Mechanical Properties of Light-cured Composite Resins Cured through Filters that Simulate Enamel

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The light-attenuating effects of enamel on the mechanical properties of light-cured composite resins were evaluated using simple experimental filters. Three filters were designed to simulate the light transmittance characteristics of 0.5, 1.0, and 1.5 mm thick human enamel. The Knoop hardness numbers (KHN) and the elastic modulus in transverse tests for twelve shades of three light-cured composite resins were examined. These resins were cured either using direct irradiation with a light source, or indirect irradiation through one of the filters. The attenuations of light by 0.5, 1.0, and 1.5 mm thick enamel filter were 45%, 67% and 81% in the 430 nm-550 nm wavelength region, respectively. For all materials, KHN and the elastic modulus of specimens irradiated through filters were significantly lower than those irradiated directly. The results suggest that the light-attenuating effect of enamel reduces the mechanical properties of light-cured resin, and may cause poor clinical longevity of restorations.

Key words: Light-cured composite resin, Filter, Mechanical properties

INTRODUCTION

There has been an increase in the popularity and the number of visible light-cured composite resins as esthetic direct filling restorative materials. The great advantage of the light-cured resin is its ease of handling and good physical and mechanical properties. However, one major limitation in the use of light-cured resin systems is that the degree of polymerization of the material depends on the intensity and spectral distribution of light irradiation. Less than optimal light intensity and inadequate spectral distribution will reduce the polymerization efficiency, which may result in diminished physical and mechanical properties of the material. Therefore, several studies have investigated the factors that affect the light intensity, such as the performance of the light source unit and the distance and orientation of the light from the resin surface.

For clinical Class III or IV restorations, light-cured restorative resin is often irradiated with a light source through the enamel layer because it is impossible to place the guide tip of the light source directly on top of the material. In such situations, the light can be attenuated depending on the light transmittance characteristics of
the enamel layer, and thus affect the cure of the resin. A limited amount of information is available concerning the light-attenuating effects of teeth on the depth of cure of light-cured resin\textsuperscript{8,10}. One problem in examining the light-attenuating effect of enamel may be the difficulty in preparing an enamel die of an adequate size to use as a natural filter for experiments because the size of enamel obtained from human teeth is limited. Moreover, another problem may be a lack of stability in the optical properties of enamel caused by dehydration. Therefore, in experiments, it is desirable to use a substantially simple filter that simulates the light transmittance characteristics of human enamel\textsuperscript{12}.

This study examined the Knoop hardness numbers (KHN) and the elastic modulus in transverse tests for twelve shades of three light-cured composite resins cured directly or indirectly through experimental filters that simulate human enamel. In this manner, the light-attenuating effects of enamel on the mechanical properties of resins were investigated.

**MATERIALS AND METHODS**

*MATERIALS*

The three commercial light-cured restorative composite resins used in this study are listed in Table 1, together with shade, code and manufacturer. Each material included 3-5 shades.

*FILTERS*

Three experimental filters were designed so that the light transmittance characteristics were similar to those of 0.5, 1.0 and 1.5 mm thick enamel layers. A paste mixture of two light-cured composite resins (95 wt% of Silux Plus, universal, 3M, St. Paul, MN, US, and 5 wt% of Lite Fil II A, A3, Shofu, Kyoto, Japan) was used as a suitable translucent material for the filter\textsuperscript{11,12}. Two pastes (0.3 g) were mixed with

<table>
<thead>
<tr>
<th>Table 1 Materials used in this study</th>
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<tbody>
<tr>
<td>Material</td>
</tr>
<tr>
<td>Silux Plus</td>
</tr>
<tr>
<td>Gray</td>
</tr>
<tr>
<td>Dark Gray</td>
</tr>
<tr>
<td>Yellow</td>
</tr>
<tr>
<td>Yellow Brown</td>
</tr>
<tr>
<td>Durafill</td>
</tr>
<tr>
<td>Gray</td>
</tr>
<tr>
<td>Brown</td>
</tr>
<tr>
<td>Lite-Fil II A</td>
</tr>
<tr>
<td>A3.5</td>
</tr>
<tr>
<td>B3</td>
</tr>
<tr>
<td>C3</td>
</tr>
</tbody>
</table>

\textsuperscript{1}St. Paul, MN, USA; \textsuperscript{2}Wehrheim, Germany; \textsuperscript{3}Kyoto, Japan
a spatula by hand for approximately 5 min. The paste was packed into a Teflon mold (30×8.0×1.0 mm). After curing, the rectangular plate was removed from the mold, and polished with #1,500 emery paper and a 1-μm soft polisher. Three rectangles with 0.15, 0.35 and 0.65 mm thickness were prepared for filters. The light transmittance spectra of the filters measured using an optical apparatus reported previously, and those of 0.5, 1.0 and 1.5 mm thick enamels in the 400 nm-600 nm wavelength region are shown in Fig. 1. The spectra of the enamels were calculated from the light transmittance characteristics of twelve enamel specimens measured in a previous study, using Lambert’s law equation. The light transmittance characteristics, including the wavelength spectral distribution, of the filters simulated well those of enamel, especially in the 430 nm-550 nm wavelength region. The values of attenuation of light intensity by the filters in this wavelength region are also shown in Table 2.

![Graph showing light transmittance spectra](image)

Fig. 1 Light transmittance spectra of three filters and 0.5, 1.0 and 1.5 mm thick enamel specimens in the 400 nm-600 nm wavelength region.

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Filter-1</th>
<th>Filter-2</th>
<th>Filter-3</th>
</tr>
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<tbody>
<tr>
<td>430</td>
<td>53.8</td>
<td>76.6</td>
<td>88.9</td>
</tr>
<tr>
<td>470</td>
<td>48.5</td>
<td>69.4</td>
<td>83.8</td>
</tr>
<tr>
<td>500</td>
<td>44.0</td>
<td>65.0</td>
<td>79.9</td>
</tr>
<tr>
<td>550</td>
<td>37.3</td>
<td>59.1</td>
<td>73.0</td>
</tr>
<tr>
<td>Overall</td>
<td>45.3</td>
<td>66.8</td>
<td>81.1</td>
</tr>
</tbody>
</table>

1Filter-1, -2 and -3 simulate 0.5, 1.0 and 1.5 mm thick enamels, respectively.
MECHANICAL PROPERTIES OF LIGHT-CURED RESINS

KHN
Specimens were packed into a Teflon cylindrical mold (12\(\phi \times 1.0\) mm) open at both ends placed on a glass slide. The resin paste was slightly overfilled, and covered by a thin glass plate (0.15 mm thick) and a glass slide (1.8 mm thick) was placed over the thin glass plate. Finger pressure was exerted on this plate to extrude the excess resin. The top plate was then removed, and a light source unit using four high power tungsten-halogen lamps (Triad, Dentsply International Inc., York, PA, US) was activated through the thin glass plate for 30 sec. The average distance from the lamps to the specimen was approximately 50 mm. After curing, the specimens were removed from the mold. All specimens were stored at 37°C for 24 hr before testing. Three KHN measurements were taken both at the top and bottom surfaces of the specimen under a 100 g load for 15 sec with a micro-hardness tester (MVK-E, Akashi Seisakusho Ltd., Tokyo, Japan). The hardness values of each surface were recorded as the mean of those three measurements.

Elastic modulus
The elastic modulus in the transverse test was measured by means of a three point flexural support and a mechanical testing machine (TCM-1KNB, NMB Co., Ltd., Tokyo, Japan). The test material was packed into a stainless steel mould (25×2.0 \(\times\) 2.0 mm) and pressed with a thin glass plate. After tightly clamping, the material was irradiated from the top surface for 30 sec with the light source. At 24 hr after the preparation, the specimen was supported on two cylinders and loaded on the top surface with an other cylinder at a crosshead speed of 0.5 mm/min, and load-deflection curves were recorded. The elastic modulus \(E\) of the specimen was expressed by the following equation\(^{(1)}\):

\[
E = \frac{Fs^3}{4buh^3} \left[ 1 + 3 \left( 1 + \frac{h^2}{2s^2} \right) \right]
\] (1)

in which, \(F\) and \(u\) are the load and the deflection during linear elastic behavior, \(b\) and \(h\) are the height and width of the specimen, while \(s\) is the span between the supporting points, and \(v\) is Poisson's ratio. If \(h \ll s\), equation (1) can be approximated as equation (2):

\[
E = \frac{Fs^3}{4buh^3}
\] (2)

Statistical analysis
For each measurement, twenty specimens of four groups were prepared for each material. One group of five specimens was irradiated directly with the light source, while the other three groups were irradiated indirectly through the filters placed on the top of the material with the light source. The mean values of the measured properties among each group were multiply compared with Student's \(t\) test at a significance level of \(P=0.05\).
RESULTS

Fig. 2 ((a) and (b)) shows the values of the KHN at the top and bottom surface of the specimen for all shades of three light-cured composite resins examined. In the figure, Control shows the mean value of the group of specimens irradiated directly, while Filter-1, -2 and -3 show those irradiated indirectly through each filter that simulated 0.5, 1.0 and 1.5 mm thick enamel layers, respectively. For all materials, the KHN of the top surface were always higher than those of the bottom surface of the specimen. At the bottom surface, the KHN of the groups irradiated through the filters for most materials were significantly lower than that irradiated directly.

Fig. 2 Comparison in the KHN for twelve shades of three materials cured directly and indirectly through the filters. Error bars are standard deviations. (a): Top surface; (b): Bottom surface
Fig. 3 shows the values of the elastic modulus in the transverse test for all materials. The elastic moduli of the group irradiated directly ranged from 2.36 GPa to 8.64 GPa, and those irradiated through the 1.0 mm enamel filter (Filter-2) ranged from 1.71 GPa to 5.31 GPa. For all materials, the elastic moduli of the specimens irradiated through the filters were significantly lower than those irradiated directly, and it decreased with increasing thickness of the filter.

To consider the effects of differences in material and shade on the elastic modulus, the changing ratios of the elastic modulus, which were the ratio of the val-

![Graph showing elastic modulus comparison](image)

**Fig. 3** Comparison of elastic modulus for twelve shades of three materials cured directly and indirectly through the filters. Error bars are standard deviations.

![Graph showing changing ratio with enamel thickness](image)

**Fig. 4** Variations in the changing elastic modulus ratio with enamel thickness simulated by filters. The changing ratio was the ratio of the value of the material cured indirectly to that cured directly. (a): SP; (b): DF; (c): LF
ues of the groups irradiated through the filters to those irradiated directly, were calculated. The results are given in Fig. 4. The ratios of the elastic modulus of SP-DG, SP-YB, LF-A3.5 and LF-C3 showed significantly decreasing ratios in comparison with the other shades of SP and LF.

DISCUSSION

This study investigated the light-attenuating effect of enamel on the mechanical properties of light-cured composite resins, using substitutional experimental filters instead of natural tooth enamel. The light-attenuating effect of enamel depends on its light transmittance characteristics including the wavelength spectral distribution. The filters were designed so that their light transmittance characteristics were similar to those of enamel, especially in the 430 nm-550 nm wavelength region (Fig. 1). Commercial visible light source units usually have a peak wavelength range between 440 nm and 500 nm\(^5\), and this wavelength region covers the range of absorption wavelengths of the catalyst system of most visible light-cured resins\(^15,16\). From the good agreements in the light transmittance characteristics, the light-attenuating effects of filters in the wavelength region were similar to those of 0.5, 1.0 and 1.5 mm thick enamel layers. The overall attenuation of light intensity by the filters in the 430 nm-550 nm wavelength region, which was given as the reduction in light intensity/original light intensity as a percentage, reached 45.3%, 66.8% and 81.1% of the original light, respectively (Table 2). Thus, the light intensity that irradiated the material through even the 0.5 mm thick enamel filter was approximately only half of the direct irradiation.

For most materials, the groups of specimens irradiated through the filters showed significantly lower KHN in comparison with those irradiated directly, although the differences in the KHN among the groups were comparatively little (Fig. 2). The hardness at the bottom surface (1-mm level from the top surface) of the group irradiated directly ranged from 88% to 98% of the top surface, whereas that of the group irradiated through the 1.0 mm thick enamel filter ranged from 74% to 92% of the top surface. This result suggests that the reduction in light intensity caused by the filter would influence more significantly the hardness at the undersurface of the material.

The elastic modulus of the group irradiated through the 1.0 mm enamel filter decreased by 12.0%-58.5% compared with those irradiated directly (Fig. 3). The marked reduction in light intensity, which was 66.8% for the filter, would cause a significant decrease in the polymerization efficiency of resin and its elastic modulus. A decrease in the elastic modulus of the material is closely correlated with some clinical problems of restorations, such as marginal fracture, loss of anatomic form and marginal leakage\(^17\). For all materials, the decrease in the elastic modulus was comparatively greater than the decrease in the hardness, which was 5.2%-24.5% at the bottom surface for the 1.0 mm enamel filter. Although the hardness test is used as an indicator of the optimal mechanical properties of light-cured resins because of
its simplicity9), a reduction in the light intensity would more significantly affect the other mechanical properties of light-cured resins beyond the magnitude of the hardness change.

The darker shades of each material, such as SP-DG, SP-YB, LF-A3.5 and LF-C3, showed larger changing ratios in the elastic modulus than the other shades of the same materials (Fig. 4). The light transmittances of these shades in the 400 nm-600 nm wavelength region, especially at the wavelength of 470 nm, which is the most efficient activation wavelength, were significantly lower than other lighter shades11,16). Resin shades with lower light transmittance levels were affected more by the light-attenuating effect of the filter in comparison with other shades of the same material. Therefore, in clinical situations, special care must be taken in regard to the mechanical properties of the resin shades with lower light transmittance levels.

Although DF showed lower values of the KHN and the elastic modulus, it had a smaller changing elastic modulus ratio in comparison with SP and LF (Figs. 2-4). Thus, the light-attenuating effects of the filters on the mechanical properties are substantially different among materials. The differences in the filler type and content, micro-filler type with 55.1 wt% for SP and 52.7 wt% for DF and a hybrid filler type with 85.6 wt% for LF18,19), chemical composition, and pigments will affect the light-attenuating effect on the properties of the materials.

The light-attenuating effect of enamel will significantly reduce the irradiation light intensity on light-cured composite resins, and affect their mechanical properties. The significant reduction in the mechanical properties of restorative materials may cause poor clinical longevity of posterior restorations. It may be possible to compensate for the light-attenuating effect of enamel by prolonging the irradiation time or using a higher power light source. This must be ascertained with further studies.

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