxillary teeth than in the mandibular teeth, indicating better adhesion on the maxillary teeth. Since moisture control was obtained with only suction and cotton rolls and no rubber dam was used during bonding brackets, inferior adhesion in the mandible could have been expected.[35] However, an insignificant amount of Ca% in the molars in the maxilla and the mandible could not cause the molars to be covered with more salivary proteins[34] or the etch pattern to be less favorable on the molars.[22]

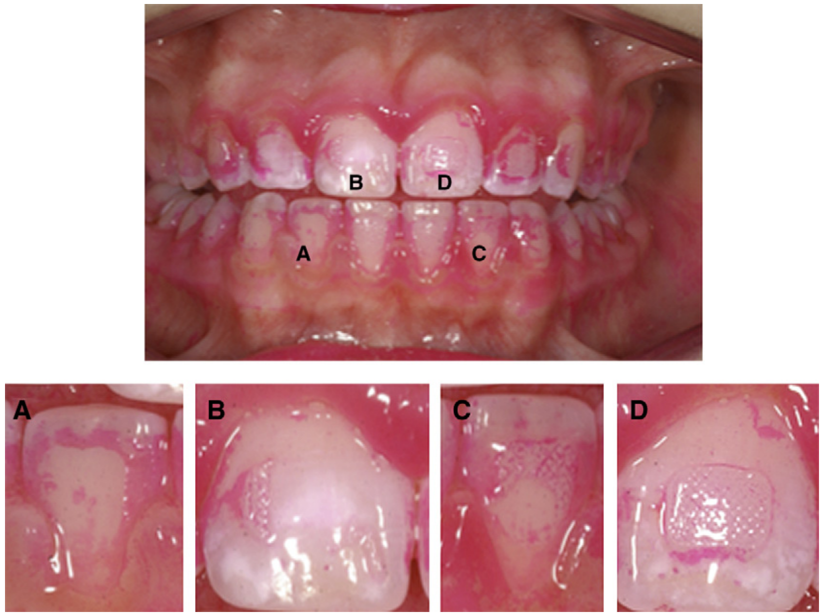

Fig 1. A-D, Intraoral digital photographs of the stained teeth with the disclosing medium after bracket debonding. Typical clinical pictures of failure types of ARI_{tooth}: *A,* score 0; *B*, score 1; *C*, score 2; *D*, score 3. See Table I for detailed descriptions of the scoring system.

Table IV. Frequencies (%) of ESI (n = 62) in the maxilla obtained from the anterior teeth (central incisors, lateral incisors, and canines)

ESI	*Score 0 (n = 0)* $\%_{tooth}$	*Score 1 (n = 40)* $\%_{tooth}$	*Score 2 (n = 22)* $\%_{tooth}$	*Score 3 (n = 0)* $\%_{tooth}$	*Score 4 (n = 0)* $\%_{tooth}$
Maxillary central incisors	0	40	55	0	0
Maxillary lateral incisors	0	53	32	0	0
Maxillary canines	0	8	14	0	0

Score 0, perfect surface with no scratchesand distinct intact perikymata; score 1, satisfactory surface with fine scratches and some perikymata; score 2, acceptable surface with several marked and some deeper scratches with no perikymata; score 3, imperfect surface with several distinct deep and coarse scratches and no perikymata; score 4, unacceptable surface with coarse scratches and deeply marked appearance.

The mean Ca% incidence in relation to silicon differed significantly in relation to the $ARI_{bracket}$ scores; the more adhesive remnants on the bracket base, the higher the Ca%. Nevertheless, based on this finding, it can be stated that, even though the ARI_{tooth} score of 0 is often considered to represent a weak bond or a lower hazard to the enamel, calcium loss is still possible.[15,18,26] This further indicates cohesive failures in the enamel prisms that could be detrimental for possible demineralization or erosion. Therefore, after bracket debonding, with ARI_{tooth} scores of 0, 1, or 2, these teeth need to be monitored for higher calcium loss from their enamel. Calcium loss for the canines and second premolars showed significant differences between the maxilla and the mandible; this could have been due to the variations in their enamel thickness.[37] Enamel thicknesses in these teeth need to be further evaluated. The thickness of notable mineral-like particles detached from enamel, present in the adhesive remnants on the bracket base after debonding, was estimated to be between 5 and 25 μm after ceramic bracket debonding.[38] In this study, stainless steel alloy brackets were used that are free of calcium and silicon. Since the whole bracket base was scanned, the lack of calcium and silicon in the bracket composition allowed us to relate the incidence of calcium loss from the enamel to the presence of silicon in the adhesive resin debonded from enamel. If ceramic brackets had been used instead of metallic ones, better polymerization of the adhesive resin could have been expected due to

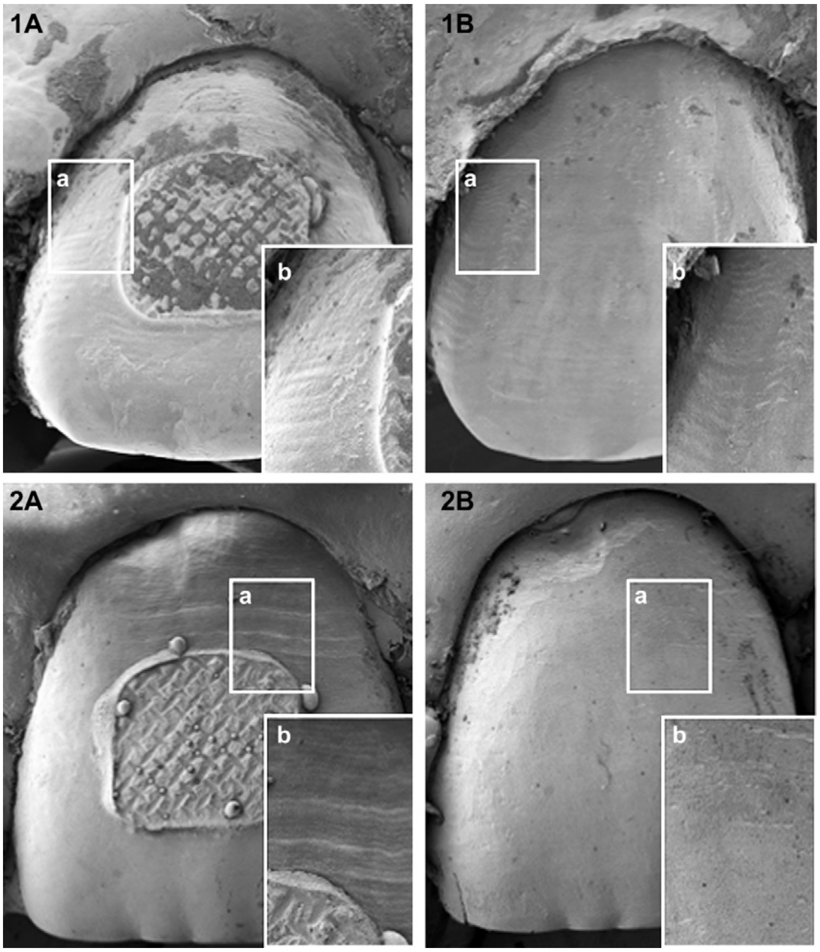

Fig 2. Representative photographs of the tooth surfaces immediately after bracket debonding (*1A* and *2A*) and after adhesive remnant cleaning (*1B*). ESI score 1, satisfactory surface with fine scratches and some perikymata; *2B*, ESI score 2, acceptable surface with several marked and some deeper scratches without perikymata) (scanning electron microscope at secondary mode; magnification, $b = a \times 4$).

the light transmission property of transparent ceramic brackets that might also affect the final failure type after debonding. However, the presence of silicon in those ceramics would then interfere with the silicon in the adhesives.

Although the thickness of enamel loss was not measured, the ARI scores provide a rough estimate of the amounts of adhesive remnants, since it is only a surface-area assessment. Furthermore, scores of 0, 1, and 2 do not imply adhesive or mixed failures between the enamel and the adhesive, since elemental loss of enamel was evident.

The torque forces created during debonding the brackets might also affect the results. However, the opinions on this aspect are controversial.[7,24] In a photoelastic stress analysis, it was found that forces applied to the outer wings of the bracket transferred the least amount of stress to the enamel, whereas forces applied to the base of the bracket and to the adhesive zone created stress concentration regions in the enamel that would cause separation at the adhesive-enamel interface.[7] Therefore, in this study, the pliers were applied at the outer wings of the bracket. Calcium scores, however, were not significantly different when the pliers were applied at either the bracket base or the tie wings.[24] Although the same bracket type and adhesive resin (Transbond XT) was used in the study of Brosh et al,[24] no bonding agent was applied. In that study, no significant difference was found by tooth type, when also first molars were not involved. The nonsignificant difference might be related to the lack of a bonding agent.

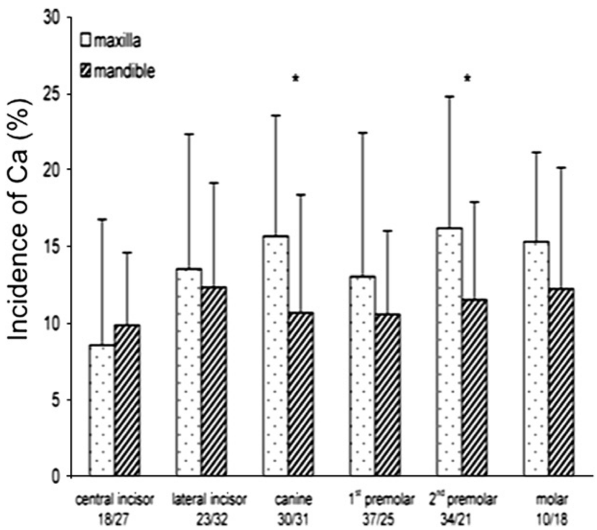

Fig 3. Calcium loss in weight (%) per tooth type based on the bracket base measurements for the maxilla and the mandible (*$P < 0.05$). Note the number of evaluated teeth below the x-axis.

The failure site at the bracket-adhesive interface macroscopically indicates safe debonding and less chance of enamel loss. However, this then requires meticulous removal of the resin remnants from the enamel surface. In this study, there were no ESI scores of 0, 3, or 4. In general, all cleaned teeth had acceptable to satisfactory enamel surfaces after debonding with ESI scores of either 1 or 2, with no correlation between the amounts of adhesive remnants. Nevertheless, the results demonstrated only minor iatrogenic damage to the enamel surface after bracket debonding with the finishing and polishing protocol used. In addition to the elemental loss of surface enamel, we also demonstrated that the use of rotary instruments for removing remaining resin leaves the enamel surface with scratches. Irregularities caused by these rotary instruments result in greater enamel surface roughness.[16] This might cause more plaque accumulation, which in turn might increase the risk of developing dental caries or gingivitis, depending on the location. However, the iatrogenic damage created by rotary devices mainly depends on the operator's control. Calcium loss was measured only after bracket removal, but, after polishing, more calcium loss could be expected that should be studied in the future. Due to easy access, the ESI scores were obtained only from the anterior teeth. Also, no loops were used while removing the adhesive remnants. Therefore, the results might not represent the posterior teeth. In our patient population, enamel surfaces had no restorations, and no distinct enamel defects were noted before bracket bonding. This was identified macroscopically and could be considered a limitation of this study. Nevertheless, the baseline information regarding preexisting defects such as scratches and grooves was considered the condition of the enamel immediately after bracket removal. However, ESI scores might be affected when brackets are bonded to restorative materials; this is typical especially for adult patients. Similar to bracket removal, during finishing and polishing, enamel surfaces next to the restorations might involve some defects. For such situations, ESI scores should be adapted in future investigations.

Although scanning electron microscope images clearly show the enamel damage, they lack a quantification scale but provide only subjective information. Volumetric quantification of enamel loss using 3-dimensional measurement techniques might provide more detailed information about the debonded enamel surface in future studies.[39] Hence, our results imply from the clinical point of view that damage to the enamel is inevitable in orthodontic applications, but, since no correlation between ESI and ARI_{tooth} scores was found, it can be said that, at least macroscopically, the damage can be restored to acceptable or satisfactory levels with the method that is most frequently recommended for use in daily clinical practice. These results from failure sites and calcium loss could be helpful information for future simulation studies.

CONCLUSIONS

From this study, the following can be concluded:

1. With the adhesive materials and the bonding protocol used, after debonding metal brackets, mainly adhesive failures between the adhesive resin and bracket base were observed (ARI_{tooth} score of 3), and they were more frequent in the maxillary anterior teeth. On the bracket aspect, adhesive failure between adhesive resin and bracket base was also more common ($ARI_{bracket}$ score of 0).
2. The highest incidence of ARI_{tooth} score 3 was observed in the central incisors, with the lowest percentage of score 0 in the first molars.
3. After adhesive remnant removal, all teeth had acceptable to satisfactory enamel surfaces with ESI scores of either 1 or 2. No correlation between ESI and ARI_{tooth} scores was found.
4. Maxillary teeth tend to show more calcium loss than do mandibular teeth. The mean calcium loss differed significantly in relation to the $ARI_{bracket}$ scores; the more ARI remnants on the bracket base, the higher the incidence of Ca% in relation to silicon.

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