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The Influence of Bonding Agents on the Decision to Replace Composite Restorations

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Clinical Relevance

Radiolucent areas around restorations may result from either a halo effect or radiographic density of the adhesives. Therefore, the use of an adhesive with radiopaque fillers may be more clinically reliable for avoiding inappropriate replacements.

SUMMARY

Abstract: This *in vitro* study evaluated the validity of the decision to replace of a restoration based upon the radiolucent zone beneath a resin composite.

Materials and Methods: Class II cavities were prepared on the approximal surfaces of 40 molars. The teeth were divided into four groups. Clearfil SE Bond, PQ1 or Single Bond was applied in the experimental groups. No bonding agent was used in the control group. Following the restorations, digital radiographs were obtained and independently evaluated by two oral radiologists and two specialists in restorative dentistry to determine the need for replacement. The coronal portions of the teeth were then sectioned and the interfaces between the restorations and cavity walls were examined using an optical light microscope. Possible adhesive pooling and voids were examined under a light microscope. Inter-examiner reliability was evaluated with the Cohen's kappa (κ) test. Sensitivity, specificity and negative and positive predictive values were calculated. Kruskal-Wallis, followed by the Mann-Whitney U-test, determined differences among the pooling thicknesses of the different adhesives.

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Results: Various sensitivity and specificity degrees were obtained from the groups in which different adhesive systems were used. The PQ1 adhesive system was the best for identifying well-adapted restorations with the highest true non-replacement diagnosis (TND=0.70). Clearfil SE Bond had the highest false positive scores. Adhesive pooling was significantly different in the experimental groups of the current study (*p*<0.05). Conclusion: Replacement decisions for a resin composite restoration based upon digital images frequently resulted in false-positive or negative decisions.

INTRODUCTION

Secondary caries is the most common reason for the replacement of restorations in general dental practice.[1-3] Retreatment decisions due to the diagnosis of this pathology leads to spending billions of dollars per year worldwide.[1] The presence of voids or gaps also indicates a need for replacement of a restoration, because they can cause postoperative sensitivity,[4] secondary caries[5-6] and pulpal inflammation.[7] Furthermore, the space between the restorative material and cavity is recognized as a deleterious factor for the biocompatibility and stability of restorations.[8]

The use of posterior resin composites has been growing. However, resin composite systems have an inherent problem of contraction stress induced during polymerization.[9-10] This stress may lead to adhesive failure, thus causing the formation of interfacial gaps between the restorations and dentin surfaces.[8,11] It was suggested that increasing the thickness of low-stiffness adhesives significantly absorbed and relieved contraction stress and, hence, prevented gap formation.[12-14] Most of the adhesive systems produce radiolucent images, since they do not contain radiopaque fillers. Dentin adhesives, particularly in thick layers, may compromise the radiographic detection of secondary caries and gaps or may lead to a false replacement diagnosis. Therefore, this current study was hypothesized that the image characteristics of various dentin adhesives would vary and, as a result, lead to true or false replacement and non-replacement decisions. The relationship among replacement decision, presence of voids and adhesive pooling was also evaluated.

METHODS AND MATERIALS

Forty extracted, caries-free molars were used in the current study. After calculus and soft tissue removal by curettes, the teeth were placed into a 0.1% thymol solution until use. Standardized Class II box-shaped cavity preparations (3 mm wide, 2.5 mm in length and 2 mm deep) were prepared on the mesial side of each tooth. The teeth were randomly divided into four groups of 10 teeth, with each group receiving a different restorative treatment. Three different adhesive systems, with varying compositions and modes of application, were applied to the experimental groups according to the manufacturers' instructions.

The fourth group did not receive any adhesive and was used as the control. The adhesive systems and protocol used in the current study are presented in Table 1. All adhesive systems were combined with the same

Table 1: *The Adhesive Systems Used and Their Composition and Mode of Application*

Group I	Group II	Group III	Group IV
Clearfil SE Bond (Kuraray Medical Inc, Tokyo, Japan) Two-step, Self-etch adhesive; 10% filled with silica particles.	**PQ1** (Ultradent Products, Inc, South Jordan, UT, USA) "One-bottle" Total-etch adhesive; 40% filled.	**Adper Single Bond** (3M ESPE Dental Products, St Paul, MN, USA) "One-bottle" Total-etch adhesive; fillerless.	**Control**
Application Self-etching primer was applied with a brush for 20 seconds, dried with mild air flow, bond was applied, gentle air flow applied, then light cured for 10 seconds.	**Application** Total-etch was applied with 35% phosphoric acid (Ultra-etch) for 15 seconds with blue micro tips, washed, excess water was blown off, leaving the surface visibly wet. + Single bottle resin bonding system, PQ1, was applied for 15 seconds with inspiral brush tips and light-cured for 20 seconds.	**Application** Total etch was applied with 35% phosphoric acid (Scotchbond Etching gel) for 15 seconds, washed and rinsed, excess water was blown off, leaving the tooth moist. + Single bottle resin bonding, two consecutive coats of Adper Single Bond were applied, dried gently for 2-5 seconds and light-cured for 10 seconds.	**Application** No separate etching step, no adhesive system was applied to the samples of this group.

posterior resin composite (Filtek P60, 3M ESPE Dental Products, St Paul, MN, USA). The resin composite was placed into the cavities in two horizontal increments. Curing of the materials was performed by a visible light-curing unit (Optilux 502 (Kerr/Demetron, Danbury, CT, USA) with an intensity output in excess of 860 mW/cm^2.

Finishing of the restorations was made with a high-speed handpiece under an air/water spray using a 12-bladed finishing bur. Subsequently, polishing was completed with Sof-Lex discs (3M ESPE).

Following the restorative procedures, the roots were sectioned from the crowns of the teeth. All of the crowns were embedded in epoxy resin (Araldit D, Ciba-Geigy, Dibeek, Belgium) and radiographed with a charge-coupled device system (Computed Dental Radiography-CDR, Schick Technologies Inc, Long Island City, NY, USA, Part Number: B1051011 Rev C). Digital images of the teeth were acquired by using bitewing projection geometry at a focus-receptor distance of 25 cm. A Heliodent (Sirona Dental System GmbH, Bensheim, Germany) dental x-ray unit was used for all exposures, operating at 7 mA with 1.5 mm Al equivalent filtration at 70 kV. Digital images were displayed on a 15-inch high-resolution (XGA) color liquid crystal monitor with a resolution of 1024 x 768 pixels and 256 gray levels (Toshiba Satellite 1900, Toshiba Corp, Tokyo, Japan). The dedicated software of the imaging system was used for digital images. Observation conditions were optimized through use of the same computer monitor when the images were displayed, and the display ratio was 1:1. The viewing distance was kept constant, at about 50 cm for all observers, and the lights were subdued during observations. The observers were given the chance to enhance the contrast-brightness of the resultant images.

Two oral radiologists and two specialists in restorative dentistry independently evaluated the resultant images for the decision to replace or not replace the restoration using a dichotomous scale: 1) restoration needs replacement; 2) restoration needs no replacement.

After all the image evaluations were completed, the test teeth were sectioned twice, crossing the center of the restorations. Bonding characteristics, possible adhesive pooling on the axio-gingival corner of the restorations and void presence were examined under a light microscope (Nikon Eclipse ME600, Nikon Corporation, Tokyo, Japan) throughout the restoration-tooth interface. When present, the thickness of the adhesive pooling was measured using the image analyzer program (Lucia Version 4.51) of the microscope. Measurements were made between the furthest two points of the adhesive pooling.

Statistical Analyses

In order to determine the proportion of the restorations with non-adapted areas that were correctly identified, sensitivity was calculated for each adhesive system. Similarly, specificity was determined for well-adapted restorations that were correctly identified. Negative and positive predictive values were calculated as well. In order to avoid confusion, however, the term "True Replacement Diagnosis" (TRD) was used instead of positive predictive value, which implies the proportion of the true test result for replacement. Likewise, the term "True Non-replacement Diagnosis" (TND) was preferred for the negative predictive value. Inter-examiner reliability was evaluated with Cohen's kappa (χ).

Differences among the pooling thicknesses of the different adhesives were analyzed with the Mann-Whitney U-test. SPSS (Statistics Package for the Social Sciences) 11.0 package program (SPSS Inc, Chicago, IL, USA) was used for all analyses. The α was set at 0.05 in all statistical analyses.

RESULTS

Replacement decisions, the presence of voids and differences among the pooling amount of the adhesives are presented in Table 2.

According to the microscopic evaluations, Clearfil SE Bond and PQ1 samples demonstrated non-adapted areas (voids) in the resin-dentin interface, while there was no void for Single Bond specimens. The mean thickness of these non-adapted areas was around 2-7.3 µm for Clearfil SE Bond, while it was in the range of 1-5 µm for PQ1.

In the microscopic evaluation, 60% of the restorations bonded with Clearfil SE Bond exhibited an ideal seal,

Table 2: *Replacement Decision, Presence of Voids and Pooling Amounts of Adhesives*

Adhesives	Replacement Decision		Voids		Adhesive Pooling
	YES (%)	NO (%)	YES (%)	NO (%)	Median (SD) µm
Clearfil SE Bond	85%	15%	40%	60%	231(65.9)¶*
PQ1	12.5%	87.5%	20%	80%	215(135.5)¶
Single Bond	60%	40%	0%	100%	74(81.5)*
Control	16%	84%	100%	0%	-

Same symbol indicates statistically significant differences.

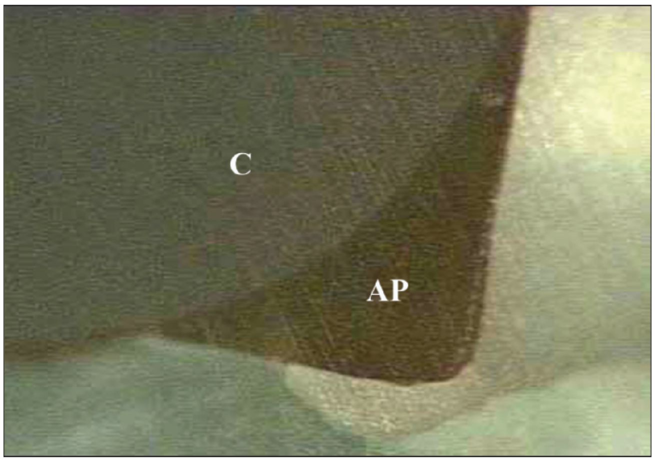

Figure 1. *Observes the adhesive pooling at the corner of a pulpal wall belonging to the Clearfil SE Bond group (AP=Adhesive pooling, C=Resin composite).*

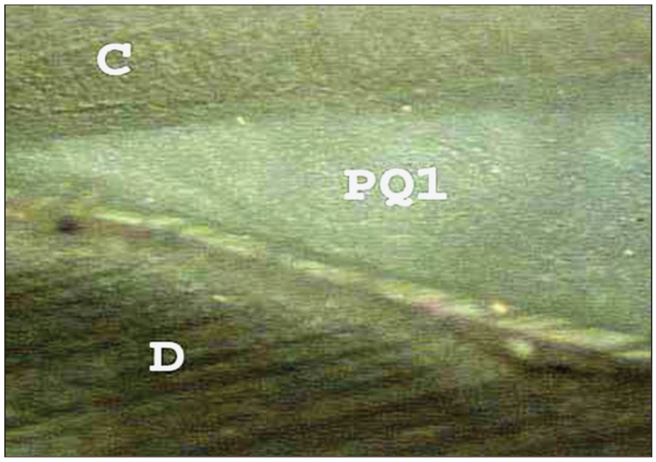

Figure 2. *Ideal adaptation of PQ1 was viewed in the microscopic evaluation (D=Dentin, C=Resin composite).*

Figure 3. *Microscopic evaluation reveals close relation between tooth structure and the restorative in the Single Bond group (D=Dentin, C=Composite resin). However, most of the restorations bonded with Single Bond were rated "replacement decision."*

whereas non-adapted areas (voids) were observed in 40% of the restorations (Table 2) (Figure 1). However, only 60% of the non-adapted restorations in this group were truly detected during the radiological evaluation (Sensitivity=0.60) (Table 3). On the contrary, all of the well-adapted restorations (100%) received a false replacement decision.

Accordingly, Clearfil SE Bond showed the highest false replacement scores. Nevertheless, with a true replacement diagnosis of 0.26, it was the most reliable adhesive for the detection of non-adapted areas when compared to the other adhesives used in the current study. PQ1 was the restorative material with the highest specificity (0.83) (Figure 2). When the PQ1 adhesive system was used, well-adapted restorations were identified as having the highest true non-replacement diagnosis (0.71). None of the restorations that bonded with Single Bond was determined as non-adapted in the microscopic evaluation (Figure 3). However, restorations with Single Bond received 60% of false replacement decisions. The specificity of this adhesive was determined as 0.40, following that of PQ1. In the control group, all of the restorations were non-adapted, as expected (Figure 4). However, of these faulty restorations, only 16% could be truly determined in the radiographic evaluation, whereas 84% of the restorations were evaluated as needing no replacement.

Adhesive pooling measurements were approximately 231 (± 65.9) µm, 215 (± 135.5) µm and 74 (± 81.5) µm for Clearfil SE Bond, PQ1 and Single Bond, respectively (Table 2). The difference between Clearfil SE Bond and PQ1 was statistically significant (p=0.027).

Similarly, the amount of adhesive pooling obtained with Single Bond was significantly different from that of Clearfil SE Bond (p=0.002).

Table 3: *Specificity, Sensitivity, PPV and NPV Degrees of Adhesives According to Radiodiagnostic Assessments*

	Specificity	**Sensitivity**	**True Replacement Diagnosis (TRD)**	**True Non-Replacement Diagnosis (TND)**
Clearfil SE Bond	0	0.60	0.26	0
PQ1	0.83	0	0	0.71
Single Bond	0.40	—	—	—
Control	—	0.16	—	—

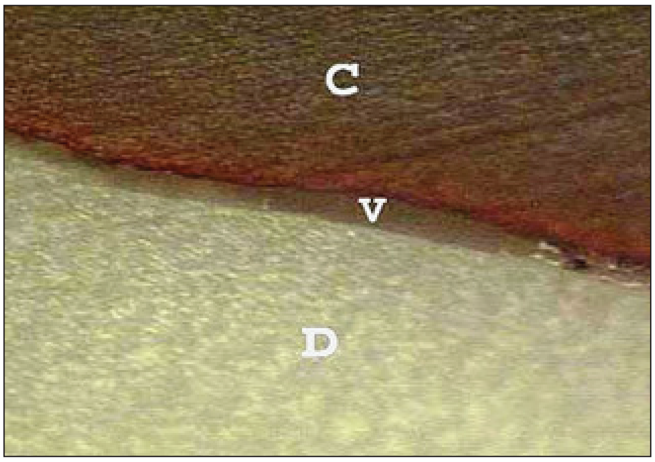

Figure 4. *Microscopic image of the sample belonging to the control group exhibiting a void due to a non-adapted area (Void=V Dentin=D, Resin composite=C).*

There was a high level of agreement between the radiographic assessments of the observers as expressed by mean kappa (χ) values in the range of 0.60-0.85 (moderate to good).

DISCUSSION

In the current *in vitro* study, digitized radiographs were preferred for evaluating the resin composite restoration adjacent to caries-free dentin, since it has been the most trustworthy method for the identification of sound teeth.[15] Furthermore, improving image quality was facilitated by digital enhancement of the radiographs. It was supposed that high diagnostic sensitivity was assumed.

It was demonstrated that radiographic assessment of a well-constructed resin composite might lead to false replacement decisions. Furthermore, adhesives with a different composition, viscosity and mode of application exhibited distinct true negative and true positive decisions in the identification of adapted and non-adapted restorations in the radiographic assessment.

Chandler and others[16] noted that radiolucent borders and halo-like areas were observed in first generation radiopaque composites. Later, the low frequency of false positive diagnoses was reported for ratings of restorations adjacent to sound tooth structure that was attributed to the use of a single-paste resin composite that eliminated mixing heterogeneities.[17] Modern composite filling materials, however, commonly contain radiopaque components in adequate amounts. It was postulated that the radiopacity of these new generation materials provided accurate diagnosis and distinction from the neighboring dental tissues on film and digital radiographs.[18] To the contrary, it was also demonstrated that one of the widely used bonding agents did not have sufficient radiopacity for accurate clinical diagnosis.[19] Insufficient radiopacity properties of bonding agents can contribute to faulty radiographic interpretations for the evaluation of the tooth/restorative interface. In the current study, it was proved that the different adhesive materials may lead to different degrees of accurate replacement and accurate non-replacement decisions. Moreover, non-adapted restorations of the control group (Figure 4) received no replacement decision in 84% of the evaluations. According to these results, it may be possible to claim that the type and composition of the adhesive system is particularly important for radiographic assessment, since different characteristics of the adhesives cause varying degrees of radiolucent areas around the restorations, which directly affects the replacement decision by the clinician. It was previously shown that the cause of radiolucent halos around the restorations was technique-related, and it was indicated that thick layers of bonding agent might lead to a compromised restoration.[20] To the contrary, a thick adhesive layer has been recommended, due to its stress relieving effect between the tooth and composite restoration, since it might act as an elastic buffer beneath resin composite restorations.[12]

In the current study, Clearfil SE Bond may be an appropriate material for the elastic bonding concept, since it exhibited the thickest adhesive pooling (Table 2) (Figure 1). However, the high number of false replacement decisions of perfectly adapted restorations sealed with Clearfil SE Bond was possibly due to the less-filled nature of the adhesive. As claimed by the manufacturer, Clearfil SE Bond is a 10% filled light-cured adhesive that has excellent elasticity. The filler is made up of silanated silica.[21] Small differences in the densities of silica, dental adhesive and dentin produced low contrast differences and resulted in a greater number of false decisions on radiographic evaluations. Accordingly, it may be possible to state that adhesives should possess a higher degree of radiopacity than dentin and enamel for the correct diagnosis of gaps originating from thick adhesive layers.[22] PQ1, on the other hand, may be regarded as better for the diagnosis of well-adapted restorations (Figure 2). Furthermore, this adhesive system may also correspond to the elastic buffer concept of bonding agents, with their adhesive thickness under the resin composite material.

PQ1 is a 40%-filled and radiopaque light-cured bonding agent, as claimed by the manufacturer.[23] In the current study, 83% of restorations bonded with PQ1 were accurately detected as "sound" and needed no replacement (Table 3). This feature can provide an advantage to the material in terms of accurate radiographic interpretation.

In the current study, Adper Single Bond adhesive was used as the unfilled adhesive. The manufacturer claims that mean film thickness of this adhesive is 10 µm. In microscopic evaluation, samples with this adhesive exhibited ideal adaptation to the cavity walls (Figure 3). Adhesive pooling of the material was approximately 74 µm, which was low compared to that of the other adhesives used in this study. However, 60% of restorations with this adhesive scored as needing replacement. The high number of false positive decisions and the lack of true negative decisions was probably due to the filler-less and, accordingly, radiolucent nature of the adhesive. Furthermore, when the thickness of the translucent zones around the restoration was greater than 40 µm, it was radiographically detected.[13] The pooling of all adhesives, including Single Bond, was greater than the manufacturers had specified. The high replacement decision of Single Bond may be explained from this viewpoint as well. In the microscopic evaluation of the adhesive-tooth interface, non-adapted areas were observed on the restoration corners, particularly on the gingival walls. This finding was in accordance with the findings of a study that demonstrated gingival specimens containing more voids.[24] Nonetheless, the greatest dimension of the void at the resin-dentin interface obtained in the current study was around 7.3 µm. A review of the literature found that gap size has no influence on the initiation of secondary caries unless the gap size exceeded 250 µm.[1]

Therefore, the incongruity between replacement decisions and the size of voids detected in this current study could be attributed to the small size of voids that were below detectable limits of radiographic discrimination.[13]

CONCLUSIONS

In conclusion, the diagnosis of secondary caries and failed restorations seems to be a challenge with the currently used adhesive systems that possess insufficient radiopacity. Accordingly, it may be recommended that teeth with suspect restorations should be watched and replacement should be postponed until further clinical or radiographic changes occur.

Within the parameters of the current study, it was determined that certain characteristics of the adhesive systems, such as application method and filler content, may affect radiographic interpretation. No significant relationship was found between the microscopic and radiographic images of the adhesive systems; in radiographic diagnoses, radiolucent areas around the restorations can lead to false replacement and non-replacement decisions; the use of a radiopaque adhesive, such as PQ1, may increase the number of accurate replacement decisions for resin composite restorations.

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