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A comparative study of qualitative and quantitative methods for the assessment of adhesive remnant after bracket debonding

S. Burcak Cehreli*, Omur Polat-Ozsoy**, Cagla Sar**, H. Evren Cubukcu*** and Zafer C. Cehreli****
Departments of *Pediatric Dentistry, **Orthodontics, Baskent University, Ankara, Turkey, ***Department of Geological Engineering, Division of Mineral-Petrography, Hacettepe University, Ankara, Turkey and ****Department of Pediatric Dentistry, Hacettepe University, Ankara, Turkey

Correspondence to: Omur Polat-Ozsoy, Baskent Universitesi Dis Hekimligi, Ortodonti AD. 11. Sk No:26, 06490 Bahcelievler, Ankara, Turkey. E-mail: omurorto@yahoo.com

SUMMARY The amount of the residual adhesive after bracket debonding is frequently assessed in a qualitative manner, utilizing the adhesive remnant index (ARI). This study aimed to investigate whether quantitative assessment of the adhesive remnant yields more precise results compared to qualitative methods utilizing the 4- and 5-point ARI scales.

Twenty debonded brackets were selected. Evaluation and scoring of the adhesive remnant on bracket bases were made consecutively using: 1. qualitative assessment (visual scoring) and 2. quantitative measurement (image analysis) on digital photographs. Image analysis was made on scanning electron micrographs (SEM) and high-precision elemental maps of the adhesive remnant as determined by energy dispersed X-ray spectrometry. Evaluations were made in accordance with the original 4-point and the modified 5-point ARI scales. Intra-class correlation coefficients (ICCs) were calculated, and the data were evaluated using Friedman test followed by Wilcoxon signed ranks test with Bonferroni correction.

ICC statistics indicated high levels of agreement for qualitative visual scoring among examiners. The 4-point ARI scale was compliant with the SEM assessments but indicated significantly less adhesive remnant compared to the results of quantitative elemental mapping. When the 5-point scale was used, both quantitative techniques yielded similar results with those obtained qualitatively.

These results indicate that qualitative visual scoring using the ARI is capable of generating similar results with those assessed by quantitative image analysis techniques. In particular, visual scoring with the 5-point ARI scale can yield similar results with both the SEM analysis and elemental mapping.

Introduction

Removal of residual bonding resin after orthodontic bracket debonding results in an irreversible damage to the enamel (Eminkahyagil *et al.*, 2006), ranging from 30 to 60 μm of surface enamel loss (Thompson and Way, 1981; Bishara and Fehr, 1997). Therefore, an orthodontic adhesive that leaves less or no adhesive remnant is highly preferable in terms of minimizing irreversible damage to the enamel. Further, a high-speed tungsten carbide bur takes approximately 40 seconds to remove all composite remnants on a single tooth (David *et al.*, 2002), and thus, cleaning the entire adhesive remnant on the upper and lower arches can be quite time consuming.

Assessment of the adhesive remnant after debonding is an important factor in the selection of orthodontic adhesives and removal of the adhesive resin from tooth surfaces. Introduced by Årtun and Bergland (1984), the adhesive remnant index (ARI) has been widely used in studies in order to evaluate the amount of adhesive remnant after bracket debonding. The categories for scoring in 4-point scale of Årtun and Bergland with respect to the bracket base are 0 = all adhesive left on the bracket base, 1 = more than half of the adhesive left on the bracket base, 2 = less than half of the adhesive left on the bracket base, and 3 = No adhesive left on the bracket base. Later, Bishara and Trulove (1990) developed the 5-point scale, where ARI scores on the bracket base range as follows: 1 = no adherence of composite on the bracket base, 2 = less than 10 per cent of composite remaining on the bracket surface, 3 = more than 10 per cent but less than 90 per cent of composite remaining on the bracket surface, 4 = more than 90 per cent of composite remaining on the bracket surface, and 5 = all composite remaining on the bracket base.

Owing to the qualitative and subjective nature of the ARI scoring system, there have been a number of attempts to develop more precise techniques for the evaluation of the adhesive remnant, including scanning electron microscope (SEM), finite element analysis, and three-dimensional profilometry (Lew and Hong, 1995; Kim *et al.*, 2007; Chen *et al.*, 2008). O'Brien *et al.* (1988) described a quantitative method to determine adhesive resin remnant. Accordingly, a ×40 magnified image of the enamel was digitized and the amount of remaining resin was revealed as a percentage of bracket base area according. Another study, evaluating the effect of magnification on the reliability of the ARI score system, showed that ARI scores were significantly different under ×20 magnification (Montasser and Drummond, 2009). At higher magnifications, the tendency was for lower scores to decrease and for higher scores to increase as compared with lower magnifications (Montasser and Drummond, 2009). Despite these results, the assessment of the adhesive remnant is generally made by qualitative visual inspection using the ARI, which indicates the need to verify the accuracy of this approach versus precision assessment techniques.

Thus, the objective of this *in vitro* study was to investigate whether quantitative assessment of the adhesive remnant using electron microscopy and elemental mapping yields more precise results compared to qualitative scoring methods utilizing the 4- and 5-point ARI scales. The null hypothesis tested was that visual assessment of the adhesive remnant using the 4- and 5-point ARI scales yields similar results with those obtained by quantitative image analysis techniques.

Materials and methods

Selection of brackets

Samples were selected from a pool of debonded metal brackets collected for the purpose of recycling. The brackets were selected according to the following criteria: 1. having been in service for at least 12 months; 2. being bonded with the same adhesive system (Transbond XT, 3M Unitek, Monrovia, California, USA); and 3. absence of deformation on the bracket base during debonding. The metal brackets used contained a mesh base for retention and were removed simply by peeling the bracket base away from the tooth using a debonding plier (Class One Orthodontics, Carlsbad, California, USA).

A total of 20 brackets, which met the inclusion criteria, were available for further examination.

Evaluation and scoring of the adhesive remnant

Two methods were used for the evaluation and scoring of the adhesive remnant on bracket bases: qualitative assessment (visual scoring) and quantitative measurement (image analysis) on digital photographs. The latter assessment was accomplished using two different electron microscopy techniques.

Qualitative assessment of the adhesive remnant was carried out by two experienced calibrated examiners under a stereomicroscope (Olympus, Tokyo, Japan) at ×20 magnification (Montasser and Drummond, 2009). A digital photograph of each bracket base was recorded at the same magnification. Following visual scoring, the brackets were subjected to SEM assessment. Because the vacuum conditions needed to sputter coat the bracket surfaces could possibly result in surface cracks and/or deformation of the composite, the images were obtained using a Zeiss EVO 50 EP SEM (Carl Zeiss NTS GmbH, Oberkochen, Germany) at extended variable pressure (XVP) mode without coating. Two types of images were obtained from each bracket to carry out the quantitative assessment (image analysis) of the adhesive remnant. The first set of electron micrographs were taken perpendicularly and recorded as *.TIFF files at 1280 × 1024 resolution. These images served as a detailed version of the light microscopy images, where edge detection of the composite resin could be made precisely by the image analysis software, leading to accurate calculation of the area of adhesive remnant (Figure 1). To obtain the second set of micrographs, a Bruker AXS Quantax 4010 Energy dispersive X-ray spectrometer (Bruker AXS Microanalysis GmbH; Berlin, Germany) was used to graph the elemental make up of the bracket surface, as well as to create separate maps of the bracket base, highlighting where selected elements appear (Figure 1). The energy dispersive X-ray spectrometer was particularly used to determine the mapping of silicium, the main component of the composite

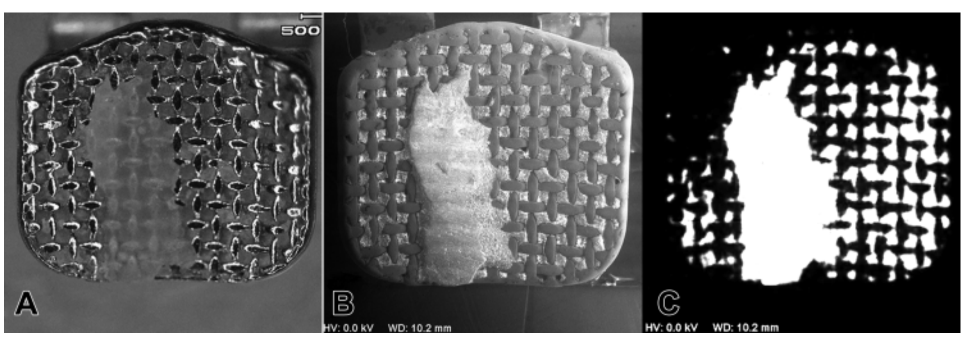

Figure 1 (A) Micrograph of a bracket as viewed under the stereomicrocope (×20) for visual scoring; (B) Electron microscopic image of the same bracket; and (C) Elemental mapping of the bracket, highlighting areas of silicium (composite resin).

resin. The mapping of silicium provided a more detailed image of the adhesive remnant that cannot be traced by electron microscopic evaluation. The elemental maps were saved with the same extension and resolution as with the first set of electron micrographs.

For quantitative assessment, the area of adhesive remnant was calculated using ImageJ open-source image analysis software (Version 1.36 for Macintosh; National Institutes of Health, Bethesda, Maryland). As a preparation to area calculation, the images were fist converted to 8-bit grayscale format, followed by a thresholding procedure to create binary images. Area measurements were conducted on binary images using the area measurement function of ImageJ. The measurements of surface area were converted into percentages, and thereafter, to the 4-point and 5-point scale scores so as to enable statistical comparisons with those obtained by qualitative assessment.

Statistical analysis

For both scoring systems (4-and 5-point scales), intra-class correlation coefficient (ICC) was used to evaluate the reliability of ratings among examiners ($P = 0.05$).

Friedman test followed by Wilcoxon signed ranks test with Bonferroni correction were used to investigate significant differences between the ARI assessment methods (visual scoring, electron microscopic image analysis, and elemental spectroscopic image analysis) with respect to the scoring systems used ($P = 0.05$ and $P = 0.017$ for Friedman and Wilcoxon Signed Ranks tests, respectively).

Results

For visual scoring, a high level of agreement was observed between examiners when the 4-point scale of Årtun and Bergland (1984) was used [ICC: 0.952; 95 per cent confidence interval (95% CI): 0.883–0.981]. Likewise, when the 5-point scale by Bishara and Trulove (1990) was used, the level of agreement between the examiners was very high (ICC: 0.969; 95% CI: 0.924–0.988).

The distribution of ARI scores with respect to the scoring system and assessment method are presented in Table 1. For scores made according to the 4-point scale, the results of the Friedman test showed that the ARI score evaluation was significantly different using the tested assessment methods ($P = 0.014$). Multiple comparisons of the data showed that assessment with elemental mapping yielded significantly 'lower' scores (more adhesive remnant) compared to those obtained with electron microscopic image analysis (Wilcoxon signed ranks test, $P = 0.014$). On the other hand, there was no significant difference between the ARI scores obtained using visual scoring and electron microscopic image analysis (Wilcoxon signed ranks test, $P = 0.655$). To further investigate the level of agreement between the assessment methods, the data were subjected to ICC statistics. The results showed no agreement between elemental mapping and electron microscopic image analysis (ICC: 0.397; 95% CI: 0.035–0.706); acceptable agreement between visual assessment and electron microscopic image analysis (ICC: 0.680; 95% CI: 0.358–0.859); and a low level of agreement between visual assessment and elemental mapping (ICC: 0.501; 95% CI: 0.096–0.766).

When scores were evaluated according to the 5-point scale, no significant difference was found among the assessment methods ($P = 0.069$). Therefore, neither multiple comparisons nor ICC statistics could be carried out.

Discussion

Only a limited number of methodological studies exist on the assessment of adhesive remnant after bracket debonding (Kim *et al.*, 2007; Montasser and Drummond, 2009). Montasser and Drummond (2009) compared ARI scores under different magnifications (×10 and ×20) and concluded that the results would be more accurate under higher

Table 1 Frequency and percentage (%) of adhesive remnant index scores with respect to the scoring system and assessment method used.

Scoring system (scale)		Visual scoring		Electron microscope		Elemental mapping	
	Score	Frequency	%	Frequency	%	Frequency	%
0–3 Scale	0	1	5				
	1	5	25	5	25	11	55
	2	11	55	15	75	9	45
	3	3	15				
1–5 Scale	1	3	15				
	2	2	10				
	3	14	70	20	100	20	100
	4	1	5				
	5	0	0				

magnifications. Accordingly, the magnification factor was set at ×20 for visual assessments in the present study.

The amount of residual adhesive can be assessed with both qualitative and quantitative methods. Being qualitative in nature, both the original (4-point scale) and modified (5-point scale) versions of have been used extensively in previous studies. Quantitative methods include stereomicroscopic (Miksic *et al.*, 2003) and SEM techniques (Campbell, 1995; Sorel *et al.*, 2002; Schuler and van Waes, 2003; Brosh *et al.*, 2005), direct measurement on models (Krell *et al.*, 1993), surface profilometry (Hosein *et al.*, 2004), or weight and area assessments (David *et al.*, 2002). In a study by O'Brien *et al*. (1988), the amount of adhesive remnant was expressed as a percentage of the mean bracket area. Later, optical coherence tomography was tested as a non-destructive technique to investigate the topographic characteristics of enamel before and after bracket debonding (Louie *et al.*, 2005). These techniques have enabled development of several indexes such as the enamel detachment index (Sorel *et al.*, 2002), calcium remnant index, composite remnant index (Brosh *et al.*, 2005), and surface roughness index (Hong and Lew, 1995) which all aim to evaluate the enamel surface after bracket debonding. However, due to its simplicity, qualitative assessment of the residual adhesive by using the ARI has remained the most frequently used method.

The present results demonstrate a significant difference between the qualitative and quantitative assessment methods, when the measurements were converted to original (4-point scale) ARI scores. Accordingly, elemental mapping yielded significantly lower ARI scores (indicating more adhesive remnant) compared with visual scoring. The elemental mapping method can precisely identify the amount of silicium, which is the main component of resin-based composites. However, since this method is capable of detecting even tiny amounts of composite within the mesh, the numerical output of the adhesive remnant causes 'lowering' of the ARI scores, when the 4-point ARI scale is used. However, despite the statistical demonstration of this difference, it is doubtful whether detection of such minute amounts of composite would have any clinical significance. Here, considered more clinically relevant was the finding that both the visual scoring and the highly precise electron microscopy analysis yielded similar results.

In the present study, there were no significant differences between the qualitative and quantitative assessment methods, when the measurements were converted to modified (5-point scale) ARI scores. These results show that qualitative visual assessment using the 5-point ARI scale was capable of yielding results similar to those that could be obtained through the use of expensive, high-precision, time-consuming quantitative assessment methods. While these results might suggest that the modified 5-point ARI scale is more accurate than its original version, it should be kept in mind that the 5-point scale may also tend to mask minor differences. Thus, clinically, there may be more adhesive present on a tooth, even though the modified ARI indicates a low score.

Conclusions

Within the experimental conditions of the present study, the following conclusions were drawn:

1. Qualitative visual scoring using the ARI is capable of generating similar results with those assessed by quantitative image analysis techniques. In particular, visual scoring with the 5-point ARI scale can yield similar results with both the SEM analysis and elemental mapping. These results necessitate acceptance of the null hypothesis for the modified (5-point) ARI scale.
2. The original (4-point) ARI scale was compliant with the results of the SEM assessments but indicated significantly less adhesive remnant compared to the results of quantitative elemental mapping. Thus, the null hypothesis was partially accepted for the original ARI scale.
3. A direct comparison between the 4- and 5-point ARI scales could not be made since the number (and/or range) of scores is not similar.

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