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ORIGINAL ARTICLE

Evaluation of the Adhesive Remnant Index of Two Different Adhesive Systems Using Two Different Curing Times

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Abstract

Objectives: To evaluate the adhesive remnant index (ARI) of orthodontic brackets bonded with two adhesive systems using two different light curing times.

Materials and methods: Fifty-six extracted premolars were divided into two groups (n = 28) depending on the type of adhesive system used; Total-Etch (TE) Transbond XT and Self-Etch (SE) Transbond Plus. Each group was subdivided into two subgroups (n = 14) based on the curing time; 20 and 3 s. The ARI was evaluated in each subgroup. The significance level was set at P value less than or equal to 0.050.

Results: The ARI showed that there was a statistically significant difference in ARI between the four groups (H [3] = 22.832, P < 0.001). Pairwise comparisons revealed that ARI was statistically significantly higher in TE subgroups (20 s and TE 3 s) versus SE subgroups (20 s and 3 s). There was no statistically significant difference in ARI between (TE 20 s vs. TE 3 s) and between (SE 20 s vs. SE 3 s).

Conclusions: Varying the adhesive system results in different ARI scores, which can affect the enamel surface during debonding. While reducing the curing time did not show a significant impact on the ARI.

Keywords: Adhesive remnant index, Adhesive system, Curing time

Introduction

Different orthodontic adhesives have been developed to improve the bonding procedure. These materials should provide adequate shear bond strength (SBS) during the treatment period to resist the masticatory stresses on the orthodontic brackets, but not too excessive SBS that leads to enamel damage and crack during the debonding procedure.1−3

Artun and Bergland,4 used an adhesive remnant index (ARI) system to evaluate the amount of adhesive left on the tooth after debacketing. This index system was developed based on a pilot study of 20 extracted teeth and the criteria were as follows: score 0 = no adhesive left on the tooth; score 1 = less than half of the adhesive left on the tooth; score 2 = more than half of the adhesive left on the tooth; and score 3 = all adhesive left on the tooth with a distinct impression of the bracket mesh.

A conventional bonding procedure includes etching of the enamel surface, priming of the etched enamel surface, and adhesive placement on the bracket base, followed by bracket placement in its place. This system provides high SBS according to many studies,1,5−8 which makes the debonding procedure unsafe for the enamel surface.9

Another approach is the usage of Self-Etch (SE) primer which allows the simultaneous etching and priming of enamel without a separate etching step.10,11 However, despite easy application and reduced chair time, the SE system account for a

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decrease in SBS according to multiple studies, but that helps in reducing the amount of adhesive remnant after debonding which decreases the chance of enamel damage during the debonding procedure.

Tavas and Watts, were the first who reported the bonding of orthodontic brackets using visible light-cured composite which had many advantages such as an adequate working time to position the brackets properly, ease in excess adhesive removal, and the risk of contamination with saliva or blood reduced. The main disadvantage of visible light-cured composite is the time spent to cure the composite to get possible polymerization of the composite to resist the force applied during ligation of the first archwire.

Over the past several years, curing lights have also experienced vast improvements. Light-emitting diode (LED) technology is now the most used for adhesive curing during the bonding procedure. Manufacturers advertise that increasing the light intensity requires less curing time to reach adequate bond strengths.

The purpose of this study was to evaluate the ARI of orthodontic brackets bonded with two adhesive systems using two different light curing times.

Materials and methods

This in-vitro study was approved by the Research Ethical Committee of the Faculty of Dentistry, Mansoura University (M08080921).

Based on a previous study by Kechagia et al., the authors hypothesized a large effect size for ARI between the four groups. Using G*Power (version 3.1.9.7), a sample size of 48 teeth (12 per each of the four groups) obtained from the groups whose means are to be compared was calculated. This total sample of 48 teeth achieves 93 % power to detect differences among the means versus the alternative of equal means using an $F$ test with a 0.050 significance level. The size of the variation in the means is represented by the effect size $f = \sigma m / \sigma$, which is 0.60. Using a rule of thumb, for Kruskal–Wallis $H$ test, the sample size will be inflated by adding 15 % extra samples. Accordingly, the study will be conducted on 56 samples (14 per group).

This study was conducted on 56 human premolars extracted for orthodontic reasons and collected from Clinics of the Oral and Maxillofacial Surgery, Faculty of Dentistry at Mansoura University. The samples were cleaned and carefully examined under $\times 5$ magnification to confirm the following inclusion criteria; intact enamel surface free from caries, restorations, cracks, fractures, enamel hypoplasia, and not previously treated by chemical agents or bleaching materials. The samples were cleaned and disinfected to remove any debris and then stored at room temperature in distilled water containing 0.1 % (w/V) thymol to inhibit bacterial growth. To facilitate the handling, the root of each sample was put in a self-cure acrylic resin leaving 2 mm from the cemento–enamel junction within a special plastic ring. Then the samples were stored again in distilled water at room temperature to prevent dehydration.

Two types of adhesive systems are used; Total-Etch (TE) and Self-Etch (SE), and two curing times; 20 s and 3 s (as the 20 s is the conventional curing time used for gaining adequate curing of the adhesive under the bracket according to many previous studies, and 3 s as the manufacture of the Woodpecker led curing unit claims to achieve adequate curing of the adhesive under bracket with reducing the curing time to 3 s only, by increasing the power intensity to 2300–2500 Mw/cm$^2$ in their curing unit.

The samples were divided into four groups according to the two types of adhesive systems and according to the curing time as the following: GIa for TE 20 s ($n = 14$), GIIb for TE 3 s ($n = 14$), GIIa for SE 20 s ($n = 14$), GIIb for SE 3 s ($n = 14$).

First, each sample’s buccal surface was cleaned and polished using fluoride-free pumice with a rubber cup on a micromotor handpiece for 10 s, then rinsed with a water spray and dried with compressed oil-free.

Upper first premolar preadjusted edgewise metal stainless steel brackets, with Roth prescription, 0.018-inch slot (American Orthodontics, Sheboygan, Wisconsin, USA) were used for all specimens. The average surface area of the base of the bracket was 10.3 mm$^2$.

For the TE group, all samples were etched with phosphoric acid 32 % (3M/ESPE, St Paul, Germany) for 15 s, then rinsed with water flow for 15 s according to the manufacturer’s instructions, followed by compressed oil-free air for 15 s for dried the tooth surface until the white frosty appearance of etched enamel appeared. After that, a tinny layer film of Transbond XT primer (3M Uniteck, Monrovia, California, USA) was applied to the etched surface by microbrush, and a gentle burst of air was applied to uniformly spread the primer. Finally, the Transbond XT adhesive paste (3M Uniteck) was applied on the base of the metal brackets, then the brackets were placed on the buccal surface of each crown 4 mm from the buccal cusp tip, each bracket was gently pressed to squeeze out all excess composite from underneath brackets and a dental probe was used to
remove the excess adhesive without disturbing the bracket. After bracket positioning, an LED curing unit, Woodpecker iLed (Guilin Woodpecker Medical Instrument Co. Ltd, Guilin, Guangxi, China) was used for curing the adhesive material from the occlusal side while touching the cusp tip of the premolar teeth for 20 s or 3 s according to their allocation in groups. All brackets were bonded by the same operator. After bonding, all samples were stored in distilled water at room temperature for 24 h until subjected to evaluation.

For the SE group Transbond Plus Self Etching Primer (3M Unitek) which incorporates the etch and primer in the same solution was used. The package contents of SE primer were mixed, then the mix was rubbed for 5-s on the buccal enamel surfaces using its microbrush and allowed to be evaporated by gentle oil-free air for 5-s according to manufacturer’s instructions. After that, Transbond XT adhesive paste was applied on the bracket base, then the brackets were placed on the buccal enamel surface of the premolar teeth following the same steps of the bracket positioning, excess removal, curing, and evaluation that were carried out in the TE groups.

After bonding, all samples were stored in distilled water at room temperature for 24 h, then thermocycling was done between 5 and 55 °C for 500 cycles with a dwell time of 30 s and a transfer time of 5 s.26 Using SD Mechatronik Thermocycler, Julabo GmbH, FT 200 (Seelbach, Germany) (Fig. 1). Thereafter, debonding the brackets and ARI evaluation was performed.

Debonding the brackets by squeezing the bracket from its base margin using a bracket removal plier, followed by an examination of the enamel surface and bracket base utilizing a stereomicroscope (MA 100 Nikon stereomicroscope, Japan) (Fig. 2) using × 20 magnification to evaluate the amount of adhesive remaining to determine the bond failure mode. For ARI assessment on the specimen surface, the scores ranged according to the system of Årtun and Bergland,4 from 0 to 3 as follows; score 0: indicating no adhesive was left on the tooth surface (that means the bond failure happened between the resin and enamel), score 1: less than half of the adhesive was left on the tooth surface (suggesting that bond failure happened principally at the resin and enamel interface), score 2: more than half of the adhesive was left on the tooth surface (indicating that bond failure happened mostly between the bracket and resin interface), score 3: all the adhesive was left on the tooth surface with a distinctive negative copy of the bracket base (indicating that adhesive failure happened at the bracket and resin interface).

Data were entered and analyzed using IBM-SPSS software (IBM Corp. Released 2019. IBM SPSS Statistics for Windows, Version 26.0.; IBM Corp., Armonk, New York, USA). Ordinal data (ARI) were expressed as median, minimum, and maximum and were compared by Mann–Whitney U test for two groups, and by Kruskal–Wallis H test for the four groups. For any of the used tests, results were considered as statistically significant if P value less than or equal to 0.050.

Results

This study involved 56 teeth divided into four groups; GIa (TE 20 s): 14 teeth with median ARI of two ranging from 1 to 3, G Ib (TE 3 s): 14 teeth with median ARI of two ranging from 0 to 3, GIIa (SE 20 s): 14 teeth with median ARI of 1 ranging from 0 to 3, GIIb (SE 3 s): 14 teeth with median ARI of 1 ranging from 0 to 3.

By using Mann–Whitney U test, comparisons of ARI in TE versus SE revealed a statistically significantly higher ARI in TE versus SE regardless of curing time (Table 1) while comparisons of ARI in
the two curing times; 20 s versus 3 s revealed no statistically significant difference in ARI between 20 s versus 3 s regardless to the adhesive type (Table 2). Kruskal–Wallis H test (Table 3) was carried out and showed that there was a statistically significant difference in ARI between the four groups ($H^3 = 22.832$, $P < 0.001$).

Pairwise comparisons (Table 4) revealed that ARI was statistically significantly higher in TE 20 s vs. SE subgroups (20 s and 3 s) with Bonferroni-adjusted $P$ values of 0.001, and 0.002, respectively. It also showed that ARI was statistically significantly higher in TE 3 s versus SE subgroups (20 s and 3 s) with Bonferroni-adjusted $P$ values of 0.013, and 0.026, respectively. There was no statistically significant difference in ARI between TE 20 s versus TE 3 s (Bonferroni-adjusted $P = 1.000$) and between SE 20 s versus SE 3 s (Bonferroni-adjusted $P = 1.000$).

Table 1. Adhesive remnant index in Total-Etch versus Self-Etch.

<table>
<thead>
<tr>
<th>Statistic</th>
<th>TE ($N = 28$)</th>
<th>SE ($N = 28$)</th>
<th>Z value</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>2</td>
<td>1</td>
<td>−4.715</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Minimum</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The test of significance is Mann–Whitney U test.

Table 2. Adhesive remnant index in 20 s versus 3 s.

<table>
<thead>
<tr>
<th>Statistic</th>
<th>20 s ($N = 28$)</th>
<th>3 s ($N = 28$)</th>
<th>Z value</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>2</td>
<td>1.5</td>
<td>−0.685</td>
<td>0.494</td>
</tr>
<tr>
<td>Minimum</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The test of significance is Mann–Whitney U test.

By evaluating the ARI of TE groups, we observed that the most frequent score was 2 followed by score 3, and the lowest score was score 0 while for the SE groups, the most frequent score was score 1 followed by score 0, and the lowest score was score 3 (Table 5).

**Discussion**

Classification according to the ARI offers information about the amount of the adhesive remaining on the enamel surface after the bracket is removed, which help in determining the amount of adhesive strength between the adhesive, enamel, and bracket and reflects the amount of adhesive removal needed that will affect the enamel surface health following debonding procedure. Lower values tend to indicate less enamel surface damage and are rarely associated with enamel fractures, although they may be associated with inadequate bond strength. In contrast, higher ARI values indicate effective adhesions between enamel and adhesive and are often linked with increased surface damage.

The results of the current study showed that there was a significant difference in ARI scores between the four groups. Comparisons revealed that ARI in TE groups was higher than SE groups. While no significant difference between TE 20 s in comparison to TE 3 s and between SE 20 s in comparison to SE 3 s. Regardless of curing time, TE system showed higher ARI scores than SE system, while regardless of the adhesive type there was no significant difference in the ARI between the curing times. TE
groups showed score 2 as the most frequent score and the lowest was score 0. While SE groups showed score 1 as the most frequent and the lowest was score 3.

Regarding the adhesive type on ARI regardless of curing time, our ARI results were comparable with those reported by the study of Sharma et al.,27 which evaluated the ARI and found; score 2 to be the most prevalent score in TE (Transbond XT) followed by score 3, while the SE (Transbond Plus) showed score 1 to be the most prevalent score followed by score 0. Bayar Bilen and Çokakoglu,9 revealed similar results to ours in the SE group (Transbond Plus) which showed score 1 as the most prevalent score followed by score 0. But differed in the TE group (Transbond XT) which showed score 1 as the most prevalent score followed by score 2. Same as Shapinko et al.,28 study which found different results from ours in the TE group (Transbond XT) as they found the most prevalent score was score 0 followed by score 1.

This might be attributed to the fact that inadequate SBS tends to show a low amount of adhesive on the enamel surface after debonding while high SBS tends to show a higher amount of adhesive remaining,7 as the previous studies,9,28 found there is a positive correlation between the SBS and the ARI and proved that with the increasing of the SBS that will be indicated for higher ARI scores as a large amount of the adhesive remains on the enamel surface after debonding. On the other hand Joseph et al.,2 evaluate the TE (Transbond XT) and SE (Transbond Plus) for SBS and ARI, and found the correlation between the SBS and ARI scores to be not statistically significant (P > 0.05), thus indicating there is no relation between the SBS and the ARI scores of an adhesive, so the ARI scores in their study were comparable in all groups as they found all groups showed the same amount of adhesive remaining on the enamel surface after debonding. They found score 2 to be the most frequent score followed by score 3 in all tested groups.

In contrast also to our result, Iglesias et al.,1 found that the TE group (Transbond XT) showed score 1 as the most prevalent score followed by scores 0 and 2 equally, while the SE group (Beauty Orthobond II BO) showed score 0 as the most frequent score followed by score 1.

Similarly, Lamper et al.,29 also contrast our findings as found that the TE group (Transbond XT) showed the most prevalent score was score 1 followed by score 2, while the SE group (Transbond Plus) showed the most prevalent score was score 2 followed by score 1.

Regarding the influence of curing time on ARI regardless of adhesive type, our results were comparable to the findings of Gomes et al.,30 in the TE system which evaluated the ARI by using TE (Transbond XT) with LED (1600 Mw/cm²) under

### Table 3. Adhesive remnant index comparisons between the four subgroups.

<table>
<thead>
<tr>
<th>Adhesive system</th>
<th>Curing time</th>
<th>Median</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean rank</th>
<th>H ³</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total-Etch</td>
<td>20 s</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>40.54</td>
<td>22.832</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>3 s</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>36.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-Etch</td>
<td>20 s</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>19.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 s</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>18.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Test of significance is Kruskal–Wallis H test.

### Table 4. Pairwise comparisons of the adhesive remnant index between the four subgroups.

<table>
<thead>
<tr>
<th>Groups interaction</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TE 20 s</td>
<td></td>
</tr>
<tr>
<td>SE 20 s</td>
<td>0.001</td>
</tr>
<tr>
<td>SE 3 s</td>
<td>0.002</td>
</tr>
<tr>
<td>TE 3 s</td>
<td>1.000</td>
</tr>
<tr>
<td>TE 20 s</td>
<td></td>
</tr>
<tr>
<td>SE 20 s</td>
<td>0.013</td>
</tr>
<tr>
<td>SE 3 s</td>
<td>0.026</td>
</tr>
<tr>
<td>SE 20 s</td>
<td></td>
</tr>
<tr>
<td>SE 3 s</td>
<td>1.000</td>
</tr>
</tbody>
</table>

### Table 5. Frequencies of adhesive remnant index scores in each group.

<table>
<thead>
<tr>
<th>Groups</th>
<th>ARI score</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total-Etch 20 s</td>
<td>1</td>
<td>1</td>
<td>7.1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>8</td>
<td>57.1</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>5</td>
<td>35.7</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>14</td>
<td>100.0</td>
</tr>
<tr>
<td>Total-Etch 3 s</td>
<td>0</td>
<td>1</td>
<td>7.1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>7.1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>9</td>
<td>64.3</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3</td>
<td>21.4</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>14</td>
<td>100.0</td>
</tr>
<tr>
<td>Self-Etch 20 s</td>
<td>0</td>
<td>4</td>
<td>28.6</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>7</td>
<td>50.0</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2</td>
<td>14.3</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1</td>
<td>7.1</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>14</td>
<td>100.0</td>
</tr>
<tr>
<td>Self-Etch 3 s</td>
<td>0</td>
<td>4</td>
<td>28.6</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>8</td>
<td>57.1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1</td>
<td>7.1</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1</td>
<td>7.1</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>14</td>
<td>100.0</td>
</tr>
</tbody>
</table>

ARI, adhesive remnant index.
different curing times (2, 4, 6, 8, and 10 s), and found; score 2 was the most frequent in all groups followed by score 3.

Also comparable to the study of Al-Khatieeb et al., in the point of view of the most frequent score within the TE system using different curing duration which evaluated the influence of variable curing durations of LED light cure: 3 s and 1 s in comparison to Quartz-tungsten Halogen (QTH) for 40 s while using TE (Grengloo, Ormco) and found; QTH group showed score 2 as the most prevalent score followed by score 1, also LED 3 s and 1 s showed score 2 as the most prevalent score followed by score 1 in the 3 s group, while followed by score 0 in the 1 s group.

This can be attributed to the concept of high-intensity curing units like high-intensity LED can achieve adequate curing of the adhesive under the bracket even with reducing curing times, as it can achieve adequate polymerization and convert all monomers to polymers by the high intensities that reach 2500 Mw/cm² according to the manufacture and the studies mentioned before. 25,26,31 So there was no difference in the ARI between the tested groups when a comparison is done between the usual curing units with conventional curing time to high-intensity curing units with reducing curing time regardless to the adhesive type, as all groups showed the same amount of adhesive remaining after debonding.

On another hand, James et al. found significant differences in the ARI scores of the 3 curing devices that utilize different curing times from each other using TE (Transbond XT) as an adhesive and showed the most prevalent score within 20 s QTH was score 1 followed by score 2. While 10 s argon showed the most prevalent score was score 3 followed by score 2. Finally, the 5 s plasma arc shows the most prevalent score was score 2 followed by scores 1 and 3 at the same percent.

The removal procedure of the orthodontic appliance involves the use of various tools, such as pliers and debonding instruments, to remove the appliance from the tooth surface. The amount of adhesive left on the tooth surface after the removal procedure can affect the chair time, which is the total time that the patient spends in the dental chair during the orthodontic appointment. If the ARI score is high, indicating that most of the adhesive remains on the enamel surface, it may take longer to remove the bracket or appliance. The orthodontist may need to use additional tools or instruments to remove the adhesive completely, which can increase the chair time. On the other hand, if the ARI score is low, indicating that little or no adhesive remains on the enamel surface, the removal procedure may be faster, resulting in a shorter chair time. This is because there is less resistance to the removal force, making the removal process relatively quicker. 32

Some limitations in this study should be considered such as; the number of thermocycling used does not mimic the actual time of the orthodontic treatment course, It is an in-vitro study that needs further in-vivo study to evaluate the failure rate of the brackets intraorally, and using a bracket of 0.018-inch slot size may affect the results in comparison to other studies that used a 0.022-inch slot.

Conclusions

(1) Varying the adhesive system results in different ARI scores, which can affect the enamel surface during debonding.

(2) The TE adhesive system showed the highest amount of adhesive remaining on the enamel surface after debonding, while SE showed the lowest amount of adhesive remaining on the enamel surface.

(3) Reducing the curing time did not show a significant impact on the ARI regardless of the adhesive type.

Conflicts of interest

There are no conflicts of interest.

References

[25] Gulcin woodpecker medical Instrument Co. LTD.