Shear Bond Strength of Tooth-colored Indirect Restorations Bonded to Mid-coronal and Cervical Dentin

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To investigate the bonding of tooth-colored indirect restorations to cervical dentin, shear bond strengths of bonded resin inlays to cervical dentin and mid-coronal dentin were investigated and compared. Indirectly fabricated composite inlays (Estenia) were cemented with a dual-cured resin cement (Panavia Fluoro Cement II) to either cervical or mid-coronal dentin. Resin cement was cured with or without light irradiation for 20 seconds. After 24-hour or one-week storage, the bonded inlays were subjected to a micro-shear bond test. The light-cure method showed significantly higher bond strengths to both dentin regions compared with the self-cure method. Further, significant improvement in bonding after one-week storage was found in the case of light-cure method rather than the self-cure method. Although the cervical dentin tended to show lower bond strength than mid-coronal dentin, significant difference between the two dentin regions was only found when the resin cement was light-cured and stored for only one day.

Key words: Resin inlay, Resin cement, Cervical dentin, Micro-shear bond strength

INTRODUCTION
The growing demand for esthetic restorations by patients has caused a recent increase in the use of tooth-colored restorative materials. Advances in polymer chemistry have led to the development of an indirect adhesive procedure for esthetic restorations. For larger restorations, indirect methods are superior alternatives to direct resin composite fillings. Tooth-colored indirect restorations are now routinely bonded to tooth structure with resin cement1-7. On the other hand, although bonding of resin cement with dentin adhesives has improved considerably over past few years, evidence of insufficient marginal sealing of bonded restorations has also been shown in various microleakage studies8-10. In particular, the cervical tooth region/composite interface has repeatedly been reported to be more vulnerable to microleakage than the occlusal or mid-coronal tooth region/composite interface in vitro8-10. From the viewpoint of bonding, our previous study showed significantly lower bonding of resin adhesive systems to the cervical dentin rather than the coronal dentin within one-cavity preparation11. Although emphasis is always placed on the adhesive system used for direct or indirect adhesive restorations, regional tooth structure as well as the margin configuration of the restoration preparation might also influence the clinical performance of a restoration8,11,12.

The purpose of this study was to evaluate the bonding of an adhesively luted resin inlay to mid-coronal and cervical dentin. Bond strength was assessed by means of a micro-shear bond test4,11,13, and failure mode was observed using a confocal laser scanning microscope (CLSM). CLSM is convenient for detecting the failure mode of debonded surfaces because accurate 3D images with no out-of-focus blur can be quickly obtained by creating a series of optical tomograms1,10,14.

MATERIALS AND METHODS
Tooth preparation
Bonding was performed on the buccal surfaces of dentin of extracted human molars that were stored at 4°C in saline. Forty teeth were used in this study. Before sectioning, two dentin regions obtained from the cervical and mid-coronal regions were chosen as substrates for the micro-shear bond test. The cervical region was 2 mm above the cementoenamel junction. Each slice, approximately 1.0 mm thick, was obtained by cutting the tooth parallel to the mid-coronal portion of the buccal surface with a slowly rotating diamond blade (Struers Minitom, Struers, Copenhagen, Denmark) under a flow of water. The dentin surfaces were then ground with wet 600-grit SiC paper. For bond testing purpose, we controlled the dentin depth by obtaining each sample at a site near the center between the dentin-enamel junction (DEJ) and the pulp.
Preparation of composite resin inlay

Cylinders from Tygon microbore tubing (R-3603, Norton Performance Plastic Co., Cleveland, OH, USA) with an internal diameter of 0.7 mm and a height of 0.5 mm were cut and used as molds for the composite resin 'inlay' (Fig. 1). A resin composite for indirect restorations (Estenia, Shade DA2, Kuraray Medical Inc., Lot # 00209B) was placed into the tubing on a flat surface covered with a paper mixing pad. A clear plastic matrix strip was placed over the resin, gently pressed flat, and irradiated for 60 seconds using a visible light curing unit for laboratory (α-Light II, J Morita Co., Tokyo, Japan) prior to heat curing at 110°C for 15 minutes in air (KL 100, Kuraray Medical Inc.). Very small cylinders of resin inlay, approximately 0.7 mm in diameter and 0.5 mm high, were removed from the Tygon tubing and silanized with the application of a mixture of acidic primer (Clearfil SE Bond Primer, Kuraray Medical Inc., Lot #00287B) and a silane agent (Clearfil porcelain bond activator, Kuraray Medical Inc., Lot #00127A) for 20 seconds.

Bonding of composite resin inlay

Dentin surfaces were treated with ED Primer II (Kuraray Medical Inc., Osaka, Japan, Lot # Liquid A: 000168, Liquid B: 00050) for 30 seconds. Then, irises cut from the same Tygon microbore tubing (R-3603) (Fig. 1) were mounted on the mid-coronal and cervical regions of dentin slices to delineate the respective bonding areas. Forty dentin slices with Tygon tubing were divided into two groups of 20 specimens each according to the curing method:

Group 1 (self-cure): Dual-cure resin cement (Panavia Fluoro Cement II, Kuraray Medical Inc., Lot # A paste: T030410, B paste: T030410) was hand mixed according to the manufacturer’s instructions. Small amount of mixed resin cement was scooped up using an explorer and injected into the tubing on the tooth surface. The small cylindrical resin inlay was then inserted into the tubing, air-inhibiting agent applied to the resin cement borders and placed in darkness at room temperature (23°C).

Group 2 (light-cure): Dual-cure resin cement (Panavia Fluoro Cement II) was mixed and injected into the tubing on the tooth surface in the same manner as Group 1. The small cylindrical resin inlay was inserted into the tubing, and light-cured for 20 seconds using a visible light curing unit from the top side.

In the manner described above, small cylindrical resin inlays were bonded to the dentin surface where 40 resin inlays were bonded to the mid-coronal and cervical regions respectively. Specimens were stored at room temperature (23°C) for one hour prior to removal of the Tygon tubing. Each group was further divided into two subgroups of 10 specimens each − 10 mid-coronal resin inlays and 10 cervical resin inlays − according to the storage period of one day or one week. All specimens were stored at 37°C.

Micro-shear bond test

Fig. 2 shows the micro-shear bond test apparatus.
The dentin slice, with the cylindrical resin inlay, was attached to the testing device (Bencor-Multi-T, Danville Engineering Co., San Ramon, CA, USA) with a cyanoacrylate adhesive (Zapit, Dental Ventures of America, Corona, CA, USA), which in turn was placed in a universal testing machine (EZ-test-500N, Shimadzu, Kyoto, Japan) for shear bond testing. A thin wire (diameter: 0.20 mm) was looped around the resin inlay making contact with half of the cylindrical base, and held flushed against the resin/tooth interface. A shear force was applied to each specimen at a cross-head speed of 1.0 mm/min until failure occurred.

Ten specimens from each group were tested. Dentin region (mid-coronal or cervical region), curing method (self-cure or light-cure), and storage period (one day or one week) were the three factors analyzed using three-way analysis of variance (ANOVA). After three-way ANOVA, one-way ANOVA and multiple comparisons were carried out using Fisher’s PLSD test. Statistical significance was defined as p<0.05.

All the debonded tooth surfaces were examined with an optical microscope at ×30 magnification and CLSM (1LM21H/W, Lasertec Co., Yokohama, Japan) to determine the mode of failure. Failure modes were categorized into six types as follows: T: 100% cohesive failure in tooth substrate; A1: 100% adhesive failure between tooth substrate or hybrid-like layer and resin cement; C: 100% cohesive failure in resin cement; A2: 100% adhesive failure between resin cement and resin inlay; I: 100% cohesive failure of resin inlay; M: mixed failure with two or more failure types of T, A1, C, A2, and I. Failure modes were analyzed using the Kruskal-Wallis test with significance level set at p<0.05.

### RESULTS

Table 1 shows the mean shear bond strength values (MPa) and their standard deviations, and Table 2 shows the failure modes. ANOVA tests indicated that there were no statistically significant interactions among the dentin region, curing method, and storage period (F=0.416, p=0.521). However, Fisher’s PLSD test indicated that significant differences existed among the dentin region (p=0.0042), curing method (p<0.0001), and storage period (p=0.0003).

The light-cured groups showed significantly higher bond strengths than the self-cured groups (Fisher’s PLSD test, p<0.05). When the resin cement was light-cured, the mid-coronal dentin showed significantly higher bond strengths than the cervical dentin (Fisher’s PLSD test, p<0.05), whereas no significant differences were seen between the self-cured groups (Fisher’s PLSD test, p>0.05).

CLSM observations revealed different failure patterns between the two curing methods (Figs. 3 and 4) — and the differences were statistically significant (Kruskal-Wallis test, p=0.0275). When the resin cement was self-cured, cohesive failure generally occurred within the resin cement (type C failure) or

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<th>Table 1 Results of micro-shear bond test (MPa, Mean±SD)</th>
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Mean values designated with a different superscript letter are significantly different (p<0.05).

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<th>Table 2 Failure mode frequency</th>
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T: 100% cohesive failure in tooth substrate; A1: 100% adhesive failure between tooth substrate or hybrid-like layer and resin cement; C: 100% cohesive failure in resin cement; A2: 100% adhesive failure between resin cement and resin inlay; I: 100% cohesive failure of resin inlay; M: Mixed failure with two or more failure types of T, A1, C, A2, and I.
adhesive failure between the resin cement and dentin (type A1 failure), as well as mixed C and A1 failures (i.e., type M failure). The light-cured specimens showed adhesive or mixed failure between the resin cement and dentin surface (type A1 or M failure); however, some specimens showed cohesive failure within the dentin (type T or M failure). In both self-cured and light-cured specimens, failure never occurred within the inlay material.

DISCUSSION

The results of this in vitro study showed that the shear bond strength of indirect restorations bonded with dual-cured resin cement was significantly influenced by the dentin region, curing method, and storage period. In particular, the light-cured resin cement could produce significantly higher bond strength rather than by self-cure alone, which was in accordance with previous results.

For both self-cured and light-cured resin cements, bond strength after one week was higher than that after one day, even though no significant differences were detected in the self-cured specimens. It is noteworthy that the light-cured resin cement showed significant improvement in bonding after one week — and the degree of improvement was greater than that of the self-cured resin cement. This disparity in degree of improvement could be attributed to a slow, continual increase in conversion of light-cured resin composite after initial photoactivation.

As a result, this continuation of curing process improved the bonding of light-cured resin cement after one week. Meanwhile, the curing of self-cured resin cement also progressed after one week. Nevertheless, the lower conversion ratio of self-cured resin cement yielded a lower mechanical property, which thus affected bonding and masked the improvement in curing. Another factor which contributed to this slow increase in conversion could be the slow homogenization of initial stress — which was initiated as a result of polymerization shrinkage. Loza-Herrero et al. also reported that the biaxial flexural strength of a photo-cured resin composite gradually increased after five days — to a level where it was comparable with that of a post-cure heated resin composite. In this study, increased bonding of light-cured resin cement after one week seemed to support these previous studies.

When resin cement was self-cured only, failure mode after the shear bond test showed that failure frequently occurred within the resin cement or at the interface between the cement and dentin (Fig. 4). This failure pattern seemed to indicate that self-cure alone without light irradiation did not enable dual-cure resin cement to develop optimal mechanical properties or bonding capacity. However, light-cured specimens showed a more complex failure pattern: some of which included dentin fracture within the debonded area. It has been reported that this mode of failure arose from a non-uniform stress distribution development by virtue of the shear test setup. Nonetheless, this complex failure pattern after light activation might also indicate an improvement in the fracture toughness of resin cement due to the higher degree of conversion, as well as good bonding to the dentin. Although the degree of conversion was not measured in this study, energy density by the light unit has been evidenced to correspond to the polymerization rate and mechanical properties of resin cement. This change of failure pattern according to the curing strategy utilized was also similar to previous studies.
This study showed that cervical dentin could not produce as good bonding with light-cured resin cement as it was with mid-coronal dentin. Likewise, Sattabanasuk et al. also reported of lower bonding at cervical dentin with direct resin composite restorations. With similar reports in both in vitro and in vivo studies, these reports pointed to a vulnerable microleakage of adhesive restorations at the cervical region. Our previous in vitro study on bonding to cervical enamel also showed a lower capacity of cervical enamel for bonding rather than the mid-coronal region. Clinically, it is often probable that light-activated resin cement in the cervical region is insufficiently cured, especially if the cavity is located in the proximal region. On this note, light-cured resin cement in the cervical region would be anticipated to show a better clinical outcome only after one week. However, with self-curing, one-week bond to mid-coronal or cervical dentin did not improve to the same degree as that with light curing. Therefore, we would recommend clinical follow-up for indirect restorations bonded to this weak region.

In the case of light curing, it has been shown that as the light penetrates through an indirect restoration, its intensity is reduced by the latter’s thickness and shade. Clearly, light emitted from a curing unit must be able to transmit effectively through an indirect restoration so as to ensure sufficient hardness and bonding of the resin cement immediately after setting. Foxton et al. showed that a 2-mm thick ceramic inlay did not adversely affect the bonding and hardness of light-cured resin cement. Since the thickness of indirect restorations in our study was only 0.5 mm, this was not a problem for our light-cured groups. However, if the thickness of the indirect restoration is over 2 mm, we would probably need to choose a different setting protocol for the resin cement – such as extension of curing time or usage of a high-intensity curing unit – to improve the bonding of dual-cured resin cement. Indeed, Aksornmuang et al. reported that extended light irradiation time could improve the bonding of dual-cured resinous material. Several in vitro studies also showed improvement in the microhardness of resinous materials after using high-intensity curing units. Although several studies have advocated subjecting indirect restorations to longer light irradiation time or high-intensity curing light to improve the curing of dual-cured resin cement, and hence to improve bonding, additional study is needed to investigate their effect on dentin bonding. Moreover, findings from these additional studies will help to develop bonding resins and cements that produce high, uniform bond strength and/or gap-free margins for indirect restorations. Despite the limitations of this laboratory study, light-curing of resin cement was found to yield better performance than by self-curing alone. In particular when the cement was light-cured, the cervical dentin region showed lower bond strength of bonded indirect restorations than the mid-coronal dentin. To validate these in vitro findings in vivo, further investigations using clinical trials are necessary.

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